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Research and development of computer support for maintenance, assembly and other auxiliary and service works

Výzkum a vývoj počítačové podpory pro údržbu, montáže a další pomocné a obslužné práce

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This dissertation thesis deals with the rising importance of computer (software) support for auxiliary and service processes in production companies, such as maintenance, assembly, and further activities.
This thesis focuses on a solution of how to practically apply sophisticated systems and computer support concepts. Further, it emphasises its effect on the company's economics, on logistics, and on the rising requirement on the discipline of collecting and using reliable and correct data. The data can be used for rationalising various activities in production companies. The data can also be applied during maintenance activities.
This dissertation thesis deals with the usage of maintenance data for a hydraulic press in a Czech production company. The distribution of data by the company's ERP system has the task to decrease financial and time requirements of machine maintenance. The following rationalisation proposal for maintenance activities is to be the basis for a detailed approach in the course of the dissertation thesis. The approach should streamline the maintenance and allow for the harmonisation of main working and auxiliary maintenance operations.
The subject of the analysis is a production company with lot production; the production process of the company exhibits instabilities on certain machines. The main tools are to implement the TPM concept, to standardise the maintenance activities, and to further economically evaluate the effectiveness of the proposal.

Key words: standardisation, maintenance, TPM, ERP systems

ANOTACE DISERTAČNÍ PRÁCE

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Doktorské disertační práce řeší stoupající důležitost počítačové (softwarové) podpory pro pomocné a obslužné procesy ve výrobních podnicích, jako jsou údržbářské, montážní a další práce.
Tato práce se koncentrují na řešení jak prakticky použít sofistikované systémy a koncepty počítačové podpory. Dále je zdůrazněn efekt na ekonomiku podniku, na logistiku a na zvyšující se nároky v disciplíně sbírání a použití kvalitních dat. Data mohou být použitá na racionalizaci různých aktivit ve výrobních společnostech.
Uplatnění mohou tato data najít i v údržbářských aktivitách. Práce se zabývá používáním dat údržbářských aktivit pro hydraulický lis v české výrobní společnosti. Distribuce dat pomocí firemního ERP systému má záměr snižovat finanční a časové nároky údržby v podniku. Vyvozený návrh racionalizace údržbářských aktivit má sloužit jako základ pro důkladné řešení v průběhu disertační práce. Návrh má zefektivňovat údržbu a umožnit sladěný průběh hlavních pracovních a pomocných údržbářských úkonů.
Předmětem analýzy je výrobní společnost s dávkovou výrobou s nestabilitami výroby na některých určitých strojích. Hlavními nástroji jsou zavedení koncepce TPM, standardizace údržbářských aktivit a následné ekonomické hodnocení efektivity návrhu.

Klíčová slova: standardizace, údržba, TPM, ERP systémy

Table of Contents

Abbreviation list

Abbreviation	English full text
A	Availability
APICS	American Production and Inventory Control Society
APS	Advanced Planning System
BI	Business Intelligence
BOM	Bill of Material
BOMP	Bill of Material Processors
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CAM	Computer-aided Manufacturing
CAPP	Computer-aided Process Planning
CAS	Computer-aided Standardisation
CASA/SME	Computer and Automated Systems Association and Society of Manufacturing Engineers
CAx	Computer-aided Technologies
CIM	Computer-integrated Manufacturing
CMMS	Computerized Maintenance Management System
CZK	Czech Crown
DF	Digital Factory
DIN	German Institute for Standardisation (German: Deutsches Institut für Normung)
DRP	Distribution Requirements Planning
DSS	Decision Support Systems
EBITDA	Earnings before Interest, Tax, Depreciation, and Amortisation
EDI	Electric data interface
EFNMS	European Federation of National Maintenance Societies
EMIS	Equipment Management Information System
EN	European Norm
ERP	Enterprise Resource Planning
GTS	Graphical Typecasting System
GUI	Graphic User Interface
HR	Human Resources
JIPM	Japanese Institute of Plant Maintenance
IS	Information Systems
JIT	Just-in-Time
KIF	Keep IT flexible
KIO	Keep IT open

KISS	Keep IT simple and stupid
KPI	Key Performance Indicator
LCC	Life-Cycle Cost
ME	Maintenance Engineering
MIS	Management Information System
MOST	Maynard Operation Sequence Technique
MRO	Maintenance, Repair, Overhaul
MRP	Material Requirements Planning
MRP II	Manufacturing Resource Planning
MTBF	Mean Time between Failures
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
OHS	Operational Health and Safety
P	Performance
PM	Productive Maintenance
Q	Quality level
RAV	Replacement Asset Value
RBM	Risk-Based Maintenance
RCM	Reliability-centered Maintenance
SMRP	Society of Maintenance Reliability Professionals
TIM	Total Integrated Maintenance
TPM	Total Productive Maintenance

1 Introduction

Computer support can be found in almost all areas of life today, as well as in professional life. In companies, computer support is used for sophisticated logic models and systems. More precise calculation, higher flexibility and saved time are provided through:

- standardised user entries and data homogenisation,
- dynamic planning and iteration,
- lower data and information transaction times.

The spread of those systems allows for a wide range of usage. Computer programs are used for design, calculations and simulations as well as for systematic company information systems. The degree of individuality depends on the size and complexity of the field the program must work in.

The development of computer support in production goes back to the 1950s (theoretical concepts) and 1960s (first practical application)[13] [54]. Algorithms, technology, and visualisation possibilities were limited making ”MisInformation systems“ instead of MIS (Management Information System)[1]. Today, various programmes from various suppliers are available for practical usage lowering time consumption and providing online support[30].

Information systems and further computer support allows companies higher flexibility through:

- lower waiting times,
- processing of data, information, and documents,
- automation of complex processes.

The software and hardware development allowed Information Systems (IS) to transform into Decision Support Systems (DSS) and further into Enterprise Resource

Planning (ERP) systems. These ERP systems allow for higher complexity, integrity, and a higher degree of user-friendliness. About 80% of companies in the Czech Republic are using such ERP systems[3] and big companies (e.g. Volkswagen) try to integrate their suppliers into the system by electric data interface (EDI) to further decrease time and cost. The data in ERP systems allow:

- work organisation and synchronisation,
- manage resources as required,
- monitor operations,
- document operations.

The coordination of available resources and their usage are a key to success in the competitive environment making ERP systems an essential part of companies. To make use of data and information in the system, they must be:

- meaningful,
- correct,
- up to date,
- consistent.

Information is data put into a context that makes it comparable. Company management requires qualitative information for its decision-making. According to Cornwell the communication structure of the company or its part has to be resembled in the computer support systems in order to be effective. In order to keep data up-to-date, re-evaluation and re-standardisation of processes and sub-processes have to take place in certain intervals.

Standardisation of activities can be used for processes and action that happen repeatedly while some processes are barely standardisable due to:

1. many factors influencing the activity,
2. unknown process composition and logic,
3. input resources are changing significantly,
4. no standardised process information for these activities available.

Maintenance activities belong to point 1. It requires a bigger effort to acquire usable data and to standardise the sub-processes composed of various activities. Due to this complexity most companies do not standardise maintenance operations making them barely projectable. By being able to plan standardised maintenance activities, companies may therefore gain more reliable production schedules and lower standing times[14].

Computerised Maintenance Management Systems (CMMS) are software tools used to plan maintenance activities[57]. CMMS are able to provide data on concrete maintenance activities but are limited to their storing and distribution. The processing of data and the further interpretation is not done as it would be required in order to achieve standardised activities. These standardised activities then may be used for planning in ERP systems.

This thesis is dealing with the optimisation of production through the use of standardisation of maintenance activities in a Czech production company with availability issues on the main raw-part production line. These availability issues cost the company approximately 1 billion CZK in 2016. It is the target to propose an approach based on the Total Productive Maintenance (TPM) concept to eliminate losses on maintenance activities by thorough planning on reliable data.

The thesis is divided into three main parts:

1. Gathering the theoretical fundamentals for the proposed approach:
   a) ERP,
   b) CMMS,
   c) standardisation,
   d) TPM.
2. Development of the practical approach using the components mentioned in part 1 on the critical production line.
3. Critical analysis of the company and the proposed approach

The approach wants to solve the issue of non-availability of vital machines in the company by using standardised data stored in a CMMS system in the planning module of the ERP. TPM sets the main objective to eliminate losses and to plan maintenance activities in due time and range.

Basic data is taken from the ERP systems and from machine suppliers' manuals, To acquire further data, standardisation of maintenance activities is done. The target is to:

- lower overall maintenance cost,
- increase availability of machines,
- give a reliable and systematic approach that can be followed to include maintenance activities into production planning.

This thesis follows its name, dealing with computer support for:

- maintenance (dis-assembly),
- installation (re-assembly),
- further auxiliary and service works.

In this objective, it is dealing with a literature review to research the current status of computer support and maintenance activities. Further, it is the aim of this thesis to further develop the computer support for all related maintenance activities and to bring the research a step further towards digital factories. Maintenance concepts such as TPM are employed to follow this task.

A case study on an existing Czech company in the heavy industry shows the benefits of the developed approach of maintenance by using computer support. The company already uses ERP and CMMS in a non-integrated manner. Both systems work independently from each other. The advanced planning module in the ERP is not able to estimate and schedule standard maintenance blocks based on experience but plans small preventive maintenance actions and reacts to breakdowns that occur in the company.

The developed approach should shift breakdown maintenance effort towards preventive maintenance. Preventive maintenance should be:

- projectable,
- reduced to a number of maintenance activities,
- saving cost and time.

Hypothesis

The target of this thesis is to find answers for the following questions:

1. Is there a systematic approach on maintenance with computer support that allows higher availability of machines in the production line?
2. Is it possible to use an integration of ERP and CMMS to achieve point 1.?
3. Does this system allow for standardised maintenance activities?
4. What are the basic characteristics of the integrated system?

2 ERP

Enterprise Resource Planning (also Enterprise-Resource-Planning, further only ERP) systems are common in today's world in many companies. It is able to display the company’s structure in a virtual network and therefore to decrease delivery time of information within the company network. The decrease of time in an ever faster working world is a main advantage in today's business world. Furthermore, the system enables a fast tracking of information and data and a pre-setting of responsibilities. The task of ERP's is the assignment of resources for different activities in the company, e.g.:

1. Human Resources,
2. Material,
3. Production Capital,
4. and others[26].

The scope in which the ERP systems is implemented into the company sphere varies from a few fields to the whole company. It is also possible to only implement certain departments or tasks-bundles into the ERP sphere. These bundles are called modules.

One of the characteristics of such systems is it that they are tailor-made and individual for each particular company they are used in. The company is therefore bound to the ERP system supplier as a partner once the decision for one ERP system is done[46].

The supplier is mostly an IT-company that has a defined ERP framework on hand. All special requests the company has due to real processes, numbering, etc. have to be implemented tailor-made. With this, the company is bound to the specialities of the ERP system provider given in the basic framework. This is why some experts tell all ERP systems to be the same[21] ignoring the individual part of the systems given by the companies culture and organisation[46].

The most used ERP systems are[26]:

- SAP ERP-System (with almost 50% of market share in 2011),
- Microsoft Dynamics NAV (approx. 12% market share),
- Microsoft Dynamics AX,
- Infor ERP,
- Oracle/Enterprice One/World (approx. 6% market share).

Even though ERP systems are widely used in companies throughout all industries and economies, the implementation of ERP systems into the company sphere is a demanding step. Many authors dealt in their books with the risks and chances of implementation of ERP systems. Grabot et al. write that *"... implementing an ERP is still considered as a risky and difficult project: many implementations indeed suffered from excessive delays and costs but also from difficult appropriation by users, with consequences which could lead in extreme cases to a partial loss of control by the companies of their daily activities."* [14].

In order to get a grab on ERP systems' theoretical basics, the next chapter will begin with the definition of those systems.

2.1 Definition

In order to understand ERP systems as a whole, it is important to have a look on their definition. With the definition, it is possible to understand the task of those systems and to be further able to explore the systems in the next chapters.

Literature and the internet provide a variety of different definitions. However, most of them are indirect stating the requirements of those ERP systems.

A first definition is given by the APICS dictionary, 9th edition, which defines ERP systems: *"a method for effective planning, and control of all resources needed to take, make, ship, and account for customer orders in a manufacturing, distribution, or service* *company."* [3].

The same source also defines ERP in its 13th edition as a *"... Framework for organizing, defining, and standardizing the business processes necessary to effectively plan and control an organization so [that]the organization can use its internal knowledge to seek external advantage."* [3]

Sthub defines the ERP system the following way:
"... operating systems are dynamic in nature. We alter one element and others are affected." [54]

Sthub's definition shows that while referring to ERP systems, it is referred to a complex system of activities and elements, while the newer APICS dictionary is defining ERP systems in a different direction. The ERP system is seen as a system enabling the processes to work in the company framework. It refers therefore to the provision and control of resources. Taking into account the first definition of the older dictionary version, ERP is understood as a *"method of effective planning"* [24].

As a summary of these three definitions, an ERP system refers to a complex system that is dealing in a pre-defined framework, mostly the company but can also be implemented in parts of the company. The underlying logic of these systems is the company organisation resembled by processes. The ERP system must act according to Conway's law demonstrated by Melvin Conway in 1968 (in other sources dated back to 1967) saying:

„Organizations which design systems ... are constrained to produce designs which are copies of the communication structures of these organizations." [6]

This means that the ERP system also has to resemble the communication network of the company dealing with the resources and resource planning of the company. The processes define how the activities have to be done and in which order. In order to provide the needed resources for these activities, the ERP system has to internalise the working steps and order to bring the resources in right time. Right time is a term referring to the availability of data or information saying that real time is neither possible nor is it mostly needed in real enterprises. But it has to be available in the moment that this data should be used by another person or software[32].

Based on these definitions, this thesis uses the following understanding of ERP systems:

ERP systems are systems that resemble the communication network in the company for following and achieving all processes and to secure activities by assigning resources to the same. ERP systems are employed in organising, planning, assigning, and controlling the different activities.

2.2 History of ERP systems

The idea underlying today's ERP systems is much older than the invention of computers and computerised information systems. Kapp et. al. refer to Eli Whitney living between 1765 and 1825 as the developer of the initial thought of an ERP system. All through the time people tried to make use of maths and logics to gain efficiency in their own business and to gain competitive advantage over their competitors[24].

Literature distinguishes between two different planning philosophies:

- Consumption-driven planning,
- Requirement-driven (deterministic) planning[28].

The consumption-driven planning is based on assumptions. Component and tool planning is done on the estimated requirement and on existing or previous consumption. This type of planning implies a degree of uncertainty whereas the second approach, requirement-driven, is dealing with exact figures. The exact figures come from the bill of material (further only BOM), in which the product structure with its components and their quantities as well as their level of integration is given[28].

The first systems that ought be mentioned from the history of ERP systems are early MRP (material requirement planning) systems. These systems were so called Bill of Material Processors (BOMP). It was their task to make extensive use of the underlying document, the BOM. From the BOM, they were able to get the quantity of components required for one piece. With the input of the product order quantity, the system was able to give the whole required quantity as output. This output was then processed further by planners, logistics, purchase, and further departments[24].

As BOMPs were lacking the complexity required to display the interdependencies (and dependencies at all) in the company, there were only a few variables that were tracked by the system. According to Kapp et al., the amount of stocks was rising frequently, as material was ordered when the final product was ordered. The time line was not considered in the system itself. Further the planning lacked newly emerging tools, but was only able to give the quantity required. The result was a totally new approach, the so-called Material Requirements Planning (MRP)[24].

MRP was a more complex system invented in the early 1960s. One of its authors was Joseph Orlicky. The use of computers enabled the system to not only include the BOMP, but to further plan (and track) material and inventory in the company. The material was brought in on a time schedule. Distribution happened also according to a time schedule. The MRP therefore prevented the company from collecting materials on stock as the BOMP had done[24].

The MRP was also able to include data from production or inventory. One of the basic logics for planning material requirement is to compare how much material is on stock with how much material is actually required. In case of sufficient material levels, the MRP was able to decide not to buy excess material. The BOMP did not take these stocks into account[24].

The output of the MRP was the planning of all kinds of material, be it raw material for production or components that were used in any of the assembly lines in the company. Also, in the early MRP-era, there were shortcomings. One was the fact that it required more system resources from the computer which were rare at that time. At that time it was quite common to work together with universities in order to secure the resources. Not only location-wise, but also time-wise, the data got dissolved. As companies worked faster than the computing process was working – one iteration is assumed to take a couple of hours - the MRP systems got to its limit. With this, data got more and more corrupt due to the fact that it was not provided in right time[24] [32].

The next step in this development were so-called “closed-loop MRP“ systems. These systems came into use with the development of faster-working and cheaper computers. Companies did not need to outsource their MRP systems any more. The MRP systems were used in-house, in a tailor-made architecture suitable for the given company. As the task of the MRP system remained the same, it acquired further functions. One new function was the comparison of actual values with the values given in the plan. The plan was checked and changes could happen according to the information given[24].

These systems were the first to be able to provide information instead of raw data. But comparing the planned versus actual state, the data was put into a context and was transferred into right-time information. Furthermore, the company got a clue about which processes went wrong and whether this was a regular habit. Processes that went against the plan regularly had to be assessed again (which implies the creation of knowledge on the given process)[24].

Another step further was the MRP II (manufacturing resource planning) systems as a logical extension of the former MRP systems. Despite the development to MRP closed-loop MRP’s, other resources were mostly neglected. The mentioned resources were not limited to material inputs, but were extended to money, human resources, stock constraints, etc. The underlying document for all calculations was the master production schedule. This schedule was already widely used at that time[24].

The system was able to communicate to the correct locations and departments which resources were required at which time (right time) to stick to the master schedule. Still, it inherited the comparison of planned and actual values and developed reports showing the delays and shortcomings of the company's production[24].

Nonetheless, also MRP II systems were not able to fully comply with the requirements of business. All information and data not related directly to production were kept in separate systems resulting in double-entries and double-work. The MRP II system edges were extended including also the accounting and financial systems. The company was therefore able to link the logics of financial reports to the logic of production already tracked by former MRP II systems. In order to also pay account to the distribution requirements planning (DRP), the former separate system was included into the MRP II[24].

The philosophy of Just-in-Time (JIT) invented by Taiichi Ohno in the course of the 1970s. Working at Toyota, it became apparent to him that all materials require a thorough planning in order to achieve a competitive advantage for the company. JIT enabled the companies to reduce stocks and save costs by relying on planning. Though misunderstood by some companies which neglected their MRP (II) systems believing in the JIT concept, reality showed the need of MRP (II) systems for achieving the goals of JIT. Both concepts had to go hand-in-hand which was a challenge that companies had to overcome[24].

In the course of the 1990s, the first systems referred to as ERP systems were developed. The systems included the MRP II and the so-called decision support systems (DSS)[24]. A DSS is *"an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights"* [57]. DSS therefore do not follow the requirement and planning line, but were installed in order to facilitate the decision-making.

Though invented in the 1990s, it took the ERP systems another ten years until they achieved the capability of providing all the functions they were developed for. The systems had the logic of MRP and MRP II systems, but had to include the DSS component as well. Therefore, the task was to have a look at the "what if" case. With this, it has to look forward and has to include the predictions of a decision into its analysis. The best outcome should be chosen due to the outcome of its analysis[24].

The complexity of such analysis is much higher than what the first systems were able to provide. It uses a wide collection of data available in the data warehouses, data of the company itself, customer data, and supplier data. The availability of data existed already for decades. Nonetheless, it took another decades until this information could be used for knowledge and for decision making[24].

Today, ERP systems are not only supporting and tracking manufacturing processes, but are also used in other, non-manufacturing fields. Classical service-providers like banks are also making use of ERP systems, as do insurance companies and others. These systems rely on one central database[24].

History shows, that the task of the BOMP systems differed greatly from the ERP systems of today. The logic of BOMP is still existing in the ERP system, but complexity and task has changed over time. BOMP is one of the basic components of an ERP system. The BOMP as the initial stage of an ERP system provided the path to further expanding the idea of an overarching computer system.

MRP systems were the first step towards more complex and more demanding systems. At the beginning, the lack of computer capacity limited the companies' use of MRP systems. With ongoing computer development, this shortage was overcome. By tracking, monitoring, and reporting of data, the MRP II system included the whole production process into its capabilities.

ERP systems linked the advantages of MRP II systems adding a decision-making logic. This logic did not only take the real state into consideration, but also included simulations and gave the opportunity to be one step ahead of the issues. The ERP system is therefore a powerful tool if it is used in this sense[24].

Rising opportunities also create rising requirements. Today's companies have to rely on powerful ERP systems. As the logic of whole manufacturing processes has changed over time, as philosophies like JIT and the philosophy of zero losses forced the companies to eliminate all wastes. The ERP system had to help to achieve the goals set. Without complex ERP systems, companies would struggle to reach their goals, thus slowing down their entire supply chain. Mostly in competitive industries like the car industry, supply chains are competing with other supply chains. It is not the sole company that is responsible but the supply chain as a whole. In order to not let the whole supply chain down, ERP systems must help keep all processes under control, to evaluate data and to conquer issues before they get urgent. This applies to all kinds of companies, not only to automotive.

ERP systems are powerful integrated tools that track and control all kinds of processes and that share data, information, and knowledge across the whole company. Today, these systems can be found in many companies. Complexity varies due to the size and processes of the company, but the logic and task is the same. These tools are tools for competitive advantage[24].

After having a look at the history of ERP systems, the next chapter will look at the main elements of those systems.

2.3 Basic elements of ERP systems

ERP systems can be used in all kinds of organisations and companies. It is also possible to only partly implement ERP systems in a company or to do this implementation gradually. Therefore, it might be split into different areas, so-called modules, that might but need not to resemble the different company departments like:

- finances,
- sales and marketing,
- inventory management,
- production planning, etc.[25]

ERP solutions can be divided into so-called ERP I and ERP II frameworks. The ERP II framework includes the ERP I framework and adds additional interface modules to it that make use of the data of the initial modules. For ERP I software solutions, the different modules resemble major functional areas[30]:

- Financial module,
- Manufacturing module,
- HR module,
- Material management module,
- Production management module,
- Plant maintenance module,
- Purchasing module,
- Marketing module,
- Sales, distribution, and service module.

Former ERP systems were limited to those modules. The ERP systems used today also include other tools which were not part of the initial ERP idea. These systems are integrated business information systems, referred to as ERP II[16]. Figure 1 gives an idea of how the ERP system is embedded into the company sphere. The image displays the relations to other information tools in the company.

Figure 1: ERP system framework[30]

The integration of different tools into one complex system gives the chance to exploit a bigger base of information and data. To be able to make use of those systems, the complexity is not allowed to spoil the workability of the whole system. As interdependencies are quite common in those systems, the whole architecture has to be able to bear the iteration. As the same data might be changed by different modules it has to be clear that the actual data has to be used.

Weiss describes 8 characteristics for ERP II systems:

- *Web-based architecture*: Today's companies use their intranet or internal cloud technologies to implement a company-wide network. This enables the company to integrate different workplaces into the ERP system. Complex work processes can also be displayed.
- *Platform independence*: As the IT world rapidly changes, users should not depend on one platform provider. In order to use the ERP system and its data after a platform change, the ERP system has to be independent. Moreover, it might also be that different people in the company might use different platforms. The independency also secures that there will not be an issue for these people to use the ERP system.
- *Scalability:* The ERP system should not be limited by company size. As companies might rise and fall in headcount, the company should be able to use the historical data from the ERP system.
- *KISS (keep it simple and stupid)*: In order to secure the operability for all users, from managers to workforce, the system must be intuitively operable. The user interface should enable everybody to use it.
- *KIF (keep IT flexible)*: Changes happen in the organisation every day. The ERP system must cope with these changes and also has to be able to display these changes. Changes in process have a direct effect on the data processing in the ERP system and therefore the ERP system must be easily adjustable.
- *KIO (keep IT open)*: Anticipated changes in the future might require further

integration of different tools into the ERP system and its elements. Therefore, the system should be able to provide access and to gather access to different tools through pre-set software interfaces.

- *Functional extension*: ERP systems are the functional basis of the company displaying all existing processes. Over time changes will happen either intentionally or unintentionally. Therefore, ERP systems require the possibility to not only be flexible but also to be able to add newly emerging tools and components. Additional tools have to be integrated in the same sense as the former modules and all interdependencies have to be displayed in the system.
- *Industry solutions*: Modern ERP systems should not only display the company framework, but should also be able to suit a certain branch. Different branch requirements should be displayed automatically in the system so that the number of necessary changes can be decreased[60].

An issue might occur in cases where the data used for the input at the beginning of the process is changed during the process. If the changed data is used simultaneously to the initial data, the parallel use of the "same" variable might lead to miscalculation. Another issue that should not be ignored is the systematic working of the system. In case of urgency it might be required to skip part of the processes or part of the process might not even be required. (ERP) systems are not made for exceptions but have to cover the usual, systematic working. Concerning the frequency of such exceptions, the ERP system must not bring the company to a hold due to limited flexibility of the system.

The next chapter deals with the ERP system architecture. This chapter explores the theoretical background of how to design an ERP system for the company.

2.4 ERP system architecture

ERP systems have the task to display the whole communication network of a company, according to the already mentioned Conway's law. Different type of people and different types of companies might use different approaches in their communication matrix, be it a centralised system (figure 2, 1.a) or a decentralised system (figure 2, 1.b.).

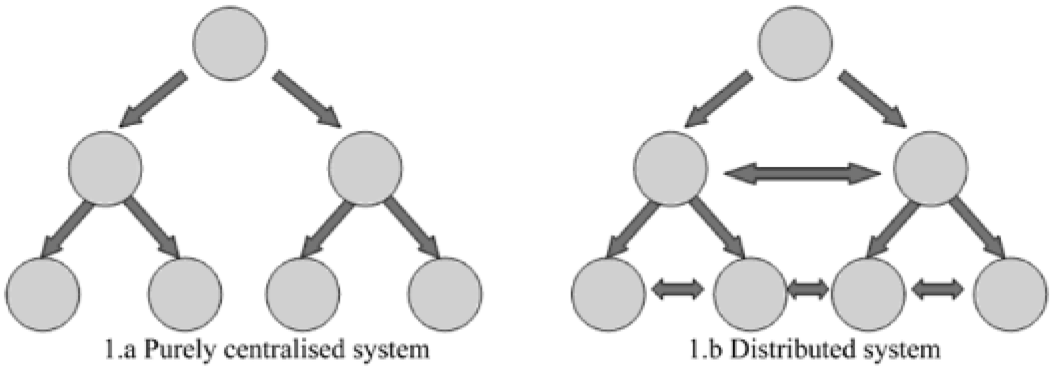

Figure 2: Communication in decision system[14]

In case 1.a (figure 2), the lower level entities are coordinated by entities of a higher level. There are only two ways of communication possible in this model:

- Top-down,
- Bottom-up.

The direct links provide the possibility that coordinators are able to collect the bottom-up information from two different areas and to spread top-down information either to both areas or only to one area depending on whether the information touches one or both of the areas. As in a company organisation model, the ERP communication model hierarchy allows to have „boss-bosses" who again coordinate several areas on higher level. An efficient information flow can only be provided if all links in the chain are efficiently able to manage top-down and bottom-up communication. Time-wise, higher level decision-making will take longer, whereas lower level decision-making will be in right time.

Another approach used is the distributed system shown in figure 2, 1.b. This system relies on the information exchange top-down and bottom-up as well as on the information exchange at the same level. This means that there are several communication channels popping up within the company. There is not one sole communication chain with pre-defined links providing communication. The information flow across areas can be facilitated as higher-level waiting times can be avoided. On the other hand, information flow and rumours might get out of control as lower level people have to decide which information to be spread to whom. This is not pre-defined in the model. It is for the particular company to decide which communication model suits best and how to implement this model into the ERP system to display the company's reality.

With regard to the integration opportunities of the different systems and also of additional systems, the obligations and rights have to be set clearly and definitely in the whole company. Giddens describes the intuitive information spreading in a de-centralised model as *"common sense understanding"*, concluding *"first, what any competent actor can be expected to know (believe) about the properties of competent actors, including both himself and others, and second, that the particular situation in which the actor is at a given time, and the other or others to whom an utterance is addressed, together compromise examples of a specific type of circumstances, to which the attribution of definite forms of competence is therefore appropriate"* [13]. The models developed and shown in figure 2 are not dealing with the real question of whether they make sense[14].

Companies do not only have formal communication, but also informal communication might happen, mostly in case of urgency. This means that the ERP system has to be able to suite the different cases occurring in reality, suiting the flexibility required by Weiss. It is therefore in doubt whether all information has to be going through the management as in a centralised model. High-level management will only be held up by the vast quantity of information that is not of their concern. However, process and information discipline is not easily controllable in case of a decentralised model. The loss of control makes it also difficult to implement new tools into the whole system. It might not be formally clear which communication links are used and which communication links have to be considered when implementing other elements into the whole system. The lack of crucial information in the area of the new elements might lead to miscalculation and misinformation in the whole system as information from the new elements will be used and further spread into the whole system. Therefore, early information systems were also called misinformation systems.

2.5 ERP sophisticated management

An ERP system has to be able to provide resources at the right time to the different processes in the company. When using an ERP system, the company may use it in different senses. The company can use the ERP system just to store and provide data (refer to “Data Management System“ in figure A) or as a whole knowledge management system (refer to “Knowledge Management“ in figure A).

The key to how the ERP system is used is closely related to the company hierarchy again. High-level executives dealing with the strategy of a company require different information than low-level executives who have to deal with the daily operational issues. The complexity and sophistication of the information rises at the executive level. This is referred to as an increased degree of values[24].

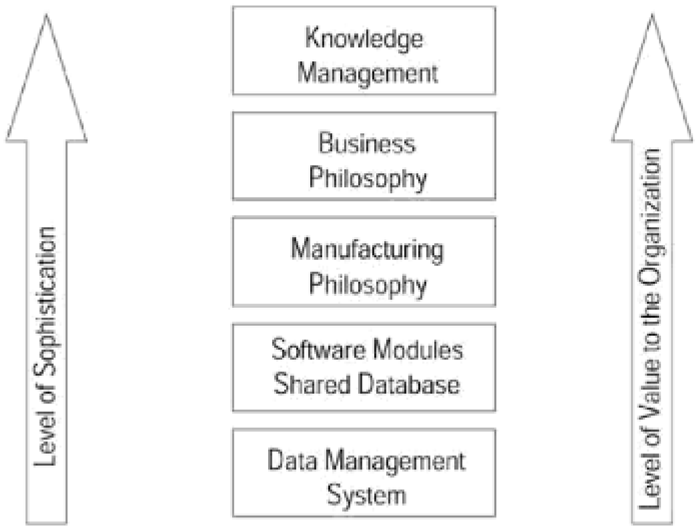

Figure 3: ERP Sophistication Hierarchy – showing the five perspectives of an ERP system[24]

In order to acquire a successful implementation of the ERP system suiting all levels of the company, the company has to understand the five levels of sophistication. In the initial stage, the computer is only used for processing a vast quantity of data. Those data come from all areas in the company and not all data is required, even not on the lowest level. The

ERP used for data management can produce records, reports and overviews on demand. Those data are not necessarily bound to the company or to a certain level but can be shared and might also be important for higher levels, either in its pure form or by transformation and aggregation (or relativisation) in a context with other data[24].

The second stage of sophistication is the Software Modules Shared Database. This database ensures that all tools and modules use the same, consistent data from a central, shared database. All data stored in the database has to be actual and has to be presented in right time[32]. Inconsistencies might arise when the data has to be presented in the system in two or more simultaneous states. For example. the environmental temperature for the last production operation might vary heavily from the temperature used in the first production operation. It might therefore lead to a mistake to assume the temperature of only one of those two numbers. The database has to be set in a way that it is able to distinguish the different states of a variable[24].

Nonetheless, the perspective of a shared, common database is widely shared today when describing the requirement of ERP systems. It overcomes the weakness of separate systems that data and data changes might not be transferred to all other separate, but dependent systems in the company. A crucial pre-condition to set up an ERP system with a shared database is the understanding of processes and process links in the company as well as between the variables and numbers. Without understanding and implementing the underlying logic of the system, the ERP system is not able to provide the help it was implemented for[24].

The third level in the pyramid is to view ERP systems not only as a mere software programme able to compute, save communication and workloads for the employees and management, but also as a part of a visual framework, embedded into the manufacturing philosophy. It is a question to the top management to present a vision and to think about how to implement a strategy for achieving this mission into the ERP system. The ERP system is therefore not only a tool for data collection or data sharing as understood on the lower levels, but it gets directly involved in pursuing the company’s strategy.

To use the ERP as part of the manufacturing philosophy, the management has to be clear with the objectives that should be achieved. The underlying logic for material purchase (e.g. safety stocks, minimal stocks, just-in-time philosophy, etc.) must be implemented into the system. The system is then able to do the maths and to communicate the further requirements based on hard facts. If this step is not done, a strong tool can either not be used properly or it might be used against the company itself[24]. Mistakes done during the purchasing and designing phase will be discovered later during implementation and usage[24].

The fourth level of sophistication of an ERP system is the “Business Philosophy“. As business is the core point of a company, the business success is a crucial measure for the whole company as well as for the ERP system as such. The ERP can work as a strategic tool following and evaluating the business plans and other strategic plans. The communication ability of the ERP system is used in order to communicate top-down and to thereby inform executives on lower levels about the objectives in the given area. The ERP system is able to provide a break-down from the strategic level into tactical and operational objectives[24].

When applying ERP on this level, the planning level and data collection and storage level combined with the communication task require a suitable architecture. Reporting at the right time to the right people becomes a crucial task for the system. Even more, it must imply all logics existing in the company to give the understandable context for the data.

A shortage of production might have its reason in a bad shift where all products produced were made incorrectly and the effective output was zero or in the lack of input material due to the failure of a supplier. The ERP system has to highlight the reason behind the production shortage and communicate the correct understanding of the reporting provided[24].

As far as the data collection system is concerned, the data is organised in data warehouses. These warehouses “store“ the data logically. Data is turned into information and at the end into knowledge that is required on higher levels. Data is the mere numbers and facts gathered from the shop floor, information is the relativisation of these numbers by putting it into context. It is referred to knowledge as the intentional usage and application of information, understanding rules and patterns from the information gathered to be able to turn processes in the company's favour[59]. The usage of these patterns and rules gathered from information is what makes the ERP system so valuable in the forth stage.

The last stage, stage five, is the knowledge management in which the ERP system is employed. The system can extract patterns and rules (knowledge) from the data and information gathered. This knowledge is provided to executives and managers. With this, the ERP system can provide a competitive advantage on the market as the system itself is able to create knowledge. The knowledge that can be created by the system is not limited to any specific area in the company but is company-wide. All data can be covered, meaning not only internal data but also data on the interface to suppliers and customers[24].

The knowledge management level is not only the most powerful usage of the ERP system for the company, but it is also the most sophisticated and therefore most complex tool. The difference in thinking between the lower level ERP systems and the higher level ERP systems is in the basic thinking and understanding of what an ERP system should do. The ERP system embodies the company structure, the lower sophisticated levels and the higher sophisticated levels. Mostly used as a data collection tool, the executives still have to bring their own, subjective logic to it to create knowledge. With designing the tool in the required way, the tool is able to produce the knowledge required itself[24].

The complexity of such models leads to self-learning software. This software is able to "understand", to learn, and to develop within its own framework. This self-learning software is also referred to as *"artificial neural networks"* [64]. The software has the ability to resemble knowledge gathering happening in the brain, where naturally a neural network is there to acquire knowledge for a human being. The design and architecture of such ERP systems therefore have to resemble the design of the neural system in the brain[64].

2.6 Computer-integrated Manufacturing

The term computer-integrated manufacturing (CIM) describes the practice of linking different computer support systems together in a company. Further, it is used to describe automated processes controlled and managed by computers. The Computer and Automated Systems Association and Society of Manufacturing Engineers (CASA/SME) defines CIM as "*... the integration of total manufacturing enterprise by using integrated systems and data communication coupled with new managerial philosophies that improve organizational and personnel efficiency.*" [49]

The CIM concept developed in the 1980s with various understandings on what the term meant. The definition range included:

- MRP II or ERP systems,
- fully-digital companies,
- computer-aided systems[20].

In order to link different systems together, the development of interfaces was facilitated to:

- ensure technical compatibility,
- prevent double-entries,
- keep all data up-to-date[20].

Fundamental technologies used in CIM systems are the CAx technologies, such as[39]:

- CAD (computer-aided design),
- CAM (computer-aided manufacturing),
- CAPP (computer-aided process planning),
- CAE (computer-aided engineering),
- and others[39].

Further, the CIM concept also includes the ERP system and lean manufacturing. All these systems are linked through a shared database[39], such as a Business Intelligence (BI) tools.

By using workflows, the ERP-systems are able to fulfil the task to distribute data, information, and tasks throughout the company. Tasks go through a pre-defined process, when one station is done, the task is passed on to another. Workflow is not even limited to data and information, but is also used to convey:

- documents,
- tasks[20].

With the development of graphic user interfaces (GUI) in the 1990s, employees without an IT background were able to work with these sophisticated systems allowing not only for faster distributions, but also for faster solutions[20].

The difference to the before-mentioned concepts, such as DSS, ERP, MIS, and others is, that the CIM concept asks those support systems to work together automatically and to allow the employees to focus only on a certain part of the work. All other work concerning processes is then automatically done by the CIM-based systems (figure 4).

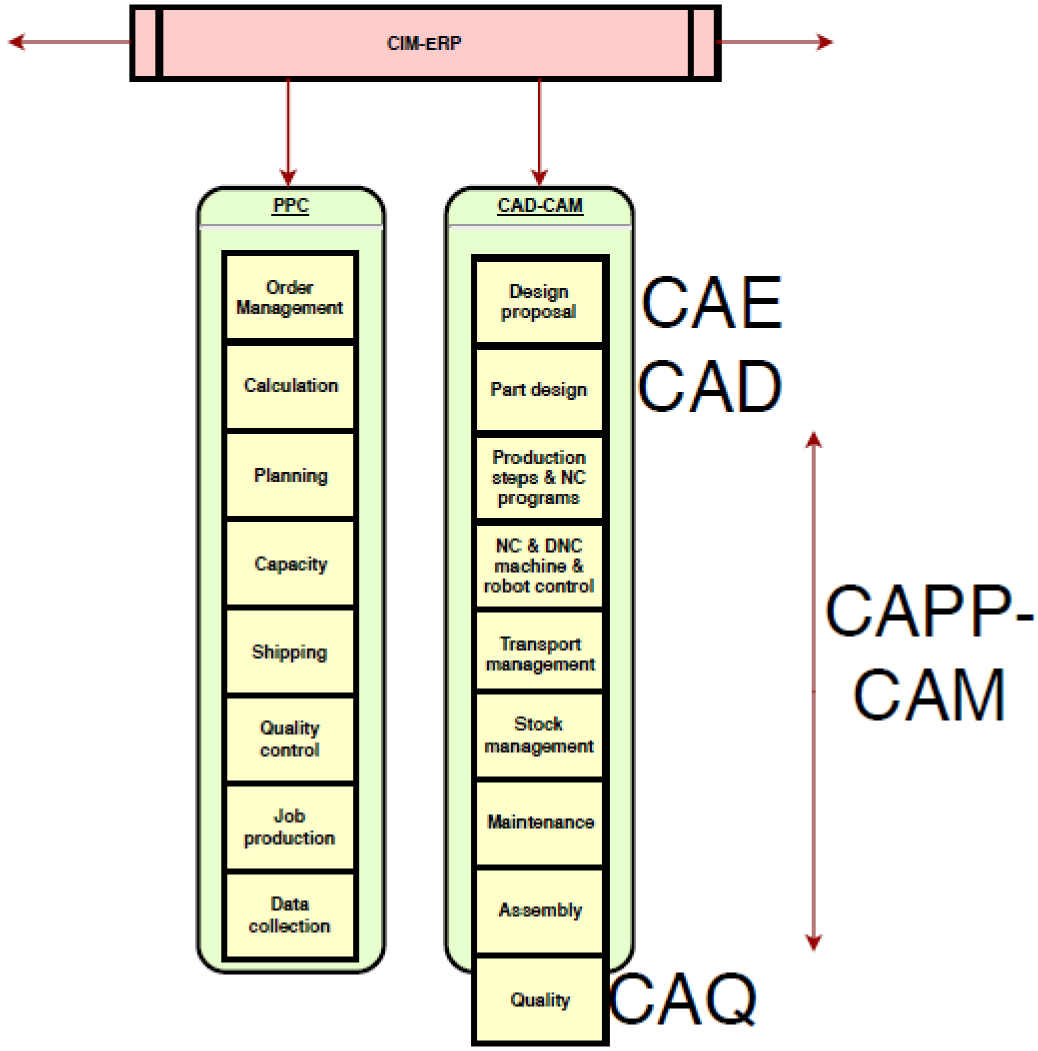

Figure 4: CIM architecture [39]

The figure shows also the maintenance field in the CAD-CAM area, belonging to the CAPP-CAM section. Maintenance does not only mean the repair of a machine or equipment itself but includes also the disassembly and re-assembly of machines to be maintained. CAD-CAM systems support maintenance activities through their whole complexity combining fields like:

- design,
- assembly,
- planning support.

These sophisticated systems rely on the automatised workflow and the strict following of process through machine-machine-communication. Various automatised systems are put together through interfaces to create a computer-integrated manufacturing system that is, once running, independent from operative human errors.

2.7 Digital factories

Digital factories (DF) are a concept using a virtual digital space for planning, managing, and controlling production processes. The outcome is a one-to-one picture of the real factory in a virtual framework (Cantella et. al write about an *"integrated synthetic manufacturing environment"* [4]). All aggregated tools contributing to this framework are the digital factory.

Displaying the real production on a computer allows to make simulations and to apply the required means afterwards in reality. The target is to:

- fully understand all processes in the company,
- plan all resources most efficiently,
- reduce losses to zero [23].

While simulation is done in a digital environment, production start-up and further setting processes may for the majority of the time be done digitally. This time is spared in production, as waiting times and further issues may be eliminated in simulations.

The concept of DF is so far used in industries with serial production where the digital framework is used to:

- eliminate non-quality,
- facilitate process capability,
- find the best suitable production method.
- verify production normatives[56].

While the simulation targets the production level, DF are useful throughout all levels of the company. Besides simulation, also the following activities can be facilitated by DF:

- planning,
- controlling,
- managing[4].

The simulation relies on full information on the object or process to be simulated. While simulations target the operative planning, DF may be used for all kinds of operational management, from the planning phase towards implementation of means to achieve the simulated benefits[4].

DF rely on information to be available fully and accurately. This information is required from all parts of the company in order to create an accurate simulation. Such an accurate simulation must duplicate reality during the course of time. Therefore, it is required to change and adjust the digital framework as real circumstances change. Ignored changes of different variables will change the result and prevent the models from being qualitative and valid.

Thus, the DF concept may be seen as a concept developed from the CIM approach. Data gathered from various systems is directly used by feeding other systems and to simulate the outcome of a company. Any deviation found can be used for analysis to improve the DF model of the company continuously.

2.8 Summary

In this chapter, ERP systems were defined as *“... systems that resemble the communication network in the company for following and achieving all processes and to secure activities by assigning resources to the same. ERP systems are employed in organising, planning, assigning, and controlling of the different activities“.* ERP systems of today have the ability to support companies in manufacturing and service industries where they are widely used.

The help of logic and computers has a long tradition in economies. Already in the pre-computer era, there where systematic approaches that tried to make the manufacturing understandable and calculable for the managers and executives in the company. The first computer-aided systems were developed for production support and came into force in the 1960s. With time, the scope of displayed company fields grew bigger and the computer possibilities and capacities extended. By grabbing more and more areas from the company (also accounting, later also decision-making), these primitive systems grew to more complex systems, called MRP, MRP II, and last ERP systems.

These classical ERP systems include modules like e.g. finance, sales and marketing, inventory management, and production planning modules[25] [30]. Today's ERP systems – also referred to as ERP II[16] – extend the understanding of ERP systems to modern business information systems. In order to cope with the still-not-finished development of these systems, Weiss postulated eight characteristics of ERP II that should secure the flexibility of the whole complex systems[60].

ERP systems have to display the communication paths of the whole company[6]. ERP systems should facilitate the level of communication and should not hinder it. This can be achieved to a purely centralised system (providing only direct links between lower and higher level) or a distributed system (communication channels also on same level possible). ERP systems are strongly individual and have to be accommodated for every company that uses them. The ERP system is a tool for efficient communication if used correctly. It is the task of ERP systems to overcome distances and to transfer data to information and bring it to the place where it is required. Due to the company's nature, this should be a mix of the both models described above[14].

Not only the company's nature has to determine the use of the ERP system and the way of communication, but it is also the manager's task to determine the target of the ERP implementation prior to its installation. The level of complexity goes hand-in-hand with the level of sophistication, and the created value for the organisation. ERP systems can be used as a mere data collection and management system in the least case. Furthermore, they can actively support the manufacturing processes in the company by implementing the manufacturing philosophy as logic into the system (e.g. JIT approach). The highest level of sophistication for ERP systems is its use in the area of knowledge management. In case the ERP system is used as a self-learning system, it is able to understand processes and patterns and to create rules out of the data and information acquired. The ERP system is then not only used as a tool to provide information after collecting data and to distribute them, but is even more able to support the higher management in how to make the next decisions and which so-far unknown logic lies behind the production processes. It is this knowledge that creates the competitive advantage in today's economies and ERP systems are able to provide a part of this competitive advantage.

ERP systems of today do not only display the company's communication network, nor do they limit themselves to the main production area. These ERP systems claim to be able to display the whole company network, monitoring and reporting all processes. These processes may include value-added and non-value-added processes.

After having a look at the ERP systems from history to its usage today, the next chapter will have a look at auxiliary work and processes.

3 Auxiliary works

This chapter will have a look at the different auxiliary processes in the company. Companies do not only consist of main production line(s) with production process(es). All other processes that support and secure the running of the production line(s) are auxiliary processes. These processes are necessary, even though not necessarily value-adding.

In order to get a grip on these processes, this chapter begins with a definition of the term before having a look at the processes.

3.1 Definition

Contrary to the previous chapter, the understanding of the nature of auxiliary work and processes is quite similar throughout the literature. There is a basic consent of what definition is to be used.

One of the definitions is provided by Dima. Dima describes auxiliary processes as *"... processes performed along with the basic production processes and lead to making some production or works which are not the object of the company's basic activity but provide the conditions necessary to achieve the basic processes"* [10].

A second definition is given by Kramer in German, stating: that auxiliary processes and service functions only support the direct value-adding activity. They are required to add value but they do not add value directly themselves[27]. Kramer defines auxiliary processes as processes that support the value-adding processes. They are required for the value-adding processes but do not add the value itself. Examples of such processes are:

- Tool exchange,
- Transport and manipulation,
- Machine maintenance[27].

From an administration and management perspective, all of those non-value-adding processes are losses. These losses occur due to the incapability of efficiently producing the main products in the production line. In order to achieve a higher efficiency and productivity of the company, these losses should be eliminated[27]. This view seems to stand totally contrary to the view point of Dima, who emphasises these processes as necessary conditions for production[10]. The auxiliary processes remain under the authority of auxiliary departments (e.g. maintenance department) and are from an organizational point of view separate from production.

From the two definitions above, it is possible to to define auxiliary processes:
Auxiliary processes are required in the company to support the main production processes. These processes do not add any value to the product itself, but ensure the production as background processes.

After defining the term of auxiliary processes, the next chapter is going further and will have a look on the nature of value-added and non-value-added processes.

3.2 Maintenance

In order to get a common understanding on what maintenance activity is and what it contains, this chapter begins with defining maintenance.

3.2.1 Definition

Machine maintenance is one of the auxiliary processes mentioned by Kramer[27]. B.S. Dillhon defines maintenance as:

„All actions appropriate for retaining an item/part/equipment in, or restoring it to, a given condition.“ [9]

Maintenance can be understood as all activities that have the target to maintain something or to restore it back into a given state. The maintenance content might be:

- an item,
- a part or component,
- an equipment or machine.

The term “Maintenance engineering“ is closely related to the term maintenance. Dillhon also defines this term:

„The activity of equipment/item maintenance that develops concepts, criteria, and technical requirements in conceptional and acquisition phases to be used and maintained in a current status during the operating phase to assure effective maintenance support of equipment.“ [9]

Maintenance engineering (henceforth: ME) therefore describes the whole framework of activities done in a company in order to ensure the maintenance goals. ME goes beyond the maintenance as such that it approaches the maintenance issue logically. It tries to find patterns and rules for providing maintenance. Thus, ME involves the creation of a maintenance plan (incl. concepts, criteria, etc.) already established during the tendering and purchasing phase of the machines or equipment.

3.2.2 Classification of maintenance activities

Depending on the literature and author, different classifications of maintenance activities can be found. The most basic classification is the classification on behalf of the maintenance time line:

- Preventive maintenance,
- Corrective maintenance (also reactive maintenance)[9] [52].

Preventive maintenance is a term that contains the maintenance activities done before a break-down occurs. These maintenance activities are done due to an established plan. The input data comes either from the machine and equipment supplier's recommendation or is due to own experience of wear-out of different components. These planned maintenance activities should make it more transparent for the company when machine maintenance will happen and should prevent unplanned (corrective) maintenance activities. The objective is to prevent unnecessary and long break-downs due to unplanned maintenance activities. Unavailable spare parts and the standing unfinished production are losses that should not occur as they will diminish the company's productivity and efficiency.

Yet, unplanned break-downs in production require corrective maintenance. This maintenance is in most cases urgent as a machine or equipment not running will cause a loss to the company. Another term for this kind of maintenance activities is reactive maintenance, as it is reacting to a break-down or standstill. The company failed to provide preventive maintenance in time (e.g. by exchanging an almost worn-out component before break-down) and therefore has to react to the given situation[45].

According to Veber, it depends on the company's flexibility up to which extent the company is able and willing to provide preventive maintenance and accordingly, up to which degree it is forced to do corrective maintenance. Refurbishment and corrective maintenance of the machines and equipment is subject to the company's flexibility. Standstills due to machine and equipment failures will have an impact on production possibilities. In case the company has a fixed production schedule, it cannot allow for unforeseen standstills and therefore has to opt for a higher degree of preventive maintenance[58].

Another view on how to classify the maintenance activities is shared widely, dividing the maintenance activities into three different categories:

- Maintaining (autonomous maintenance),
- Repairs,
- Controlling and inspection activities[52].

Autonomous maintenance contains activities done on a daily basis. These activities are done on machines and equipment, or in the workplace area. Items included in autonomous maintenance are:

- Cleaning,
- Lubrication,
- Check-up of machine components.

Usually, autonomous maintenance is done by the machine or equipment operator[45].

The second item is the repair in cases of break-down and unavailability of machines and equipment. Contrary to the autonomous maintenance done by the operator himself, repairs (break-down maintenance) are subject to the maintenance department in the company. In case of companies not having their own maintenance department, the company will have to rely on external maintenance support. Repairs have the task to eliminate the reason for the standstill and to make the machine and equipment available again for production[45].

The third item of this maintenance classification is the check-up activities. These activities are done in order to collect information on the status, wear-out, etc. of the machine or equipment. Also included into this item are the inspection activities for all measuring and controlling equipment that ensure the correct working of the production line and are therefore necessary for production[45].

These three items together create a logic framework for the maintenance activities. Maintenance acts as a service activity for the machines and equipment, thus in a greater scope, for the whole production operation. The task includes the availability of the machines and the correct functioning of machines and equipment. Thoroughly provided maintenance is therefore a tool for production and product quality[45].

The German standard institute issues German standards with the abbreviation DIN. One of these DIN standards, DIN 31051, deals with the maintenance activities and divides maintenance in four different categories:

- Wartung (maintenance),

- Inspektion (inspection),
- Instandsetzung (repair),
- Verbesserung (improvement)[7] [8].

This approach of maintenance classification increases the number of maintenance items to four. The German standard takes also the improvement in maintenance activities and in the maintenance concept into consideration. This improvement does not mean the improvement of the quality of the maintenance activities, but it means the direct machine and equipment improvement due to the usage of better, more actual components when disposing the original ones. The outcome should be higher productivity, higher quality, and / or a higher lifetime expected for the given components. A similar concept can be found in the American literature, shortened to the abbreviation MRO (maintenance, repair, overhaul) where the linkage between maintenance and production is emphasised and gets into the centre.

The different maintenance approaches given in the various theories have an even wider range in practice. It is up to each maintenance and production department in individual companies to decide which concept suits best. The company philosophy and the flexibility of production is a determining factor of which concept should be chosen.

The next chapter goes deeper into the existing maintenance frameworks.

3.2.3 Maintenance frameworks

Production and quality philosophies developed in the recent years are barely comparable with the initial understanding of these two terms. Today's determinants focus on the customers' understanding and requirement of production and quality. Higher customer requirements towards suppliers urged the suppliers to develop their facilities and philosophies accordingly. Suppliers had to adapt the concept of continuous improvement into their philosophy.

Auxiliary activities like integrated quality and service processes directly and indirectly related to production are part of the whole company's framework. Therefore, these activities have to be monitored, controlled, and managed. Companies understood that auxiliary and service activities do not add value to the product, but were able to decrease costs that have to be added to the production costs as overhead[42]. An overview of the maintenance concepts can be found in the following figure:

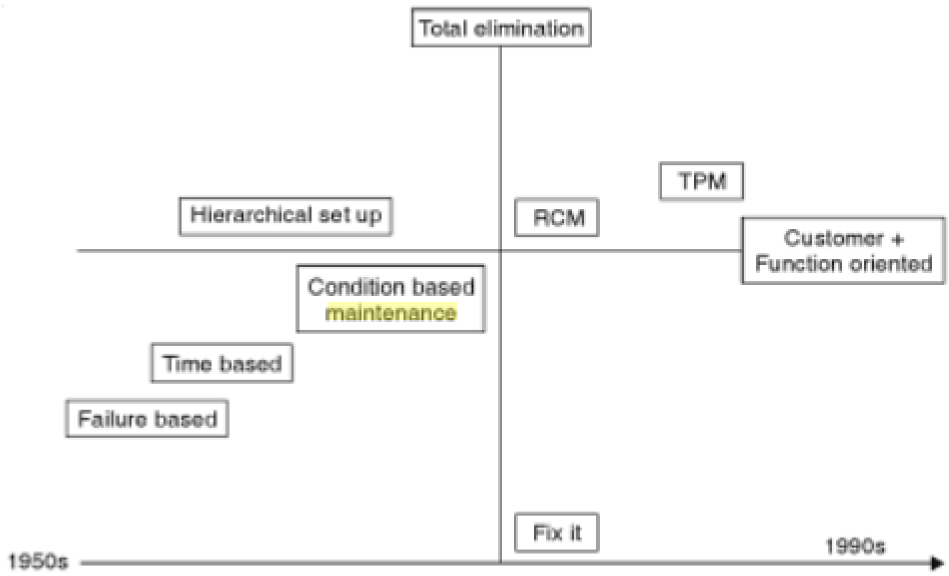

Figure 5: Evolution of the maintenance concept [35]

The figure shows the time on the x-axis between the years 1950 and 1990. The y-axis shows the maintenance activities. Maintenance can only be the repair of equipment (here: fix it) or it can be a tool for increasing company productivity. The strategic decisions behind this are intended to lead to the complete elimination of break-down losses and the related repairs[7] [8].

The beginning of the 1950s only knew the oldest maintenance concept, the so-called failure-based maintenance. Maintenance activities were only done in case of failure (break-downs). The only way to get machines and equipment back to work was to do repairs. Planning of maintenance activities or further items of maintenance theory discussed above were not yet in existence in the companies. When it came to the need, the companies did repair maintenance[35].

The area on the other side of the time axis shows the modern maintenance concepts:

- RCM (Reliability-centered maintenance),
- TPM (Total productive maintenance).

RCM is a concept that combines and integrates former existing concepts into one. For various issues, further values and variables can be defined and monitored . An example are maintenance activities that are done in exactly pre-defined intervals (e.g. recommended oil exchange for cars) or due to exactly pre-defined consumption numbers (e.g. maintenance after 300 pieces)[35].

Depending on the nature of the variable that has to be monitored, the company has to find the ideal approach for maintenance activities. Not all variables can be tracked through intervals. There are also differences in whether the maintenance needs a few minutes or whether the maintenance activities require a bigger time slot and have to be planned (also with respect to the purchase of spare parts). TPM is an approach that focuses on the link between production and maintenance trying to support production (tracked through the variable of productivity) by eliminating all losses in the company through proper maintenance[35].

RCM and TPM are conceptional approaches that introduce a process approach the maintenance activities. The company is then able:

- to forecast the spare parts‘ requirements,
- to provide fast problem-solving maintenance,
- to achieve higher machine and equipment availability[35].

In order to get a better understanding of these conceptions, the next chapter will have a look at the RCM approach.

3.2.3.1 RCM

RCM is a concept invented at the end of the 1970s. This maintenance concept relies on the process approach. From the primitive maintenance activities it had taken approximately 20 years of monitoring and understanding, until this concept was developed as:

- the failure-based maintenance concept was already outdated before the 1970s,
- and more developed concepts were missing.

The underlying theories of this concept were published in 1978 by the Department of Defence of the United States. The maintenance subject was the air force. The goals and focuses of this research activity was related to the flight safety and the reliability of the equipment. That is also how this concept came to its name RCM (reliability-centered maintenance)[36].

The RCM concept combines the three existing approaches:

- Failure-based maintenance,
- Time-based maintenance,
- Condition-based maintenance.

The following figure compares the different maintenance approaches:

	Failure-based	Time-based	Condition-based
Properties	- After failure occured	- Tries to avoid failure through service intervals for part exchanges and inspections	- The wear is stated and further action is planned based on the condition.
Requirements	- Spontaneous and fast working, - maintenance worker‘s capability, - spare parts on site	- Planning of maintenance personnel and spare parts.	- Laborious inspections, - often with sensors
Usage	- Equipment with small probability of failure,	- Equipment where time between two failures is	- Equipment that allows for extensive monitoring

	- small units, - noncritical equipment	known	and analysing
Advantages	No cost if no failure	- Maintenance can be planned, - Availability should rise	- Ensure high availability
Risks, Disadvantages	- Production standstill	- Part exchange, even if it is good, - No guarantee for availability, - Failure can occur within intervals	- High cost for monitoring

Figure 6: Comparison of existing maintenance concepts[12]

The RCM concept tries to use the strong sides of all three mentioned strategies. For the shortages, the concept tries to eliminate these shortages by substituting them with strength from one of the other two concepts. In case that one of the strategies does not work as predicted, it is possible to switch to another strategy. Still, the RCM is dealing with the reality that for some maintenance requirements, it is possible to plan the maintenance activities without any further issues whereas other maintenance activities have to be done on an urgent basis at the time of failure[36].

Even though there is a concept widely used, each company has to find its way of dealing with maintenance due to the production requirements. RCM is in this case mostly used as a method for budgeting and cost monitoring of maintenance activities. To a certain extent, also maintenance departments have a budget that they have to follow. On the other hand, unplanned maintenance costs (due to a non-forecast failure or due to a bigger scope of maintenance required) have to be borne in order to ensure the production. It is therefore on the company and the company strategy to decide which ratios should be used in RCM between the different underlying logics.

3.2.3.2 RBM

RBM is an abbreviation for risk-based maintenance. This concept is not related to RCM as it uses different, though similar strategies. These strategies are [22]:

- Run to failure,
- Preventive maintenance,
- Predictive maintenance.

In some literature, preventive maintenance and predictive maintenance are erroneously used interchangeably. Predictive maintenance:

- is going beyond the concept of preventive maintenance,
- deals with the optimisation of life cycle cost (LCC)[22].

As usual in risk-assessment approaches, also RBM has its basis in the theory of probability. The statistical information should help to assess the failure risk. Even though this failure probability does not say anything about the threat for the company, it is an important variable in the calculation. Another important variable is the probable impact caused (e.g. in terms of cost). It is therefore a difference whether the equipment is used frequently and is a bottle neck in the company or whether the company can afford the standstill for a while. This is why probability and impact are used to determine the risk[42].

The risk assessment is then the basis for the decision which maintenance concept should be chosen for the given machine or equipment. As the question of which method should be chosen is fundamental in RCM, the RBM is often used as basis prior to RCM implementation[42].

3.2.3.3 TPM

TPM is used for

1. Total productive maintenance (as understood in this thesis),
2. Total productive management,
3. Total productive manufacturing.

The predecessor of the TPM concept was the PM (Productive maintenance) concept that was developed in the 1960s to combine Preventive maintenance, Corrective maintenance, and Maintenance prevention. In this approach, all maintenance activities are clearly defined and the authority dealing with the maintenance concept and activities is the separately-existing maintenance department[42].

At the end of the 1960s, the PM concept was developed further to the TPM concept. In TPM, the maintenance department is not alone responsible for the maintenance activities in the whole company. The maintenance activities were divided between the maintenance department and further departments within the company[42].

The operator's job description was widened to the ability of checking and to maintaining the machine or equipment, as well as the whole workplace[42]. The reason for this change was that:

- smaller maintenance activities could also be done by operators,
- no expensive and specialised personnel was needed,
- the operator got a tighter link to the machine.

The ultimate target of TPM is zero break-down, zero scrap, and zero accidents. The available time should only be used for work. For this, all losses must be eliminated. TPM is based on 8 pillars in order to achieve these goals:

- Orientation on improvement,
- Autonomous maintenance,
- Planned maintenance,
- Training and knowledge development,
- Preventive maintenance,
- Maintenance quality,
- Improvement in administration,
- Environmental safety.

Top management and all departments in the company have to understand that maintenance is not only a cost item but very closely related to the company goals. Machines and equipment are one crucial factor of the successful production of products required by the customer. Available machines have to secure these goals.

The maintenance goals do not only apply to the product quality. Today's system audits also include management systems, production management, and quality systems[53]. The production quality has to ensure that the correct production steps are concluded in the right time. This production is done as planned and promised to the customer.

All losses in the company result in a productivity loss without limitation to the maintenance and production department. Suzuki therefore developed a two-level TPM:

- Production-department TPM,
- Company-wide TPM[55].

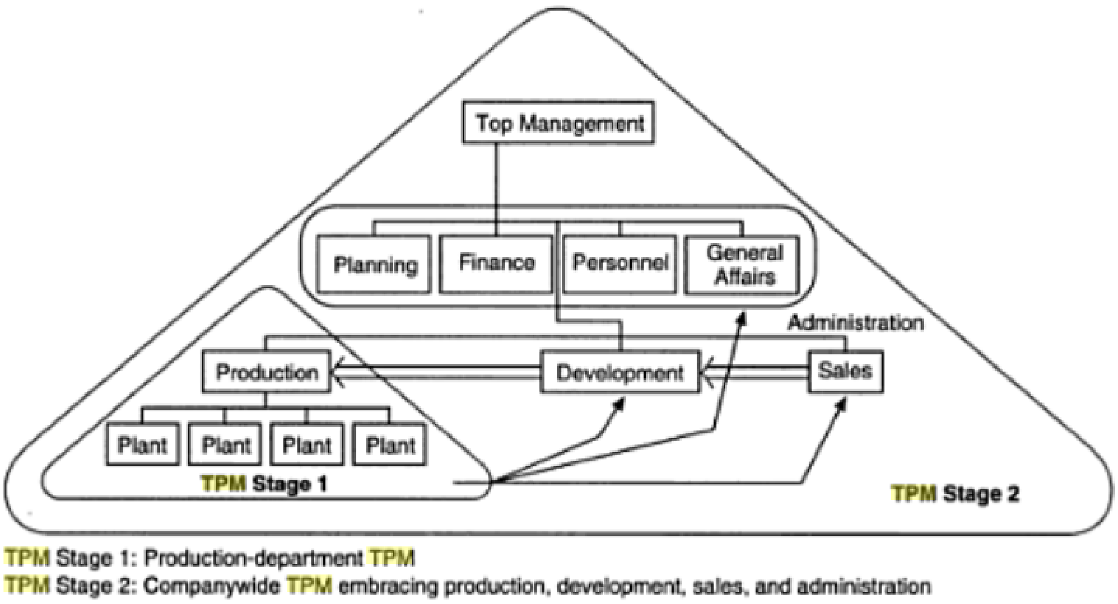

Figure 7: Two-stage TPM[55]

Suzuki understood already in the 1990s that TPM had to be supported by all units in the companies, be it departments or different shop-floors. In order to involve all employees into the TPM concept, he decided to first introduce TPM to production and the to link it to all other auxiliary and service departments.

3.2.4 CMMS

Computerized Maintenance Management Systems (CMMS) were developed to monitor maintenance actions in the company. They are also known as Equipment Management Information Systems (EMIS). The task of these systems is to store and distribute important maintenance data and to make them available at any given time. The CMMS has to ensure data to be:

- correct,
- actual, and
- meaningful[62].

The requirement on data leads to individual CMMS differing from company to company. According to Wireman, a significant amount of those systems is also created in house[62]. The systems are closely related to the way of how maintenance is working in particular companies. Further they determine the way of:

- how data is collected,
- how maintenance is organised,
- how supporting processes (e.g. purchase) are organised,
- which data is to be reported to the management[62].

One task is to support the reporting of maintenance actions to the higher management levels. These levels need correct and accurate data in order to make use of the system as a whole. The system is in therefore a supporting tool for decision-making as far as maintenance is concerned. Figure 8 shows the standard modules required for a CMMS.

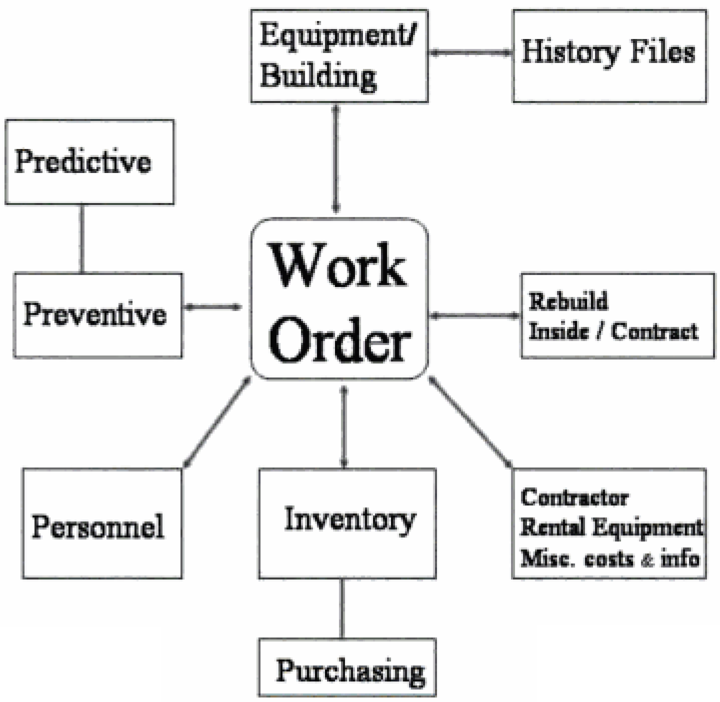

Figure 8: Standard CMMS modules[62]

Wireman characterises CMMS as an important tool to support TPM in an organisation. In reality, companies found the following issues preventing achieving targets:

- inaccurate data,
- not-utilised data.

As with all computer support systems, it is important to make use of the data. CMMS is no exception. A CMMS can therefore also be a part of ERP systems implemented as a maintenance module. According to Manzini et. al. many companies fail to link CMMS and ERP systems in reality[33]. The companies require:

- higher availability of machines,
- more accurate time and cost estimations,
- better planning of maintenance activities[63].

CMMS are therefore tools to allow maintenance to go for a zero-loss approach, as given in the TPM concept. The zero-loss approach requires the company to eliminate all kinds of activities and patterns that result in losses and which affect the Overall Equipment Effectiveness (OEE).

Availability	Performance	Quality
Set-up & Adjustment	Minor stops	Scrap/ Rework
Breakdowns	Reduced speed	Start-up defects

Figure 9: 6 big losses[51]

While contemporary literature has identified the six big losses shown in figure 9, other publications identified a higher number of losses in a more differentiated manner. Maintenance and maintenance management are a strategic tools to reduce and eliminate those losses. Thus, it makes sense to use CMMS in order to reduce maintenance costs, the *"largest controllable operating cost"* [34].

CMMS were further developed into CAS (computer-aided standardisation) systems. These CAS increased the range of data stored and distributed amongst others by:

- work and technological process description,
- standard activity time,
- required standard tools.[38].

The CAS is an approach working in an integrated environment by trying to collect and use standardised data for activities. The wide range of maintenance activities are a challenge to map. The approach of the CAS is to establish standards for preventive maintenance actions and to eliminate breakdown maintenance losses. This should bring down the six big losses.

3.2.5 Total integrated maintenance

Total integrated maintenance (TIM) brings maintenance another step forward. It counts on maintenance conducted as given in the TPM framework[40]. Further, it makes use of the company's information system. Data and information required concerning machines and equipment are:

- identification of all machines and equipment in the system,
- regular diagnostics to assess the status of each equipment,
- creation of a full “CV“ for each equipment evidencing all maintenance actions.

The information gathered from the data collected is used for further actions in the workflow, such as:

- planning and anticipating maintenance and repair activities,
- planning and monitoring spare part purchases,
- planning maintenance blocks into the production plan.

As with the TPM concept, also TIM relies on the co-operation of operators and shop-floor personnel during:

- autonomous maintenance,
- co-operation of maintenance and production workers during maintenance,
- regular training of production personnel.

The TIM concept relies on a thorough controlling of maintenance and further activities. Findings during maintenance actions are used as tasks to be solved. Conducted analysis from gathered data can bring a further development into companies through visualisation and alerting. Such analysis might have an impact on the following areas:

- finance,
- purchase,
- maintenance,
- production.

TPM is a concept focusing on its eight pillars; in the first stage only for maintenance department, in the second stage for the whole company, TIM focuses on the usage of data gathered by conducting maintenance actions. TIM is seen as an integrated system to bring TPM and computer support systems practically together.

The next chapter will have a look at the link between production and maintenance in companies.

3.2.6 Link between maintenance and production

Maintenance is a service and auxiliary activity in companies. Maintenance has a crucial part in the company network and is not limited to component exchange. If managed strategically, it is possible to significantly reduce costs, even though maintenance is always regarded as an item creating them.

Machines and equipment (capital) and human resources are together with the raw material main inputs in the technological production process. These processes are a set of activities required to create the required output from the available input[43]. The process inputs are:

- Input material,
- Human resource/ Operator,
- Technology and machines/equipment.

The lack of any of those input factors can not be compensated. Auxiliary and service departments like logistics and planning have to ensure the availability of input material and the correct material flow within the company.

In case of a break-down, the output of the whole machine or equipment production is zero. Besides break-downs, there are also other issues in production which require maintenance:

- Tool correction,
- Component correction (e.g. screw fixing),
- Calibration, etc.

These smaller issues do not necessary mean that the equipment is idle. But the output product quality is not according to the requirement and there is a tendency that this issue will go on with the next production pieces. Therefore, maintenance (provided by production or the maintenance department) is resetting the machine to allow for the required product quality. In case of a small maintenance activity, the operator or pre-setter is able to conduct this activity.

The production is not only depending on whether the equipment is on break-down or not. Even more, it is also depending on the manufactured quality of the products. Also OHS guidelines have to be followed in order to keep the operators on the shop-floor safe. Maintenance therefore has a higher task than only to provide functioning equipment for the production.

Therefore, maintenance plays a major role in the daily production business. Break-downs and repairs are only one side of the required maintenance aspects. It is more the target to achieve higher availability and to maintain this high level. The quality of production and products can be expressed by the number of good pieces produced by equipment. This number is higher with better maintenance activity. With this, the link between maintenance and the productivity of production lines are established such that both contribute to company revenue. Therefore, maintenance is an investment into the production and the machines and equipment.

In case of other dimensions of maintenance activity it is harder to show the link between maintenance and production quality, productivity, and also revenues. The company and its management have to understand, that losses are crucial input factors. The same is valid for human resources, its skills, and the question of exchangeability.

Maintenance can be easily understood as a tool to allow equipment functionality, furthermore to secure quality and to comply to the OHS guidelines.

4 Methodology and targets

This dissertation thesis is based on its title by dealing with the research and development of computer support for maintenance, including:

- maintenance (repair, checking, etc.),
- installation (dis- and re-assembly),
- other auxiliary work,
- service work.

The thesis is focusing on the optimisation of production with the help of computer support of the whole maintenance process in an existing production company (name withheld). It is the target of the thesis to develop a new proposal for the maintenance system based on the TPM approach and its practical application. By acquiring and processing data the system has the task to provide a foundation to increase the compatibility of the company through increasing the machine and equipment availabilities. Further, a higher availability of machines and equipment should lead to a higher productivity in production.

The previous chapters gathered the theoretical basics to make an analysis of the company and its current situation. Currently available systems and software providing computer support for companies developed during the recent 50 years. The range is widespread, providing sophisticated software tools for:

- central ERP systems,
- CAx,
- further specialised software.

While the specialised software and the underlying concepts are already existing in theory, it is the aim of this thesis to provide a framework for the part of maintenance, basing on:

- TPM,
- CIM,

- TIM.

This thesis is limited to the section of computer support in the area of maintenance and its further processes. While the basic research is already done and was presented in the previous chapters, this thesis has the aim to bring the topic of computer support for maintenance and its related processes a step further.

It is the aim of this thesis to make use of already invented frameworks and develop them a step further towards DF's. DF's provide a framework to plan and control the ongoing events in companies by visualising all processes. The result is a complete picture of the company on a computer screen. In order to get such a complete picture on the computer screen DF's require:

- actual and accurate data,
- visualisation software,
- software integration to make corrective actions.

This implies that DF's require data from all kind of resources, amongst others:

- raw, semi-finished, and finished parts,
- machines and equipment,
- operators and personnel.

Machine and equipment information have to be gathered from manufacturer's manuals and from historic data. Different subsystems have to work efficiently together, such as:

- ERP,
- planning,
- standardisation,
- CMMS.

Therefore, the practical part of this thesis covers proposals for these software and modules.

The proposal is shown on a case study of a Moravian-Silesian company that has been on the market for 60 years. The company faces the situation of ageing machines and equipment that require higher amounts of maintenance. While the company uses computer support through ERP and CMMS systems it is dealing with increasing cost in the maintenance area.

The company faced a situation of a one-month standstill in production due to the standstill of key equipment at the beginning of the production process. The company was not able to cover the loss of production capacities in the short term which led to a complete standstill of the production of the whole company with the following effects:

- one-month delay in production,
- shifting all orders backwards – smaller production quantity,
- decrease of production capacity.

While the proposal in this thesis wants to overcome the shortcomings mentioned above, it puts a strong emphasis on maintenance to:

- decrease total maintenance cost (incl. downtime cost),
- increase of compatibility,
- provision of a systematic approach for long-term maintenance tasks.

The benefit from this analysis shows the requirement to also include maintenance and its processes into a company-wide computer support system. The integration of different systems leads to the topic of DF's that require the integration of all kinds of systems in order to display the ongoing in the factory properly. Therefore, this thesis develops the concept of DF's in the maintenance area.

For the maintenance and the integration of the before-mentioned systems, preparation must be done. The standardisation of maintenance activities and their whole processes are done based on predetermined motion sequence time (MOST). With this, it is possible to generate the standards of the first (if not already available) and second level. Further standards will be computed through the CAS system. A checking cycle is implemented to check the CAS data with the production data acquisition system.

The maintenance system develops into an integrated system based on data taken from production. The system can lower the effort required to provide maintenance and has to further enhance the state of machines and equipment. The system must ensure the projectability of production and maintenance and their full preparation.

The theoretical basics are taken from Czech and international publications. The maintenance approach is linked to authors such as Shirose and Suzuki and to the JIPM, an institute dealing with productivity. Rationalisation and its usage in various fields is closely linked to Japanese research and economy. The basic philosophies are thus taken from Japanese authors in this area. Further international publications from various countries are taken into account to get a picture of the development in the maintenance area.

While PM, TPM, and further approaches have its beginnings in Japan, for integrated systems such as

- CIM,
- TIM,

are also present in Czech literature and Czech authors contributed to their development. The trend towards integration is based on the increased capacities of processors and pre-defined interfaces. These interfaces make it possible to link software solutions together and are available either as standard or as customisation. Interfaces allow for machine-to-machine communication to make processes faster and to eliminate human errors.

Interfaces are required to link various specialised software solutions to the ERP system which is the central software tool in companies. The vast majority of applications are linked to the ERP system which is storing and distributing all vital data. As these ERP systems including different modules such as planning and maintenance are used worldwide and in various branches, the literature is also coming from resources worldwide, amongst which there are American, German, and Czech authors.

Another package of software solutions is represented by CAx technologies. Computer aid is used widely in technological branches such as for:

- manufacturing,
- planning,
- design,

for which a wide range of international literature is available. For the mentioned CAS module, literature is mostly available in Czech. The CAS system as a development of the CMMS is a part of TIM. The international publications from Germany, America, and India are focusing on CMMS systems. The CAS does not only include the data from the CMMS but extends it to the usage of technical processes and standardisation.

Standardisation includes different techniques such as activity sampling or MOST. Literature is available from various countries and is practised in different parts of the world.

The literature review shows that publications are available for almost all software solutions separately. For integrated systems, less and less literature is being published. As CAS is barely mentioned, the topic of its integration into a company sphere is lagging. Therefore, it is the aim of this thesis to target the integration of the CAS to develop a suitable system to manage actual maintenance shortcomings.

The proposed system integrating ERP and CAS is based on standardisation and reliable maintenance planning. The case study of a production company shows the basic architecture of the system and the benefits companies can generate through a different understanding of maintenance and its character.

Summarising, it can be said for the hypothesis:

The target of this thesis is to find answers for the following questions:

1. Is there a systematic approach on maintenance with computer support that allows higher availability of machines in the production line?
2. Is it possible to use an integration of ERP and CMMS to achieve point 1.?
3. Does this system allow for standardised maintenance activities?
4. What are the basic characteristics of the integrated system?

5 Practical part

5.1 Introduction

The legal definition of a company is that it is an entity with the aim to create profit. In order to be able to create profits on the market, companies have to withstand competition and have to react to the daily challenges arising from competitors' impulses. Computer software is able to support the companies in this aim.

Computer systems have been developing over the years and are today able to even organise production itself (e.g. fully-automatised welding lines). However the reality is that some production are still functioning at a low level of automation. Computer systems are put to use in every department throughout companies. In doing so, computer support is seen as a means to achieve competitiveness.

ERP systems are widely used in companies throughout all sectors in order to decrease data distribution time. Lowering the distribution times leads to a compression of time required for acquiring decisions, feedback, or further data. Further, these systems are able to monitor the ongoing activities in the company.

While the ERP as the central computer system in the company, is able to distribute and process data in order to transform it into information, the companies rely on human beings to work with the system. Misunderstandings and losses occur on the interface between man and system.

5.2 Subject of analysis

The company is relying on several production lines in the second part of the manufacturing process. All these production lines are fed by only one production line, consisting of five machines, in the first stage. All machines are of the same age and almost 60 years old.

As representative for the case study one of the machines was chosen. The machine is a hydraulic press with the following characteristics:

- pressures (65 megatons),
- product temperature (> 1000°C),
- humidity (> 80%).

Due to the insufficient maintenance approach of the company, the machine went out of service for one month. The effects were:

- one-month production delay,
- incomplete breakdown maintenance was conducted due to time pressure,
- one month of production capacity was lost.

Conveying the effects into monetary terms, the result was a loss of approx. 500 million Czech Crowns (equivalent to a one month revenue). Further, there is the threat that the incomplete maintenance provided would lead to another breakdown in the future. The cost for this breakdown might be equivalent or even higher as the temporary fixation might not be possible in future cases.

In order to avoid unforeseen maintenance costs and unwelcomed breakdowns, the approach in this dissertation thesis is to make maintenance projectable. Theoretical concepts such as TPM provide the framework to prevent machines from breaking down. Autonomous maintenance (incl. controls to be carried out in a certain interval of time) and periodic maintenance activities should ensure that breakdowns are eliminated. Failure-searching and the upcoming connection of trials and part exchanges consumes valuable time and spare parts.

The approach is based on the following components:

1. Standardisation of maintenance works,
2. ERP system for maintenance data distribution,
3. TPM approach with autonomous and predictive maintenance.

5.3 Presentation of the company

Different concepts exist in operation in order to organise the production and its interdependent areas. Operations may include:

- production,
- procurement.
- maintenance,
- quality, etc.

Maintenance may be done

- externally,
- internally by a separate department,
- internally within the production department (usually in smaller companies).

In the given company maintenance is done by a separate department belonging to the field of operations.

The analysis was carried out in a heavy industry company, in the Moravian-Silesian region of the Czech Republic. The company produces only one product group, of which there are only two product types in variations according to the customer's requirements.

The production can be characterised by.

- lot production (lots between 20 and 500 pieces),
- three-shift production (22,5 hours per day),

- continuous production (7 days per week),
- universal machines used for the products,
- raw products arise only from one product line,
- finished products are manufactured from different product lines.

The company itself belongs to a small, oligopolistic industry. In the recent 20 years has been expecting steady growth in revenues and quantities. The revenues and quantities also exceeded the budgetary plans.

Along with the increase in revenues, an increase in production capacities, workforce, and maintenance force was required, leading to an increase in the maintenance budget. Together with the production capacities the requirement for maintenance also rose:

- for old machines which were not replaced as planned,
- for new machines with were additionally bought.

With the steady growth, the company was able to present the following numbers for 2015:

- revenues: approx. 220 million Euro (6 billion Czech crowns)
- workforce: approx. 1700 employees
- output: 180 000 products/ year
- planned output for 2016: 200 000 products / year
- number of machines: 70

While the company has been growing continuously in the recent years, the maintenance department has experienced a growth as well. Therefore the maintenance department consists of:

- maintenance workforce: approx. 50 employees,
- maintenance divisions: 4,
- maintenance budget: 770 000 000 CZK per year.

The organisation and maintenance organisation scheme can be found in ANNEX B – Organisation schemes.

Maintenance is divided into different divisions (see ANNEX B). The company can be divided into three divisions:

- raw part production,
- finish part production,
- painting, packing, etc.

The maintenance department is divided into four divisions, whereas two divisions are responsible for the raw part production area and the other two are responsible for finishing and painting, packing. In both areas, there is a mechanical and an electrical maintenance division in order to take proper care of the different needs of the machines.

Maintenance is conducted following a maintenance plan. This maintenance plan includes:

- annual electrical maintenance on 1st May,
- weekly maintenance of the raw production line (whole production line),
- planning of maintenance activities as required,
- breakdown maintenance in case of any repair required.

The third and fourth items above require the most attention as they can occur suddenly and have to be scheduled into an already-planned production schedule. The result is:

- pressure on the maintenance personnel to finish work as fast as possible,
- pressure to skip the testing phase after maintenance works are conducted,
- pressure on the operators to work faster to get back to the initial plan.

Further:

- spare parts are not available,
- other planned maintenance activities have to be shifted having a direct effect on the established plan again.

The result is a reacting maintenance system that does not provide any protection from future breakdowns. The machines are usually used as long as possible in order to achieve the highest output in the meantime. The maintenance as such does not forgo any issues that might be able to occur.

With the machine park getting older, the company faces an increased requirement of financial resources in maintenance. Instead of decreasing the maintenance budget the company is forced to increase it while these issues persist:

- machine availability is much lower than planned,
- maintenance budget is much higher than planned,
- breakdowns occur more frequently than forecast.

The maintenance situation is not satisfying for the company management. The frequent occurrence of breakdowns in the company means a high risk of losing revenue and customers as new competitors from overseas try to get into the market. The task of the company management is:

- to increase revenues,
- to increase reliability for all deliveries,
- to decrease costs.

The pressure on the management led it to think about the maintenance management in the company. A change to its maintenance approach in order to support the company targets was seen as required and left room for the development of a more reliability-focused approach.

5.4 Current situation

The current maintenance plan shows that maintenance is done when required. The past shows that there was an overhaul block for the whole production line each second year. This overhaul block had a duration of three to four weeks. However, it was not able to prevent the line from breaking down.

The main issue was the size of certain issues and the limited spare parts available for the machines. This led to constant delays of maintenance / part-exchange activities. The machines were fixed as good as possible. Spare parts were not ordered afterwards. During the next overhaul the fix, again, was only temporary as the spare parts had not been available and not in stock.

As the press line is the only line feeding the rest of the company with raw parts, a standstill means a standstill for the whole company. As there is no fall-back scenario, the company is not able to shift their production elsewhere. The line is still suffering from two factors:

1. age of the line (approx. 60 years),
2. product change requires higher forces to be applied.

The second point has become more important in the recent decade. The assortment changed towards a higher percentage of heavier products to be produced. Modifications had been done to prepare the line for this requirement. It was decided to keep this line and not invest into a newer one.

The breakdown of one of the presses in the line brought the line to a stop for one month. The spare parts were again missing. Therefore, the line was temporarily repaired within four weeks (one week was anticipated to be needed half a year later). The outcome was:

- Revenue generated for products produced in this month: 0 (500,000,000 CZK less than normal),
- The one-week maintenance block was needed for other repairs and activities,
- The production of all parts was in delay, parts had to be sent by costlier airfreight,
- The temporary solution lasted approx. six months until a further breakdown (same issue) caused the same effects. Again, the repair was temporary.

The strategic management of the company is seeing two options to overcome these issues:

1. purchase a new line,
2. review and adjust the management approach in order to have a balanced cost-benefit-ratio.

The company decided that the purchase of one machine would only eventually shift the issue to the other machines. Therefore, option 1 deals only with the purchase of the whole line. The approach followed in the next chapters deals with a proposal how to follow option 2.

5.4.1 Current maintenance approaches

The current maintenance focuses on a reacting approach. Preventive or predictive maintenance concepts are not applied, except for the autonomous maintenance done by the operator.

The operator is providing autonomous maintenance for his machine at the beginning of the shift due to an existing autonomous maintenance plan. In case, a failure or an indication of a failure is detected during his operation or during autonomous maintenance, maintenance might be scheduled and planned before an actual breakdown existed. This relies in a lot of ways on coincidence whether or not the operator recognises any potential issue.

The analysis of the current maintenance system shows a variety of different ways used due to a historic development. The approaches seem not to follow one consistent rule but are subject to how it had been done from the time the machine or equipment had been installed. Altogether it can be summarised:

1. Maintenance activities are sometimes entered into a maintenance database (CMMS). This database displays:

- the starting time and ending time of the maintenance work,
- the name of the maintenance worker,
- the machine the maintenance was conducted on,
- a short description (text) what was done.

The maintenance system lacks further information such as:

- production parameters,
- reason of breakdown,
- maintenance cost (spare parts, etc.),
- drawings, parts numbers, and further information,
- detailed description of diagnostics applied.

This maintenance system is applied for some machines, but not for all. The reason is that only machines that belong to the value-added chain are considered.

2. Entries in the CMMS are not shared with other systems in the company. Other departments cannot access the data and cannot use them in order to facilitate the company's systematic approaches, such as logistics. The CMMS system is only used internally in order to:

- report the maintenance tasks,
- as evidence for the production employees to justify the lower output,
- as evidence for the production area leaders.

It can be deduced from these points, the production leaders have no clear picture has to what maintenance tasks are carried out. There is no link between maintenance, production, and logistics that gives a clear picture for all what is going on. A system that brings production and maintenance together does not exist.

3. There is no diagnostics carried out in order to do preventive maintenance. Analogously, there is no system for maintenance diagnostics existing in the company. Only the coincidental findings of the operators during their autonomous maintenance round may lead to a maintenance activity.

4. Except for the autonomous maintenance, the company does not use any means to provide preventive or predictive maintenance. Maintenance is done when repair is required and the breakdown state already occurred. Maintenance is planned in fixed (usually yearly) terms and requires the machines and equipment to last until this time.
Preventive maintenance takes place only in case the operator assumes an issue during his

autonomous maintenance session. Maintenance can only be conducted when spare parts are available. These unplanned maintenance blocks require company logistics to update its planning and to shift other production orders.

5. The spare parts management is done on the basis of experience. The data from experience are not actualised regularly and do not represent the actual needs for spare parts in the company.

The spare parts are ordered on a regular basis. The company's ERP system gives the impulse to order by checking the actual pieces versus the required pieces on stock. The ordering is later done through the purchase department without a feedback from the production or maintenance departments.

The spare parts are not ordered and stored as required in the current situation. Spare parts are only ordered based on the quantities required. The lead times of these parts are not considered. As a consequence, the stocks are full of parts with a short lead time while parts with long lead times are not available when required. This leads to a longer downtime.

The spare parts' stocks evolved over the years. Stocking is done based on experience and historically grown structures. The most required spare parts might therefore be in the last corner and not accessible, whereas spare parts rarely needed are in the first row ready for take-away.

The inventory on stock is about 1300 million CZK.

6. The machine operators have a plan for autonomous maintenance. This plan describes the basic actions to be conducted:

- check
- clean,
- maintain/repair (smaller maintenance actions such as changing filters).

There is no evidence whether the autonomous maintenance is carried out by the operator. There is a monthly audit conducted by the head of production and the head of maintenance where it is checked whether the autonomous maintenance was done. As this is known beforehand, the effect of the audit should be tending towards zero.

7. The focus of the company and its maintenance is on each task individually. The coordination of the maintenance is done by the logistics department. One occurring, unplanned tasks make it difficult to stick to the plan. The focus on the customers' needs and the internal customers is not present. The maintenance is left to the maintenance department with pressure from top management to decrease maintenance costs.

Other departments

- production,
- logistics,
- purchase,

are only touched if required. In case of an emergency, the beforementioned departments become involved in maintenance. The coexistence of the different departments leads only to a minor degree of cooperation. Systematic approaches to facilitate the maintenance are not pursued. The concept of internal customers and internal suppliers is not respected.

8. Time-wise, maintenance and production cannot use the same timeslots to carry out their work. The time can either be used for production or maintenance, but not both. It is on the logistics to plan the timeslots.

The logistics department plans the timeslots with the following priorities:

a) annual maintenance,

b) production,

c) short-planned maintenance,

d) breakdown maintenance.

This means that the maintenance, except for the annual maintenance, is planned after production is planned. The result is that maintenance is seen as the reason why production is delayed. Logistics itself is not able to change these priorities as the information is not available beforehand.

Production time is further reduced by the autonomous maintenance activities. Autonomous maintenance is carried out at the beginning of a shift. Until autonomous maintenance is conducted fully, the machines are idle and wait for the shift to start.

9. After maintenance activities are carried out related data might be put into a separate software program. The software program has the function of a CMMS. For some machines and equipment that are seen as crucial the maintenance departments make entries in the CMMS program (see point 2).

The relevant data and parameters from the maintenance activities are not taken into the CMMS. This data is lost for the company. Further maintenance activities are conducted without detailed knowledge and information from the activities carried out before. Only a rough overview is present in order to track why the production output was lower than planned.

Financial analysis of the maintenance activities is not conducted, nor is any further detailed analysis of spare part requirements, resources, etc. The analysis carried out is:

- analysis of total maintenance cost by year,
- analysis of maintenance cost by production entity and year,
- a comparison of maintenance cost for machines of the same type in different production entities.

Financial pressure is applied on the maintenance department as far as maintenance cost in total is concerned. The availability of machines and the cost through breakdowns and non-availabilities are not calculated. This financial information is not used for investment and maintenance budgets.

10. While rudimentary financial analysis is carried out based on the data available, other important indicators are not checked. The analysis is only concerning direct cost for maintenance. Indirect maintenance cost, such as stocking cost, is not considered. Total maintenance cost therefore only represents the direct maintenance cost.
The analysis is not used for facilitating developments in the company or in order to change the maintenance approach. The maintenance analysis is seen as a separate issue. The impulse for change among all departments (production, logistics, etc.) is missing.

The maintenance approach of the company is a historically-grown approach. The gaps in the maintenance activities grow bigger with an increase in company size and production amount. The shortcomings of the company require a systematic approach of maintenance. In order to make use of the gathered data, the approach considered is based on the TPM concept and the aim to eliminate the losses related in the production-maintenance-interface in the company.

5.4.2 Current maintenance situation

In reality, it is possible to distinguish three maintenance algorithms depending on the situation:

1. Annual maintenance (ANNEX C, figure 27),
2. Preventive maintenance (ANNEX C, figure 28),
3. Breakdown maintenance (ANNEX C, figure 29),

The annual maintenance is planned with highest priority. The need is known beforehand and the mentioned process is applied.

For preventive maintenance, the algorithm is similar. The difference is in the priority of production and further planning. Preventive maintenance is planned when a production plan is already existing and the quantities are assigned.

Breakdown maintenance requires immediate action. This maintenance activity is directly linked to the output of the company. The faster it is organised and conducted, the faster the company can resume production. This breakdown maintenance process is required when preventive maintenance activities are not able to cover the required scope as it is the case in the given company. Missing information leads to inadequate preventive maintenance activities. The inadequacy shows off in breakdowns that must be covered with a higher amount of other resources (e.g. maintenance personnel).

The processes shown above are taken from the current situation. It shows the maintenance activities as they were conducted in reality. The processes do not fully correspond to the processes that should have been established in the company.

The processes in the papers show a much higher consistency. This means, that the processes are very similar and the algorithm should only be different as far as the impulse is concerned.

As with the consistency, the processes also lack information and logic to a certain extent. Important relations such as between maintenance and procurement or between maintenance and logistics are neglected in the breakdown scenario. The process is taken over by impulsive action. Organisational orders are not taken into account. The situation is not prepared and everybody involved is trying to do something uncoordinated within the limited field of authority that he has.

The result of the uncoordinated work is that crucial departments are not getting informed in time. An example is the maintenance ordering the external maintenance supplier without notifying the procurement department. As a consequence, issues occur during the authorisation of invoices in the ERP system as no proper order was released from the system.

Impulsive action taking place leads to a majority of inaccurate information on the basis of which the company wants to decide and manage maintenance. A further issue is the lack of commitment to diagnostics in the company that are seen as a financial burden. The state of machines and equipment might therefore be different to what it should be. The absence of a TPM-focused approach leads to a higher amount of unplanned maintenance activities to be conducted. Maintenance as a whole is planned on behalf of wrong and inaccurate data, leading to those unplanned maintenance activities, such as breakdown maintenance.

During breakdown maintenance, it is on the maintenance department to conduct the maintenance. The logistics department is informed about possible times of resuming the work. Proper planning can only happen when the correct time frame is known. After that, the logistics department takes care of rescheduling the orders. Depending on where in the production the breakdown occurred, it might be impossible to meet the initial plans.

As data (such as standards) are not corresponding to the actual situation in the company, it might still be possible that the company can ship its goods as planned. Taken from the perspective of a production planner, the company is wasting its resources by not scheduling its production properly. The losses through improper planning are not considered, neither for production nor for maintenance.

From the issues involved in the different maintenance situations it is visible that the biggest issue is the breakdown maintenance. Breakdown maintenance is not prepared and also not properly coordinated. The results are:

- huge amount of productivity and time lost,
- no complete overview on the items conducted and not conducted existing during maintenance,
- no complete data available after maintenance is conducted,
- financial information exists only for direct costs,
- additional work required afterwards due to a lack of system.

5.5 Current maintenance cost

The company is able to generate revenues of approximately 6 billion CZK. The majority of these revenues is generated from the production within the company, only a small part of production is outsourced. Outsourcing is only done in the following cases:

- production capacity are already full,
- the contracts allow for outsourcing (cooperation),
- the outsourcing cost is lower than the internal manufacturing cost.

While outsourcing is done for the finishing operation, all raw products are manufactured in-house. The production of the raw parts is done only on one production line. In order to be able to manufacture all these raw products on the 60-year old production line, the line is working three-shift seven days a week.

From 6 billion Czech Crowns on the income side, the company has to neutralise all its cost, such as:

- material cost,
- production cost,
- labour cost,
- maintenance cost.

Deducting the cost from the revenues, the company gets the gross profit and further indicating numbers on the operational performance:

Revenues	(net sales)
- Cost of goods sold	
= Gross profit	
- SG&A expenses	
- R&D cost	
= **EBITDA**	(earnings before interest, tax, depreciation & amortisation)
- depreciation	
+ amortisation	
= **EBIT**	(earning before interest & tax)
- interst expense	(cost of borrowing money)
= **EBT**	(earnings before tax)
- tax expense	
= **EAT**	(net income)

Figure 10: Calculation of EBITDA and net earnings from revenues

The EBITDA represents the company's operational result. Therefore, this number is taken as the indicator to show the success of the company in its field of production. The official EBITDA in the recent years was between 15 and 20 percent. Having a look at the operational result of the company – it has to be considered that such numbers are not usual for companies in other segments – shows the already high standing of the company as the European market leader.

The EBITDA is the operational result of the company calculated before depreciation. The company's depreciations do not represent a high amount as the machines and equipment in the company (the so-called capital stock) are already depreciated and have only a symbolic value. This means that the capital stock is already of age.

With age, the maintenance cost for each equipment increases. In order to have a relation of how much of the incoming money is spent for maintenance, the maintenance cost-revenue-ratio (further only M-R-ratio) is calculated:

$$maintenance\,cost - revenue - ratio = \frac{total\,maintenance\,cost}{total\,revenues}$$

The recent official maintenance cost-revenue-ratio of the company is:

	2015 [MCZK]	**2014 [MCZK]**	**2013 [MCZK]**	**2012 [MCZK]**
Total revenues	6 100	5 900	5 600	5 800
Total maintenance cost (official)	770	770	770	700
M-R-ratio	12,6 %	13,1 %	13,8 %	12,1 %

Figure 11: Calculated official M-R.ratio in the company (in million Czech crowns)

The official total maintenance cost of the company does only take certain maintenance costs into account. These maintenance costs calculated include:

- all costs for maintenance personnel,
- material and spare parts costs,
- costs for external maintenance services.

Other costs related to maintenance are not calculated such as:

- breakdown costs (lost revenue),
- spare-part storing costs,

- autonomous maintenance costs,
- costs for machine standstills during planned maintenance blocks.

As these costs are neglected, the actual maintenance cost with regard to the total revenues of the company are higher than the official numbers. Due to non-existing data in this area, only a rough estimation could be made for the year 2014 and earlier.

	2015 [MCZK]	**2014 [MCZK]**	**2013 [MCZK]**	**2012 [MCZK]**
Total revenues	6 100	5 900	5 600	5 800
Total maintenance cost (actual)	2 410	1 145	1 145	1 070
M-R-ratio	39,5 %	19,4 %	20,4 %	18,4 %

Figure 12: Calculated actual M-R.ratio in the company (in million Czech crowns)

The total revenues of the company remained almost constant in the recent years. In order to not lose grip and to be able to secure the same EBITDA, the company management has been pressed by the company's stockholders to decrease the cost.

One area that is only regarded as a cost area is the maintenance department and all its activities. The management has been trying to freeze the maintenance budget and to ask for decreasing the cost by a more effective approach towards maintenance with the already gathered experience. The possibilities for the maintenance department head are however limited.

The official structure of the company's maintenance cost is divided into three different areas. These costs are costs that can be directly put into relation with the maintenance department and with maintenance activities.

	2015 [MCZK]	2014 [MCZK]	2013 [MCZK]	2012 [MCZK]
Maintenance personnel cost	300	295	270	260
Material & spare parts	150 revised: 380	160	180	140
Cost for internal maintenance	**450** **revised: 680**	**455**	**450**	**400**
Cost for external maintenance	320 revised: 370	315	320	300
Total maintenance budget	**770** **revised: 1 050**	**770**	**770**	**700**

Figure 13: Official structure of maintenance cost (in million Czech crowns)

By analysing the company's real maintenance cost structure, the picture changes from figure 12 to figure 13. The costs also include costs that are related to maintenance but do not show up that easily. The existing three categories remain while further categories are added.

The costs for unplanned standstill of machines (lost profit) could be further divided into such items as:

- costs of pieces not manufactured (revenues not generated),
- costs for late delivery (penalties),
- increased costs for using other transport means with higher costs in order to deliver the products as soon as possible.

For avoiding a too high degree of complexity of the analysis, these cost items are summarised in one item. Further immaterial costs (such as loss of image) are not considered.

	2015 [MCZK]	2014 [MCZK]	2013 [MCZK]	2012 [MCZK]
Maintenance personnel cost	300	295	270	260
Autonomous maintenance personnel cost	0	0	0	0
Material & spare parts	380	160	180	140
Inventory storing cost	60	75	75	70
Cost for internal maintenance	**740**	**530**	**525**	**470**
Cost for external maintenance	370	315	320	300
Cost for planned standstill of machines (not-generated profit)	150	150	150	150
Cost for unplanned standstill of machines (lost profit)	1 150	150	150	150
Total maintenance cost	**2 410**	**1 145**	**1 145**	**1 070**

Figure 14: Actual structure of maintenance cost (in million CZK)

Graphically, the situation looks the following way:

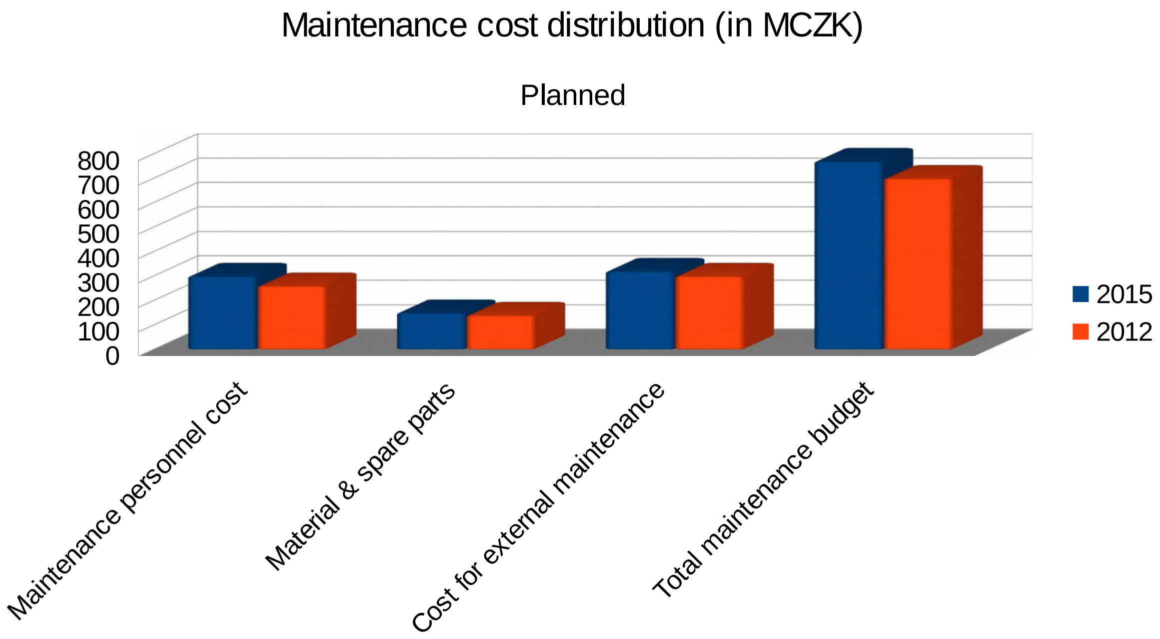

Figure 15: Planned maintenance cost distribution 2012 and 2015 (in million Czech crowns)

As can be seen, the majority of the maintenance cost is the unconsidered maintenance cost. These lost revenues due to breakdowns represent the vast majority of the costs in certain years. In 2015, the amount is even higher due to the breakdown of one machine in the crucial production line for raw parts production.

As these costs are officially not considered as maintenance costs, the incentive to maintain the machines properly is not having the weight it should have. To make it more understandable the following graphs should visualise the proportions of the maintenance costs actually considered as such and the maintenance costs hidden within the company.

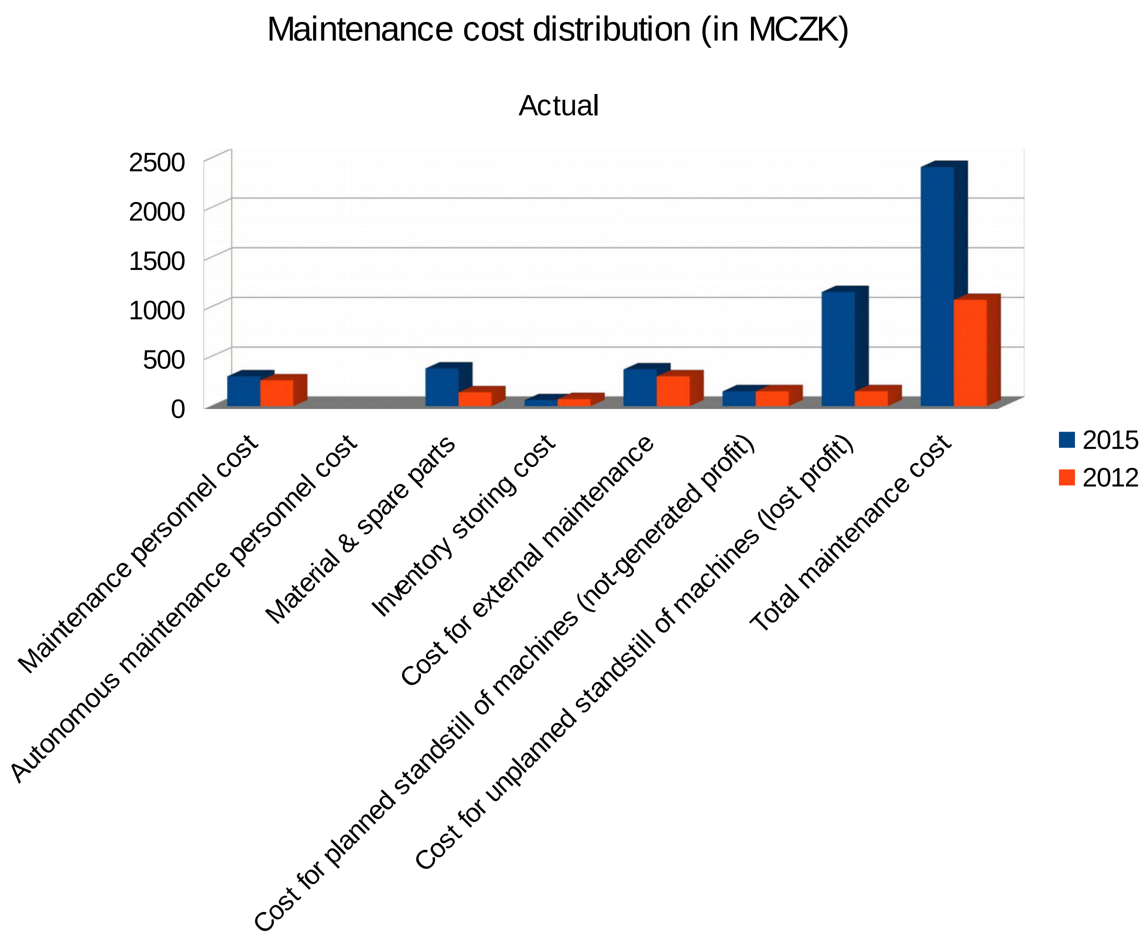

Figure 16: Actual maintenance cost for 2012 and 2015 (in million Czech crowns)

The upcoming approach is focusing on decreasing the costs of unplanned machine breakdowns by increasing planned maintenance (in the form of preventive maintenance). Further, a systematic approach to the inventory (spare parts) on stock should ensure the availability of the machines will be raised.

The official target for new machines in the company is 98 percent availability. As the following tables show, availability in one area is not even close to the target. Still, the machine age is taken as an excuse. Figure 17 shows the availability of machines and equipment in the company. Officially, only the first column (total availability in the company) is reported. The rest of the numbers are not shown in official statistics.

Area	Availability
Total machine availability in 2015	57 %
Raw part production	50 %
Finishing area I	60 %
Finishing area II	76 %
Finishing area III	86 %
Finishing area IV	30 %
Painting area	80 %

Figure 17: Machine availability in the company

The analysis shows that the indicators the company are using are not appropriate or are not correctly followed in order to get the correct interpretation. The company is counting with better numbers than what is real. The management's picture of the company is therefore not correct.

In order to give the management a correct picture of the maintenance state in the company, a set of ratios will be calculated. One these indicators is the aforementioned M-R-ratio.

6 Systematic proposal

The systematic proposal is based on the TIM approach and is shown in figure 18.

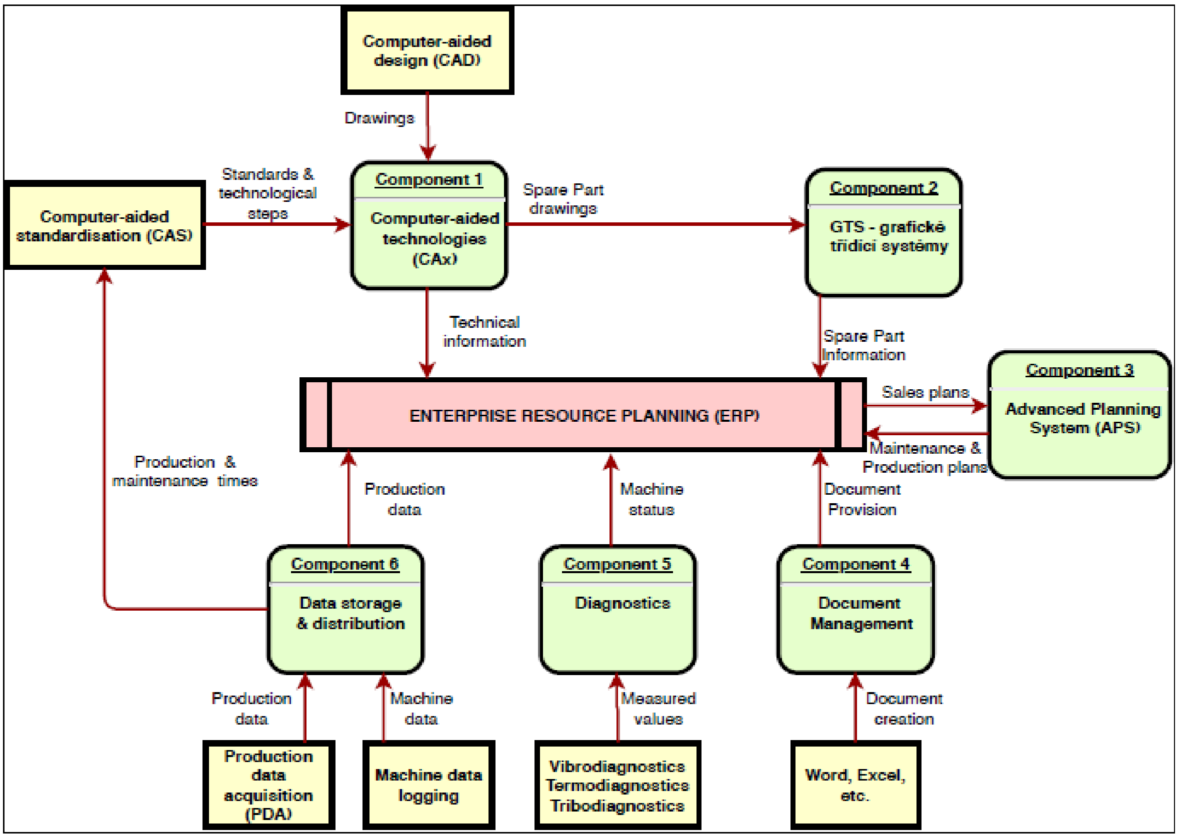

Figure 18: Systematic integrated computer-support proposal

The proposal consists of an integrated computer-support system with an ERP system in its centre. The role model is the TIM-structure (figure 21, p. 90) that is applicable for a given ERP system (SAP, IFS, etc.).

The proposal consists of the cooperation and improvement in four areas:

- TPM,
- standardisation,
- CAS,
- ERP system usage.

Component 3 (APS) may belong to the ERP system or is developed separately. In the given company the APS is available with the ERP system. Component 4 (GTS – graphical typecasting system) exists for maintenance purposes in form of the CMMS. The proposed solution is to incorporate the CMMS in the CAS system and supported by the Inventor software. Component 6 (data storage and distribution) is also a component that is already incorporated into the company's ERP system. Digital machine and production information such as

- machine status,
- bar code reading information,
- produced part stock location,

are stored in the ERP system. The entry mode is handled automatically through sensors (machine status) or by human (manual bar code reading). All the information is available in the system as far as production is concerned. A part of this information may also be used for maintenance planning and its optimisation.

The operability of the machines shows an opportunity for improvement the TPM concept and other systems targets. The trend goes towards complex integrated systems which eventually lead to the DF concept. The ERP system and all components mentioned are already existing on the market. They do not need to be developed from scratch and can include all required information.

The research uses existing systems and integrates them into a complex TIM system. While basic research is already done for all components the research of their integration and co-working is done in this thesis.

6.1 TPM

The basis of the proposed system requires a TPM approach in the company for maintenance activities. For the maintenance part this means:

- parts should be used in an optimal way,

- maintenance begins with the machine operator's doing periodic check-ups, cleaning, etc.
- all maintenance activities will follow a strict planning procedure that has to be obeyed to.

The approach requires discipline in order to be fruitful. The algorithm of this concept relies on the abovementioned activities to provide:

- highest availability of resources,
- lowest cost on maintenance,
- projectable production.

With cost and production getting projectable, the company is able to provide better service to their customers, internal and external. The fiercest opponent of this approach is the actual ongoing activities in the company with prioritised customers and products, as well as the pressure to decrease financial funds for maintenance as a non-value-added activity. It is on the management to support the introduction of a company culture obeying the rules of TPM.

For the sample machine, the TPM approach means to establish a plan for the autonomous maintenance. Autonomous maintenance refers to all activities to be done by the machine operator itself. Activities usually happen shift-, week-, month-wise. The autonomous TPM maintenance activities generally consist of:

- small maintenance processes,
- cleaning,
- visual/ function checks.

In addition to the autonomous maintenance, all other activities have to be planned in a way that losses are eliminated. Further maintenance activities that cannot be conducted by the operator in the course of his shift have to be handled by the maintenance team.

These maintenance blocks have to be planned in advance and the required time has to be stated in order to provide a smooth transition from production to maintenance and back.

All resources have to be available, such as:

- human resources (maintenance workers, external suppliers),
- spare parts (internally and externally produced),
- manipulation means (trolleys, forklifts, etc.),
- time,
- energy,
- equipment (power and hand tools, if not taken by the maintenance person automatically).

The different maintenance activities are therefore characterised. The overview of this characterisation can be found in chapter 6.2 (standardisation) where additional data is available. The table should provide an overview of the maintenance activities due to the CMMS information already existing. The existing data from the CMMS and the maintenance manual is used to establish the list, standardisation determines the time required for the activities or for the set of activities.

Break-downs such as in the past should be prevented. Existing concepts such as reliability-centered maintenance (RCM) provide the basis upon which maintenance will be conducted/ parts will be exchanged. While in the past parts were used until their breakdown, this approach uses parts until a certain characteristic limit.

The characteristic limit depends on the part itself as well as on the usage. Parts undergoing a periodic movement may be limited by cycles conducted or pieces produced. For oil and grease it may be more accurate to limit it by the duration of usage.

The complexity of the different characteristics and dimensions used to determine maintenance activities can be monitored by a sophisticated computer-aided system. Further it is on the maintenance system to determine when it is useful to conduct two activities together and when to separate them.

In order to retain flexibility in production, the exchange interval should be seen with a tolerance of e.g. 5% (value was taken randomly). This means, for a part that can do

10 000 cycles, the exchange interval is between 9 500 and 10 500 cycles. The maintenance activities are to support the production activities, not to limit them unnecessarily.

In the supplier's manual, the maintenance activities are listed (see Annex B).

While approximately 50 per cent of the mentioned activities are done randomly by the operator during his work, the manual mentions further information:

1. Control of function-related parts:
- Once per year,
- After repairs, and
- During production start-up

2. Preventive maintenance:
- 1x in 4 to 5 weeks to control mechanical, hydraulic and electric parts of the press

3. Further:
- Small maintenance: 1x in 12-15 months
- Intermediate maintenance: 1x in 3-5 years
- Overhaul: 1x in 8-12 years

* These plans represent minimum times. The actual maintenance and repair plan depend on the production technology, work load, number of shifts, maintenance quality, etc.

While the CMMS data is poorly maintained, it can provide information on:

- which issues occurred,
- how often, and
- how long it took to eliminate those.

The company did not follow the instructions given in the maintenance manual, nor did it extend the maintenance instructions to the degree it needed. Individual issues were not targeted and autonomous maintenance as proposed in ANNEX D (figures 30 and 31) were not used and not evidenced.

6.2 Standardisation

Standardisation has the task to standardize a certain process, to keep factors like time, resource requirements, etc. constant. Standardisation can be done by different methods, e.g.:

- activity sampling (also work sampling),
- time study,
- standard data,
- predetermined motion time systems (MOST, etc.).

The basic work approach for maintenance work is defined by the maintenance manual given by the machine or equipment supplier. Further, the approach takes the actual circumstances in the production into consideration. This concerns mostly:

- working space
- ongoing production needs.

Standardising maintenance activities is seen as a tough task as maintenance activities, diagnostics, etc. are hugely dependent on:

- individual skills,
- individual approaches,
- uniqueness and understanding of failure message,
- resource availability.

The approach therefore is limited for maintenance activities to a standardisable amount[2] [50]. It must include all works that have to be carried out. In order to only apply the standardised work approaches all other unwanted cases have to be foregone by proper planning. As these tasks are carried out periodically, the data available has to be used in the production plan for advanced planning.

The focus of the analysis lies on the press that already broke down twice. It is taken as a representative for the other presses in the line. The standardisation of maintenance activities was done on the basis of:

- Maintenance manual provided by the suppliers,
- Information from the actual CMMS system,
- Standardisation method: Predetermined motion time system.

An overview of the standardisation outcome is giving in figure 19:

Zařízení	Visual Control	Exchange	Actual exchange time
Conveyor	25 min	255 min	410 min
Brakes	12 min	190 min	187 min
Gear unit	10 min	95 min	110 min
Clutch	6 min	80 min	205 min
Greasing unit (Valves)	4 min	25 min	27 min
Oil filter	5 min	30 min	80 min
Bearing	6 min	50 min	58 min
Ending switch	3 min	14 min	25 min
Electric motor	11 min	200 min	322 min

Figure 19: Standardisation overview

The measured standard values rely on the fully applied technological process (Annex A). These standards show an improvement of approximately 60 percent in average. These standards have to be maintained and re-standardised (actualised)

- periodically,
- in case of process changes,
- in case of technological changes.

6.3 CAS system

Computer-aided standardisation (CAS) systems have to support the company during its standardisation work. Its tasks are:

- Storing,
- Distributing, and

- Aggregating relevant data.

The CAS system is able to provide rudimentary standards for the company. These standards have been available for several decades describing the simplest and most elementary work steps. To make use of these standards for any individual company, these standards may be already included in the CAS software.

By aggregating rudimentary standards it is possible to compile a logical set of secondary level standards. Those standards use the rudimentary standards that are mostly universally given. Where lower level standards have the task to monitor just simple actions higher level standards have the task to monitor sub-processes and full processes of a certain kind.

While higher level standards display (sub)processes, these standards have a higher degree of individuality. Depending on the exact composition of the (sub)processes, major differences might arise during their standardisation. The historic development of these companies differed, which led to current differences in processes. With the differences in processes and standards, companies are not able to share a common database within an industry.

The CAS system has therefore to be able to promote the development of higher level standards. The higher-level standards comprise of:

- lower-level standard(s),
- individually standardised (sub)processes.

Higher-level standards may be used as input for further standardisation of a standard of the next higher level.

Besides the standard, CAS systems may also include further information such as:

- work and technological process description,
- standard activity time,
- required standard tools.[38].

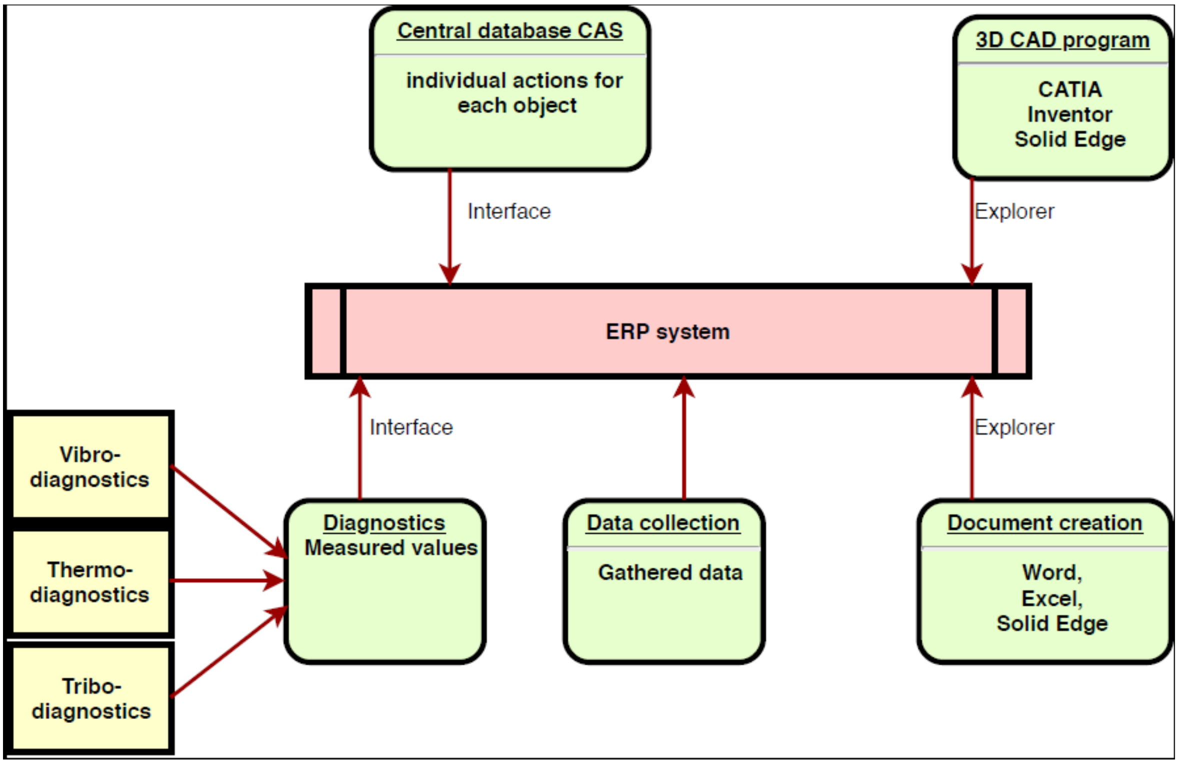

Figure 20: Relations between software and TIM, taken from Novák, J.[38]

As can be seen in figure 20, the CAS system is working as a subsystem that is providing information on standards to the ERP system. The ERP system is distributing the information further to the place of requirement in the time of requirement.

Another important task of the CAS system to be mentioned is activity preparation support. This means, that it gives information on all circumstances, tools, and resources required. For maintenance activities, those are:

- spare parts,
- components,
- tools,
- tooling equipment [38].

The CAS database has to be equipped with the low-level standards. These standards have a universal character. These standards do not only have to display production activities but also activities related to maintenance, installation, and further auxiliary and service works. The character of those activities differs as maintenance and further works are not repeated steadily as it is in serial production.

Nonetheless, it is possible to use standards for maintenance activities. The range of standards is bigger as there are several activities to be carried out. This is manageable with today's computer support. Systems like the CAS are equipped well enough to provide a solid fundamental database that can be used as lowest-level standards. For all further activities, the system has to enable the company to create further standards for required activities[38].

While CAS enables the company to use standards for different kinds of activities, it has to be said that the standards for auxiliary activities might not be as accurate as they are for serial production standards. In order to get a better projectability of production and maintenance activities together, it makes sense to use the standards to get closer to reality. With time, these standards have to be re-evaluated on the basis of:

- actual times required,
- changes in the production or maintenance process.

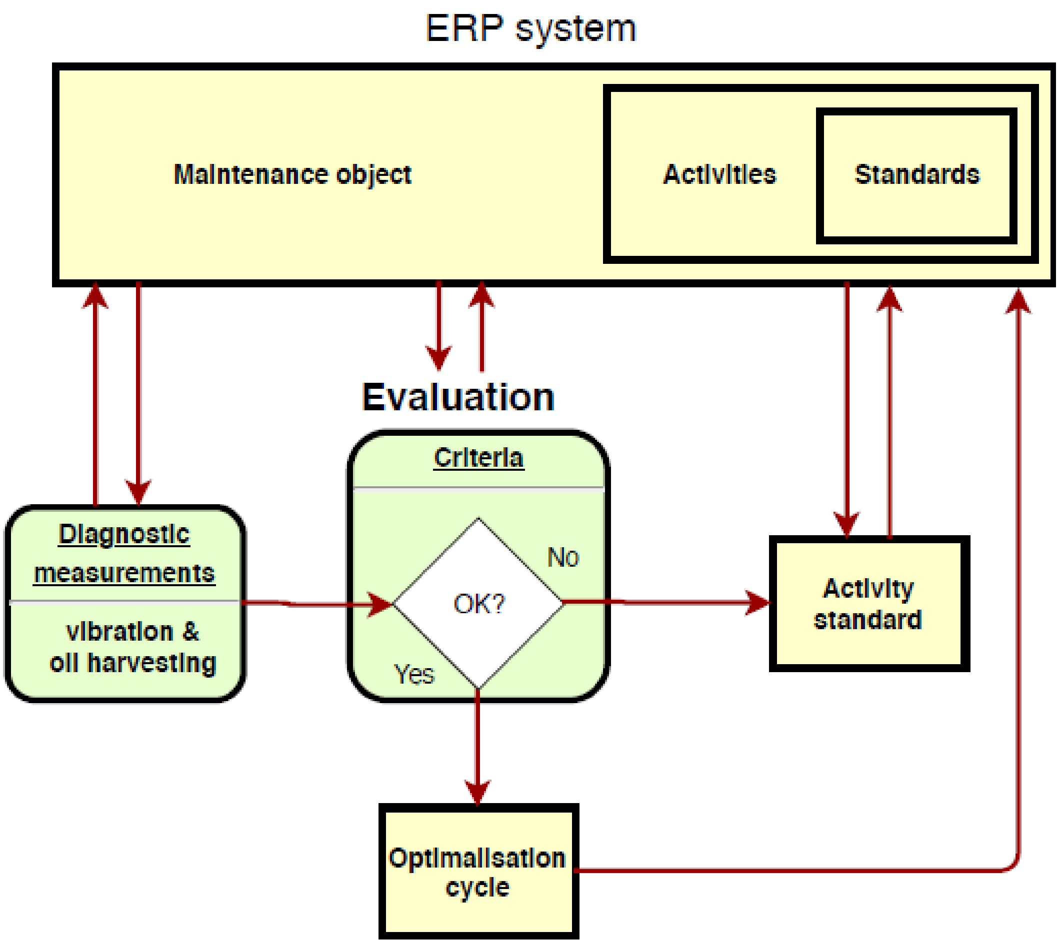

Figure 21: General scheme of relations, taken from Novák, J.[38]

As figure 20 and figure 21 show the CAS system has to work closely together with diagnostics. Diagnostics mean checking the state of the equipment by providing tests and analysis. The measured values are compared with the optimal values or the tolerated range of the value. In case, the measured value is not acceptable, it is on the CAS to give an alert and to provide information on the equipment.

6.4 ERP system

The ERP system is the core of the computer support system without which establishing a system of integrated subsystems would hardly be possible. Computers help to order, filter, and distribute the data as required and to link different systems into one big unit.

This computer support is vital for the proposed architecture. The company is already relying on computer support in various areas, but misses the link to maintenance activities, such as:

- disassembly and re-assembly (maintenance and installation),
- maintenance preparation (auxiliary),
- maintenance production (service).

The company uses an ERP system for different areas to distribute data within. Modules used are such as:

- finances
- sales,
- inventory,
- projects.

The company makes use of ERP and ERP II modules. The company also uses a technology module which consists of information such as:

- which product types can be done on which machine,
- how long the process takes,
- how much it costs.

This information is available for all direct production processes. Since 2016, an Advanced Planning System (APS) module has been implemented. The former guessing-style was substituted by a data-based planning system.

For maintenance activities, there is no module existing. Maintenance activities are not monitored in the system. Only monitored information is stored in the ERP-external CMMS system. This system monitors:

- Date and time of breakdown,
- Responsible worker,
- Date and time of start-up,
- Description of failure found and maintenance activities conducted.

This information is stored but not used. It only serves as an evidence that the worker was not able to conduct his usual work at the time of maintenance. The knowledge that could be retrieved from it remains unexplored.

In order to make maintenance activities projectable, the company has to use data and information from production and maintenance. This information is to be found in the CMMS and on the shop-floor. A module similar to the technology-module in the ERP has to be created for the maintenance-activities that needs to:

- be directly linked to the APS-module with priority,
- collect all data on planned maintenance activities (time, cost, spare parts, etc.),
- put focus to plan the activities in certain intervals.

Data on planned maintenance activities come from the standardisation described in the previous step. The maintenance module needs to be implemented into an already-existing ERP system, having relations to modules such as:

- APS,
- finances (for cost and controlling reasons),
- inventory.

The described maintenance module needs to contain the following information for planned activities:

- Maintenance activity conducted,
- Date of maintenance activity conducted,
- Time required,
- Conductor's name,
- Spare parts required,
- Maintenance cost,
- Activity frequency.

Further, the system also has to be able to adjust to differences between plan and reality. Therefore, the system also tracks:

- Actual beginning,
- Actual working time,
- Actual cost.

The planned values have to be stored for a whole set of activities. The actual values have to be gathered for each maintenance activity again. Planned values might vary (by time) from the reality. In order to plan most accurately, the company has to re-standardise the activities in a given time interval.

The constant gathering of data leads to a database that is able to predict the frequency of planned maintenance activities required in order to avoid unscheduled breakdowns. To monitor this precisely, a column stating whether the maintenance was scheduled or unscheduled has to be present in the module.

In case there is no data available in the CMMS for a machine or equipment, data can be retrieved from the supplier's manual. The maintenance manual should give an inside on:

- recommended frequency of maintenance activities,
- spare parts required,
- name and producer of required spare parts.

6.5 Cost and benefit

Besides the financial cost of the system introduction, the company is also giving up its flexibility. The rule of the company's maintenance activities belongs to the algorithms given in the APS. The spontaneous delay of maintenance activities or their deletion should not be allowed. Individual concerns cannot be taken into account.

Maintenance discipline also requires financial discipline. By making the maintenance activities projectable it is assumed that also their cost should be projectable. There should therefore be no more space for cutting these costs from the company's finance side. After standardisation, only re-standardisation will happen in order to actualise data. The APS system will take control of how to use this data due to an algorithm. It is on the company's management to accept this approach and to accept the decisions of the APS in order to make the whole system work.

Costs included in the proposal made:

#	Activity	Cost [CZK]
1	Keep autonomous maintenance	0
2	Widen autonomous maintenance scope (2%)	120 000 000
3	Software solution to include ERP maintenance support	13 000 000
4	Standardisation of maintenance activities	100 000 000
5	Faster exchange of components (not waiting until breakdown) (5%)	30 000 000
6	Inventory of spare parts (7%)	42 000 000
SUM		305 000 000

Figure 22: Proposal cost

Benefits

#	Activity	Benefit [CZK]
1	Higher availability of machine	1 060 000 000
2	Higher productivity of machine	180 000 000
3	Inventory of spare parts (3%)	18 000 000

4	Savings on late-delivery penalties	200 000 000
SUM		1 458 000 000

Figure 23: Proposal benefits

Further benefits that are not explicitly conveyable into monetary units are:

- higher projectability,
- higher reliability and better image towards the customers,
- smoother communication throughout the company,
- development of a reliability-driven company culture.

7 Critical assessment of the study and its results

The study had a look at the current situation of the company and its maintenance system. Regarding the recent break-down in production and the faced losses the study was able to show a result of half a million crowns that could be saved.

Several shortages of the analysis have to be listed:

- The time frame that is considered is only the year 2017.
- The analysis regards only one machine.
- The analysis regards one of the oldest machines.
- The analysis targets a machine that has had an actual issue.
- The issue occurred was one of the biggest in company history.

The shortages listed imply that while having a different look at the analysis, the outcome might be different. Therefore, the given proposal might only be valid for the year 2017. For most of the other years the situation might be different. Also analysing other machines might lead to a different outcome.

The analysis regards the situation in a year with record losses due to a breakdown of a crucial machine. The results are:

- sudden decrease of production capacity in 2017,
- penalties due to late deliveries,
- lower corporate image due to issues in production,
- shifts of maintenance blocks,
- urgent requirement of spare parts at higher prices.

The disadvantages resulting from the breakdown should be overcome by the proposed approach. As the main production line consists of four presses of the same age, the results should be the same as in the analysis. For these crucial machines a sudden breakdown will result in a drop to zero as far as production capacity is concerned. This risk has must be avoided.

The TPM approach as a basis of the proposal requires a high degree of discipline of all employees. Without sticking to the fundamentals of the concept, the result of the applied measures will not unfold. The proposal then provides:

- higher reliability,
- higher projectability,
- less flexibility.

The company gives up a high degree of its flexibility. It is substituted by reliability which is an issue not only in the analysed situation but throughout the years. The logistics department had only a rough estimation of when the products might have been finished and which capacities were free at a given time. The introduced APS system was able to improve the situation but did not eliminate the issues. Projects were still delayed due to insufficient planning and projecting abilities.

As shown in other industries, e.g. in the automotive industry, the planning issues can be overcome by:

- investing in maintenance and reliability-improvement,
- relying on real, actual data,
- promoting TPM and maintenance as a core of the company culture,
- sticking to the system without exceptions.

The company culture and the company targets are linked to each other. A stably-running necessitates obedience to the system itself. The stability is required also from less-important machines and equipment to remain the order in the whole system. Thus, the approach also should be applied to all other sorts of equipment used. In reality, the extent to which the approach is used for less crucial machines and equipment will be less as other pressing issues will show up. The task to give a reason why the same effort should be made for these small machines will be a challenge in reality.

Also it is the task of the finance managers of the company to keep the finances together, to lower the cost and to increase the profit wherever possible. Therefore, finance will attack the maintenance managers with the request to lower the maintenance cost. It is on the company's highest executive to develop a framework in which the proposed approach may work. Developing technologies, changes of machines and equipment, and further factors will require adjustments in finances. It must be secured that the maintenance is able to provide its internal services as given in the approach.

The company culture is the factor most crucial for the introduction of the system. Changes in the culture and organisation require a high degree of commitment from the top management down to the operators on the shop-floor. The approach will prove fruitful after a certain time when comparing the state with the results before its introduction. The indirect feedback makes it difficult for the company management to resist the pressures from owners or shareholders. Results in numbers will not show immediately. In reality, the approach is therefore very contestable and requires strong support from within the company.

7.1 Maintenance indicators

The maintenance indicators are taken from the European Federation of National Maintenance Societies (EFNMS). The EFNMS defines a set of maintenance benchmarking indicators. The total set contains 71 indicators of which 14 will be used during this thesis in order to assess the state of maintenance in the sample company.

Maintenance benchmarking has the task to compare the company's values on certain indicators with the average within the industry. By standardising the calculation method for each indicator, the comparison is an apple-to-apple comparison.

The 71 benchmarking indicators are applied to compare and assess various fields within the company. These indicators are divided into:

- strategic,

- tactical,
- technical,
- economic,
- safety,
- organisational,
- environmental[37].

The 71 indicators today are part of the standard EN15341 where they are defined as so-called Key Performance Indicators (KPI). The KPI's in this standard are categorised by three categories:

- economic indicators (time/ money, money, money/ money),
- technical indicators (time/ time, quantity/ time, time/ quantity),
- organisational indicators (e.g. person/ person, etc.)[37].

The 14 maintenance benchmarking indicators are (names are taken from the American SMRP metrics)[15]:

1. Annual maintenance cost per replacement asset value (RAV):

This indicator represents the percentage of maintenance cost relatively to the value of new machine and equipment prices. It gives an indicator of what is the relation between the investment into the equipment and the cost of the equipment itself. This indicator gives feedback when the equipment should be exchanged for a new one as the maintenance costs are getting too high in relation to the new purchase price.

$$I_{01}=\frac{total\,maintenance\,cost}{asset\,replacement\,value}[\%]$$

2. Annual maintenance cost per RAV:

This indicator gives the percentage of the values of spare parts and other maintenance materials on stock and sets it into a relation with the purchase prices of the new equipment. It shows how capital intensive the inventory stocks are compared to the new prices of equipment. Too expensive spare parts may also lead to the thinking of buying new machines instead.

$$I_{02} = \frac{average\ inventory\ value\ of\ maintenance\ materials}{asset\ replacement\ value} [\%]$$

3. Contractor maintenance cost:

The I_{03} represents the third indicator. It shows how intensive the cost of external maintenance services is compared to the total maintenance cost of the company. The external maintenance cost includes outsourced activities and external services by machine suppliers or other contract partners. The indicator gives a hint to which extent the company is depending on external supplies and whether the size of the internal maintenance department is adequate.

$$I_{03} = \frac{total\ contractor\ cost}{total\ maintenance\ cost} [\%]$$

4. Preventive maintenance cost[11]:

This indicator shows a relation between the preventive maintenance cost and the total maintenance cost. A higher percentage of this indicator shows that the preventive maintenance works out and the further costs related to maintenance are minor. The task of preventive maintenance is to eliminate further, bigger maintenance costs by investing beforehand (preventively). A degree of 100 percent means that there is no breakdown maintenance, neither any further reactive maintenance works is conducted.

$$I_{04} = \frac{preventive\ maintenance\ cost}{total\ maintenance\ cost} [\%]$$

5. Preventive maintenance hours:

This indicator shows how much of the maintenance workers' time is used for preventive maintenance. This also gives information on how time intensive the preventive maintenance is in relation to the whole maintenance action. It gives an indication of how time-consuming the preventive maintenance is compared to the maintenance action in total. Further it shows how effective the measures are, whether the availability of the machines is secured and whether the unplanned maintenance activities are time-wise lower.

$$I_{05}=\frac{preventive\ maintenance\ man-hours}{total\ maintenance\ man-hours}[\%]$$

6. Total cost per sales:

This indicator is the same as the beforementioned M-R-ratio. It shows how much money is put into all maintenance activities in the company compared to the financial funds acquired in the given year through sales. It shows the ratio of the maintenance cost on the total funds in the company. Too high maintenance costs will eat up the profit in the company.

$$I_{06}=\frac{Total\ maintenance\ cost}{Company\ revenues}[\%]$$

7. Maintenance training hours:

The seventh indicator, I_{07}, shows the intensity of the training conducted for the maintenance personnel in the company relative to the whole time the maintenance employees have in the company. A higher degree of training could indicate a too low degree of education and training of the maintenance employees. Depending on the sophistication and complexity of machines and equipment, this proportion might increase with time. It might decrease due to the experience and skills gathered during conducting maintenance.

$$I_{07}=\frac{number\ of\ maintenance\ internal\ personnel\ man-hours\ for\ taining}{total\ internal\ maintenance\ man-hours}[\%]$$

8. Corrective maintenance hours:

The eighth indicator, I_{08}, gives an overview of the percentage of working time of the maintenance used for breakdown maintenance. The higher the value of this indicator the longer the time the machine or equipment is out of service due to machine breakdown.

Further, this indicator can also be used to indirectly assess the percentage and success of the preventive maintenance actions taken in the company. Higher percentages of breakdown maintenance conducted also involve a lower percentage of preventive maintenance in the company. Preventive maintenance has the aim to reduce the breakdown times and to increase machine availabilities. Preventive actions are seen as an investment in order to eliminate breakdowns and related losses. Successful prevention has the aim to lower the total cost by increasing the preventive cost slightly while decreasing the breakdown cost and times.

$$I_{08}=\frac{corrective\ maintenance\ man-hours}{total\ maintenance\ man\ hours}[\%]$$

9. Planned maintenance percentage:

This indicator provides a hint on how sophisticated the maintenance planning is done. It is defined as the percentage of the planned maintenance time and the working time of the maintenance personnel.

The value only describes the planned state. However, it makes no statement about the real values achieved in the company. Events, such as breakdowns, force the company and its maintenance team to provide additional maintenance time in order to eliminate the reason on the breakdown. Comparing the planned and the real value gives a good indication of how well maintenance planning is conducted. It further gives a hint on how realistic the initial maintenance plans are.

$$I_{09}=\frac{planned\ maintenance\ man-hours}{total\ actual\ maintenance\ man-hours}[\%]$$

10. Availability:

The tenth indicator is I_{10}. The indicator represents the planned value of machine usage given in percent. The machine usage is calculated compared to the maximum amount of time. Within one year, the available capacity is counted as full operation in 365 (or 366) days. Sometimes, in order to reduce complexity, the amount of days is reduced to 30 days per each month, summarising up to 360 days.

The annual nominal time equals the days that the machine or equipment is planned to run. It contains the time of all calendar days minus the days when the production is planned to be closed. This value does only indicate the maximum possible time the machines or equipment may run. It does not take any further required times into account, such as:

- setting,
- resetting,

- rework,
- preventive maintenance,
- breakdown maintenance.

The indicator gives a hint on the maximum possible usable time in a year.

$$I_{10} = \frac{total\,usable\,hours}{total\,calendar\,hours} [\%]$$

11. Equipment utilisation rate:

Compared to indicator I_{10}, indicator I_{11} has a look at the real situation in the company. This indicator measures the real time the machine or equipment was used and working. Other times, such as maintenance times, etc. are lessening the result and are not displayed in the indicator.

$$I_{11} = \frac{total\,production\,hours}{total\,calendar\,hours} [\%]$$

Comparing indicator I_{10} and I_{11}, the three potential outcomes may be:

1. $I_{10} < I_{11}$: The real production time of the equipment is higher than the nominal time available. This case is unlikely as the maintenance time and other times preventing production would be close to zero. The company would further spontaneously increase its working time without having any significant issues in production.

2. $I_{10} = I_{11}$: The real production time is equal to the nominal time available. No issues such as maintenance or pre- and re-setting would occur to diminish the usable time for production. However, this case is quite improbable.

3. $I_{10} > I_{11}$: In reality, this third possibility should occur in the vast majority of the cases. Downtimes and further issues decrease the production time of the equipment and do not allow the company to use its full production potential.

12. Mean time between failures (MTBF):

The real production time is also used for indicator I_{12}. The indicator is seen as an indicator that represents zero breakdown of the machine or equipment. A higher value of indicator

I_{12} is a positive indicator.

Having a look at the calculation of this indicator as such, it shows the average value of real machine production time between two breakdowns. Hence, a higher number of indicator I_{12} equals a more stable process with less breakdown maintenance calls from the production.

The indicator does not give a hint of how long the equipment maintenance activities lasted and whether the same mistake occurs again. But it gives the average production time until a new breakdown maintenance case occurs.

$$I_{12} = \frac{total\,time\,of\,correct\,operation}{number\,of\,failures}[\text{time}]$$

13. Mean time to repair (MTTR):

This indicator provides an understanding of how long the maintenance activities needed on average after a breakdown. It eliminates the mentioned shortcomings of indicator I_{12}. It gives an indication of how long on average breakdown maintenance activities need in the company. The lower the value, the faster the breakdown maintenance is conducted.

The indicator gives the average time of maintenance but does not say anything about the quality of the maintenance works conducted. A higher number of maintenance activities may indicate a reoccurring issue while it might decrease the I_{13}-value in case the maintenance activities are conducted quickly. Vice versa, it may also happen that reoccurring maintenance activities on a concrete equipment may cause a wrong impression of the company reality, in case they require a long time to find the root cause of the breakdown issue.

$$I_{13} = \frac{total\,hours\,of\,downtime}{number\,of\,failures}[\text{time}]$$

14. Overall Equipment Effectiveness (OEE):

The indicator I_{14} equals the already mentioned OEE. It is an indicator created by taking three indicators into account:

- Performance P,
- Availability A,
- Quality level Q.

This combined indicator has a positive spin. This means that a higher value of this indicator reflects a better performance, availability, or quality level.

$$I_{14} = Performance \times Availability \times Quality = P \times A \times Q [\%]$$

The actual numbers of the benchmark indicators are above the limit. Further, they show a negative tendency for the recent years. The quality level of the equipment maintenance level in the recent years seem to decrease while cost and time of maintenance activities grew.

Figure 24 summarises the 14 indicators and its relation to company profit. Where an indicator indicating cost will have a negative impact to profit while raising a higher percentage of preventive maintenance has a positive impact. It is to the advantage of the company to think of maintenance as an essential part of the company's cost-saving activities. Carefully-carried out maintenance might result in higher planned maintenance costs but should pay off in lower breakdown times and costs.

Indicator	Actual value	Planned value	Relation
I_1	44,63%	19,25%	(-)
I_2	3,52%	1,88%	(-)
I_3	15,35%	41,56%	(-)
I_4	6,22%	6,49%	(+)
I_5	25,00%	31,25%	(+)
I_6	47,25%	12,62%	(-)
I_7	4,46%	5,21%	(+)
I_8	70,54%	63,54%	(-)
I_9	71,43%	83,33%	(+)
I_{10}	99,45%	99,45%	(+)
I_{11}	54,79%	61,64%	(+)
I_{12}	77,14	86,11	(+)
I_{13}	42,86	33,33	(-)
I_{14}	44,94%	58,45%	(+)

Figure 24: Values and impacts of maintenance indicators

The maintenance indicators show a much higher value of I_1, I_2, I_6, I_8, and I_{13}. The reason is mostly the two-month breakdown that increased the values of

- total maintenance cost,
- corrective maintenance cost,
- corrective maintenance hours,
- breakdown times,

and further reduced the value of total revenues.

The indicators also show that the indicators for planned and real values differ significantly for a lot of indicators. The assumption of inaccurate planning showing off in differing numbers holds therefore true. The attempt to invest into preventive maintenance and further supporting tools and techniques should show up as shown in figure 24 (see column “relation”).

With investing into preventive maintenance, it is assumed I_3 will rise, allowing also I_1 and I_2 to decrease as total maintenance costs should decrease. Further, the approach has the aim to increase the factors

- performance,
- availability,
- quality

for I_{14}. By increasing availability by 20 per cent, it is possible to increase the OEE also by 20 per cent. For this, a systematic shift of cost from corrective to preventive maintenance is required as well as thorough planning and reliable data to monitor the indicators carefully over a significant period of time. It is assumed that at the beginning corrective maintenance indicators may remain while preventive maintenance costs increase. Also preventive maintenance times increase and it should take time until the negative impact indicators (e.g. corrective maintenance cost and time) begin to decrease.

An integrated system establishing maintenance as an important pillar of the production company leads to an investment into production capital on behalf of monitored values. It is therefore of importance to gain a full picture of the company and the maintenance status step-by-step. Actual data and frequent feedback allow for integrated systems to adjust and develop gradually.

The proposed integrated system using the TIM approach is a step forward towards a digital factory. Maintenance is only one pillar but it oversees controlling the costs and expenses related to production capital. When handled in advance maintenance is able to create a competitive advantage by reducing cost and establishing the basis of realistic planning.

8 Generalisation of Results

As already discussed in the chapter “Critical assessment of the study and its results”, there are differences between machines and equipment already within the company. Among other factors, the approach depends on:

- the field of production,
- the utilisation of machines and equipment,
- the age of machines and equipment,
- the planned life of machines and equipment,
- the long-term plans in the company,
- the maintenance approach and company philosophy.

While the company implements the approach of TPM and planned maintenance it will take time to see actual results. It requires patience from the stockholders to wait for the effects. Further, these effects are indirect. The financial result is a new balance between investment into maintenance and the maintenance and breakdown costs. As discussed, the investment is a cost in advance. The effect will show up later in decreasing costs.

For the company, the direct effects of such a system influence the everyday business. The company’s flexibility might be limited through:

- lower degree of flexibility in order to stick to the approach,
- lower degree of flexibility in the maintenance budget,
- lower degree of flexibility in the planning of maintenance activities.

This means for the management of the company to give up part of its sovereignty by accepting the lower degree of flexibility. The pressure in big, multinational organisations coming from the shareholders will put additional focus on active cost reduction and budget reduction for the maintenance department. It is questionable whether managements can withstand this pressure.

Another aspect for criticism and against generalisation of the presented approach is the sector in which it is introduced. While the TPM approach was developed as an approach in production maintenance, the definition was widened by the JIPM (Japanese Institute of Plant Maintenance) to also cover administrative positions and office work. Maintenance in production companies plays a different role than it does in the IT or banking sector. The approach introduced in this thesis is meant for the production sector. The application and adjustments to introduce this approach in other sectors has yet to be tested.

The degree of utilisation of machines and equipment is another factor that might limit the utility of the proposed approach. The will to continuously maintain machines and equipment that are seldom used is small due to the limited output generated. Further, it is not necessary to maintain machines twice in a quarter when the machines are only standing idle. The benefits gathered from introducing the TPM approach in this area may not stand in any positive relation to the cost involved. In such a case, the management has to carefully prove whether it makes sense to introduce the TPM standardised maintenance approach or whether other maintenance concepts are able to cover the needs of the company. This decision depends on the further plans of the company in the upcoming years. As a conclusion it can be said:

- the logic applied in the presented approach can be used,
- the question is whether benefits are higher than cost.

The average age of machines and equipment has an impact on the maintenance strategy. The difference lies in the following facts:

- a new machine park usually does not require as much maintenance work,
- lack of knowledge of the machines and their requirements might lead to a more conservative approach at the beginning,
- standards have to be re-standardised more frequently at the beginning,
- a reliability-focused approach (RCM) might be sufficient at the beginning,
- the combination of old and new machines might require maintenance at different times. Maintenance work might be packed together in order to avoid too many standstills.

- the logics applied in the approach will work for old and new machines likewise. The overall picture of the production working has to be concerned.

The care for machines and equipment depends on the planned usage as far as the product is concerned as well as the time frame it is planned to work. This means:

- the maintenance interval might be longer than the lifetime of the machine,
- standardisation and data collection costs might be higher than their benefits,
- the machines are made specifically for a certain product (e.g. automotive industry),
- the flexibility of production (e.g. automotive industry)
- the logic of the presented approach can still be applied.

As far as the long-term plans of the company are concerned, it depends very individually on the company, its stakeholders, and its current situation. The logic of the approach can be applied in the these situations. There might be several reasons why the approach is not introduced:

- the company is planning in shorter terms and does not to wait for benefits,
- the company wants to reduce maintenance costs now instead of investing into maintenance,
- the company management might plan to invest into new machines and to shift the introduction of a TPM maintenance approach,
- the existing machines might be substituted in the upcoming years,
- the company's current situation is unclear and no proper plans are made for the next years.

Such scenarios can be a reason for why the proposed approach is not introduced. While the logic of the approach is untouched, there are real and actual issues in the companies that can prevent the introduction of such a system. Another possibility can be that the system is introduced once the plans are more stable or more concrete, for example.

Another field to be touched is the management and the company culture. The management as such might be interested in the short-term effects of a system and in the ease of managing the company during their time of responsibility. As the management has a big influence on the company culture, this might be considered a field of reluctance. Further factors might be:

- the management might be reluctant to change,
- the management does not want to give up company flexibility,
- the management does not want to give up current company culture for the new one,
- the management is not strong enough to change company culture,
- the management might decide for another management approach due to the cost pressure applied.

While all these factors represent factors and reasons for why the proposed system could not or would not be implemented, the reasons do not rely on the system itself. Summarising the factors it can be said:

- the costs are higher than the benefit,
- the discussion of the introduction is shifted to a future point in time,
- in the current situation it is not appropriate to introduce the system,
- the initial cost for the system are too high or cannot be justified.

In all the cases it is theoretically possible to introduce the proposed approach. A lack of logic is not an issue. The approach can be generalised for the production industry. The character of maintenance work (e.g. server and data maintenance), for example in the banking and insurance sector, differs from the manufacturing industry.

The approach predicts a high amount of savings through the standardisation of maintenance activities and its thorough planning. The prediction estimates 80 per cent of today’s maintenance costs can be spared by investing into the equipment beforehand. The reason for this high percentage lies in the long lead times for the machine parts and the uniqueness of the equipment. As there is no other line that could consume part of the production orders the company is inflexible in its choice and relies fully on the production on the old production line.

Further, the company itself has high maintenance costs and relatively low availability rates. In other industries, such as the car industry, such values have to be far higher in order to be competitive. As the company here is in an oligopolistic market, it seems that the pressure to reduce cost and to increase availability is not as high as in other competitive markets. The logistic priorities of what to produce and when are not met and the practical part showed that existing potential is not used fully. Auxiliary processes are seen as non-value-added and are therefore neglected, though they have the potential to support main production processes.

While the approach limits the flexibility of the companies, it requires customisation in order to work in the various environments. As the approach relies on the company culture it depends hugely on the management, its strength and the operators working with the approach. There is no logical limitation for the approach as such. Thus, the proposed approach can work in different environments and industry sectors in case the whole company staff is committed to the approach and its activities.

Summarising we can say for the hypothesis:

The target of this thesis is to find answers for the following questions:

1. Is there a systematic approach on maintenance with computer support that allows higher availability of machines in the production line?
   Yes, RCM, RBM, and TPM are maintenance approaches targeting amongst others also higher availability of machines.

2. Is it possible to use an integration of ERP and CMMS to achieve point 1.?
   Yes, in order to facilitate maintenance, ERP and CMMS need to work closely together to eliminate losses.

3. Does this system allow for standardised maintenance activities?
   Thorough planning is required in companies and is done for production orders. In order to bring maintenance to the same level of importance as production, this system requires standardisation and proper scheduling.

4. What are the basic characteristics of the integrated system?
   Integrated systems require a set of tools to work together:

- central ERP system (incl. data acquisition),
- APS system,
- TPM maintenance approach,
- standardisation and maintenance data distribution in the CAS system.

9 Summary

The thesis had the objective to find a solution for an existing issue in a Czech production company. In 2017 the company faced issues from a complete production breakdown. This led to:

- a one month production delay,
- incomplete breakdown maintenance was conducted due to time pressure,
- one month of production capacity was lost.

The approach to be found therefore focused on the target to eliminate the source of the breakdown and to achieve a higher reliability of the production in the future. With the focus on service and auxiliary works such as maintenance, the system evolved consists of the following elements:

- TPM approach for maintenance,
- usage of ERP system (APS module) for maintenance planning,
- standardisation of maintenance works in order to make them better projectable.

The TPM approach requires the company to adapt to a new company culture searching the way in preventing breakdowns and further issues related to maintenance. The costs occurring during a breakdown should be foregone by investing into measures making maintenance projectable. Emergency maintenance should be prevented in order to reduce maintenance costs. The company is required to:

- adopt a new company culture,
- accept investment into non-value-added activities such as maintenance,
- systematise maintenance by giving up flexibility.

In order to develop and test the approach, the approach was done on one of the company’s crucial machines. Due to its age, the machine tends to breakdown frequently and for a longer time. The breakdown of this machine leads to a standstill of the whole production in the company as it is a crucial machine in the production of raw products. This machine represents the biggest issue (as far as money is concerned) for the company.

The machine is already 60 years old. It is running in three shifts, almost continuously. The maintenance block is done once per year. In the recent years emergency maintenance has been applied as the machine breaks down more frequently. During the emergency maintenance, the work progress slowly as the maintenance work is not planned and spare parts are not available at the needed time.

The system to be presented had the task to overcome the shortcomings for which the company paid directly and indirectly. The aim to diminish the shortcomings by standardising the maintenance work presents an approach that requires discipline from all company levels to stick to the rules of the system. Flexibility, such as the shift of maintenance work or production lots, is only possible in a smaller range than before. The limiting factors are:

- TPM principles are followed by all employees to avoid breakdowns and other losses,
- standardised maintenance works are carried out as planned without surprises coming up.

The core of the system is that the company is carrying out planned maintenance activities. As all activities are pre-planned, scheduled, and standardised, the company is able to provide a thorough planning and feedback when products will be finished. The planning task is given to the APS-module and further modules in the ERP system to make sure that:

- the required inventory is available,
- the maintenance resources are available,
- no production is planned in the maintenance slot on the given machine,
- maintenance can be carried out without further adjustment in the plan.

The approach tries to transfer unplanned and different maintenance activities into a set of projectable ones. Projecting decreases the requirement of searching for the mistake. While foregoing the breakdowns and its search for the failure occurred, the standardised approach can be used. The standardised approach has the advantage to provide the exact time slot and resources required for the work. The failure detection part vanishes as only planned maintenance blocks with a clear task exist.

By projecting the maintenance task more efficiently, the company is able to avoid costs amounting to 500 million CZK. As the case repeated in the same year once again with all its details (e.g. spare parts not on stock, no plan B for production), the amount increased to one billion Czech crowns. The approach used is therefore able to decrease the financial loss to a minimum compared to what the company spent in the year 2017.

Production losses	= 1 458 000 000 CZK
Cost for TPM, standardised maintenance, etc.	= 305 000 000 CZK
Total benefit by introducing TPM	= 1 155 000 000 CZK

Even with this high benefit calculated the company and its management are reluctant to change. Reasons for the company management not to do so are:

- the benefits show up indirectly,
- maintenance activities are non-value-added activities,
- the initial budget must be expanded to facilitate investments,
- the change in company culture requires a change in thinking that did has not yet begun at the management level.

As it can be seen, even with almost one billion Czech Crowns in losses, the company management has not been able to change its thinking. The losses calculated do not even include further indirect cost such as:

- loss of image,
- loss of reliability in customer’s ratings,
- loss due to penalties to be paid,
- loss due to change of transport means to more costly ones.

Nonetheless, the company management itself took part of the proposal into reality. The company overtook:

- full application of the APS system in the company,
- maintenance work was included in the planning process,
- a separate plan for maintenance work was issued to share the data with the logistics department,
- the ERP system was not taken as a source for calculating and sharing maintenance data.

The company is working with a unique machine and does not have any backup option. It is therefore vital for the company to have this machines (and all other machine in the line) working. Further, the situation does not allow for any flexibility in production or maintenance and requires a fierce preventive approach in order to not lose money. The production has to integrate the maintenance planned through logistics which does not identify these parts as independent.

Still, the company is dealing with suddenly occurring maintenance blocks due to machine breakdowns. The company realised the need for changing the maintenance approach but has not yet been able to fully change its culture to obey the TPM concept. Further, maintenance standardisation does not happen, relying on the experience of the maintenance workers to already know the situation and to work in their own standardised way.

The new approach wants to forego big maintenance blocks by identifying issues at the very beginning, making all resources available, and having as small but intensive blocks as possible. The company will get the opportunity to:

- predict maintenance needs,
- avoid breakdowns,
- avoid waiting times.

As the company faced another, identical breakdown on the same machine in the same year, 2017, the company already paid for its maintenance approach once again. So far, the competitive pressure on the company seems not to be high enough to urge the company management to change. As long as the company is able to survive a decline in revenues by 20 percent without major consequences, the management will not fear continuing. It is anticipated that the presented approach will be introduced in the future when competitive pressure is higher and the management is pressed to introduce major changes.

Since 2017, the offered and produced number of the biggest products has been reduced in order to spare the old equipment. This market is not competitive and provided a safe and profitable income. In 2018, the company decided to increase its production capacities by buying a second parallel production line. While it must be doubted that the whole capacity of these products can be sold, the company will buy flexibility in case the old line will face issues. Before the predicted full production of the line in the year 2020, the company still has to target the decrease of maintenance costs and the increase of equipment availability through the proposed approach.

The company belongs to the heavy industry sector and acts in an oligopolistic market. As was said, the proposed approach makes sense in companies that rely heavily on availability of their equipment. The worse the status of the equipment, the more time and care are required. The approach shows (preventive) maintenance is a good investment for such kind of companies. Systematising and standardising processes provide the ability to forecast and plan based on reliable data. The feedback from autonomous maintenance blocks provide the required actual data. This approach can also be applied in other industries. Digital factories or industry 4.0 work with status data that are updated almost in real time. Therefore, a maintenance concept based on actual data such as the one proposed may be applied in the most modern frameworks throughout various manufacturing industries.

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