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Production Disturbance Handling in Swedish Industry – a survey study

Master's thesis in Production Engineering, PPUX05

JON BOKRANTZ

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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JON BOKRANTZ

Department of Product and Production development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

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JON BOKRANTZ
Department of Product and Production Development
Chalmers University of Technology

Abstract

Manufacturing companies are today faced with increased demands on extreme flexibility and speed in operations, and are therefore searching for new ways to improve their manufacturing practices. This has led to a development towards more streamlined production processes, resulting in that the consequences of failures are increasing. Therefore, the need for improved Production Disturbance Handling (PDH) has been raised, this since effective correction, prevention and elimination of Production Disturbances (PD) is a prerequisite for a company's profitability and long-term survival.

The purpose of the study is to identify the perception of PD, and how the application of PDH has evolved in the past decade, investigate how OEE figures, risk assessment tools and software, and reliability engineers are used in relation to PDH, as well as assess the usage and level of awareness of the concept of Lean Maintenance in Swedish industry.

The thesis has been carried out as a questionnaire study where 76 respondents from 71 Swedish companies answered an online questionnaire distributed by email. Literature research was conducted in order to establish the content and construct the design of the questionnaire, as well as for performing and presenting statistical analysis. The data has been analysed using Statistical Package for Social Sciences (SPSS) and presented in terms of the context-dependent factors industry type, company size, and management position, as well as in an in-depth view of companies working with Total Productive Maintenance (TPM) and Lean Maintenance.

Results of this study indicate that there has been rather little development of the perception of PD during the past decade, and that PDH and maintenance operations in Sweden are still primarily reactive and slightly underdeveloped. Furthermore, low use of potentially valuable tools and software for risk assessment and reliability analysis is found, as well as a large improvement potential for applying work practices and principles from various maintenance concepts. Finally, the results highlight the need for increased safety awareness and improved work with safety in maintenance organizations in Swedish industry.

The concluding remark of this study is that a fundamental change in the perception of maintenance in Sweden is required in order to achieve sustainable production in the future.

KEY WORDS: Maintenance, Production Disturbances, Production Disturbance Handling, TPM, Lean, Performance measures, Risk assessment, Reliability engineering, Safety, Improvements, Sustainability.

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I also thank the SMGC network, and especially Filip Adielsson, for all the help with distributing the questionnaire and enabling the high level of participation amongst the SMGC companies. Simply put, this thesis would have been impossible to realize without the support from SMGC, and I am grateful for the opportunity to present my findings during the Sustainability Circle Meeting in Trollhättan.

Last but not least, I would like to all the individuals who have shown their vested interest in this study and shared their valuable experiences through the questionnaire.

Jon Bokrantz

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Terminology

CM – Condition Monitoring

CBM – Condition-Based Maintenance

CFT – Cross-functional teams

DES – Discrete Event Simulation

EEM – Early Equipment Management

ETA – Event Tree Analysis

FMEA – Failure Mode and Effect Analysis

FTA – Fault Tree Analysis

JSA – Job Safety Analysis

LCC – Life Cycle Costing

LTA – Logic Tree Analysis

MDT – Mean Down Time

MTBF – Mean Time Between Failures

MTTF – Mean Time To Failure

MTTR – Mean Time To Repair

MPM - Maintenance Performance Measures

MP – Maintenance Prevention

MPI – Maintenance Performance Indicators

OEE – Overall Equipment Efficiency

PD – Production Disturbances

PDH – Production Disturbance Handling

PdM – Predictive Maintenance

PM – Preventive Maintenance

PPD – Potential Production Disturbance

RCA – Root Cause Analysis

RCM – Reliability Centered Maintenance

SMGC – Sustainability and Maintenance Global Center, community for maintenance.

SPSS – Statistical Package for Social Sciences, software for statistical analysis

TA – Technical Availability

TPM – Total Productive Maintenance

VMEA – Variation Mode and Effect Analysis

VSM – Value Stream Mapping

1 Introduction

1.1 Background

Manufacturing companies are faced with increased demands on extreme flexibility and speed in operations in order to stay competitive in today's fast-changing market. To manage this challenge, companies are searching for new ways to improve their manufacturing practices. During the past decade, adopting Lean production principles has been widely popularized in order to allow for increased profitability and productivity, but a result of striving for more streamlined processes is that the consequences of failures are increasing (Ericsson, 1997). This development has raised the need for improved Production Disturbance Handling (PDH) since effective correction, prevention and elimination of Production Disturbances (PD) is a prerequisite for a company's profitability and long-term survival. A main reason for the occurrence of PD is absence of proper maintenance (Ericsson, 1997; Nakajima, 1988), and the most important factor that determines the magnitude of production losses is in fact how much emphasis that is put on minimizing these disturbances (Ericsson, 1997). However, despite the clear evidence that reducing PD is crucial for operational performance, Jonsson (1999a) highlights how the maintenance function is often underdeveloped and has low status in Sweden, and there is a great improvement potential for more effective maintenance in the average Swedish manufacturing firm.

An industrial survey performed by Ylipää & Harlin (2007); (Ylipää et al, 2007) investigated various aspects of PDH and maintenance in Swedish industry, and concluded amongst other things that the use of PDH-methods and tools lack integration and that PD during the running-in of new products can threaten the entire life-cycle revenue of the product. In addition, they found that there are several divided views regarding PD: the factors that are classified as PD differs between individuals, the classification of PD differs from definitions found in literature, and there is a difference between the individuals' classification of PD and what is registered in the companies follow-up system as PD. The study was initially carried out through a mail survey during 2001-2004 with the intention of establishing longitudinal studies on PDH in Swedish production industry. Therefore, a second round of the study can identify changes, developments and trends regarding PD and PDH and shed further light on the current demands and prerequisites for effective maintenance operations.

Lean principles such as Just-In-Time (JIT) and aggressive inventory reduction makes the production flow more sensitive to disturbances and equipment failures, and high reliability is therefore essential for a Lean production system (Faria & Nunes, 2012). In turn, high reliability requires effective maintenance and a systematic approach to avoiding failures and managing uncertainties (Johannesson et al, 2013), and a transition towards a Lean production system also requires fundamental changes in the maintenance operations (Baluch et al, 2012; Moyaed & Shed, 2009). However, most companies are solely focusing on manufacturing efficiency through the use of Lean production tools, but a prerequisite for the success of a Lean manufacturer is the concurrent adoption of Lean Maintenance (Baluch et al, 2012). Lean Maintenance is seen as an improved and fine-tuned version of the Japanese maintenance concept Total Productive Maintenance (TPM) (Smith & Hawkins, 2004), in which losses due to PD are measured in terms of Overall Equipment Effectiveness (OEE). However, despite the fact that OEE is often viewed as an effective way of analysing the efficiency of production processes, the classification of losses are much-disputed, and the awareness of the impact from minor chronic losses are in many cases not prevalent (Ljungberg, 1998). Moreover, the use of risk assessment tools and methodologies is a way of identifying and predicting scenarios that leads to unwanted consequences (e.g. PD), and a structured and systematic use of these techniques allow for risks to be assessed and mitigated as early as possible (Shahriari, 2011). This scenario highlights that there is a trend towards development of more sensitive production systems, but there are also emerging principles, methodologies and tools that might allow for new possibilities to effectively identify and eliminate PD at an early stage, resulting in an advancement in the often overlooked area of maintenance operations and ultimately improved overall operational performance.

1.2 Purpose

The purpose of the study is to identify how the perception of PD and the application of PDH has developed in the past decade, investigate how OEE figures are used in relation to PDH, asses the utilisation of risk assessment tools in relation to PDH as well as investigate the awareness and level of usage of Lean Maintenance operations in Swedish industry.

1.3 Objective

To specify the objective of the thesis, a set of research questions is formulated. The research questions provide a focus for the aim of the study, and they are formulated with the intent of being answered by the results of the study. The following four research questions are stipulated:

What factors are regarded as PD?

How is PDH applied in industry?

What risk assessment tools are used in relation to PDH?

To what extent is Lean Maintenance principles used?

The first and the second research questions are to be studied in a repeated cross-sectional manner to highlight how the view of PD and PDH has evolved in the past decade, and the results will therefore be put in comparison to those stated in Ylipää & Harlin (2007) and Ylipää et al (2007). The third and fourth research question is aimed at investigating the current state regarding the use of risk assessment tools and Lean Maintenance principles. The results from the questionnaire will be further analysed based on the context-dependent factors industry type, company size, and management position.

The first research question identifies which factors that are classified as PD and which are registered as PD, based on the same 21 factors used in the previous survey.

The second question is stated in order to assess how PDH efforts are structured by giving answers to what maintenance methodologies, tools and principles that form maintenance operations. It also aims at answering how results of OEE figures are used in relation to PDH efforts, as well as investigates the risk of chronic PD and PD during running-in of new products, machines or lines as highlighted in Ylipää & Harlin (2007). This research question also involves an investigation regarding the extent to which reliability engineers are employed in the maintenance department to perform various analysis and improvement work.

The third question evaluates to what extent risk assessment tools and methodologies are used in order to predict and prevent risk factors that can contribute to PD and enable effective PDH.

The fourth and last question is stated in order to assess to what extent Lean Production principles are adopted in maintenance operations. This is done by investigating the level of usage of Lean Maintenance methods, tools and principles, and linking this to the awareness of the concept and the degree of which the prerequisites for effective Lean Maintenance operations are fulfilled.

1.4 Scope

The master thesis was conducted at the Department of Product and Production Development at Chalmers University of Technology with a focus of PD and the structure of PDH. Therefore, the scope focuses on maintenance operations with the intent of investigating the classification and registration of PD, how PDH efforts are applied and their connection to OEE figures, the use of risk assessment tools and reliability engineering in relation to PDH, as well as the level of usage of Lean Maintenance operations. However, due to the strong connection between maintenance and production operations, it is relevant to include how production planning and control, organizational structure and economic aspects affect the maintenance operations.

In order to investigate PD, PDH, risk assessment tools and Lean Maintenance, an online questionnaire is distributed to various Swedish industrial companies. The questionnaire include questions in the following subject areas based on the content of the previous study as well as in relation to the stipulated research questions:

1. Measurements and work practices
2. Classification of events and performance measures
3. Running-in and organisation
4. Risk assessment tools and reliability engineers
5. Lean Maintenance
6. General information

1.5 Delimitations

In order to ensure adherence to the objectives and limit the analysis of the thesis work, a number of delimitations are made. The aspects that will be studied in a repeated manner are limited to the preeminent findings reported in Ylipää & Harlin (2007) and Ylipää et al (2007), and those that can highlight important changes in the subject are of PD and PDH. Therefore, the subject areas of "Discrete Event Simulation (DES)", "Type of maintenance system" and "Future developments – needs and trends" is excluded from the questionnaire, and the content in the subject areas of "Set-up reduction" and "Working practices and IT-support" is reduced in order to allow for a wider scope of the study. Therefore, only the subject areas of "Classification and registration of PD" and

"Running-in" is primarily analysed in a repeated manner. Moreover, to allow for a coherent level of analysis, the different subject areas is investigated independent on level of significance.

Questionnaires are not as flexible as interviews due to limited possibility to ask follow-up questions or obtain comprehensive and elaborate answers to open-ended questions (Wilson, 2013). However, in order to reduce the risk of unmanageable amounts of data, interviews as a primary method of data collection is not included in the scope of this thesis.

Regarding OEE, the level of performance itself is not a subject for the study, and the focus is rather on how OEE figures are used in relation to PDH efforts.

2 Methodology

The methodology for the study consists of three main phases; literature review, empirical research and statistical analysis. The content and structure of these phases are further described below.

2.1 Literature review

In order to gain understanding of PD, PDH, maintenance concepts, OEE measurements, risk assessment tools and Lean Maintenance, a literature review was conducted. Although the results from the study presented in Ylipää & Harlin (2007) and Ylipää et al (2007) serve as the primary reference for the repeated analysis, a broader understanding of the above stated subject areas must be emphasised in order to expand the content of this thesis. Therefore, articles and books have been chosen from a wider array of subject areas to enable a larger perspective of the thesis.

The literature were collected from the following scientific databases that are available through the Chalmers library:

- Scopus (scopus.com)
- Emerald Insight (emeraldinsight.com)
- Google Scholar (scholar.google.com)
- Ebrary (ebrary.com)
- Books 24/7 (books24x7.com)
- ProQuest (proquest.com)
- Knovel (knovel.com)

To find relevant literature regarding the theoretical framework related to PD, PDH, maintenance operations, OEE, risk assessment and Lean Maintenance, the following key words were used in combination with each other:

- Production
- Manufacturing
- Disturbances
- Maintenance
- Reliability
- Improvement
- Overall Equipment Effectiveness
- Lean
- Risk
- Measurement
- Performance
- Cost

Regarding design and implementation of survey studies and online questionnaires, the following key words were used in combination with each other:

- Longitudinal
- Cross-sectional
- Survey
- Questionnaire
- Design
- Online

Furthermore, additional literature was chosen based on recommendations from the supervisor as well as from cited references in existing relevant literature. The literature review provides a theoretical framework for the thesis, which was used to establish the content of the questionnaire as well as discuss, validate or discard results conducted in this thesis.

2.2 Empirical research: survey study

The data for the previous study (Ylipää & Harlin, 2007; Ylipää et al, 2007) was collected through a paper survey distributed by mail. In order to decrease the response time, the survey in this thesis was reconstructed into an online questionnaire distributed by e-mail using the online survey tool *SurveyGizmo* (surveygizmo.com). In order to design and implement the questionnaire, literature research was conducted in order to identify the difference in design criteria between paper and online questionnaires to ensure equivalent quality of the responses between the two surveys.

According to Ployhart & Vandenberg (2010), *longitudinal research* has to contain a minimum of three repeated observation to provide enough observations to have captured the change action. Lynn (2009) states that a *longitudinal survey* collects data from the same sample element on multiple occasions over time, but features such as study topics, study population, interval between waves and mode of data collection may vary. Since longitudinal surveys have these distinct methodological features that cannot be fulfilled in this thesis, the subject areas aiming to perpetuate change over time will be studied in a repeated cross-sectional manner. The major difference lies in that longitudinal surveys follows the same group of individuals for each wave whilst a repeated-cross sectional survey allows to use independent samples for each wave that can be considered representative for the studied population. However, repeated cross-sectional surveys can still give good estimates to changes or movement that have occurred since the last survey (Lynn, 2009; Ployhart & Vandenberg, 2010).

2.2.1 Structure of the questionnaire

The factors related to PD used for the questions in the previous survey was initially derived from case studies performed in a longitudinal research project, which suggests that they are still suitable to use in continuous studies of PD. The remaining content of the questionnaire was constructed based on the findings in the literature review.

Norman et al (2001) suggests that form-based designs that presents the entire questionnaire in a continuous scrollable window allows for better preservation of the context of the questions compared to presenting one question at a time. Furthermore, they indicated that scrolling does not seem to pose any problems for the respondent. In general, shorter questionnaires stimulate higher response rates than longer ones (Dillman, 2000; Wilson, 2013), and the more demanding tasks in the questionnaire, the lower the sample coverage and the higher frequency and variety of errors (Davino & Fabbris, 2013). However, if surveying a specific population (e.g. maintenance and production experts in the context of this thesis) the questionnaire may be longer if the respondents have vested interest in participating (Dillman, 2000). For long surveys up to about 20 minutes (which is a recommended maximal time limit), dividing the questionnaire into subgroups can assure a respondent's perseverance with the survey (Lauer et al, 2013; Wilson, 2013). In addition, naming each section clearly and giving a very brief description of what answers are asked for allows for better sense of the importance of the questions (Lauer et al, 2013). Furthermore, Lauer et al (2013, who site many others) states that including a progress indicator has an appreciable effect in reducing frustration about the knowledge of how far the respondents are along in the survey or how much that is left. In line with these recommendations, the questionnaire conducted in this thesis was constructed using one separate page for each the six subject areas, with a continuous scrolling design for each page, including a progress indicator and a brief description of the subject of each section and what answers that was desired.

Lauer et al (2013) highlight that pre-packaged online survey tools limits the researcher to only ask simple types of questions, which in fact resulted in some implications for this thesis. The majority of the questions in the previous survey required answers through checkboxes, multiple choices lists or Likert-scale lists (see also 2.3.1 Data collection), which is possible to model in a pre-packaged online survey tool. However, the structure of the classification, registration and calculations of PD was originally designed with several sub questions and multiple checkboxes, which was impossible to model in the survey tool (note; several survey tools was tested in this regard). Therefore, the questions regarding which PD factors that are included in calculations of TA or OEE had to be excluded. In addition, a "Do not know" answer alternative was not available for the questions regarding the classification of PD in the previous questionnaire, only for the registration of PD. However, due to a limitation in the survey tool, a "Do not know" answer alternative was used for both classification and registration of PD in this questionnaire.

2.2.2 Pre-testing of the questionnaire

In order to test the functionality of the questionnaire and ensure that the questions are formulated in a comprehensive way, Dillman (2000) strongly suggest that a pre-test prototype questionnaire is distributed prior to fielding the final survey. Consequently, pre-testing of the questionnaire in this study was performed by distributing a preliminary version to one individual representing a company from the SMGC group. After the respondent had completed the survey, an unstructured interviewed by phone regarding the structure, content, comprehensiveness and user friendliness of the questionnaire followed. The feedback from the respondent resulted in that the answer alternatives of one question were revised. To be able to include the answer from the pre-testing questionnaire in the final survey, the selected participant was asked to revise the responses to the questions where the answer alternatives had changed, as well as complement with answers to added questions.

2.2.3 Distribution of the questionnaire

The questionnaire was primarily distributed by email to selected participants where direct contact information could be obtained. In addition, an open invitation to the questionnaire was listed publicly on the SMGC website, included in an SMGC newsletter and sent to previous participants of Chalmers Lean Production courses. This enabled the questionnaire to be distributed to a large number of potential respondents, but naturally resulted in that it was impossible to establish a definitive overall response rate. The questionnaire was open for submission during a time span of 39 days.

2.2.4 Selection of respondents

The selection of respondents followed the same approach as reported in Ylipää & Harlin (2007). The focus of the study is to indicate an expert view at a high strategic level from the perspective of maintenance or production management. These respondents are considered to possess specific knowledge related to the subject area of PD and PDH, and have a central role in achieving high reliability of the production system. The survey however also included production and maintenance managers and other actors that are involved with PDH at their company.

In total, 84 respondents answered the questionnaire. Out of the 82 selected respondents (who represented 74 different companies) that were given a direct invitation to the questionnaire, 62 answered, resulting in a response rate of 75 percent. 36 out of the 80 companies in the previous survey also participated in this study.

After choosing the respondents with highest management level and only allowing one response from each plant or definitive division of each company, 76 valid responses from 71 different companies was selected. Out of these respondents, 62 percent could be regarded as the maintenance department, 25 percent as the production department and 13 percent as both maintenance and production department.

2.2.5 Data about the participating companies and respondents

The majority of participating companies, 37 in total, have between 101-500 employees, but there is a rather equal distribution of the capital turnover per year, ranging from below 200 MSEK to over 10000 MSEK per year. Regarding industry type, the majority of the respondents, 52 in total, represented discrete manufacturing companies. Thereafter, 11 respondents represented process industry companies, and 13 represented other types of companies. A vast majority of the respondents have long work experience, where 74 percent have worked for 6 years or more within the area of operations and maintenance. For full description regarding the companies and respondents, see Appendix A, table 10-15.

2.3 Statistical analysis

Since the results of the previous survey was analysed using Statistical Package for Social Sciences (SPSS), this thesis follows the same methodology. The data from the previous survey is available in its entirety, which enables direct analysis between the two in a repeated cross-sectional manner. SPSS is used since it is a powerful statistical software that can calculate and present statistical analysis in a very efficient manner (Lee Abbott, 2013).

2.3.1 Data collection

The questionnaire is designed to collect either ordinal or nominal data. Nominal data is defined as the scoring of cases into broad categories, where the different categories are mutually exclusive but there are no hierarchy between them (Fisher & Marshall, 2009). In this questionnaire, an example of collecting nominal level data is to answer which risk assessment tools that the company are using. Ordinal level data is instead the scoring of hierarchically ordered categories that cannot be directly measured, but the categories are still mutually exclusive. Likert-scales are a common way of collecting ordinal level data, which require answers from a scale that ranges from high to low (Fisher &

Marshall, 2009). An example of collecting ordinal level data in this questionnaire is to answer to what extent PD increased during the latest running-in phase. This is the primary level of measurement in the questionnaire, and the two Likert-scales used in the questionnaire can bee seen in Appendix.

2.3.2 Data analysis

SPSS supports statistical analysis of several levels of measurements including ordinal and nominal level data. These are suitable levels of measurements for analysis using descriptive statistics (Fisher & Marshall, 2009), which is the primary method of analysis in this study. Descriptive statistics is a convenient way of reducing the data to a manageable form by ignoring the degree of randomness that underlies the data (Faber, 2012). Therefore, descriptive statistics are often regarded as one of the simplest forms of analysis, but it allows for summarizing the results into numbers and graphs that are easy to interpret (Fisher & Marshall, 2009).

The primary approach used to analyse and display the dispersion of the answers is to identify the frequency distribution, essentially meaning the number of cases in each category or answer alternative. In order to compare variables or groups against each other and detect differentiating patterns between them, contingency tables are commonly used. The analysis of these tables is performed by so called cross-tabulation. The cross-tabulated data is constructed as tables where the frequencies within each category is presented, allowing the researcher to identify patterns through simple visual inspection. The conventional way of constructing a contingency table is to present the independent variable in columns, and the dependent variable in rows, which results in that the column data percentages are created to a total of 100% (Lee Abbott, 2013).

In this study, the data from all responses were first analysed together to display the overall results of the survey. Thereafter, all responses were cross-tabulated based on industry type and company size, and some questions based on the respondents management position within the company. The partitioning of these categories followed the same structure as reported in Ylipää et al (2007): Industry type was divided into two categories – discrete manufacturing and continuous production, and company size in three categories – <100 employees, 101-500 employees and >500 employees. The respondent's management position was in Ylipää et al (2007) divided into the two categories maintenance or production, but in this study it was divided into three categories – maintenance, production and maintenance/production (i.e. respondents who's primary responsibilities are equally distributed between production and maintenance). Moreover, additional cross-tabulations between specific questions were carried out in order to further identify possible correlations between variables and groups.

In order to display the development since the previous survey, the frequency distribution of the selected subject areas for repeated analysis (as described in section 1.3 Objective) was compared both overall as well as within the three cross-tabulated categories.

When survey data is gathered from different groups and compared against each other through cross-tabulation analysis, a common approach to validate the findings is to use statistical tests such as t-tests, ANOVA or Chi-square tests. The purpose of these tests is to assess whether there is a statistically significant difference amongst the groups, essentially meaning that the probability of a certain effect is not purely random. Chi-square tests are of particular importance, and they are based on counting frequencies and assessing whether the patterns of differences between the groups are different enough to be considered statistically meaningful (Lee Abbott, 2013). However, to apply chi-square tests, the sample size must be big enough so that the estimated frequencies are not too small. Due to the small sample size and wide range of answer alternatives in the Likert scales used in this study, the estimated frequencies was almost always too low for Chi-tests to be applicable. Some authors (see for example Powers & Knapp (2010)) suggests that Fishers exact test should be used in small sample studies with low frequencies. However, the results from statistical tests are often difficult to communicate and present in a comprehensible manner (Saary, 2008). Due to the many implications with conducting statistical tests, and since the primary purpose of the study is not to identify the causes of differences between groups or variables, this analysis was solely based on descriptive statistics.

The effect of this decision is that none of the identified differences identified through cross-tabulation can be assessed as statistically significant or not, and there is therefore a possibility that they are purely a result of chance. Further discussion regarding the effects of this decision on the validity of the results presented in chapter 5.2 Methodology discussion.

2.3.3 Presentation of data

The results are presented in two types of graphs, bar charts in combination with a data table, or polar diagrams. Simple bar or pie charts can become difficult to interpret if there is a large number of variants and groups to be displayed at the same time. This is the case for multivariate data, i.e. data that is collected on several variables for each sample unit (Saary, 2008). This scenario is most prominent in this study regarding the classification and registration of PD factors where the respondents are asked answer both whether 21 factors are by them classified as PD and whether they are registered as PD at their company. As the data is also cross-tabulated in three different aspects, this naturally results in a tremendously large set of multivariate data. In order to present this data in a comprehensible way, polar diagrams (also called radar charts, radial plots, spider diagrams, star plots etc.) are used since it is a graphical tool that allows for a better and more graspable display of multivariate data in comparison to bar charts or text (Saary, 2008).

In order to simplify the interpretation of the bar charts and the underlying data table, the results from questions with Likert scale answer alternatives are grouped and presented in only two categories: "Yes" or "No". The "Yes" category displays the sum of the two affirmative answers "Yes, absolutely" and "Yes, to a certain extent", or the sum of "To a very high degree" and "To a relatively high degree". In contrast, the "No" category comprises the sum of "No, scarcely" and "No, not at all", or the sum of "To a relatively low degree" and "Not at all". Moreover, the bar charts almost exclusively presents the results from the overall analysis, and the results from cross-tabulations are instead presented shortly in text and refers to the complete data tables in Appendix.

2.4 Time plan

The Master Thesis was completed during a time horizon of 20 weeks of 40 hours, resulting in a total time of 800 hours. The thesis was divided into four main phases; literature research and problem framing, survey design, survey distribution and follow-up, and statistical analysis. In addition to these phases, mandatory elements in form of attendance at two master thesis presentations as well as thesis opposition were included in the project.

3 Theoretical framework

The following section provides the reader with the required theoretical understanding of the context of the thesis and the subsequent findings, and it will furthermore be used to discuss, validate or disregard the results from the study.

3.1 Maintenance fundamentals

To introduce theories related to PD and maintenance operations, a clarification of basic concepts related to production system performance is necessary. There are several varying definitions and views regarding the relationship between these concepts, which can easily cause some confusion for the reader. Therefore, to ensure a coherent use of technical terms in this thesis, the guidelines of the Swedish Standards Institute (SIS, 2000) and the European Standard CEN/TC 319 (1998) will be followed.

The primary event that is the basis for most maintenance activities is *failure*, which occurs when an item stops performing its required function. However, one shall note that failure is not the only cause for an item to be out of use since planned actions or lack of resources can require a state of downtime.

Availability is defined as "a unit's ability to perform a required function under given circumstances, at a given point of time or interval, under the assumption that required external maintenance resources are provided", essentially meaning that when a failure occur, availability decreases. Moreover, *dependability* is a collective term used to describe availability in a non-quantitative context. In this broad sense, a system's dependability is influenced by its hardware, software, management and environment. However, if you are to express yourself in a quantitative context or refer to a specific characteristic, the more precise term availability should be used. Furthermore, dependability is affected by the factors *reliability, maintainability* and *maintenance support*. The relationship between these basic concepts of dependability is further described in Figure 1 - Relationship of dependability.

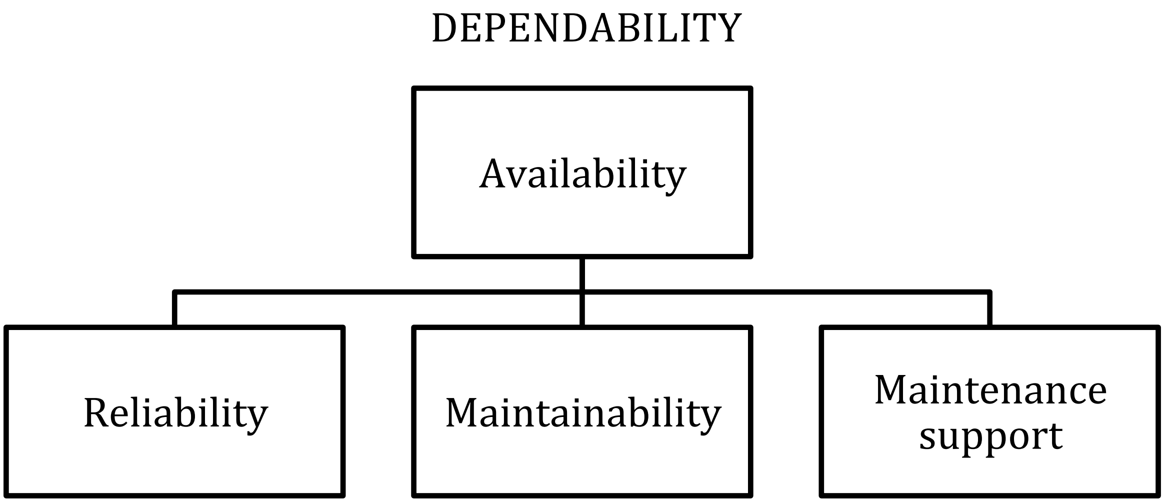


Figure 1 - Relationship of dependability

Reliability is defined as "a unit's ability to perform a required function under given circumstances during a given time interval", which is almost identical to the term availability. However, to separate these two from each other, Birolini (2013) describes availability as a broader term that expresses *the ratio of delivered to expected service*, whilst reliability is a specific characteristic of an individual item expressed either as its *ability to remain functional,* or the *probability that no operational interruptions will occur,* during a given time interval. In that sense, reliability can be used as a performance measure to evaluate the probability to failure.

Maintainability is defined as "the probability that a given active maintenance step can be carried out within a given time span, for a unit during given circumstances, when the maintenance is carried out under given circumstances, when the maintenance is carried out with support from given procedures and resources". Slightly simplified, it describes how easily an item's function can be restored.

Finally, *maintenance support* is defined as "a maintenance organisation's ability to, during a given condition, when needed, supply resources required to maintain a unit according to a given maintenance policy".

Together, all of these terms relate to the fundamental purpose of maintenance operations: to ensure the functioning of technical equipment. In that sense, maintenance aims at achieving high dependability of the production system, and *maintenance* can in detail be defined as (SIS, 2000):

"The combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it, or preserve it, to a state in which it can perform the required function."

The maintenance function plays a vital role for every company in today's competitive environment due to the simple fact that properly maintained manufacturing equipment makes many products with high quality, improperly maintained equipment makes fewer products of questionable quality, and inoperative equipment makes no products at all (Smith & Hawkins, 2004). Despite this, maintenance is traditionally seen as a necessary evil since it can account for a large part of a company's entire operating budget (Tsang et al, 1999) whilst not always having an obvious connection to improved productivity and profitability (Alsyouf, 2007). In addition, Ylipää (2000) highlight that maintenance is not only highly neglected and oversimplified in the industrial world, but also in the academic.

However, Alsyouf (2007) argue that effective maintenance will in fact result in increased utilization of the production system and ultimately increase the profit as a result of decreased manufacturing cost. Patterson et al (1996) presents a similar view and state that in companies where maintenance is viewed as an operating expense to be minimized, the maintenance practices decrease their competitiveness by reducing throughput, increasing inventory, and leading to poor delivery performance. On the positive note, Jonsson (1999a) reports that company-wide integration of maintenance has been emphasised during the last decades, and we are now talking about how maintenance contribute to life cycle profit rather than life cycle cost.

Maintenance policies are most commonly divided into two major categories: *corrective* and *preventive* maintenance. Note however that the CEN/TC 319 (1998) standard defines in total 13 maintenance types and 13 maintenance activities (and several additional maintenance types and classifications exist, see for example Daley (2008); Sherwin (1999b); Jonsson (1999a)). Different authors use different definitions and widely argue what actually constitute these maintenance types, so to reduce the confusion of the subject, this thesis will concentrate on the types as described in Figure 2 - Maintenance types according to SIS (2000).

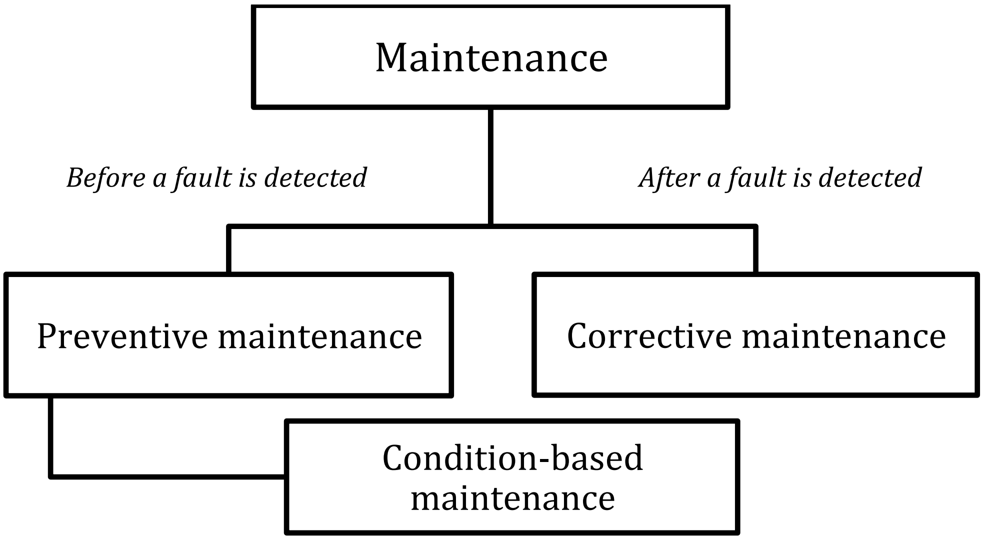


Figure 2 - Maintenance types according to SIS (2000)

3.1.1 Corrective maintenance

Corrective maintenance is defined as "maintenance carried out after fault recognition and intended to put an item into state in which it can perform a required function" (Cen/Tc319, 1998). This is the classic approach to "fix what's broken", where you only address the specific items that has failed through emergency actions or repairs, or in general un-scheduled maintenance activities. Corrective maintenance normally results in significantly increased maintenance costs (up to three times compared to preventive maintenance) as well as decreased availability (Mobley, 2004). However, it shall be noted that in some contexts with purely random breakdowns and low breakdown costs it can be the most appropriate maintenance strategy (Jonsson, 1999a).

3.1.2 Preventive maintenance

Preventive maintenance (PM) is defined as "maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item" (Cen/Tc319, 1998). PM is based on the idea of identifying an items usable life and perform maintenance at the appropriate time, thus preventing most of the failures and maximizing the utilization of the item throughout its lifetime (Daley, 2008).

PM strategies are often described with the use of the so called "bathtub curve" as seen in Figure 3 - Bathtub curve. Initially, a machine has higher probability of failure due to installation issues. Thereafter, the probability of failure is significantly lower for an extended period of time (i.e. normal life), and then increases sharply with elapsed time. PM activities can then be scheduled based on statistics of the probability of failures during this time (Mobley, 2004).

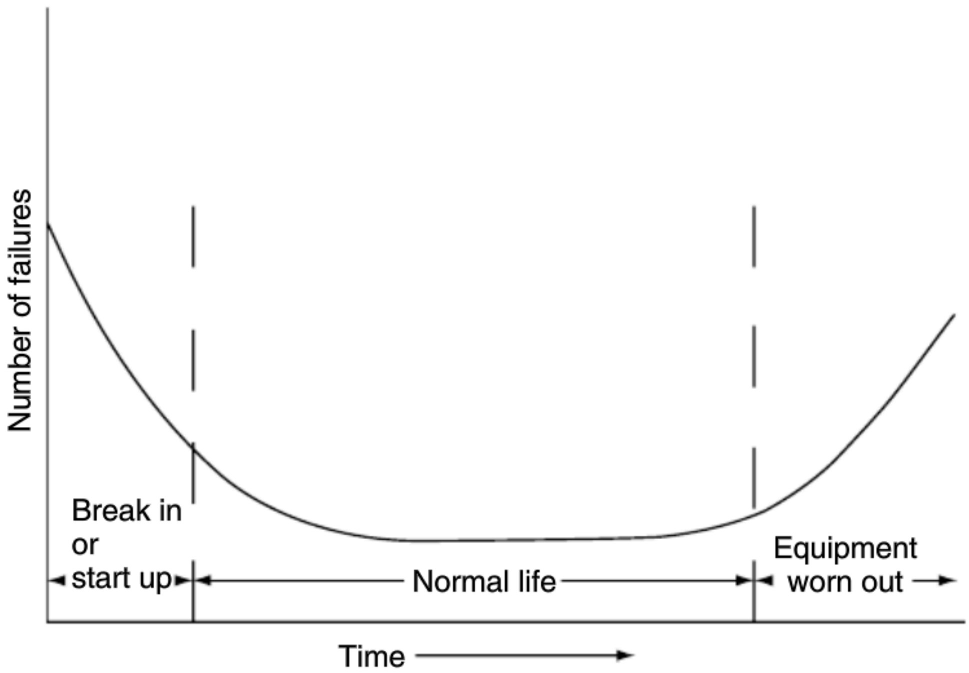


Figure 3 - Bathtub curve

The validity of the bathtub curve is much disputed, but it is a simple way of perpetuating the lifecycle of equipment and the goal with preventive maintenance: schedule regular repairs before the equipment completely wears out and the "drain" is reached (where failure occurs) in order to maximize the useful life.

However, PM should not solely focus on addressing the equipment that is approaching its end-of-life. It is essential to also restore the usable life of all worn components, as well as understand which components that determining the life of the equipment and the order of failure. The latter also includes to make the components with the shortest life more robust by considering reliability and maintainability during the design-phase (Daley, 2008) (see also section 3.5.1 Reliability Engineering & Maintenance Prevention). It is still important to highlight that PM does not only consist of complex activities, but also include simple tasks performed by operators such as cleaning, preparation of the workplace for maintenance as well as obtaining spare parts, tools and support equipment (Cen/Tc319, 1998).

3.1.3 Predictive maintenance

According to Birolini (2013), the aim of PM must also include to identify and repair hidden faults, such as undetected failures in redundant items. A maintenance type that is often equated with PM is Predictive maintenance (PdM). Both are pro-active strategies, but the difference however lies in that PdM consists of actively searching for previously unknown conditions that can cause deterioration or lead to failure, whilst PM deals with conditions that are already known to exist. In addition, PM is frequently invasive whilst PdM is typically non-invasive (i.e. cause downtime). A PdM task is aimed at identifying signals that are characteristic of end-to-life conditions, such as increased vibration, noise or temperature (Daley, 2008).

In relation to the bathtub curve, the real value of PdM is to actually find the drain. Intuitively, it is located at the transition point between the period of low failure rate and the beginning of the end-of-life failures, but in most cases the exact location of this point is unknown. By placing a PdM task in the proximity area of the drain point, the end-to-life characteristics can be identified and a PM task can be scheduled before failure occurs (Mobley, 2004).

3.1.4 Condition-based maintenance

A maintenance strategy that combines the objectives of both PM and PdM is condition-based maintenance (CBM). The purpose of CBM is to preserve an item's required function through a systematic application of analysis techniques and use of monitoring equipment in order to both minimize PM and reduce corrective maintenance (SIS, 2000). Since PM activities inevitably leads to downtime of equipment, carrying out PM without investigating the condition of the equipment can lead to unnecessary reduction in availability (Alsyouf, 2007). According to (Smith & Hawkins, 2004), planning maintenance activities according to the condition of the equipment is in fact to realize that most failures do not occur instantaneously. In that sense, CBM is a preventive maintenance strategy that applies PdM techniques in order to plan PM actions in relation to the equipment condition, thus minimizing the overall amount of maintenance activities.

The key component in CBM is the PdM technique Condition Monitoring (CM), which can include advanced vibration or thermography analysis as well as simple techniques such as visual inspection or oil samples performed by operators (Alsyouf, 2007). In fact, one of the most profitable PM policies can be that operators use their five human senses to monitor equipment and prevent problems by performing lubrication, routine cleaning, spannering and adjustments (Idhammar, 1992).

3.2 Maintenance concepts

Several maintenance concepts are defined in literature, but this thesis will focus on those that are best known and most commonly used: TPM, and Reliability-Centered Maintenance, RCM. Due to the immense popularity of Lean Production and its high requirement on reliability, the concept of Lean Maintenance has gain interest in recent times and is therefore also considered to be relevant for this thesis. In fact, Lean Maintenance is in principal a combination of TPM and RCM (Smith & Hawkins, 2004). The concepts will be briefly described in this section, and their connection to PD and PDH will be clarified.

3.2.1 Total Productive Maintenance, TPM

TPM was developed in Japan during the 1970's as maintenance concept with the goal of achieving zero defects, zero breakdown, and maintenance-free equipment (Nakajima, 1988). Smith & Hawkins (2004) describes TPM as an initiative to optimize the reliability and effectiveness of manufacturing equipment, and it has according to (Nakajima, 1988) a strict definition in five steps:

1. Maximizing equipment effectiveness through optimisation of equipment availability, performance, efficiency and product quality
2. Establishing a maintenance strategy (level and type of classical preventive maintenance) for the life of the equipment

3. Covering all departments such as the planning-, the user and the maintenance department
4. Involving all staff members from top management to shop-floor workers
5. Promoting improved maintenance through small-group autonomous activities

Ylipää (2000) explain that TPM work with three basic concepts: control of the production process by measurements and continuous follow up, autonomous maintenance by operators, and continuous improvement by small improvement teams.

To control the production process, continuous measures of Overall Equipment Effectiveness (OEE) is carried out. By calculating OEE figures, the performance of processes can be evaluated, issues can be followed-up and improvements can be identified (Dal et al, 2000). OEE's role in TPM and its connection to PDH is further described in section 3.3.3 Overall Equipment Effectiveness - OEE.

TPM is a team-based approach on every company level, but strong emphasis is put on autonomous maintenance carried out by operators during production. Operators can perform "in-operation" maintenance more efficiently than maintenance staff, and it can eliminate the need for waiting for a work order and the proper conditions to perform maintenance. It also goes the other way; maintenance mechanics can include setup or pre-setup calibration of equipment as a step of the maintenance requirement more efficiently than the operator. Therefore, cross-training of operators and maintenance mechanics, as well as a team-based approach to maintenance can achieve much more efficient maintenance operations and build a base for a learning organization (Smith & Hawkins, 2004).

The small improvement teams is the engine in this kind of PDH work, and it is also a forum for analysis, consultations, problem-solving etc. as well as for learning and competence development (Ylipää, 2000).

3.2.2 Reliability-Centered Maintenance, RCM

RCM was initially evolved within the civil aviation industry based on the approach to determine the maintenance requirements of physical assets in their operating context. The concept emerged from an investigation of the reliability of aircraft equipment where it was discovered that scheduled overhaul had little effect unless the item had a dominant failure mode, many items lacked an effective forms of scheduled maintenance, and cost reductions in maintenance could be achieved without decreased reliability. RCM was thus developed to consider operational experience and failure history to generate technical rational and economic justification in order to select the most appropriate maintenance tasks (Smith & Hawkins, 2004). The name RCM emphasises that *reliability* is put in the *center* of the maintenance planning process (Hinchcliffe & Smith, 2003).

The process of RCM combines the approaches of corrective maintenance, PM, PdM and CBM, and it is primarily a pro-active process based on asking seven question regarding the system or asset in review (Smith & Hawkins, 2004):

1. What are the functions and associated performance standards of the asset in its present operating context?
2. In what ways does it fail to fulfil its functions?
3. What causes each functional failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What can be done to predict or prevent each failure?
7. What should be done if a suitable pro-active task cannot be found?

A way of applying the basic features of RCM is to follow the seven steps as described by Hinchcliffe & Smith (2003):

1. System selection and data collection
2. System boundary definition
3. System description and functional block diagram
4. System functions and functional failures – preserve functions
5. Failure Mode and Effect Analysis (FMEA) – identify failure modes that can defeat the functions
6. Logic (decision) tree analysis (LTA) – prioritize function need via the failure modes
7. Task selection – select only applicable and effective PM tasks

The result of following these steps is that a preferred definition of PM tasks is provided based on well-documented records of how and why the tasks where selected and considered to be the best alternative. What sets RCM apart from other maintenance concepts is the underlying purpose of the four last steps described above. To *preserve functions* means to know the expected output and make the preservation of that output (i.e. function) the primary task. *Identify failure modes that can defeat the functions* highlights that failures can come in many size and shapes, and that there can be several in-between states that are of great importance and needs to be examined. *Prioritize function need via the failure modes* is based on the notion that all functional failures are not to be treated equally, and the importance of the failure modes is prioritized. Finally, *select only applicable and effective PM tasks* aims at only choosing the most cost-effective option of the available PM activities (i.e. being *effective*) that will prevent or mitigate failure, detect onset or failure, or discover a hidden failure (i.e. being *applicable*) (Hinchcliffe & Smith, 2003).

To demonstrate the possible benefits of RCM, Hinchcliffe & Smith (2003) reports a case study of a RCM project in a wind tunnel that resulted in a reduction of corrective maintenance with 40-60%, and that the identification and improvement of “items of interest” alone generated economic returns that exceeded the entire project. However, RCM is a method with many variants and is not a cure-all or magic bullet to resolve industrial problems. The success depends on the support of management, the creativity of the RCM team, and the degree of co-operation of plant personnel involved with the system (Jones, 1995 cited in; Ylipää, 2000). In fact, Sherwin (2000) directs strong criticism towards RCM and claim that the perception that overhaul is only effective when a dominant mode of failure is present origins in a misconception of the bathtub curve. Furthermore, he considers RCM to perpetuate the myth of over-maintenance and believe that the popularity of the concept probably depends on its low requirement on input or investment from higher management.

3.2.3 Lean Maintenance

According to Ylipää (2000), there is a synergism in integration of the TPM and the RCM concepts. This is in fact what Smith & Hawkins (2004) defines as *Lean Maintenance*: fine-tuning TPM through integration of RCM elements. However, the subject is rather unclear due to many diverging views in literature, so in order to further describe the concept of Lean Maintenance, a brief clarification of the fundamental approach of Lean Production and its relation to maintenance operations is required.

Lean Production

The term "Lean Production" was first coined in an article by Krafcik (1988) called *"Triumph of the Lean Production system"*, but the real popularization of the concept started after the publication of the book *"The Machine that Changed the World"* (Womack et al, 1990) that highlighted the superiority of Toyota's Production System (TPS). The term "Lean" is thus an American concept to describe TPS, and although Lean principles are rooted in manufacturing, they are in general universally applicable (Dennis, 2007).

The ultimate goal of TPS is to reduce all activities that do not add value to the customer, and all non-value adding activities are considered *waste*. There are three major types of waste: *muda, muri* and *mura,* and they are all influencing each other. Mura means unevenness or unnecessary variation, muri is overburden of equipment or operators, and muda is described by the 7+1 wastes: transportation, inventory, motion, waiting, over-processing, over-production, defects and unused creativity of operators. The goal with Lean Production can also be described by 5 guiding principles: (Liker, 2003).

1. *Value:* specify what creates value for the customer
2. *Value stream:* identify all the steps along in the process chain
3. *Flow:* make the processes flow
4. *Pull:* make only what the customer demands
5. *Perfection*: strive for perfection by continuously removing waste

What actually constitute the concept of Lean Production varies between authors, but Dennis (2007) explains it with the use of the classic "House of Lean Production" as seen in Figure 4 - House of Lean Production.

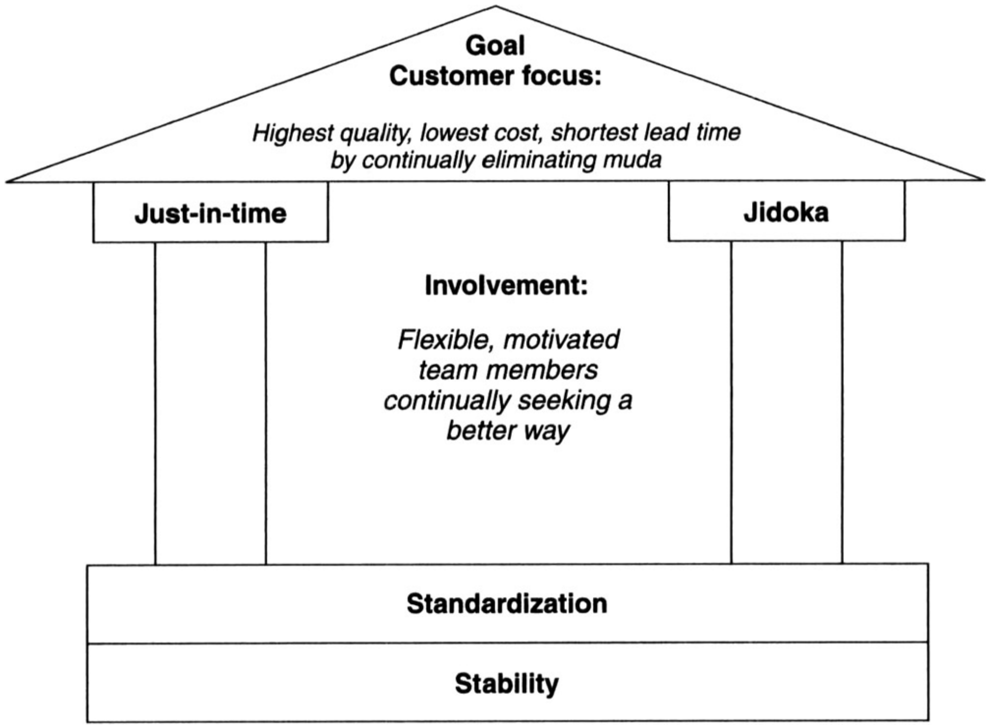


Figure 4 - House of Lean Production

The foundation is the stability and standardization; the walls are JIT, deliveries of parts and products, and Jidoka, or automation with a human mind. The heart of the system is involvement: flexible motivated team members continuously seeking a better way, and the roof describes the goal with the system: customer focus – to deliver the highest quality to the customer, at the lowest cost, in the shortest lead-time.

Stability starts with the 5S system, which is a necessity for standardized work. 5S is a simple system for creating clean and well-functioning workplace by following the steps of Sort, Set in order, Shine, Standardize and Sustain. Furthermore, 5S leads to TPM which is the key to machine stability. Standardized work means to establish the safest, easiest and most effective way of doing the job. Note however that it expresses the *current* best practice, and standardized work is constantly changed and improved. This is based on the fact that without a standard, there is no way to evaluate how to improve. JIT means to produce the right item at the right time in the right quality, anything else is waste. Jidoka refers to creating defect-free processes by continuously strengthening process capabilities, quickly identify and contain defects and emphasize feedback so that rapid countermeasures can be taken. Finally, involvement develops the team members and creates long-term success by never ending efforts for continuous improvements (Dennis, 2007).

Lean Production is of particular interest since it is one of the most commonly adopted manufacturing principles today, which in fact has a massive impact on reliability aspects. Today, the market demands shorter lead times and lower production costs, which are two of the main pillars of competitiveness for supply chains operating in a JIT manner. Due to this market demand, companies are almost forced to adopt JIT techniques and aggressive inventory reduction programs to remain competitive. This can effectively reduce production costs, but it increases the sensitivity of the production system and the severity of consequences from disturbances and failures. Therefore, high reliability is essential for a Lean production system (Faria & Nunes, 2012). To achieve a successful transition towards a Lean production system, fundamental changes in the maintenance operations are required (Baluch et al, 2012; Moayed & Shell, 2009). Moayed & Shell (2009) further explains that when changing from a non-Lean to a Lean production system, the maintenance system must be upgraded from unplanned to planned maintenance, then to preventive maintenance, and eventually to TPM. Actually, a fundamental prerequisite for the success of a Lean manufacturer is the concurrent adoption of Lean Maintenance (Baluch et al, 2012). Succeeding with a Lean transformation is in fact proven not to be easy task. In a large survey conducted by Industry Week in 2007, only 2 percent of the responding companies had fully achieved their objectives of their Lean implementation plan, and less than a quarter reported achieving significant results (Pay, 2008).

On the basis of this brief introduction of Lean Production, a more in depth description of Lean Maintenance can follow. As mentioned, TPM is an important part of Lean Production due to its purpose of creating stable production conditions, and RCM addresses the core of the customer need: a reliable production system. Together, they are what constitute Lean Maintenance (Levitt, 2008). In order to effectively combine TPM and RCM, two actions are required: assessing equipment criticality and establishing maintenance task priority codes. Criticality assessment quantifies how important an item or system function is in relation to the indented mission, which normally is production. Maintenance task prioritization is used to assigning the priority of maintenance work orders based in the equipment criticality; the equipment with the highest criticality is scheduled first, and subsequent tasks are scheduled in order of priority until all available maintenance resources has been utilized (Smith & Hawkins, 2004). In addition, since high reliability is crucial for a Lean production system, Lean Maintenance operations emphasize the use of Reliability Engineering (see section 3.5.1 Reliability Engineering & Maintenance Prevention).

All of the characteristic Lean manufacturing tools can be applied for maintenance operations. Idhammar (2014a) describes that the equivalent to over-production in a maintenance context is over-maintenance; performing more maintenance than required is waste. Overproduction is often recognized as the most severe waste since it leads to all the other wastes, but naturally, all types of wastes can arise during maintenance activities. The major improvement potential for over-maintenance lies in the optimization of PM by questioning if all repairs performed during stoppages are actually needed, as well as to prioritize, plan and schedule work orders in a disciplined manner (essentially equal to what Smith & Hawkins (2004) describes with criticality assessment and work order prioritization). Inventory reduction is a key component for effective JIT., and standardizing the range of spare parts and maintenance equipment and reduce the overall inventory levels can easily result in 10-20% reduction in inventory cost without sacrificing production reliability (Idhammar, 2014a). Furthermore, standardized work is also applicable for maintenance operators, and Andon-signals can be used to initiate corrective maintenance. Built in sensors and mechanisms (Poka-Yoke) can identify and prevent disturbances, and Value Stream Mapping (VSM) can effectively identify waste in maintenance activities. Daily morning meetings and kaizen-events can include maintenance operators in improvement activities, and Root Cause Analysis (RCA) can effectively identify and address equipment failures (Levitt, 2008). Finally, Ericsson

(1997) suggests that visualization system, which is strongly emphasised in Lean concepts, is one of the most important tools for minimizing PD losses.

This scenario highlights that Lean Production principles in general, and Lean Maintenance in particular, offer plenty of methods and techniques for improved maintenance operations, and Ericsson (1997) points out that companies that are truly successful with Lean Production is a logical result of effective PDH. This is supported by Liker (2014) who explains that the equipment at Toyota's plants work so well because of rapid responses to breakdowns and rigorous problem-solving when a reoccurring cause is detected.

3.2.4 Integrating maintenance

In a broad sense, the objective of maintenance is to maximize the dependability of the manufacturing system, and reliable equipment is an absolute necessity for productivity and profitability. However, maintenance itself cannot resolve all the issues that impacts manufacturing efficiency, and an integration of maintenance with other organizational functions are therefore vital. This approach is emphasized in such maintenance concepts as TPM where partnership between maintenance and production is stressed. By viewing maintenance as a contributor to not only equipment efficiency and effectiveness, concepts such as TPM can also generate improvements in other areas.

This can be showcased by the case implementation performed by Shamsuddin et al (2005), where TPM was combined with ecology oriented manufacturing (i.e. initiatives that results in both decreases environmental impact and increased efficiency) and 5S in order to accomplish organizational goals far beyond equipment maintenance. The implementation resulted in improved equipment efficiency above the initial targets, and such high OEE figures as 77-86% is reported. These improvements then resulted in dramatically increased capacity and drastically reduced capital costs. In addition, a number of both tangible and intangible gains are reported. Intangible effects include improved customer impressions about product quality and reliability, enriched working environment, increased manpower skill and zero defects orientation and operation. Tangible effects include shorter MTTR, longer MTBF, lowered accident frequency, reduced maintenance cost and increased net profit of sales.

3.3 Performance measures

Measurements of manufacturing performance can be used for top management to control production, for continuous shop-floor improvements or internal or external benchmarking (Jonsson & Lesshammar, 1999b). Performance measures are also important for maintenance staff to help in improving its operations and thus reduce direct and indirect cost of failure processes (Ylipää, 2000). It is however not always clear how and what should be measured (Jonsson & Lesshammar, 1999b), and this section will primarily cover two of the most widely used performance measures; Technical Availability (TA) and Overall Equipment Effectiveness (OEE). Moreover, other relevant measures of industrial engineering will be presented in short, followed by a presentation of more holistic frameworks for maintenance performance measures.

3.3.1 Technical Availability - TA

TA is a measure of the total amount of time that a machine or system has been available for performing its required function, and it is calculated as followed (Haarman & Delahay, 2004):

$$TA = \frac{Availabile\ time - Stop\ time\ losses}{Available\ time}$$

The precise definition of TA can vary between companies since available time can be interpreted differently. Consequently, defining it as the total number of hours within one calendar year will not yield the same results as if it was defined as the number of scheduled manned hours. Moreover, the number of scheduled manned hours naturally differs between having one or two shifts. What is included in stop time losses can also vary. Stop times that reduces the availability can be for example due to set-ups, adjustments or unplanned breakdowns, but planned maintenance activities can also results in down time of equipment (although Ljungberg (2000) advocate for not including PM activities in TA). This variation in definitions requires extra consideration when TA is to be used for external benchmarking (Haarman & Delahay, 2004).

3.3.2 Measures of industrial engineering

There are numerous measures related to dependability, but most are a combination of the following fundamental terms (SIS, 2000):

Mean Time To Failure (MTTF) measures the average time to failures with the assumption that the failed system is not repaired.

Mean Time To Repair (MTTR) represents the average time required to repair a failed system.

Mean Time Between Failures (MTBF) is used to display the average time between occurred failures. MTBF represents the sum of MTTF and MTTR, but it is not uncommon to equate MTBF and MTTF since MTTF is much larger than MTTR in many cases.

Mean Down Time (MDT) is the average time that a system is non-operational, which can be both due to system failures as well as scheduled downtime such as planned maintenance or logistic or administrational delays. The inclusion of scheduled downtime is what differentiates MDT from MTTR since MTTR only takes consideration to downtime that requires repairs.

Two other important measures for production performance and process improvement in general is *cycle time* and *lead time*, which are in fact widely misunderstood and used interchangeably. Lead time describes the time from when a request is initiated until delivery is finalized, whilst cycle time describes the time from when actual work begins on the request until the item is ready for delivery. In that sense, cycle time measures the completion rate whilst lead time measures the arrival date to the customer. According to Little's Law, lead time can more precisely be described in terms of cycle time, WIP and Throughput as (Little, 1961):

$$Lead\ time = Cycle\ time \times WIP$$
$$or,$$
$$Lead\ Time = \frac{WIP}{Throughput},$$

where WIP (Work-In-Progress) is the average number of units or customers in the system and Throughput is the rate at which items are passing through the system (units of period of time).

3.3.3 Overall Equipment Effectiveness - OEE

In TPM, OEE is the primary performance measure. Its definition includes downtime and other production losses that decreases throughput in relation to three dimensions of effectiveness (Ljungberg, 1998):

1. Availability (A)
2. Performance rate (P)
3. Quality rate (Q)

The exact definition of OEE differs between authors, and there are diverging opinions regarding all the content of the three dimensions. Availability measures the total time that the system is not operating due to breakdowns, set-ups and other stoppages, which essentially displays the ratio between planned production time (i.e. loading time) and the actual operating time. The main argument regarding availability is whether planned downtime, such as PM, should be included in the calculations or not. Jonsson & Lesshammar (1999b) argue that including it will result in much lower availability (since the *true* availability is shown) but it would create a motive for decreasing planned downtime by more efficient set-ups and PM. However, it is not included in the original definition by Nakajima (1988). Performance rate measures the ratio of actual operating speed and the ideal operating speed, which is defined as the ideal speed minus speed losses, minor stoppages and idling. Quality rate depicts the number of items rejected due to quality defects, but it only measures it at the point of the equipment, not issues that appear downstream. Similarly to TA, the difference in OEE definitions between authors and companies deserves attention when using it for external benchmarking (Jonsson & Lesshammar, 1999b). In its original definition, the OEE figure is calculated as (Nakajima, 1988):

$$OEE = (A) \times (P) \times (Q)$$

$$(A) = \frac{Loading\ time - downtime}{Loading\ time}$$

$$(P) = \frac{Ideal\ cycle\ time \times output}{Operating\ time}$$

$$(Q) = \frac{Input - volume\ of\ quality\ defects}{Input}$$

To address the issue of not considering PM activities, Dal et al (2000) presents an alternative way of calculating OEE. Planned downtime then typically include waiting, lack of labour, PM activities, improvement activities, operator maintenance and operator training, and availability is calculated as followed:

$$Availability = \frac{Actual\ operating\ time}{Planned\ operating\ time}$$

where

$$Planned\ operating\ time = Total\ shift\ time - Planned\ maintenance$$

and

$$\begin{gathered} Actual\ operating\ time = Planned\ operating\ time \\ -Unplanned\ maintenance \\ -Minor\ stoppages \\ -Setup\ \&\ Changeover \end{gathered}$$

Regarding the Performance rate, Dal et al (2000) argues to measure it as the achievement of stable processing speed over a period of time (e.g. a production shift), instead of the deviation of actual production time from the ideal cycle time based on a fixed output as suggested by Nakajima (1988). By doing so, minor recorded stoppages as well as those that go unrecorded (e.g.. small issues and adjustment losses) will be included, and performance efficiency is thus calculated as:

$$Performance\ efficiency = Net\ operating\ time \times Operating\ speed\ rate$$

where

$$Net\ operating\ time = \frac{No.produced \times Actual\ cycle\ time}{Actual\ cycle\ time}$$

and

$$Operating\ speed\ rate = \frac{Theoretical\ cycle\ time}{Actual\ cycle\ time}$$

The calculation of Quality rate is not modified and therefore only considers defects that occur at the designated machine, as describes by the formula (Dal et al, 2000):

$$Quality\ rate = \frac{Total\ no.produced - No.scrapped}{Total\ no.produced}$$

Data collection

In most cases, downtime is measured in an ad-hoc manner with such means as administrative maintenance systems that records the repair time or logbooks where operators record major stoppages. Neither of those gives an appropriate or comprehensive picture of the losses, and it is common that minor stoppages and speed losses are ignored whilst major time losses such as from set-ups are seen as productive time. Furthermore, performance losses are often ignored since regular measures of the cycle time or production speed is required to identify minor losses.

For OEE to be a comprehensive measure, large amounts of data do have to be collected. It could be carried out by either operators or computerised systems, but both have their downsides, and in some cases especially skilled engineers might be required. In order to overcome this, starting with a simple model of OEE that gradually evolves into a more comprehensive model makes it worthwhile to collect and analyse the data (Ljungberg, 1998). Jonsson & Lesshammar (1999b) describes that it should be performed at such a detailed level that it fulfils its objectives without being unnecessarily demanding of resources, this since too detailed data collection may result in unmotivated personnel. An example of a simplification would be to conduct frequency studies of the losses rather than recording the actual time (Dal et al, 2000; Jonsson & Lesshammar, 1999b; Ljungberg, 1998).

Operational improvement

Collecting data and calculating OEE is however of little value unless it is used in some context of improvement. This also follows the classic saying that what has not been measured cannot be improved, but there are diverging views upon how to make use of OEE figures. It could as mentioned be used for internal or external or external benchmarking, but Jonsson & Lesshammar (1999b) state that the most important objective of OEE is not to be an optimum measure, but rather a simple measure that tells production personnel where to spend their improvement resources. In contrast, Liker (2014) directs criticism towards using OEE as a KPI or any type of comparison across departments and plants. He means that OEE is relative to a baseline for a specific piece of equipment, which disables it from being compared against other machines or processes. He does however agree upon that it can be used as a single detector for directing improvement activities. On the other hand, Dal et al (2000) mean that OEE goes far beyond just daily monitoring and control and also take into account process improvement initiatives, prevents sub-optimisation of machines or lines, provides a systematic method for establishing production targets, and incorporate practical management tools and techniques to achieve a balanced view of process availability, performance rate and quality. In addition, both operators and management becomes aware of what constitutes waste and how such activities could be controlled and managed more effectively.

For OEE to be a bottom-up approach, a decentralized organization with autonomous teams is required, in which the measures are critically analysed and improvements are generated (Jonsson & Lesshammar, 1999b). If these are cross-functional teams (CFT) with maintenance representatives, reduced disruptions and improved overall production performance can be achieved (Jonsson, 1999a). CTF combines all the necessary skills and knowledge of the entire production system, enabling correct identification of practices and activities related to the production losses. It is also likely that CFT gains higher responsibility from top management and thus increased authority to carry out improvements (Bamber et al, 2003). Note however that if the issue of proper data collection is not addressed, and it might lead to that operator maintenance and small group activities are carried out without investigating the configuration of the losses (Dal et al, 2000). In addition, Liker (2014) argue that OEE might not be ideal for small group improvement activities since it aggregates so much and is hard to act upon, and he mentions that Toyota often instead use simplified measures for availability that everyone understands.

3.3.4 Frameworks for maintenance performance measurement

Despite TA and OEE possibly being the two most commonly used metrics, a more holistic approach to maintenance performance measures is emphasized by several authors. Van Horenbeek & Pintelon (2014) argue that maintenance performance measure (MPM) systems need to be aligned with corporate strategy and translated throughout all organizational levels, and maintenance priorities must be set in accordance to the company's business goals. In addition, it is crucial that maintenance performance indicators (MPI) are selected in line with the business environment and the maintenance strategy.

However, most available frameworks are too generic, resulting in a weak connection between corporate strategy, maintenance objectives, MPI, decision-making and continuous improvement. To overcome this, Van Horenbeek & Pintelon (2014) presents a MPM framework to vertically incorporate all organizational levels of decision-making. To develop such a MPM system, a 5-step methodology is suggested:

1. Translate a generic MPM system to a customized MPM system considering all organizational levels
2. Prioritize maintenance objectives on all organizational levels to derive business specific maintenance objectives
3. Translate the business specific maintenance objectives to relevant MPI on each organizational level
4. Measure, monitor and control maintenance performance based on the defined MPI
5. Continuous improvement by redefining maintenance targets according to the business environment

A list of examples for possible maintenance objectives on strategic and tactical levels includes:

- Maintenance budget, maintenance cost, maintenance value
- Availability, reliability, maintainability, OEE, productivity, output quality
- Life-cycle optimization
- Inventory of spare parts, logistics
- Safety/risk/health, environmental impact

These maintenance objectives can then be further concretized to operative level in form of such measures as specific direct or indirect costs, MTBF/MTTR, shortage and holding cost of inventory, number of accidents and number of maintenance interventions.

This maintenance framework is, in contrast to TA or OEE figures alone, usable for comparison and benchmarking between business sectors and environments. In addition, directly linked objectives makes it possible to evaluate maintenance performance on all organizational levels unlike isolated measures only carried out on the production floor.

3.4 *Production Disturbances*

This thesis revolves around the subject area of PD, but defining and describing what actually constitute a PD is not all that clear. There are diverging views in literature, between and within companies as well as in relation to different contexts. One of the primary findings reported in Ylipää & Harlin (2007) is that there can be a clear difference between what is classified as PD by individuals and what is registered as PD in companies' follow-up systems. Ljungberg (1998) also report that in some cases operators believe that some disturbances have a major impact on efficiency, but that later measurements can show that it was completely wrong. Therefore, this section presents some different views upon PD in order to establish a clearer view of what constitute PD in the context of this thesis.

Ylipää (2000) describes how PD can be interpreted differently depending on the perspective: maintenance might view PD as technical failures in terms of MTBF, production sees it from an efficiency perspective where human errors are the limiting factor, the quality area focuses on deviation on product quality, ergonomics highlights safety and see PD as causes for accidents, and in Lean Production PD is considered waste. A consequence of classifying PD differently is naturally that they will be resolved differently, and a narrow point of view can easily result in sub-optimization. Since this thesis is conducted from a maintenance perspective, PD in relation to failures is primarily emphasized.

3.4.1 Chronic and sporadic PD

Jonsson & Lesshammar (1999b) explain that depending on how often they occur, PD can be divided into two main categories; chronic and sporadic. Chronic are small and hidden disturbances that are hard to detect since they are often seen as the normal state. They are also complicated to resolve since they are a consequence of several causes. Sporadic PD instead occurs irregularly and are easier to detect since they in general lead to serious problems. Despite sporadic PD having the most obvious effect, it is the chronic PD that result in low utilization of equipment.

3.4.2 TPM losses

In the TPM concept, the purpose of OEE is to identify and eliminate the "six big losses" which are categorized in downtime losses, speed losses and quality losses (Nakajima, 1988). The term "losses" can in this context be equated with PD since chronic and sporadic PD are activities that absorb resources and thus result in these losses. Smith & Hawkins (2004) argue that there are in fact 5 additional losses, and they define 11 major TPM losses divided into four categories as followed:

Planned-shutdown losses

1. No production, breaks, and/or shift changes
2. Planned maintenance

Downtime losses

3. Equipment failure and breakdowns
4. Setups and changeovers
5. Tooling or part changes
6. Start-up and adjustment

Performance efficiency losses

7. Minor stops
8. Reduced speed or cycle time

Quality losses

9. Scrap product/output
10. Defects or rework
11. Yield or process transition losses

Note however that there are diverging views regarding the time limit for differentiating downtime losses from performance efficiency losses. Ericsson (1997) reports 10 minutes as a common limit in accordance to original TPM literature. Ljungberg (1998) claims that it is common that operators measure stops as short as 1 minute, but suggests that stops shorter than 5-10 minutes should be classified as minor stoppages and calculated as a lump sum. From a case study, Ylipää (2000) reports that despite small stoppages in total have a large effect on performance, it is often quicker to solve them than to register them. Furthermore, Ljungberg (1998) concludes that companies are in general focusing on downtime losses, and especially breakdowns, whilst planned downtime, cycle time losses and minor stoppages are not emphasised enough.

Ericsson (1997) divides PD into the three categories similar to TPM; downtime, speed and quality losses. Stoppages are classified as either planned (including PM activities) or unplanned stoppages, and he further explains that 50% of the manufacturing capacity disappears due to these losses. In addition, he highlights that the largest loss is PD in maintenance, which again raises the recurrent question regarding the view of PM activities in relation to PD. Ylipää (2000) sees PM as a kind of paradox; it can be a disruption if it is carried out during production even though it is also aimed at avoiding failures. It can furthermore be a cause of failure due to the probability of introducing failures during the PM activity.

3.4.3 Defining PD and PPD

In an attempt to describe PD from a holistic engineering perspective, Ylipää (2000) defines a *Production Disturbance* as:

> *"Production disturbances are discrete or decreasing, planned or unplanned disruptions or change during planned production time, which might affect availability, operational performance, product quality, security, work conditions, environment, etc."*

This definition thus includes planned stoppages as well as every measureable stop regardless of any time limit, but the essence is that PD should be separated from the planned, desirable conditions. However, Nakajima (1988) emphasises that it is the "hidden defects" that are the real problem. Such things as dirt, dust and scratches might seem insignificant on their own, but they can in fact cause major breakdowns. Ylipää (2000) calls this *Potential Production Disturbances* (PPD) and defines it as:

> *"Potential production disturbances are unnoticed or neglected deviations from the planned situation or desired state, such as dust, defects, faults, deficiency in interventions, incidents, violations, changes, etc. with an ability to propagate towards a production disturbance."*

3.4.4 PD during changing conditions

Most studies regarding PD are performed during stable conditions, and Ylipää (2000) state that changes in the production system significantly reduces total process efficiency. Such a change is during the introduction of new products, and by overlooking reliability during this phase, PD are impossible to detect. In general, when new process technology is introduced, major losses occurs and OEE figures tend to be lower (Ljungberg, 1998). From case studies of a Swedish auto manufacturer, Almgren (1999) identified an increase in frequent small PD during the start-up phase. These PD were however not regarded as something special, and they where in fact neglected in favour for the technical availability that was in focus. If these PD are not eliminated during the start-up phase, they can remain as chronic PD even after full production pace has been reached (Ylipää, 2000). In order to ensure a rapid and efficient start-up phase, PD must therefore be considered during the pre-production phase and reliability should be put in focus during process development activities.

3.5 Production Disturbance Handling

Ylipää (2000) argue that it has traditionally been the responsibility of maintenance to keep up the availability of machinery and for operators to run the system. However, a more holistic and proactive approach to process reliability is needed, and he therefore defines *Production Disturbance Handling* (PDH) as:

> *"All the activities that are carried out or should be carried out in connection with correction, prevention, and elimination of production disturbances and potential production disturbances in both existing and future systems during their life-cycles."*

This definition involves co-operative work of operators, maintainers, technicians, engineers, managers, suppliers, consultants, etc. A model for sustainable PDH in a high-reliability manufacturing system is further visualized in Figure 5 - Sustainable PDH model according to Ylipää (2000).

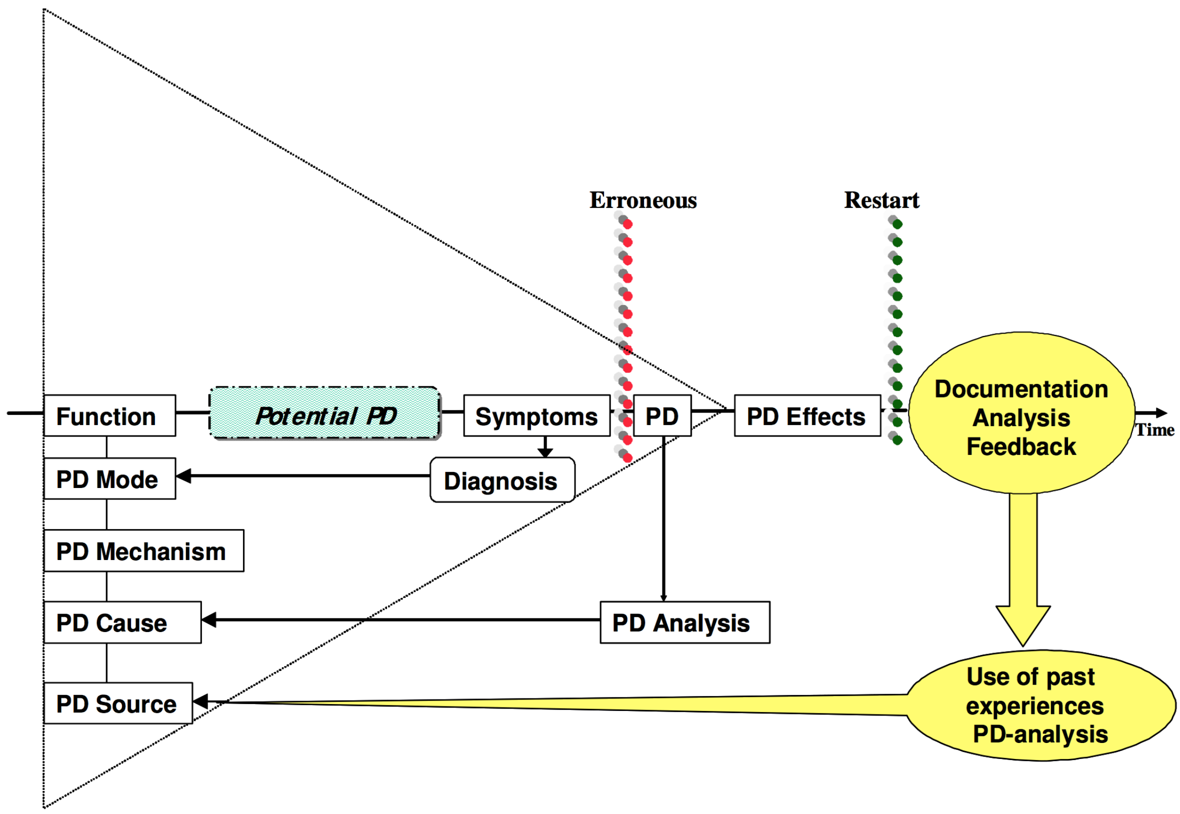


Figure 5 - Sustainable PDH model according to Ylipää (2000)

According to this model, PD and PPD are to be handled in three time phases: before, during and after a PD has occurred. Furthermore, it aims at describing how frequently occurring PD forces the manufacturing system to the right in the figure – towards the erroneous state. The dotted triangle describes how a PD is a result of many PPD as well as, for example, lack of PM. After the PD has occurred and effects have become visual, there is a restart of the production system and a follow-up period of documentation, analysis and feedback in order to gain experiences that can be used in future PD-analysis. The goal for sustainable PDH is to preserve the system's ideal state, which is possible if PPD are controlled and if PD symptoms is detected and diagnosed, and actions are taken, prior to that the PD occurs.

The area within the dotted triangle can further be described with what Ericsson (1997) calls *chain of events*. When a PD occurs, it is most commonly due to a series of events that eventually results in a visual disturbance. Different PD can also show a connection to each other, such as that there is an increased risk for breakdowns right after a set-up has been performed. Therefore, in order to reach a long-term reduction of PD, improvement efforts should focus on the underlying reasons instead of merely trying to address the symptoms. The strategy to address PD during the design phase is strongly emphasized by several authors (e.g. Almgren, 1999; Jonsson, 1999a; Tsang et al, 1999; Ylipää, 2000), and principles and systematic methodologies for this approach is available through the concepts of Reliability Engineering and Maintenance Prevention.

3.5.1 Reliability Engineering & Maintenance Prevention

To address PD during the design- and development phase of new products, processes or equipment have many advantages. The relationship between cost of changes and degrees of freedom is of particular interest. The largest possibility, to the lowest cost, to affect the final result is during the development phase, and the cost of changes increases almost exponentially when they are carried out at a later stage in the life cycle. Therefore, it is essential to focus on elimination of PD during the design phase, and Bellgran & Säfsten (2009) mentions several advantages of this:

- Reduced start-up problems
- Reduced ramp-up time
- Reduced number of PD during operation
- Improved co-operation between production and maintenance as a part of the work with eliminating PD

The concept of *Reliability Engineering* is according to Birolini (2013) aimed at developing methods and tools to evaluate and demonstrate reliability, maintainability, availability, and safety of components, equipment and systems, as well as to *support* development and production engineers in *building in* these characteristics. Gulati & Smith (2009) argues that up to 60% of failure and safety issues can be prevented by making changes during the design phase. However, Faria & Nunes (2012) states that systematic reliability analysis is often neglected during the design phase, and argue that the reason for this might be the absence of ground engineering tools and methodologies to perform the analysis. To be able to effectively make use of Reliability Engineering techniques, Idhammar (2014b) explains that it becomes more and more common that companies employs *Reliability Engineers*. Such engineers can have the responsibility to address reliability and maintainability during the design phase of new equipment or production processes, but also to perform simpler tasks such as installing sensors for CM and enable inspection during production. Examples of work tasks are:

- Develop and document methodologies for RCA
- Educate the organization to ensure that RCA is performed
- Continuously identify and develop constructions with improved reliability and maintainability
- Continuously improve the content of PM programs
- Read incident reports and suggest appropriate improvement efforts on a daily basis in order to eliminate problems

From this description of work tasks, it is clear that not only products and equipment, but also production processes and work practices can be designed with reliability and maintainability aspects in mind. This relates to the concept of *Maintenance Prevention*. Wireman (2000) refers to "TPM's Five Pillars" and explain that the fifth pillar, known as "Manage equipment in order to prevent maintenance", is often neglected. By the use of *Early Equipment Management (EEM)* and *Maintenance Prevention (MP)*, the amount of maintenance required can be influenced during the design phase. This has a direct effect on the life cycle cost of the equipment since the overall maintenance costs will be reduced if the maintenance requirements are minimized at an early stage. Consequently, as maintenance costs is regarded as an expense in most companies, reducing the amount of money spent on maintenance activities will result in increased overall profitability.

The principle of maintenance prevention is based on analysing equipment data in search of failure trends, frequency of failures or root causes of failures. Such information can then be used to determine how to eliminate or reduce maintenance by a change in equipment and process design. The reason that companies are overlooking this strategy is lack of accurate equipment data to calculate such measures as MTBF or MTTR. In most cases, only a portion of the work activities is recorded, and if the data quality is poor, the ability to do maintenance prevention is lost.

3.5.2 Life Cycle Costing - LCC

To further consider the cost aspect of maintenance, the idea of *Life Cycle Costing* (LCC) is applicable. It is a method for comparing decision alternatives and identifying the most cost-effective one. For example, one can assess the economic consequences of continuing using existing equipment in comparison with the expenses of substituting it for an alternative that offers improved performance or new technology. LCC is based on the notion that the largest opportunity to influence life cycle cost is at the earliest stage of the design process. During the design-phase of new equipment, information regarding best and worst building features, potential cost-saving modifications, and operational effectiveness can be used as ideas to improve the life cycle cost-effectiveness and minimize obsolescence. A LCC analysis considers such aspects as the discount rate, effects on inflation, and the total time of ownership, and it includes cost of acquiring, owning, and disposal. By doing so, one can identify that an alternative might lead to increased initial costs but a dramatic reduction in operation and maintenance costs, which makes it a cost-effective alternative seen over the entire life cycle. LCC thus considers all significant costs of ownership over the entire economic life of the equipment with the ultimate objective of optimizing design decisions (Dell'isosa & Kirk, 2003).

3.5.3 Risk assessment

All of the described pro-active approaches to maintenance are based on the fundamental goal to mitigate, eliminate or prevent production losses due to unwanted events, which essentially is about managing risks in a production environment. A *risk* is described as a the product of the consequences of an event and its probability of occurring, and investigating risks is about evaluating the potential effects of some kind of losses due the occurrence of an unwanted event (e.g. a PD). In practice, risks are treated by the use of *risk analysis, risk assessment* and *risk management*. As a tool, risk analysis is about identification and evaluation of losses in order to predict future risks. This involves both quantitative and qualitative analysis, where quantitative analysis aims at answering *what can happen* and *how likely it is to happen*, and qualitative analysis consists of identifying possible incident scenarios and ranking their severity. The process of risk assessment consist of using the results from the risk analysis in making decisions to determine the most cost-effective way to reduce the risks. Risk management is the systematic application of management policies, procedures, and practices to the task of analysing, assessing, and controlling risks. It consists of the three faces risk analysis, risk assessment, and risk reduction and control (Shahriari, 2011).

Risk assessment will be emphasised in this thesis. It is an elaborative method that consists of several steps, starting with hazard identification and development of accident scenarios, and finalized by preparing strategies for risk reduction and control of damage. The process of hazard identification is of particular interest, which is to identify the sources of risk and incident scenarios. The result of hazard identification is information about incident scenarios of failure descriptions that can be used to determine where changes can be made to improve a system design (Shahriari, 2011). In fact, Raz & Michael (2001) showed that tools such as risk impact assessment, risk classification, and ranking of risks offered great potential for contributing to project risk management processes.

This can naturally be of great importance for effective PDH. Identifying risks in the production environment can be a way identifying PPD and determining the root causes for PD, and incident scenarios are much like revealing chain of events. The information can then be applied during the design phase through reliability engineering and maintenance prevention, as well as during operation in terms of guidance of PM activities or monitoring of critical equipment.

3.5.4 Maintenance and safety

Risk assessment is however not only concerning risks in terms of business, economic or environmental aspects, but also safety. Safety is defined as a situation without intolerable risk, and high safety can be achieved by minimizing the risks to an acceptable level in the system (Shahriari, 2011). As a matter of fact, safety is of extreme importance for maintenance operations. In 2010, the European Agency for Occupational Safety and Health at Work (EUOSHA) published a statistical report regarding maintenance and operational safety and health. It was concluded that maintenance operators are exposed to many and varied hazards at work, primarily in the following categories:

- Setting-up, preparation, installation, mounting, dissembling, dismantling
- Maintenance, repair, tuning, adjustments
- Mechanised or manual cleaning of work areas and machines
- Monitoring, inspection of manufacturing procedures, working areas, means of transport, equipment – with or without monitoring equipment

It is furthermore shown that 10-15% out of all fatal accidents related to these categories and all subcategories within the variable “working process” were related to maintenance operations. In addition, work-related health problems such as cancer, hearing problems and musculoskeletal disorders were more prevalent among maintenance workers. Lind & Nenonen (2008) several additional risk-increasing factors for maintenance workers such as working under the pressure of time, working while the machines are in motion, and carrying out independent maintenance work during night shifts. They also conclude that poor work practices and deficiencies in safety devises, work guidance and risk assessment are contributing factors to accidents to maintenance operators. Moreover, Toulouse (2002) identified through a case study in an industrial bakery that approximately 50% of the occurred PD resulted in a direct accident risk and reduced safety for the maintenance operators.

Poor maintainability of machinery and processes increases the safety risks, which again stresses the importance of performing appropriate risk assessment and take consideration to these factors during the development phase (Eu-Osha, 2010; Lind & Nenonen, 2008). As a consequence of that most accidents occur during corrective maintenance activities, preventive measures to ensure the safety and health should be employed and strong emphasis put on increasing the amount of PM (EUOSHA, 2010).

In line with other European countries, the Swedish Emergency Services Authority (S.E.S.A., 2007) state that one of the most common causes for work place injuries in Sweden are in fact due to machine accidents. On the positive note, S.E.S.A. (2007) also report that the severity of work place accidents in Sweden are decreasing, likely due to increased awareness of risks and improved work with safety. In addition, Strömgren & Andersson (2010) reports that safety management tools such as risk inventories, risk analyses, and safety rounds are broadly used amongst Swedish municipalities, and they hypothesize that these tools can be of great value.

Moreover, the cost of accidents and occupational injuries can be enormous. In a Public Citizen's report (2012), it is stated that the combined cost of fatal and non-fatal occupational injuries in Washington during 2008-2010 was $762 million, and in 2013, the *Deepwater Horizon* oil spill had cost BP $42.4 billion in criminal and civil settlements and payments alone (Fontevecchia, 2013).

Williamsen (2013) argue that reporting of *"near-misses"* is a missing link in safety culture, and explain how near miss reporting can be a useful tool for reducing work place injuries. He highlights the relationship between a major injury and the number of near misses, which displays that for every major injury, there are 10 minor injuries, 30 property damage events, and 600 near miss incidents. In addition, he also found that registration and measurements of near misses not only correlated with improved safety performance, but also other KPI's such as scheduling and budget. Moreover, he discusses several barriers that affects near miss initiatives, such as fear of punishment and retaliation, lack of feedback from reporting, peer pressure, concern about record and reputation, desire to avoid work interruption, and a mindset to finding who can be blamed for the incidents.

3.5.5 Risk assessment tools

There are numerous tools available for performing risk and safety assessment, but the following will be considered in this study:

Job Safety Analysis - JSA

Job Safety Analysis (JSA) is a simple risk assessment method with the purpose of reviewing job procedures and practices to identify hazards and determine risk-reducing measures. Each job is broken down into tasks where observation, experience and checklists are used to assess possible hazards and safeguards. JSA are most commonly performed in teams and focused on non-routine jobs, dangerous routine jobs and new work procedures. Examples of advantages with JSA are operator training in safe and efficient work practices, increased awareness of safety problems and enhanced operator participation in workplace safety (Rausand, 2011).

What-if analysis

What-if analysis is based on brainstorming around a process or an operation in order to come up with possible problems and potential outcomes of risks. It is a fast and simple process and can be used in all stages of a project due to its informality and flexibility. Its procedure revolves around asking the question "What if?", which intends to highlight a possible problem or incident scenario. In a production environment, such a question could be "What if there is a breakdown on this machine?", and the answer to the question consist of stating the possible consequences/hazards of the incident, establishing safeguards and recommendations to prevent the hazard as well as assigning the responsibility to implement the safeguards (Shahriari, 2011).

HAZOP

HAZOP stands for Hazard & Operability Study and its purpose is to identify potential deviations in processes or operations. It can be used for both existing equipment as well as during development projects, and the final HAZOP report includes all the deviations and their causes, analysis of the consequences in equipment performance, implemented protection, and resulting suggestions. The process of HAZOP is performed through the following steps:

1. Select a study node (i.e. possible causes)
2. Identify operating conditions (i.e. guidewords and key parameters in the operation)
3. Identify deviations (from design or operation)
4. Evaluate possible consequences of the deviations
5. Establish required actions and recommendations

The guidewords and key parameters are together describing the deviation, and a simple example is regarding temperature. The guideword can be “Higher” or “Lower”, the key parameter is “Temperature”, and the deviation is then “Higher temperature” or “Lower temperature”, and the possible consequences of those deviations are then analysed (Shahriari, 2011).

Fishbone diagram

A fishbone diagram (also called Cause-and-Effect diagram) is a graphic tool used to identify, sort, illustrate and map different causes to a problem. The structure of the diagram is similar to the bone structure of a fish, hence the name. The “head” of the fish is where the problem is stated, and from the “backbone”, a number of “bones” are connected where the possible main causes of the problem is stated. From these main bones, smaller bones are written that displays more detailed information about the causes to the problem. It is a simple qualitative tool that collects ideas of a group in a systematic way and easily facilitates understanding of a problem (Shahriari, 2011).

Fault Tree Analysis - FTA

FTA is one of the most common techniques for system reliability analysis, and it is a deductive procedure that determines the possible combinations of errors that can cause an undesired event (i.e. *top event*). The method starts by identifying a top event and its immediate causes. Thereafter, each immediate cause is further examined in the same manner, and the procedure continuous until the bases causes are identified. This provides the possibility to break down a top event into chains of errors, and the hierarchy of the causes is graphically described in a tree structure. By the use of Boolean Algebra, various combinations of the different causes can be analysed in order to identify which individual faults than can cause the top event (Shahriari, 2011).

Event Tree Analysis - ETA

ETA is very similar to FTA, but it is an inductive approach instead of deductive. Instead of identifying the faults through the effects that are created as in FTA, ETA is based on identifying the effects created by a fault. Building up an ETA structure starts by stating initial events (i.e. a decision, a fault or undesired condition), and thereafter decide upon sequences of events that follows the initial one and eventually leads to a top event. The analysis aims not only on describing initial events that can cause a failure, but also how various events are connected to each other logically and sequentially as well as decision situations that can cause a problem (Shahriari, 2011).

Logic Tree Analysis - LTA

LTA deals with uncertainties regarding what might happen and whether it matters, and it is used to analyse, compare, and choose decision alternatives that are the most profitable. The decision alternatives can be compared based on the possible outcomes in terms of revenue, loss and probability of success or failure, and the payoff (i.e. expected value) of each outcome can be calculated to display the most profitable choice. Advantages of this tool are that it is visual, quick and easy to perform and enables comparison between alternatives even though there is limited information available (Shahriari, 2011).

Root Cause Analysis - RCA

RCA, or RCFA when considering failures, is a logical sequence of steps that aims at isolating the facts surrounding an event or a failure. The investigation starts when an incident has occurred and been reported. Thereafter, the type of problem is classified, which could be equipment failure, operating performance, safety etc. Different methods to resolve the problem can be used depending on the classification, but in general, the process is divided into three phases: data collection, analysis and solution. The data collection can consist of personal testimonies (i.e. interviews with operators, maintenance staff etc.), recorded evidence (i.e pictures, operating logs) or physical evidence (i.e. failed components, fluid/filter samples etc.). The analysis thereafter uses the collected data to construct a cause chain and identify immediate, contributing and root causes for failures, where the immediate cause is normally first in the chain and the root cause is last. The analysis can be conducted differently, but a common way is asking a series of “Why?”-questions, but FTA or Fishbone diagrams could also be used. Finally, the solution phase aims at breaking the cause chain by determining appropriate corrective or preventive actions (Mobley, 1999).

Failure Mode and Effect Analysis - FMEA

FMEA is a structured approach to finding possible modes of failures, determine their effect, and identify actions to minimize the failures. It is in most cases performed during the development stage, and it can be used in many purposes, for example:

- Develop product or process requirements and minimize the likelihood of failures to those
- Identify design criteria that contribute to failures and remove them from the system
- Ensure that any failure that could occur will not have a serious impact of the customer of the product or process

Advantages with FMEA are:

- Increased product/process reliability and quality
- Early identification and elimination of potential failure modes
- Minimizes late changes and associated costs
- Reduced time-to-market

FMEA is a step-by-step process that consists of choosing an item for analysis, describing its function, identifying potential failure modes and failure causes, evaluating the effect of the failures, determine safeguards and state recommendations for implementation (Shahriari, 2011).

Variation Mode and Effect Analysis - VMEA

VMEA is a further development of FTA and FMEA that aims at identifying noise factors that has an effect on certain Key Process Characteristics (KPC). It is a failure-oriented approach but puts large emphasis on risk related to excess variation in the process. The noise factors are smaller sources of variation that contribute to the variation of the KPCs, which might result to unwanted consequences. A Fishbone diagram is most commonly used to construct a structure that connects the noise factors to the KPCs, and by rating the degree of variation of the noise factors and the sensitivity of the KPC to the noise factors, a total Variation Risk Priority Number (VPRN) is calculated. This number is then used to direct attention to the most critical areas where sources of variation might be detrimental (Shahriari, 2011).

Several of these risk assessment tools are in fact emphasised in various maintenance concepts. RCM analysis is based on a detailed FMEA and also utilizes LTA, and RCA analysis is used to evaluate the major TPM losses in OEE figures (Smith & Hawkins, 2004). There are today several computer software for conducting risk assessment, reliability analysis and maintenance planning, and they incorporate many of the above-mentioned tools. The following will be regarded in this study:

@RISK

@RISK is a risk analysis tool that works as a plugin for Excel. It mathematically and objectively computes and tracks different failure scenarios and displays the possibilities and risks associated with each one. In addition, the software can perform sensitivity- and scenario analysis to display critical factors (i.e. machines or equipment) and rank them according to their effect on the desired output (Palisade, 2014).

Reliasoft

Reliasoft offers a platform called the Synthesis Platform, which includes several tools and methodologies for reliability analysis such as: Weibpull plot to display failure rates, RCM, FMEA, and FTA analysis etc. The purpose of the platform is to collect all information regarding reliability in one place and enable information sharing amongst several organizational units (Reliasoft, 2014).

Risk Based Work Selection - RBWS

The RBWS methodology is a tool to enable risk-based decision making in equipment operation, inspection and maintenance. By evaluating tasks based on a various criteria (e.g. cost of mitigation relative to benefit of mitigation), the program can aid in planning, prioritizing, and scheduling of work orders. CFTs are emphasised to calculate the risk, cost of action, etc. for each task and make a justification on the decision to carry out the task or not. Management reports can be exported to highlight the justification, risk reduction achieved and economic benefits of the work list items (Becht, 2014).

Relex

Windchill Quality Solutions, formerly known as Relex, is an engineering software by Reliacore that includes the majority of the most common reliability analysis tools: FTA, ETA, FMEA, Life Cycle Costing, Weibull-plots, Maintainability and Reliability Prediction, etc. (Reliacore, 2014).

3.6 Results from the previous survey

As the findings reported in Ylipää & Harlin (2007) and Ylipää et al (2007) serves as the basis for identifying developments regarding PD, PDH and maintenance over the past decade, the central results from that study is presented in this chapter. This data is later compared with the results achieved in this survey and discussed in chapter 5 Discussion.

3.6.1 Classification and registration of PD

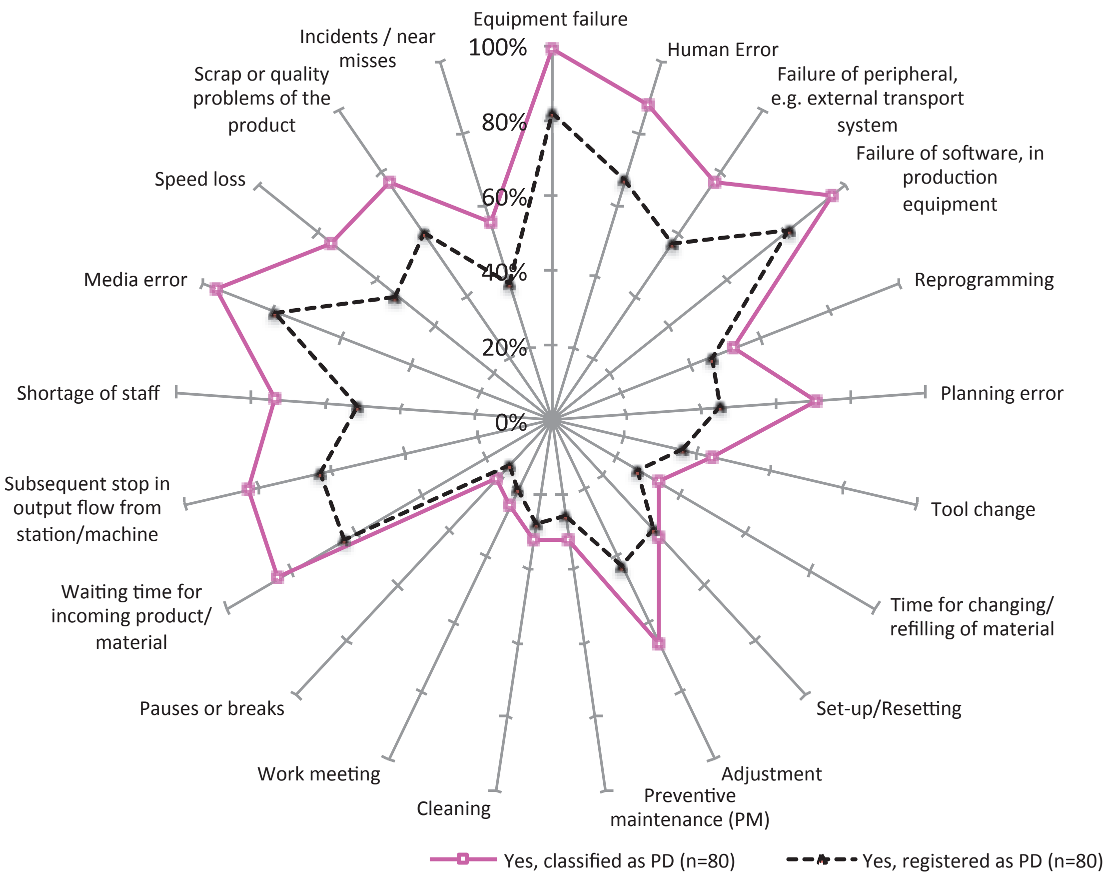


Figure 6 - Classification and registration of PD in previous survey

The polar diagram in Figure 6 displays to what extent the companies in the previous survey classify and register the 21 factors as PD. It indicates that almost all respondents classify the factors *"equipment failure", "failure of software", and "media error"* as PD. Moreover, the factors *"human errors", "failure of peripheral", "waiting time for incoming product/material", "subsequent stop in the output flow", "speed loss"* and *"scrap or quality problems"* were classified as PD by more than 75 percent of the respondents. The factors *"tool change", "set-up/resetting", "preventive maintenance"*, and *"cleaning"* were however classified as PD by less than 45 percent. The data also indicates that the experts at the companies are more prone to classify the factors as PD compared to what is registered in their follow-up systems.

It is moreover shown that smaller companies classify these factors as PD to a lower degree, and respondents representing discrete manufacturing on average classify more factors as PD than the respondents from continuous production companies. However, a shared view upon the subject is found between the people working in production versus those who work in maintenance. A more in-depth description of this data, including cross-tabulation based on discrete versus continuous production, company size and the perception from production and maintenance people is reported in Ylipää et al (2007).

3.6.2 PD and PDH in practice

The occurrence of frequent PD in production that are not being resolved was indicated by 69 out of 80 respondents, where some respondents commented that *"the failures are hard to find", "here are much hidden to improve"*, and *"new types of failures as new equipment has been introduced in the last two years".*

A majority of the respondents, i.e. 41 out of 55, indicated that PD increased during the latest running-in. In addition, fairly low satisfaction was found regarding the documentation of experiences from the running-in, as well as how these experiences have later been taken care of in improvement work. However, most respondents indicated that they during the latest running-in did in fact reach the goals for time-to-cost, time-to-quality, and time-to-volume according to plan.

Operator maintenance as emphasized in TPM was identified to be utilized at a fairly low level, and almost all companies to some extent hires external personnel to perform maintenance activities. Despite that a large belief in improvement teams for handling PD was identified, a majority of the respondents still claimed to be dissatisfied with how improvement teams in regards to PD worked. Moreover, dissatisfaction was indicated regarding how analysis tools and methods such as FMEA and Fishbone diagrams worked, as well as how experiences from PD are tied back to development departments. Furthermore, about half of the respondents indicated that PD are prioritized by management and that experiences from PD are documented in a satisfactory way, but a large number of respondents also indicate dissatisfaction regarding this.

Although DES was identified to be used to a fairly low extent, the companies who did in fact use it was satisfied with it as a PDH tool and assessed it as very useful for various aspects of PDH such as visualization of problems and to serve as a basis for improvements. Moreover, using a methodology like SMED for reducing set-up times was found to be fairly uncommon, and very few respondents was absolutely satisfied with how these efforts have worked.

4 Results

The results from the questionnaire are in this section presented as answers to the research questions. Data analysis of all responses combined is presented first, followed by the results from cross-tabulation of industry type, company size and for some questions also based on management position. Thereafter, various in-depth cross-tabulations of companies working with TPM and Lean Maintenance are presented in a separate chapter.

4.1 What factors are regarded as PD?

The first research question was aimed at investigating what factors that are classified by the respondent as PD and registered as PD at the company. The respondents were asked this regarding 21 different factors, and also had the possibility to add further factors.

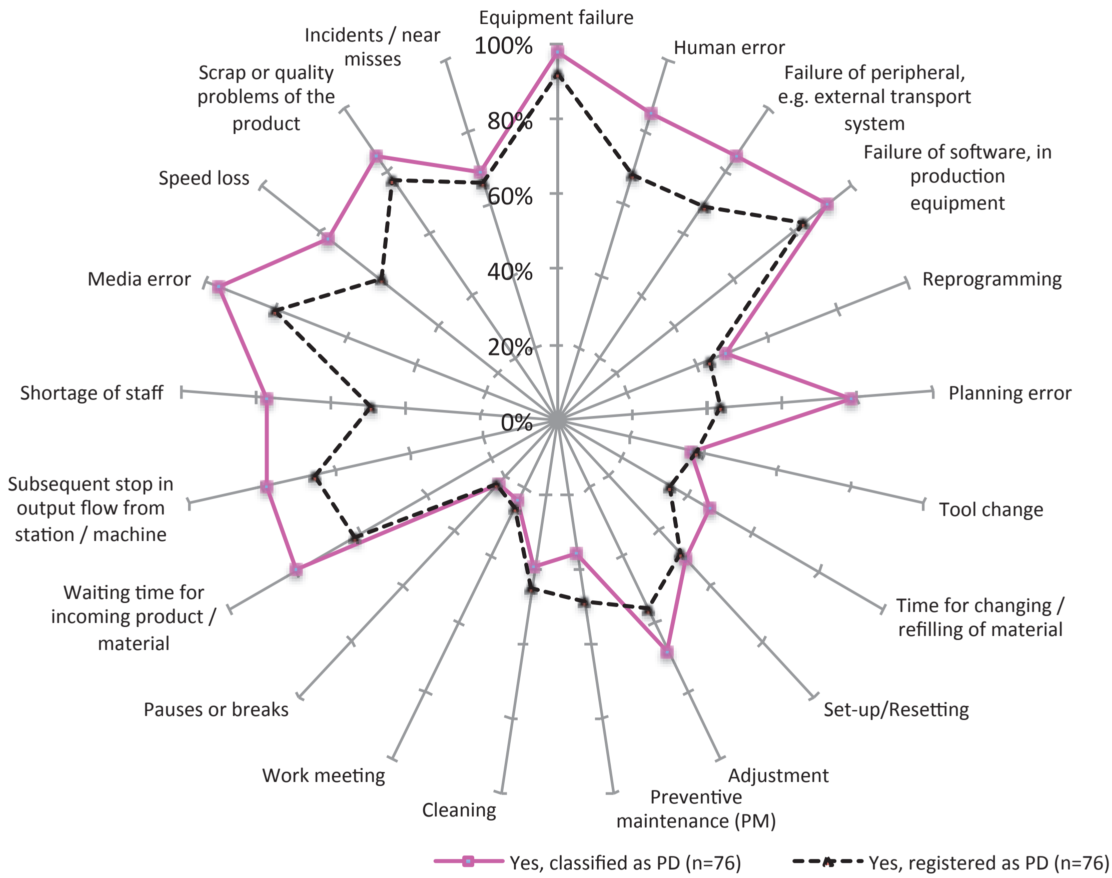


Figure 7 - Classification and registration of PD in all companies

The radar chart in Figure 7 displays the overall results from all responses and shows the comparison between what the individuals classify as PD and what is registered in the companies follow-up systems. It shows that almost all respondents (more than 90 percent) classified the factors *"equipment failure"*, *"failure of software in production equipment"*, and *"media error"* as PD. Moreover, the factors *"human error"*, *"failure of peripheral"*, *"planning error"*, *"subsequent stop in output flow"*, *"shortage of staff"*, *"speed loss"*, and "*scrap or quality problems"* was classified as PD by more than 75 percent of the respondents. The factors *"tool change"*, *"preventive maintenance"*, and *"cleaning"* was however classified by less than 45 percent of the respondents, and *"work meetings"* and *"pauses or breaks"* by less than 33 percent. These results illustrates that several PD factors that relates to the 6 big losses in TPM are classified and registered to a low degree.

Beyond the initial 21 factors, the factors *"errors in drawings", "minor stoppages", "delivery service", "OEE", "process waste", and "consumables"* was reported to be classified and registered as PD at some companies. One respondent also classified the factor *"negative employees"* as a PD, but it was not registered as a PD at the company.

The chart furthermore shows that the individuals at the companies are more prone to classify the factors as PD to a larger extent than what is registered in the company's follow-up systems. 7 out of the 21 factors have a difference of 16-35 absolute percent, and the largest difference can be found for the two factors *"planning error"* and "*shortage of staff*", with a difference of 35 and 28 percent respectively. On average, there is a difference of 65 versus 56 percent between what factors that are classified and registered as PD. It is however noticeable that the factor *"preventive maintenance"*, which is widely debated in literature as to whether it should be recognized as a production loss or not, is in contrast registered as PD to a greater extent, with a difference of 13 absolute percent.

4.1.1 PD based on industry type

If the data is cross-tabulated based on industry type, i.e. discrete versus continuous production companies, it is possible to indicate some noteworthy differences.

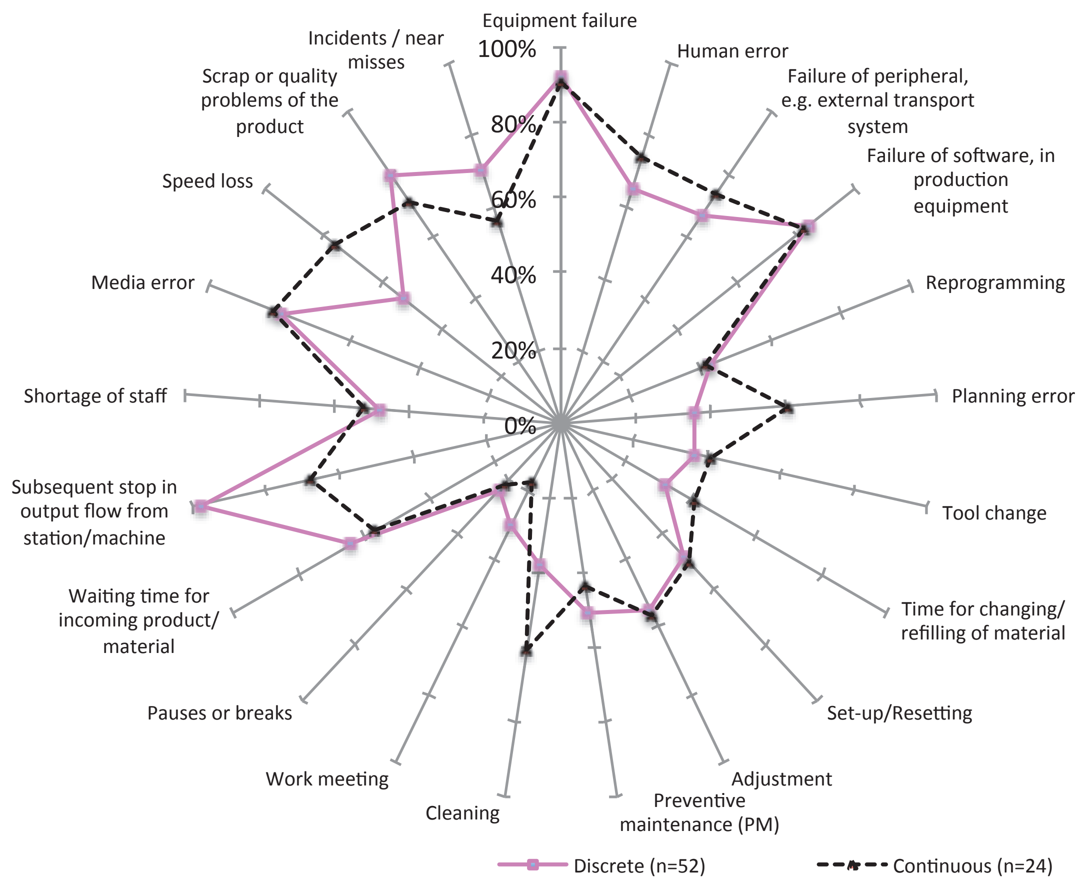


Figure 8 - PD based on discrete vs. continuous production

Figure 8 displays the difference in registration of PD between the two groups of companies. On average, there is almost no difference between the two; where in total 57 versus 58 percent of the factors are registered as PD. The data however shows that the factors *"planning error", "cleaning"* and *"speed loss"* are registered as PD to larger extent by continuous production companies, with a difference of 23-25 absolute percent. The two factors *"work meetings"* and *"incidents/near misses"* are in contrast slightly more often registered as PD in discrete manufacturing companies, with a difference of 13 absolute percent. It is also noticeable that one factor that concerns the production flow of material or products, *"subsequent stop in the output flow*", is clearly registered as a PD more frequently in discrete manufacturing companies, with a difference of 30 absolute percent.

Regarding the classification of PD, the same factors that are more frequently registered as PD by continuous production companies are also to a larger extent classified as PD, all with a difference of 18-31 absolute percent. On the contrary, the factors *"preventive maintenance"* and *"work meetings"* are, with a difference of 14-15 absolute percent, classified as PD to a higher degree by discrete manufacturing companies. It is moreover interesting to note that all of the respondents working for continuous production companies classified errors in the preparatory work, i.e. *"planning error"*, as a PD, and all of the respondents from discrete manufacturing companies classified the immediately visual production failures, i.e. *"equipment failure"*, as PD.

4.1.2 PD based on company size

To identify differences based on the company size, the data was also cross-tabulated based on the three categories <100, 101-500 and more than 500 employees.

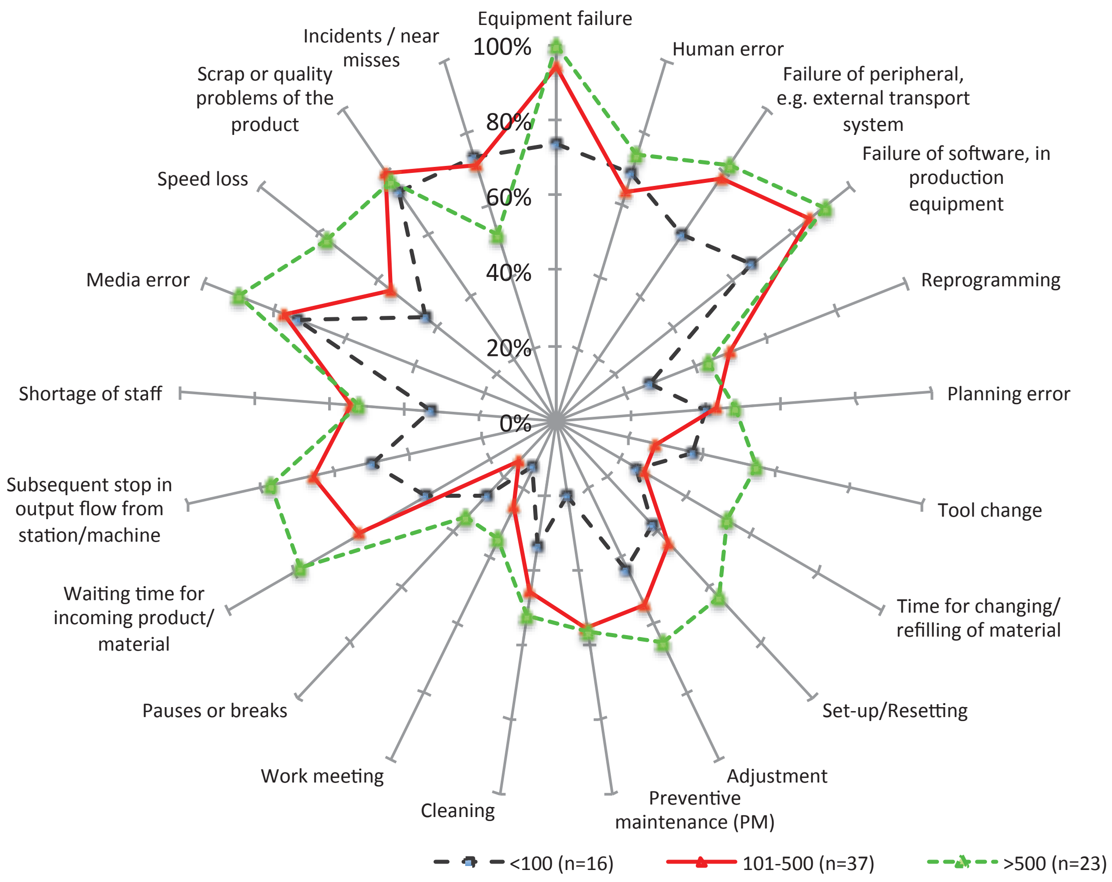


Figure 9 – Registration of PD based on company size

Figure 9 shows the difference between what factors are registered as PD in the three different company sizes. The data indicates a clear trend towards that larger companies both classify and register more factors as PD. On average, 52, 66 and 73 percent of the factors are classified as PD, and 46, 56 and 65 percent of the factors are registered as PD amongst the different groups, ranging from the smallest to the largest companies.

Between the smallest and the largest companies, i.e. <100 versus >500, 16 of the 21 factors are to a higher degree registered as PD in the large companies, with a difference of 17-27 absolute percent. The largest difference of 34-38 absolute percent can be found for the factors regarding the production flow (i.e. *"waiting time for incoming product or material", "speed loss")* as well as *"preventive maintenance"*. It is however noteworthy that the factor *"incident/near misses"* are to a larger extent registered as PD in the small companies, with a difference of 21 absolute percent. Between the two company sizes <100 and 101-500, 7 out of the 21 factors are to a greater extent registered as PD in the larger company, all with a difference of 18-23 absolute percent. Most significant are yet again regarding *"preventive maintenance",* which display a difference of 36 absolute percent. Finally, 6 of the 21 factors are to a higher degree registered as PD in the >500 companies compared to the 101-500 companies, all with a difference of 18-27 absolute percent. Again these factors are concerning changes *(i.e. "tool change", "time for changing/refilling of material",* and *"set-up/resetting"*) and the production flow (i.e. *"waiting time for incoming product or material"*, and *"speed loss"*). However, the factor that concerns the safety of the employees, i.e. *"incident/near misses"* is also in this case registered to a higher degree in the smaller of the two company sizes.

In general, the classification of PD follows the same patterns as the registration, where the larger companies especially classify the factors due to changes and concerning the production flow to a higher degree as PD. There is however a noteworthy detail regarding the safety factor *"incidents/near misses".* The respondents who represent companies with more than 500 employees seem to be more prone to classify this factor as PD compared to the extent it is registered in the follow-up system. In detail, 70 percent of these respondents classify safety issues as a PD, but it is only registered as a PD in 52 percent of the companies.

4.1.3 PD based on management position

Finally, the PD factors were analysed based on management position of the respondents, which are divided into the three groups maintenance, production, and maintenance/production (i.e. equal responsibilities regarding production and maintenance operations).

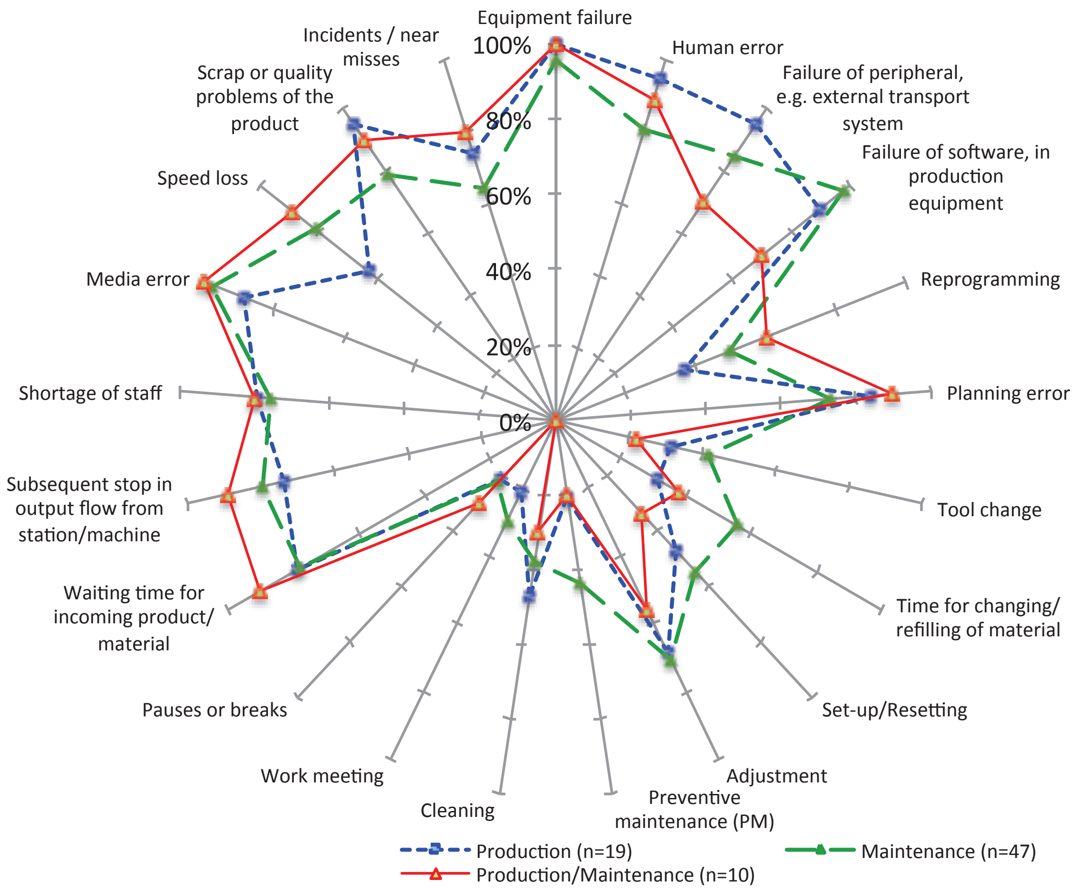


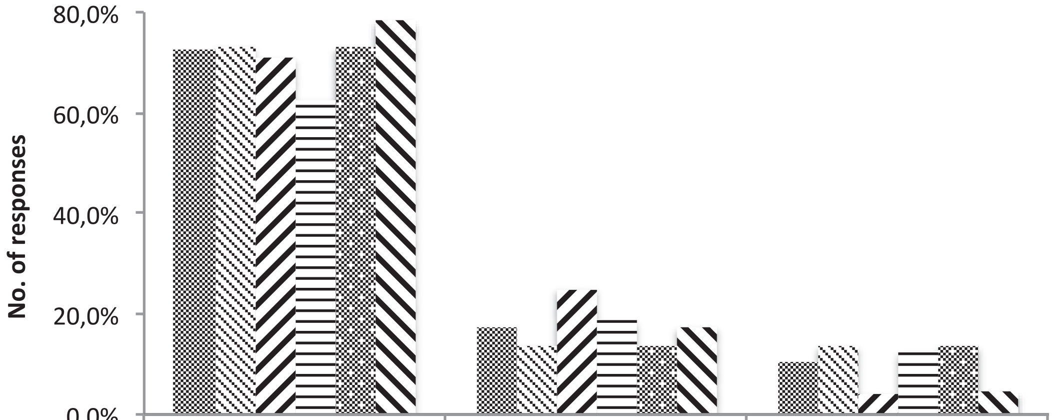
Figure 10 - Classification of PD based on management position

Figure 10 shows the difference in what the three groups classify as PD. The data indicates that there is a shared view upon the subject, where the average number of factors classified as PD is 64, 66 and 63 percent respectively. There are however some noticeable difference worth highlighting. If the range between the three groups is calculated (i.e. the difference between the smallest and the largest value), 9 out of the 21 factors display a range of 20-30 percent. The maintenance people classified 4 of these factors as PD to the largest extent, namely *"failure of software", "time for changing/refilling of material", "set-up/resetting", "preventive maintenance"*, and *"work meetings"*. One of the factors, *"failure of peripheral"* was to the highest degree classified as PD by the production people. The maintenance/production people classified the factors that concern changes, i.e. "tool change", and "reprogramming", to the largest extent. Finally, a drop in production performance in form of *"speed loss"* was to a larger degree classified as PD by the maintenance and the maintenance/production people, compared to the dedicated production people.

The primary responsibilities of the maintenance/production group is however hard to distinguish. If the two groups production and maintenance/production is instead combined and compared against maintenance, the production people are more prone to classify 9 out of the 21 factors as PD, and maintenance more prone to classify the remaining 12 factors as PD. In this case, the largest differences can be found regarding *"failure of software", "time for changing/refilling of material", "preventive maintenance"* and *"work meetings",* which is with 18-23 percent more often classified as PD by maintenance people. In contrast, the production people are slightly more prone to classify *"human error", "scrap or quality problems",* and *"incidents/near misses"* as PD, with a difference of 11-13 percent.

4.1.4 PD during changing conditions

To investigate the extent to which PD are occurring at the companies, the respondents were asked whether they experienced an increase of PD during the latest running-in of a new product, machine, or line.

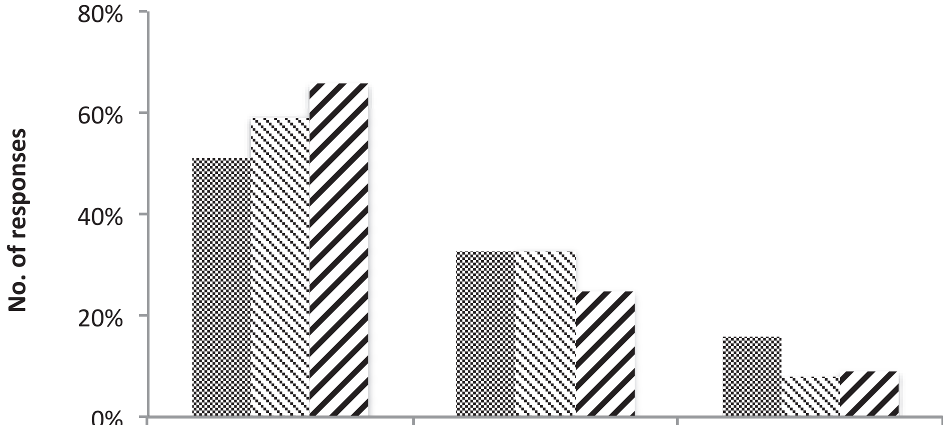


	Yes	No	Do not know / not applicable
Overall	72,3%	17,1%	10,5%
Discrete	73,0%	13,5%	13,5%
Continuous	70,8%	25,0%	4,1%
<100	62,5%	18,8%	12,5%
101-500	73,0%	13,5%	13,5%
>500	78,3%	17,4%	4,3%

Figure 11 – Increased PD during the latest running-in

Figure 11 displays to what extent the respondents, including all cross-tabulated groups, experienced that PD increased during the latest running-in. The results indicate that the latest running-in resulted in an increase of PD in almost all companies. Note however the difference between the companies with <100 and >500 employees experiences, where the smallest company experienced increased PD to a lower extent with a difference of 15,8 absolute percent. In addition, as seen Appendix D, it is indicated that the production people are slightly more prone to experience an increase of PD during running in than the maintenance people, where 16 out of 19 of the production people state that they absolutely or to a certain extent experienced it.

Moreover, the respondents were asked how well the latest running-in worked in terms of goal fulfilment, documentation of experiences, and whether these experiences have been taken care of in the subsequent improvement work.



	Yes	No	Do not know / not applicable
Achieved the goals for cost, quality and volume	51%	33%	16%
Experiences documented in a satisfactory way	59%	33%	8%
Experiences taken care of in improvement work in a satisfactory way	66%	25%	9%

Figure 12 - Experiences from the latest running-in

The data in Figure 12 indicates that approximately half of the respondents considered that they to some extent achieved the goals for production cost, product quality and production volume according to plan. In detail, 33 out of 76 respondents stated that they achieved the goals to a certain extent, and 6 answered yes, absolutely. A majority of the respondents also found that experiences from the running-in was documented in a satisfactory way, where 40 out of 76 was satisfied to a certain extent, and 15 was absolutely satisfied. Furthermore, a large portion of the respondents seem satisfied with how the experiences have been taken care of in the improvement work, indicated by that 40 out of 76 respondents was to a certain extent satisfied, and 10 was absolutely satisfied. In fact, only one respondent was not all satisfied in this regard.

If this data is viewed based on discrete versus continuous production, as seen in Appendix C, it is indicated that the respondents who represent continuous production companies considered that goals was achieved to a slightly larger extent. In fact, none of the 24 respondents from continuous production companies considered that the goals was not at all achieved, compared to 5 out of the 52 respondents from discrete manufacturing companies. In addition, these respondents were also to a slightly higher degree more satisfied with the documentation of experiences. The opposite is however identified regarding the satisfaction of how the experiences have been taken care of in the improvement work, where the respondents from discrete manufacturing companies seem to be slightly more satisfied.

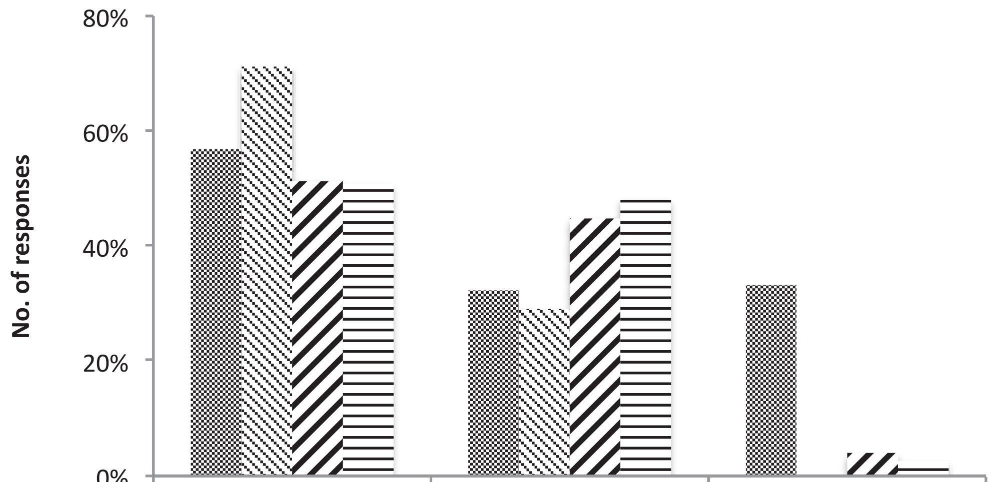
The experiences does not differ greatly depending on the size of the company, but it is interesting to note that none of the 16 respondents from companies with <100 employees indicated neither that they absolutely reached the goals, nor that they did not reach the goals at all. In addition, companies with >500 employees tend to be more satisfied with the documentation of PD during the running-in compared to the <100 group, where 16 out of 23 are to a certain extent or absolutely satisfied in the large companies compared to 8 out of 16 of the small companies.

Furthermore, the production people seem to be more satisfied with both the documentation of PD and how the experiences have been taken care of in the subsequent improvement work, where 15 out of 19 are satisfied with documentation and 16 out of 19 are satisfied with the improvements.

4.2 How is PDH applied in industry?

The intent with the second research question was to assess how PDH efforts are structured by giving answers to what maintenance methodologies, tools and principles that form the maintenance operations. In addition, it aims at answering what performance measures that are used and how the results from these figures are utilized in improvement work.

4.2.1 Performance measures



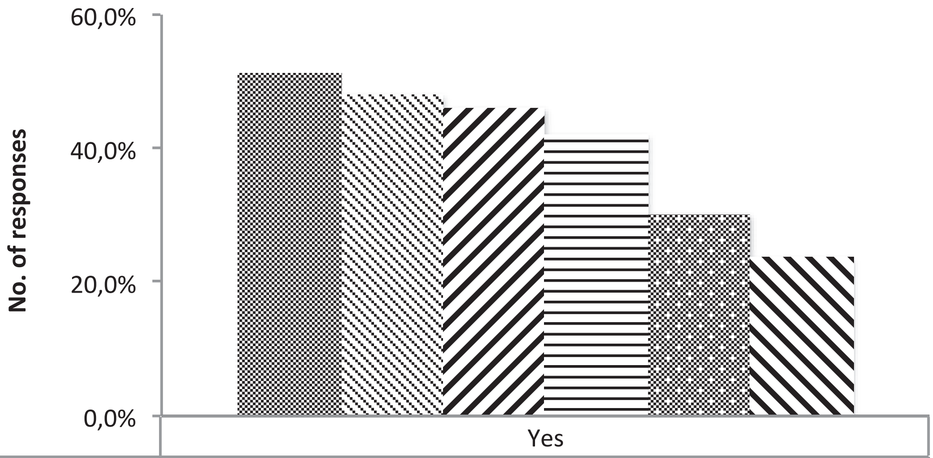
	Yes	No	Do not know / not applicable
Cycle time	57%	32%	33%
All stops, including minor stoppages	71%	29%	0%
TA	51%	45%	4%
OEE	51%	48%	3%

Figure 13 – Measurements of production performance

Figure 13 displays to what extent the companies are regularly measuring cycle time in production, recording and registering all production stops including minor stoppages, as well as performing calculations of TA and OEE. The results indicate that measurements of cycle times in production is fairly common, where 42 out of 74 respondents indicated that it is recorded to a relatively high or very high degree in their company. Moreover, a majority of the respondents state that all stops are measures and registered, where in fact 33 out of 76 indicate that it is performed to a very high degree, and only 3 answered that it is not done at all. Regarding the performance measures TA and OEE, approximately half of the companies are calculating them to some extent, where 26 out of 76 indicate that they calculate TA to a very high extent, and 26 out of 75 calculate OEE to a very high extent.

If the data is interpreted based on the industry type, as seen in Appendix B, the results indicate that continuous production companies are measuring all stoppages as well as calculating both TA and OEE to a higher extent than discrete manufacturing companies. In particular, 23 out of 23 continuous production companies register all stops to some extent, and only 1 state that they are not at all calculating TA.

Differences between company sizes can also be identified. As seen in Appendix C, larger companies are measuring all stops as well as calculating TA and OEE to a higher extent than smaller companies. In fact, out of in the 23 the companies with >500 employees, all stops are registered to a relatively high or very high extent in 21 of them, and 18 and 15 companies are calculating TA and OEE to a relatively high or very high degree respectively.



	Yes
Development and follow-up of KPI's	51,3%
Identify critical equipment	48,0%
Identify improvements	46,1%
Monitoring and control	42,1%
Internal benchmarking	30,3%
External benchmarking	23,7%

Figure 14 – The use of OEE figures

Figure 14 displays what the results from OEE figures are used for. The results indicate that out of these alternatives, the most common use for OEE is for development and follow-up of KPI’s in production, where 18 out of 76 respondents state that they use in that context to a very high degree, and an additional 17 to a fairly high degree. There are however only small differences between the four most frequently used alternatives. In detail, 15 out of 75 respondents indicate that they use OEE to identify critical equipment such as bottlenecks to a very high degree, and 17 out of 76 claims to use it for identification and development of improvements or monitoring and control of processes or equipment to a very high degree. Using OEE for internal or external benchmarking is however done to a lower extent, indicated by that 44 out of 76 respondents state that OEE is to a low extent or not at all used for internal benchmarking, and 50 out of 76 states the same for external benchmarking.

If this is viewed based on industry type, as seen in Appendix B, there are no significant differences between the two groups except for identifying improvements and critical equipment, where continuous production companies are using it to a slightly higher degree.

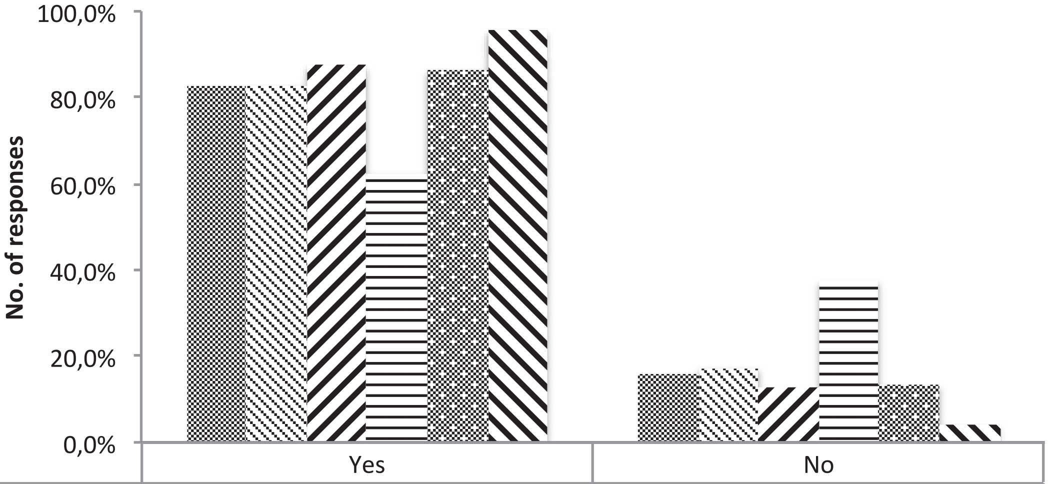
However, as seen in Appendix C, larger differences can be found if the results are based on company size, where the companies with >500 employees are using OEE for all of the alternatives to a larger extent than the two groups of smaller companies. Note however that as stated previously, calculation of OEE is in general performed to a higher extent in large companies. In both the >500 and 101-500 group, OEE figures are most frequently used for development and follow-up of KPI's, whereas the companies with <100 employees tend to use OEE primarily to identify improvements and critical equipment. It is also noted that the smallest group of companies are almost not at all using OEE for internal or external benchmarking.

4.2.2 The need for effective maintenance

In order to highlight the importance of effective maintenance, the respondents were asked whether they had estimated the cost of stoppages and to what extent they experience frequent and unsolved PD in production.

In total, 43 out of 76 respondents indicated that the cost of stoppages had been estimated at their company. The data furthermore shows that continuous production companies are more prone to calculate the cost of stoppages compared to discrete manufacturing companies. This is shown by that 18 out of 24 continuous production companies have done it, compared to 25 out of 52 companies with discrete manufacturing. In addition, the companies with >500 employees are calculating cost of stoppages to a larger extent than the two groups of smaller companies. In detail, 17 out of the 23 companies with >500 does it, compared to 17 out of 37 and 9 out of 16 for the 101-500 and <100 group respectively.

Moreover, the respondents were also asked to clarify the actual cost of the stoppages. The reported number range from 325 SEK/h all the way to 330000 SEK/h, indicating a large span depending on the industry and the size of the company. In addition, several respondents stated that the cost is dependent on such aspects as which plant, department, line, or product that the stop concerns, the rate of the production flow, as well as that it is based on forecast spot prices. One respondent also mentioned that they had 27 different departments in which the cost of stoppages has been calculated separately.



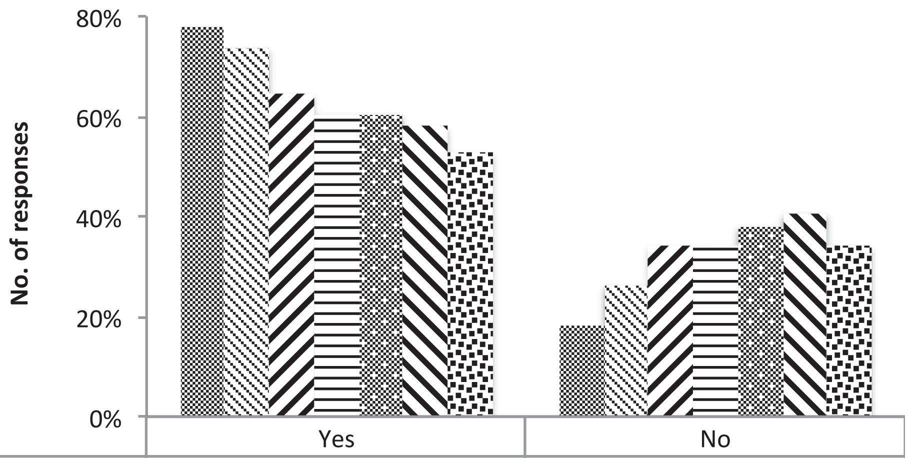
	Yes	No
Overall	82,9%	15,8%
Discrete	82,7%	17,3%
Continuous	87,5%	12,5%
<100	62,5%	37,5%
101-500	86,4%	13,5%
>500	95,7%	4,3%

Figure 15 - Frequent and unsolved PD in production

The data in Figure 15 displays to what extent the respondents experience that there are frequently occurring PD in production that are not being resolved. The results indicate that this is prevalent in a vast majority of the companies, where 49 out of all 76 respondents state that they experience it some extent, and an additional 15 absolutely considers there to be frequent PD in production. In fact, only one respondent indicated that frequent PD not at all exists at the company. The most noteworthy difference between the groups can be found for the smallest versus the largest companies, where the companies with >500 experiences frequent PD in production to a notably larger extent than the companies with <100 employees. Furthermore, as seen in Appendix D, there seems to be a shared view upon the occurrence of frequent PD between the production and maintenance people.

4.2.3 PDH and maintenance in the organization

In order to identify how the maintenance function is managed and how PD are handled within the organization, the respondents was asked several questions regarding their perception of work practices, methods, goals and education related to maintenance and PDH.



	Yes	No
Maintenance goals and planning is synchronized with production	78%	18%
Satisfied with how PD are handled and prioritized by management	74%	26%
Satisfied with documentation of PD	64%	34%
Satisfied with improvement teams regarding PD	61%	34%
Satisfied with follow-up of improvements	61%	38%
Satisfied with education and competence development regarding PD	58%	41%
Experiences from PD are tied back to development deparments	53%	34%

Figure 16 – Work practices related to maintenance and PDH

The data in Figure 16 displays the respondents' perception regarding several aspects connected to how maintenance and PD are managed within the organization. Formation of maintenance goals and planning of maintenance seems to be synchronized with the production in most companies, where 59 out of 76 find them to be absolutely or to a certain extent synchronized. In fact, none of the respondents claim that they are not at all synchronized. Moreover, a vast majority is satisfied with how PD are handled and prioritized by management at their company, where 32 out of 76 are satisfied to a certain extent, and an additional 24 are absolutely satisfied. Likewise, more than half of the respondents are satisfied with the education and competence development regarding PD, how improvement teams regarding PD are working, and how improvements are followed up. However, only 6 out of 76 the respondents are absolutely satisfied in any of these three questions. Finally, 49 out of 76 are satisfied with how PD are documented, and 40 respondents consider that the experiences from PD are tied back to development departments. Note however that 9 out of 76 respondents answered that they do know if the experiences are tied back to development or that it is not applicable at their company.

When comparing the data based on industry type, as seen in Appendix B, no substantial differences could be identified regarding most of these questions. However, it can be shown that the continuous production companies to a higher extent experience that maintenance is synchronized with production. This is indicated by 22 out of 24 these respondents, where 10 believe that they are absolutely synchronized. In contrast, 37 out of 52 respondents from discrete manufacturing companies find them to be synchronized to some extent, of which 15 answered yes, absolutely. Likewise, there seems to be a slight tendency towards higher level of satisfaction regarding how management handles and prioritizes PD in continuous production companies, where 21 out of 24 are satisfied to some extent compared to 35 out of 52 in discrete manufacturing companies. However, in both groups, approximately one third of the respondents claim to be absolutely satisfied in this regard.

As seen in Appendix C, no considerable differences could be found based on the size of the company for 4 out of these questions. Yet, the largest companies, i.e. >500 employees, tend to be slightly more satisfied with education and competence development regarding PD, documentation of PD and follow-up of improvements. Within this group, 16 out of 23 are satisfied with education, 17 out of 23 with documentation, and 16 out of 23 with improvement follow-up. In contrast, approximately half of the respondents in the two other groups are satisfied concerning these topics.

Moreover, the data in Appendix D, shows that the people working primarily in production seem to be more satisfied with improvement teams and how experiences from PD are tied back to development departments. In this case, 14 out of 19 are satisfied to some extent regarding both aspects, and 4 are absolutely satisfied. In addition, only one of these respondent is not at all satisfied with improvement teams, and none claims to be not at all satisfied with how PD are tied back to development.

4.2.4 Structure of maintenance operations

To display how the companies are structuring their maintenance operations, the respondents was asked to what extent they are working according to various maintenance concepts and how they are planning and carrying out maintenance activities.

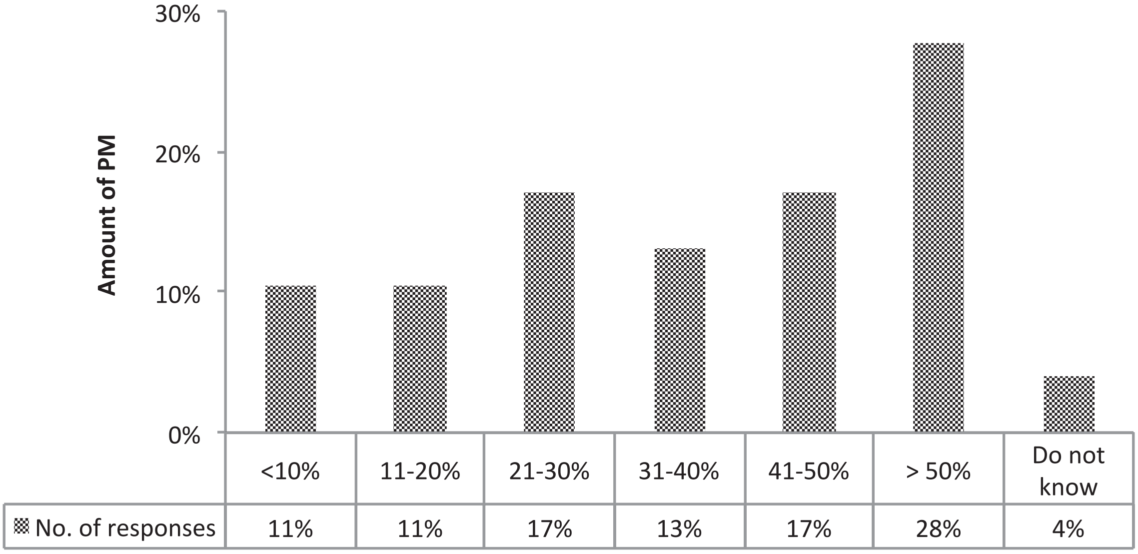
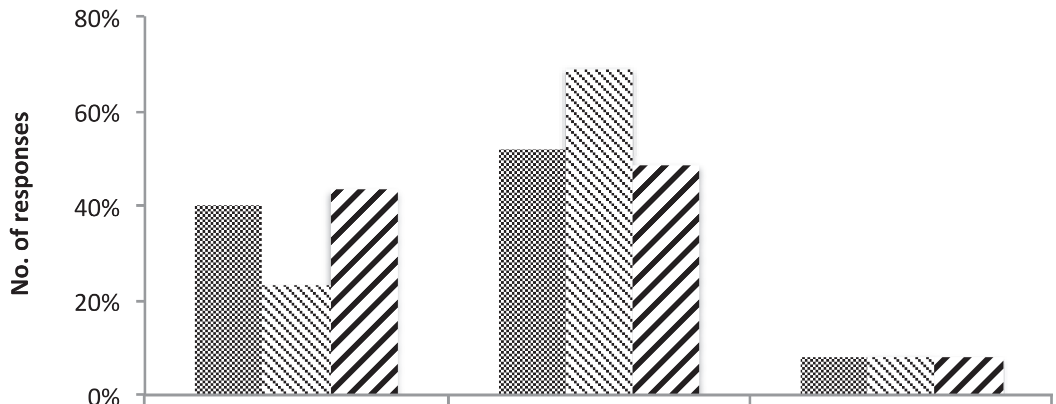


Figure 17 - Amount of PM

Figure 17 displays how much of the total maintenance operations that are carried out as PM. The results indicate that the amount of PM relative to corrective maintenance is fairly low, where in total 52 out of 76 respondents, i.e. 68 percent, state that there is less than 50 percent PM at their company. Consequently, only 21 out of 76 responded that their company has more than 50 percent PM.

As seen in Appendix B, continuous production companies is furthermore shown to have slightly larger amount of PM, where half of the companies have more than 40 percent PM, and 9 out of 24 have more than 50 percent PM. In contrast, 22 out of 52, i.e. 42 percent of the discrete manufacturing companies have more than 40 percent PM, and 12 of these respondents indicated than they have more than 50 percent PM. On the contrary, the data in Appendix C, shows no significant differences based on the company size, where approximately one third of all the companies in each group have more than 50 percent PM.



	Yes	No	Do not know / not applicable
TPM	40%	52%	8%
RCM	23%	69%	8%
CBM	43%	49%	8%

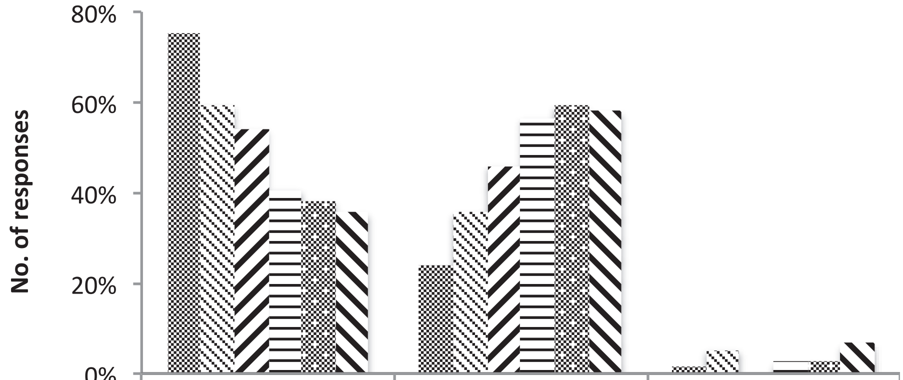
Figure 18 – Maintenance concepts TPM, RCM, CBM

Figure 18 displays to what extent the companies are applying principles and work practices according to the maintenance concepts TPM, RCM and CBM. Note however that as explained in the theoretical framework, CBM is not comparable to TPM and RCM in the context of being a full maintenance concept. The data indicates however that all three are utilized at a fairly low level, where especially RCM is rarely employed. In detail, 17 out of 75 state that they work with TPM to a very high extent, 10 out of 74 work with CBM to a very high extent, and merely 4 out of 75 claim to be working with RCM to a very high extent. On the contrary, 13 out of 75 are not at all working with TPM, 25 out of 74 not all with RCM, and 7 out of 74 not at all with CBM.

On average, there are no clear trends as to whether these concepts are utilized to a larger extent in different types of industries, as seen in Appendix B. Nonetheless, it can be identified that all of the 4 respondents who state that they are working with RCM to a very high extent are representing discrete manufacturing companies. Moreover, half of the continuous production companies are working with CBM to a high degree, versus 20 out of 50, i.e. 40 percent, for discrete manufacturing. However, CBM is slightly more often used to a very high degree in discrete manufacturing companies, indicated by 8 out of 50 respondents, compared to 2 out of 24 in continuous production companies.

There are clearer trends concerning these concepts and the size of the company, which can bee seen in the data in Appendix C. The companies with >500 employees are using TPM, RCM and CBM to a substantially larger extent than the smaller companies. In fact, no respondent representing a large company state that they are not at all working with TPM or CBM, nor that they do not know or that it is not applicable. On the contrary, it is especially rare that the companies with <100 employees are working with these concepts to a high or very high degree, where only 2 out of 15 state it regarding TPM, 1 out of 15 concerning RCM, and 1 out of 15 for CBM.

As described in the theoretical framework, these concepts are based on certain principles and the use of specific tools and methodologies in order to achieve effective maintenance. To investigate to what extent these guidelines are followed, the respondents was asked several questions regarding to what extent they are following various principles from TPM, RCM and CBM.



	Yes	No	Do not not / not applicable
Production operators involved in improvement teams	75%	24%	1%
Maintenance operators involved in improvement teams	59%	36%	5%
Outsourced maintenance	54%	46%	0%
Operator maintenance	41%	57%	3%
Collaboration between production and maintenance operators	38%	59%	3%
Systematic method (EEM/MP) for reliability and maintainability during design phase	36%	58%	7%

Figure 19 – Principles and work practices emphasized in TPM

Figure 19 shows to what extent several principles and work methods emphasized in TPM are utilized. TPM is largely based on production operators carrying out maintenance in contrast to hiring external maintenance personnel, that shop floor workers are heavily involved in team-based continuous improvement activities, and that there is a company-wide collaboration between production and maintenance people. In addition, another pillar of the TPM concept is to improve reliability and maintainability of equipment and processes during the design phase.

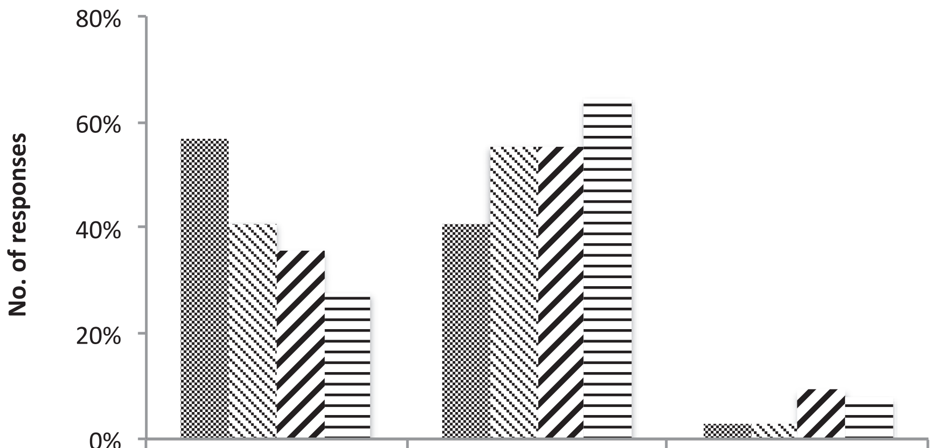
The data indicates that operator maintenance is employed to a fairly low degree, where only 9 out of 76 respondents claim that it is utilized to a very high extent. In contrast, maintenance carried out by external personnel (i.e. outsourced maintenance) is utilized in more than half of the companies, where 12 out of 76 state that it is used to very high extent. In fact, only 2 out of 76 responded that external personnel are not at all performing maintenance at their company.

Production operators and maintenance personnel does not seem to plan and carry out maintenance together to a high degree, where in fact only 6 respondents indicate that they collaborate to very high degree in their company. On the positive note, production operators seem to be involved in improvement teams to a large extent, where 57 out of 76 state that they are involved to a high or very degree. In fact, only one responded that production operators are not at all involved in improvement teams, and one that it is not applicable at their company. Maintenance personnel are also involved in improvement teams to a fairly large extent, however to a slightly less degree than production operators. In this case, 45 out of 76 state that they are involved to high or very high degree. 5 out of 76 did however respond that maintenance operators are not at all involved in improvement teams.

It can furthermore be shown that it is rather rare that companies have a systematic method like EEM or MP in order to improve reliability and maintainability during the design phase. In detail, 21 out of 76 indicated that they have it to a certain extent, and only 6 stated that they absolutely have such a method.

If the data is investigated based on the industry type as seen in Appendix B, there are no substantial differences concerning the extent of operator maintenance or the collaboration between production and maintenance operations. However, continuous production companies seem to be more prone to have external personnel carrying out maintenance, where in fact 17 out of 24 state that it is utilized to a high or very high degree, and none that it is not utilized at all. On the other hand, discrete manufacturing companies seem to have slightly more production and maintenance operators involved in improvement teams. EEM or MP is on average slightly more common within continuous production companies, but it is still only 1 out of 24 continuous production companies that absolutely have such a method.

Moreover, the data in Appendix C shows that companies with <100 employees tend to utilize external personnel for maintenance to a larger degree than medium sized and large companies, in which 11 out of 16 indicate that it is used to a high or very high degree. In average, there are no major differences between the different sized companies concerning the amount of operator maintenance, but collaboration between production and maintenance operators is found to be rare in the smallest companies, where only 3 out of 16 state that they collaborate to a high or very high degree. All groups have production operators involved in improvement teams to large extent, but it is notable that only 2 out of 23 of the largest companies have it to very high degree. A similar scenario can be seen for the involvement of maintenance operators in improvement teams, where both of the two larger groups have in average high degree of involvement, but only 2 out of the 23 largest companies to a very high degree. Additionally, the companies with <100 have substantially less maintenance operators in improvement teams, where only 5 out of 16 state it to high or very high degree. Finally, having a systematic method like EEM or MP seems to be almost exclusive to companies with more than 100 employees, as it in the <100 group is only indicated that 3 out of 16 have it to some extent, and none stated that they absolutely have such a method.



	Yes	No	Do not know / not applicable
Bottleneck analysis	57%	41%	3%
Condition Monitoring (CM)	41%	55%	3%
Establish criticality levels for equipment	36%	55%	9%
Continuously update criticality levels	28%	64%	8%

Figure 20 - Tools and methods emphasized in RCM and CBM

Figure 20 shows to what extent the companies are using tools and methods that are emphasized in RCM and CBM. Note however that bottleneck analysis is not a specifically suggested maintenance method, but it can be used to identify and monitor critical equipment in production, which is essential in both RCM and CBM. The data indicates that to identify and analyse bottlenecks in production is performed to a fairly large extent, where 43 out of 76 state that they use it to a high or very high extent, and only 6 out of 76 says that it is not at all performed.

To monitor the condition of equipment by the use of CM is however utilized in less than half of the responding companies, and only 8 out of 76 use it to very high degree. CM is one of the core tools in the CBM approach, and 24 out of the 32 companies that state that they work with CBM to a high or very high degree does in fact also use CM to a high or very high degree.

Moreover, establishing criticality levels for maintenance of equipment, production processes and components are not performed to a large extent, where only 27 out of the 76 respondents state that it is performed to a relatively high or very high degree in their company. In addition, 16 out of 17 state that it is not at all performed, and 7 respondents do not know or answered that it is not applicable. Strongly connected to the establishing of criticality levels is to also continuously update them, which is performed to even less extent. Only 21 out of 76 state that they update their criticality levels to a relatively high or very high degree, and 22 did in fact indicate that they are not updated at all. Important to note however, is that 5 out of the 7 companies that establish criticality levels to a very high extent also update their levels to a very high extent.

If the data is viewed based on discrete versus continuous production, as seen in Appendix B, it is indicated that all of these tools and methods are utilized to a larger extent in continuous production companies. Establishing and updating criticality levels is especially rare in discrete manufacturing companies, where only 14 out of 52 are establishing criticality levels to a relatively high or very high degree, and 11 out of 52 updates them to a relatively high or very high degree.

Appendix C displays the data based on the company size, where it is indicated that bottleneck analysis is performed to the same extent in all groups, but both CM and establishing of criticality levels is clearly more common in larger companies and especially rare in companies with <100 employees. However, the larger companies are not that much better when it comes to updating the criticality levels. For example, out of the 16 of the companies with >500 employees that are establishing criticality levels to a relatively high or very high degree, only half of them are updating these levels to a relatively high or very high degree.

	Basis for criticality levels
ABC	31%
Other	12%
Operator influence	11%
Bottleneck analysis	9%
Cost-based	7%
Time of purchase	4%
Do not know / not applicable	25%

Figure 21 - Basis for establishing criticality levels

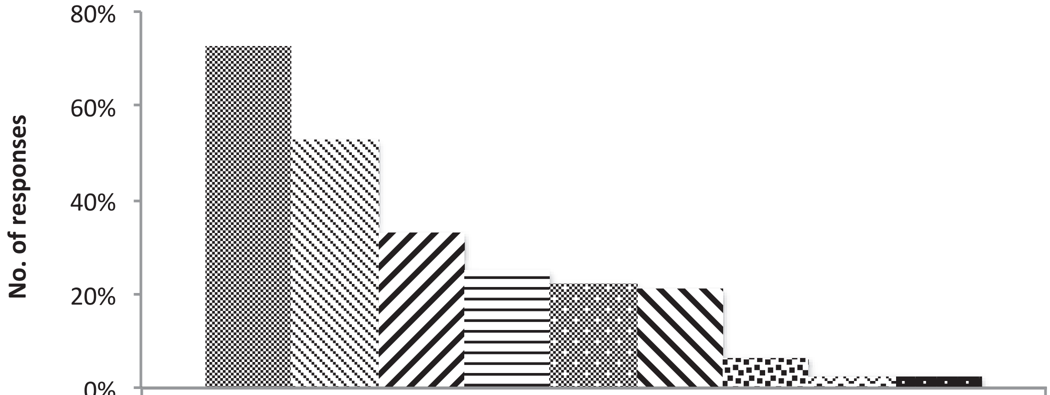
It is moreover of interest on what basis the criticality levels are established on. This is displayed in Figure 21, where it is indicated that ABC-classification is the most commonly used approach. The "Other" category shows the 9 respondents who answered the question by stating that they use another approach. These respondents instead state that they base their criticality levels on *"enterprise system"*, *"cost of root cause category"*, *"similar to ABC classification but with 1-5 scores"*, *"product mix"*, or *"RCM/FMECA"*. In addition, three respondents indicated that they base it on safety aspects in form of *"reactor safety"*, *"safety"*, and *"the equipment's importance for reactor safety"*. Moreover, it can be found that ABC-classification is in fact the most common method in the companies that to a very high extent both establish and update criticality levels.

Likewise, the data in Appendix B shows that ABC classification is still the most common approach if the data is interpreted based on discrete versus continuous production.

However, besides ABC-classification, discrete manufacturing companies are more prone to base their criticality levels on operator influence and time of purchase, and continuous production companies more frequently use bottleneck analysis. Differences can also bee seen in the data in Appendix C that is based on company size, where companies with 101-500 and >500 employees primarily use ABC-classification, whilst the companies with <100 employees indicate that they primarily base it on cost-based priority, operator influence or the time of purchase.

4.3 Risk assessment and reliability engineering

In order to identify to what extent risk assessment and reliability engineering approaches are employed at the companies, the respondents what asked to what extent using various risk and reliability analysis tools, methods and software as well as whether they have reliability engineers in the maintenance department working with them. In addition, the extent to which JSA is performed for both corrective maintenance and PM is investigated to further highlight if companies are actively working to improve the safety of maintenance operations.



	Risk and reliability tools
RCA	72%
Fishbone	53%
FMEA	33%
FTA	25%
HAZOP	22%
What-if	21%
ETA	7%
LTA	3%
VMEA	3%

Figure 22 - Risk assessment and reliability analysis tools

Figure 22 displays to what extent the companies are using various risk assessment and reliability analysis tools in the maintenance department. The data indicates that RCA is by far the most common tool, which is used in 55 out of 76 companies, followed by Fishbone diagrams, which are employed in 40 companies. Besides these two, risk and reliability tools are in general utilized to a fairly low extent. FMEA is the third most popular and utilized by 25 companies, but all the other tools are used by less than 19 out of the 76 companies. ETA, LTA and VMEA are especially rare, where ETA is only used by

5 companies, and LTA and VMEA only in 2. It is noteworthy to point out that the most frequently used tool, RCA, is primarily used reactively (i.e. after a failure or incident has occured). In contrast, the proactive tools (i.e. used to identify risks or failures before they occur) such as HAZOP, What-if, LTA and ETA are clearly utilized to a much lower extent.

As seen in Appendix B, discrete manufacturing and continuous production companies use most of these tools to approximately the same extent. What-if analysis, HAZOP and RCA is however utilized to a greater extent in continuous production companies, and it is noteworthy that 23 out of 24 continuous production companies use RCA. In general, most tools are also identified to become more common as the size of the company increases, as seen in Appendix C. In particular, RCA is utilized in all companies with >500 employees, in contrast to only 9 out of 16 companies with <100 employees.

The respondents were also asked whether they used various risk and reliability software in the maintenance department. The data indicates that this type of software is utilized to a low extent, as only one respondent state that they use DES in maintenance, one respondent used RBWS, and none claimed to use any of the three suggested software in the questionnaire; Relex, Reliasoft or @Risk. 37 respondents answered however that they instead used another software, out of which 6 clarified that they did not use any of the suggest software or that they do not have software at all in the maintenance department. The other 31 respondents instead listed the software that they used, which can bee seen in Appendix A. A vast majority did however refer to their normal maintenance planning software, where the following was mentioned more than once: “API”, “IFS”, “SAP”, and “Tekla”.

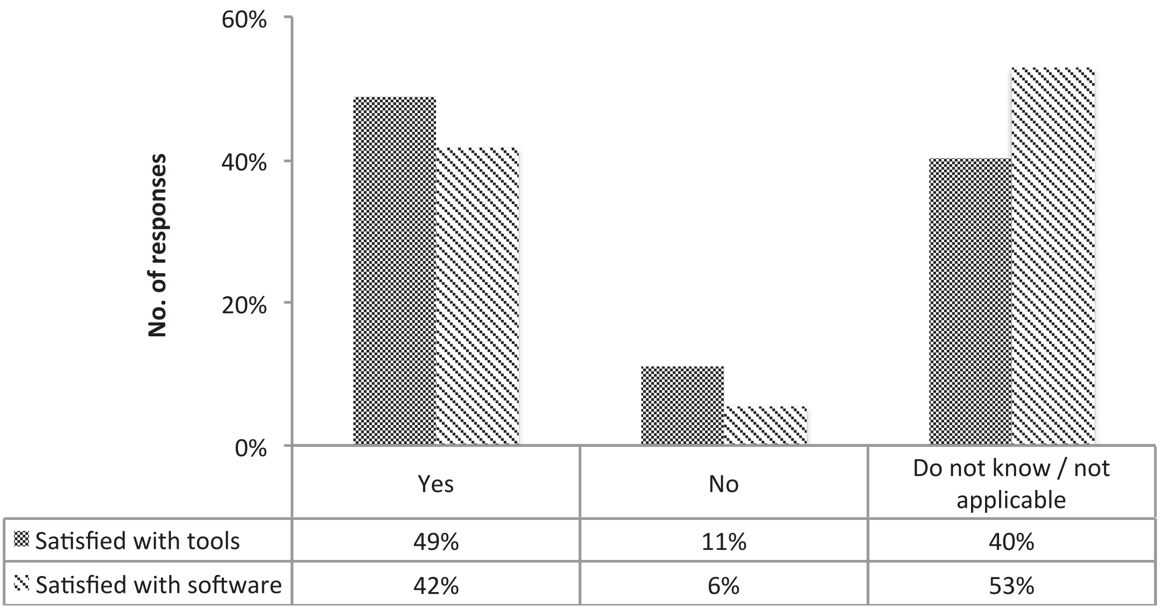
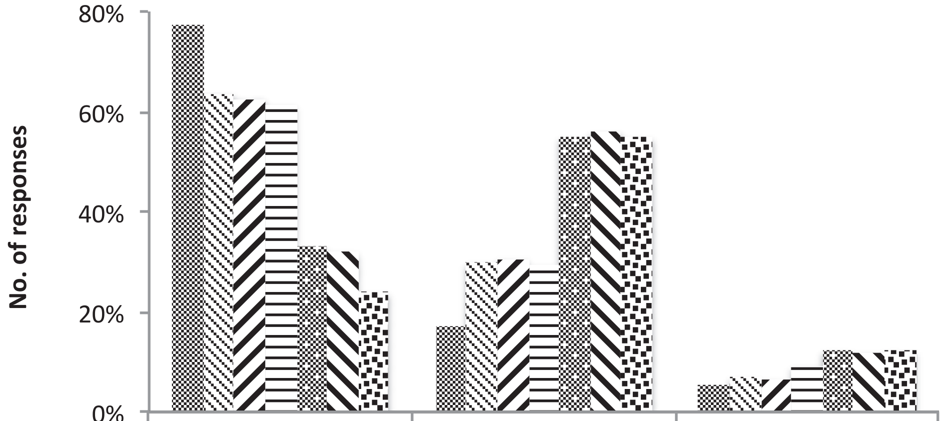


Figure 23 - Satisfaction with the use of tools and software

In addition to stating which tools and software that is used at their company, the respondents was also asked if whether they found them to work in a satisfactory way. Figure 23 displays this data, which indicates that most respondents that in fact use the tools and software are also relatively satisfied with them. In detail, 32 out of 72 stated that they were to a certain extent satisfied with the tools, and 3 were absolutely satisfied, whilst only 8 claimed to be scarcely or not at all satisfied. Regarding software, 27 out of 72 were to a certain extent satisfied, 3 absolutely satisfied, and 4 scarcely or not all satisfied. Take also in consideration that 29 and 38 respondents indicated that they did not know if they where satisfied with the tools and software respectively, or that it was not applicable at their company (i.e. not using the tools or software).

To also investigate to what extent these types of tools and software are put to use in practice, the respondents was asked to what extent they have reliability engineers in the maintenance department carrying out various types of reliability analysis and engineering improvement work.



	Yes	No	Do not know / not applicable
Develops and improves PM	77%	17%	5%
Risk analysis	64%	30%	7%
RCA analysis	63%	31%	7%
Improves maintainability and reliability during design phase	61%	29%	9%
Failure mode analysis	33%	55%	12%
LCC analysis	32%	56%	12%
Failure frequency analysis	24%	55%	12%

Figure 24 – Reliability engineering in maintenance department

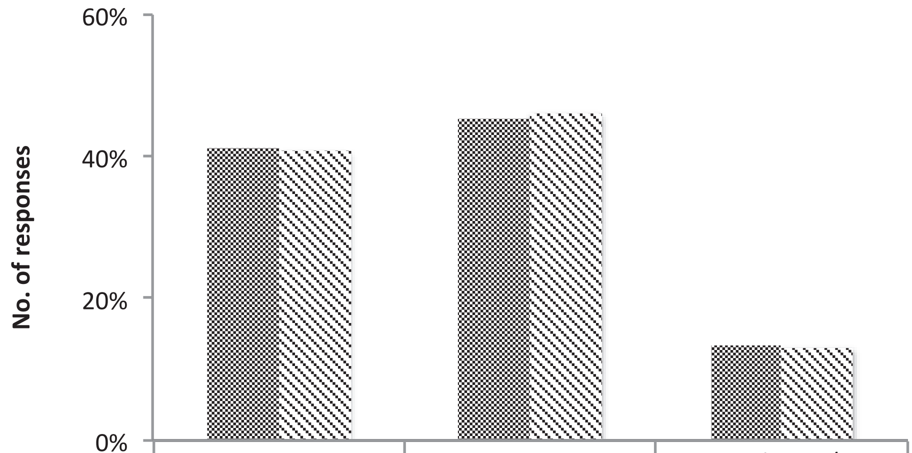
The data in Figure 24 displays to what extent the companies have reliability engineers in the maintenance department performing these types of analyses. It indicates that development and improvement to PM activities, and risk and RCA analysis are utilized to a fairly large extent. Development and improvements of PM is performed to the largest extent, which is indicated by that 39 out of 75 respondents state that they have engineers at their company who does it to a certain extent, and an additional 19 claims that they absolutely have such engineers. Likewise, 19 absolutely have engineers performing RCA analysis, and an additional 28 indicates that they have it to a certain extent. Regarding improvement of maintainability and reliability during the design phase, 41 respondents indicates that they to some extent have engineers doing it, but only 5 absolutely have it. Analyses of failures in production are however performed to low extent, where only 4 out of 71 respondents indicate that they absolutely have engineers who work with failure frequency analysis, and 6 out of 73 state the same for failure mode analysis. Likewise, LCC analysis is also fairly uncommon, where 24 out of

75 companies to some extent have engineers who are working with it, out of which only 5 states to absolutely have it.

Moreover, having maintenance and reliability engineers performing this type of analysis work seem to be more common in continuous production companies, as seen in Appendix B. Especially RCA, risk analysis and development and improvement of PM are performed to a high extent in these companies, where in fact 22 out of 24 to a certain extent or absolutely has engineers who develops and improved PM, and 21 out of 24 regarding RCA. In discrete manufacturing companies, failure frequency and LCC analysis are rare, shown by that only 2 out of 48 and 3 out of 51 companies absolutely have engineers conducting the two types of analyses respectively.

If the data is interpreted based on company size, as seen in Appendix C, it is clear that having reliability engineers carrying out these types of analyses is far more common in larger companies. Particularly, 22 out of the 23 companies with >500 employees have engineers performing RCA analysis, 19 out of 22 are working with risk handling and risk analysis, 21 out of 23 improves maintainability and reliability during the design phase, and 22 out of 22 develops and improves PM activities.

Several of the risk assessment tools can be used to identify safety hazards in maintenance operations. However, to further investigate how companies are working to improve the safety of the working conditions, the respondents was asked to what extent they are conducting JSA for both corrective maintenance and PM.



	Yes	No	Do not know / not applicable
JSA for corrective maintenance	41%	45%	13%
JSA for PM	41%	46%	13%

Figure 25 – Job Safety Analysis (JSA)

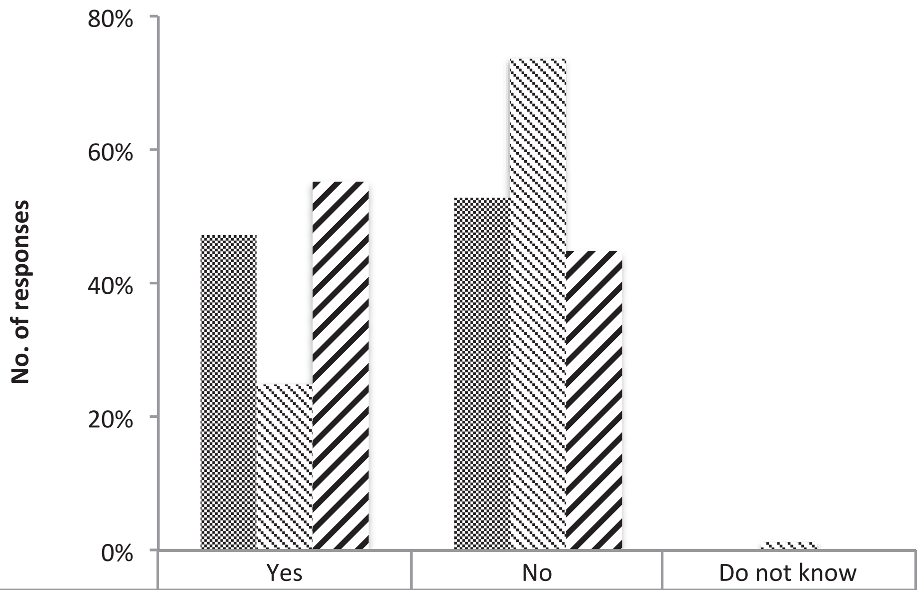
The data in Figure 25 displays to what extent the companies are performing safety analysis in form of JSA, and it indicates that it is employed to a fairly low extent. In fact, only 4 out of 75 respondents state that JSA for corrective maintenance is to a very high extent performed at their company, and 6 out of 76 states it regarding JSA for PM. In contrast, 34 out of 75 indicate that they to a fairly low extent or not at all does JSA for corrective maintenance, and 35 out of 76 state it regarding JSA for PM.

On average, there is no difference between discrete and continuous production companies, as seen in Appendix B. It is however noteworthy that none of the 24 respondents representing continuous production companies indicated that they to a very high degree does JSA for corrective maintenance, and only one claim that JSA for PM is performed to a very high degree.

The data in Appendix C shows however that JSA is performed to a higher degree in larger companies, where the group of >500 employees clearly differentiates from the two groups of <500 employees. In the largest companies, 16 out of 23 does JSA for corrective maintenance to a relatively high or very high degree, and 14 does JSA for PM to a relatively high or very high degree.

4.4 Lean Maintenance

In the final part of the questionnaire, the respondents was asked to what extent they work with Lean principles in both production and maintenance, as well as whether they use various Lean tools in a maintenance context.



	Yes	No	Do not know
Working with Lean Production	47%	53%	0%
Working with Lean Maintenance	25%	74%	1%
Have knowledge about Lean Maintenance	55%	45%	0%

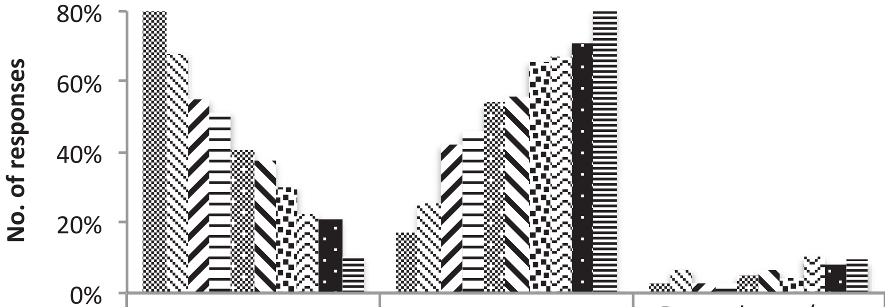
Figure 26 - Lean principles in production and maintenance

Figure 26 displays to what extent the companies are working with Lean Production, Lean Maintenance as well as whether the respondents have knowledge about the concept of Lean Maintenance. The data indicates that Lean Production is fairly common, where 36 out of 76 state that they work with it to a relatively high or very high degree. Lean in maintenance is however adopted to a low extent, where only 7 out of 76 work with it to a very high degree, and an additional 12 to a relatively high degree. Furthermore, 21 respondents indicated that they are not at all working with Lean Maintenance. Note however that a majority of the respondents indicate that they have rather good knowledge of the concept of Lean Maintenance, where 9 out of 76 have it to very high degree and an additional 33 to a relatively high degree.

When a respondent answered with any of the alternatives “No, not at all”, “Do not know”, or “Not applicable” regarding the extent their company is working with Lean Maintenance, they were instead asked if they have discussed to start working with Lean Maintenance. This was the case for 22 respondents, out of which 5 answered that they had indeed discussed to start working with Lean maintenance, and 17 that they had not, or that they did not know whether it had been discussed.

As seen in Appendix B, there are no differences between discrete and continuous production companies regarding the extent of working with Lean in neither production nor maintenance. However, a larger portion of the respondents who represent continuous production companies considerer themselves to have good knowledge of Lean Maintenance, where 16 out of 24 have relatively high or very high knowledge of the concept.

Moreover, working with Lean Maintenance tends to be almost exclusive to larger companies, as seen in Appendix C. Out of the 16 companies with <100 employees, only one indicated that they work with Lean maintenance to a relatively high degree, whilst the remaining 15 answered that they work with it to a relatively low degree or not at all. In contrast, none of the 23 companies with >500 employees stated that they not at all work with Lean Maintenance, and 11 indicated that they work with it to a relatively high or very high degree.



	Yes	No	Do not know / not applicable
Daily morning meetings	80%	17%	3%
Work orders based on priority	68%	25%	7%
5S in maintenance areas	55%	42%	3%
Visualization of work orders	51%	46%	3%
Standardization of spare parts and maintenance tools	41%	54%	5%
Maintenance inventory reduction	37%	56%	7%
Standardized work	30%	66%	4%
Andon for corrective maintenance	22%	67%	11%
Poka-Yoke to prevent maintenance errors	21%	71%	8%
VSM for maintenance activities	11%	80%	9%

Figure 27 - Lean Maintenance tools

Figure 27 shows to what extent the companies are working with various Lean tools in a maintenance context. It indicates that having daily morning meetings for maintenance personnel is employed in a majority of the companies, where 60 out of 75 state that they arrange these kinds of meetings to a relatively high or very high degree. In fact, only 5 state that they not at all have morning meetings, and 2 that it is not applicable at their company. Thereafter, having an approach to schedule work orders based on the priority of the maintenance requirement is also common, where 51 out of 75 respondents state they to a relatively high or very high degree arrange their maintenance in this manner. Approximately half of the respondents state that their company is working with 5S in maintenance areas and visualization of work orders through monitors, whiteboards etc., where in fact 17 out of 76 work with 5S to a very high degree.

The remaining tools are however seldom used to a very high degree, and the majority states that they are utilizing them to a fairly low degree or not at all. Standardizing the range of spare parts and maintenance tools, or reducing the inventory levels of maintenance storage areas, are prevalent in 31 and 28 out of 76 companies respectively. Furthermore, implementing standardized work procedures for maintenance operators are to relatively high or very high degree done in 23 out of 76 companies. Although the majority of the companies utilize Andon-signals to initiate corrective maintenance to a fairly low extent, there are still 8 who claim to be using it to a very high degree. Finally, applying the approach of Poka-Yoke to prevent maintenance errors are only done to a relatively high degree in 14 out of 76 companies, and to a very high degree in an additional 2. Analysing maintenance activities in order to map the process and identify waste by the use of VSM is almost not performed in any company, indicated by that only 7 out of 76 does it to a relatively high degree, and only one company to very high degree.

On average there are no major differences between discrete manufacturing and continuous production companies regarding the extent these tools are used. As seen in Appendix B however, it is indicated that discrete manufacturing companies are slightly more prone to use visualization for work orders and inventory reduction of maintenance storage, whilst continuous production companies tend to more frequently schedule their work orders based on maintenance requirement priority, as well as standardizing the range of spare parts and maintenance tools.

Moreover, the use of Lean tools follows the same tendency as Lean Maintenance in general, where it in Appendix C can bee seen that larger companies are to a much greater extent using them. For example, maintenance work orders are to a relatively high or very high degree scheduled based on maintenance requirement priority in 18 out of 22 companies with >500 employees. In addition, 17 out of the 23 largest companies work with 5, and 22 out of 22 have daily morning meetings for maintenance personnel. In contrast, Andon for corrective maintenance, VSM or Poka-Yoke is only reported to be used to high degree in 1 out of the 16 companies with <100 employees.

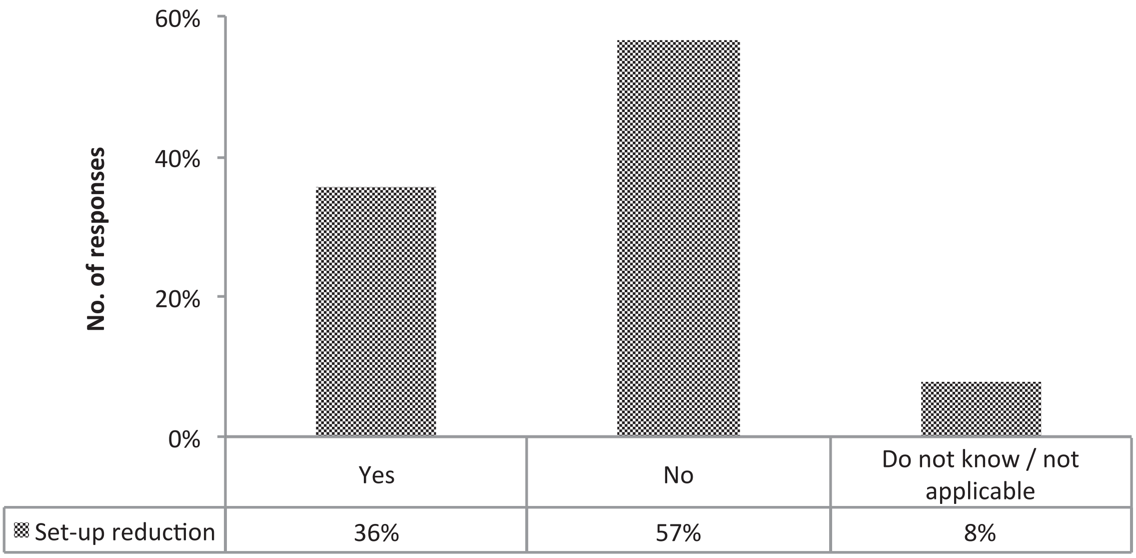


Figure 28 - Set-up reduction

The data in Figure 28 shows to what extent companies are working with set-up reduction using SMED or a similar method data. It indicates that few companies are working with set-up reduction, where only 7 out of 76 works with it to a very high extent, and an additional 20 to a relatively high extent.

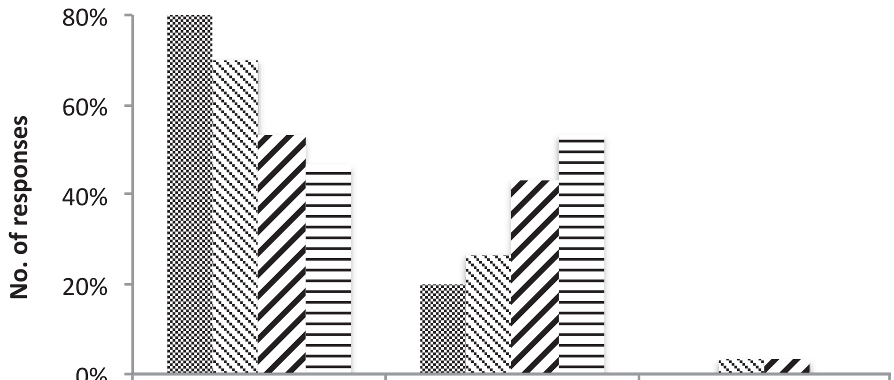
Moreover, the data based on industry type indicates that set-up reduction is slightly more common in discrete manufacturing companies, but there are no major differences depending on the size of the company.

4.5 *In-depth view of TPM and Lean Maintenance companies*

In addition to compile the overall data and cross-tabulate all responses based on industry type and company size, various in-depth cross-tabulations was made in order to further display the present state of maintenance operations in Swedish industry. Of primary interest is to explore whether the companies who state to be working according to maintenance concepts are in fact employing the fundamental principles of these theories. In addition, an investigation was made to see whether companies who are in fact using tools and methods from these maintenance concepts also perform better in terms of PDH and maintenance effectiveness. The full results of this cross-tabulation can be found in Appendix E.

4.5.1 TPM

The overall data indicates that TPM is the most applied maintenance concept in this survey, and it is therefore of interest to investigate whether the companies who claim to be working with TPM are in fact basing their maintenance operations on what is preached in the concept. This data was constructed by cross-tabulating the questions that concerned the fundamental principles of the TPM concept with the 30 respondents who indicated that their company work according to TPM to a relatively high or very high degree (from now on referred to as the *TPM companies*).

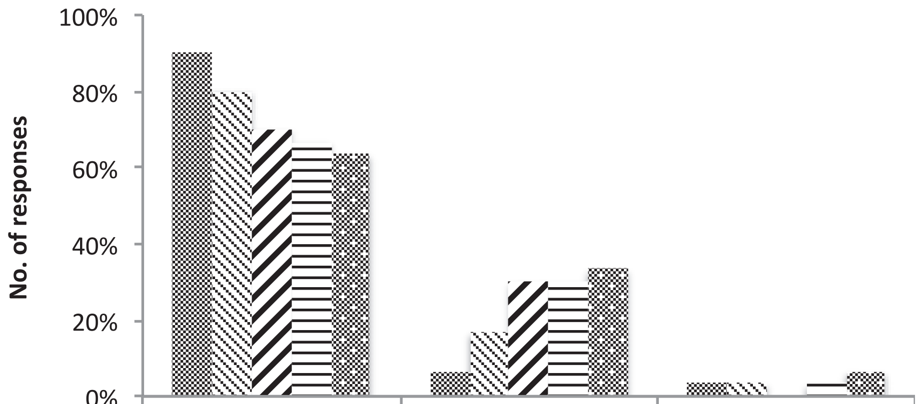


	Yes	No	Do not know / not applicable
Production operators in improvement teams	80%	20%	0%
Maintenance operators in improvement teams	70%	27%	3%
Operator maintenance	53%	43%	3%
Collaboration between production and maintenance operators	47%	53%	0%

Figure 29 - Operator maintenance and improvement teams

Figure 29 displays to what extent the TPM companies are working with two of the fundamental building blocks of TPM: autonomous operator maintenance and team-based continuous improvement work. The data suggests that the strong emphasis on operator maintenance in TPM is not fully employed, indicated by that merely 16 out of 30 companies have operators carrying out maintenance to a relatively high or very degree. On the other hand, both production and maintenance operators are involved in improvement teams to a large extent in a vast majority of these companies. In fact, none of these respondents answered that either production or maintenance operators are not at all participating in team-based improvement work. Cross-trained shop floor teams are argued to enable more effective maintenance, but the data in this survey indicates that having production and maintenance operators collaborating in planning and carrying out maintenance is fairly uncommon in the TPM companies. This is shown through that 10 out of 30 state that they have this kind of teamwork to a relatively high degree, and only 4 out of 30 to a very high degree.

If the data is compared to the average in the entire survey, it can be found that all of these 4 work practices are used in the TPM companies to a slightly higher degree. Having production operators in improvement teams displays a difference of 5 absolute percent, and the other three 9-12 absolute percent.



	Yes	No	Do not know / not applicable
Maintenance synchronized with production	90%	7%	3%
PD prioritized by management	80%	17%	3%
Calculations of OEE	70%	30%	0%
EEM / Maintenance prevention	67%	30%	3%
Satisfied with follow-up of improvements	63%	33%	7%

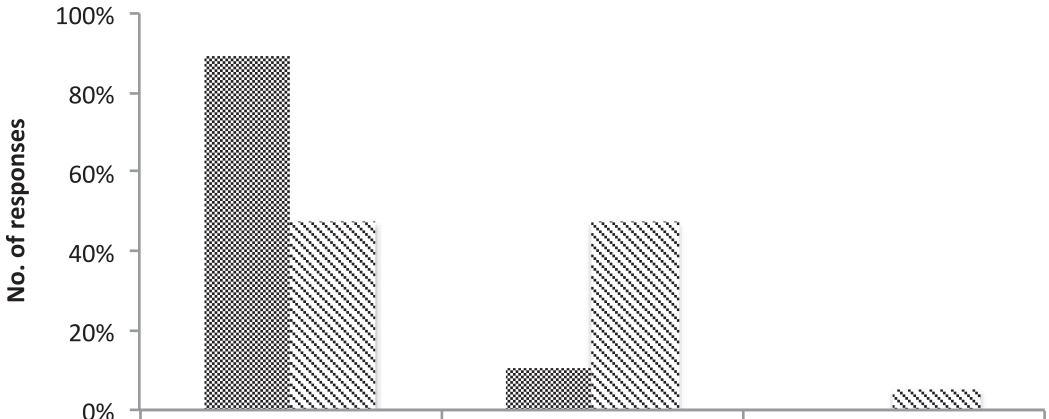
Figure 30 - Control of production process, maintenance prevention and involvement

Figure 30 reflects the third fundamental pillar of TPM: control of the production process by measurements and continuous follow-up of improvements. In addition, it takes in consideration the emphasis that TPM puts on involving all staff members, including top management, in the process of achieving high reliability, as well as the use of a systematic method like EEM or Maintenance Prevention to improve maintainability and reliability during the design-phase. The data indicates that a majority of the TPM companies are calculating OEE figures, where in fact 17 out of 30 does it to a very high degree. However, there seems to be few TPM companies that definitely work with EEM or Maintenance Prevention, indicated by that only 6 out of 30 states that they absolutely have such a method. On the positive note, almost all respondents both considers goal-formulation and planning of maintenance to be synchronized with production as well as that PD is prioritized by management. In fact, none of the respondents experiences either that maintenance is not at all synchronized with production, or that PD are not at all prioritized by management. However, only 4 out of 30 respondents are absolutely satisfied with the follow-up of completed improvement efforts, and an additional 15 are to some extent satisfied.

If compared to the average, it can be found that the TPM companies to a larger extent have a systematic method for EEM or Maintenance Prevention, indicated with a difference of 31 absolute percent compared to the average. In addition, calculation of OEE and considering that maintenance is synchronized with production is also slightly higher in these companies, shown with a difference of 20 and 12 absolute percent respectively. However, the TPM companies are not more satisfied with how PD are prioritized by management or the follow-up of completed improvements.

4.5.2 Lean Maintenance

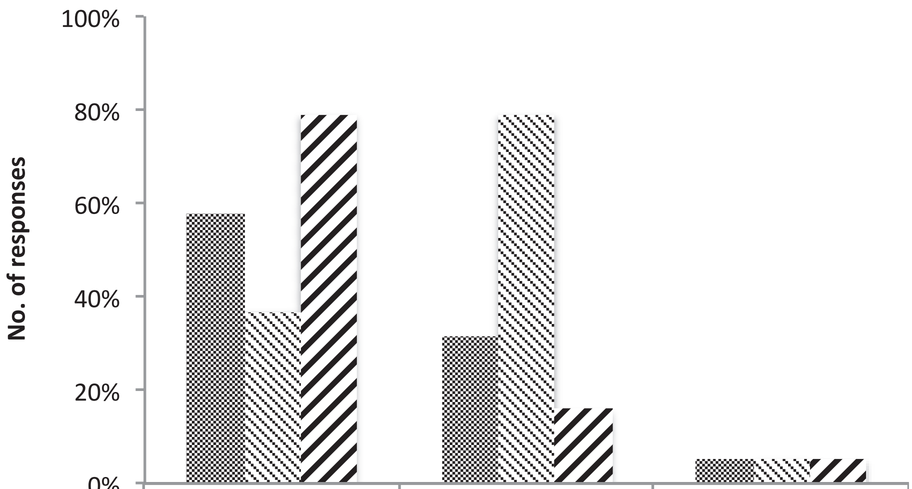
Since the fourth research question was aimed at exploring Lean Maintenance, the same approach as the investigation of TPM companies was utilized to further study to what extent the companies claiming to work with Lean Maintenance are in fact employing the principles of the concept. The 19 companies that indicated that they work with Lean Maintenance to a relatively high or very high degree are from now on referred to as the *Lean Maintenance companies*.



	Yes	No	Do not know / not applicable / missing answer
TPM	89%	11%	0%
RCM	47%	47%	5%

Figure 31 - TPM and RCM in Lean Maintenance companies

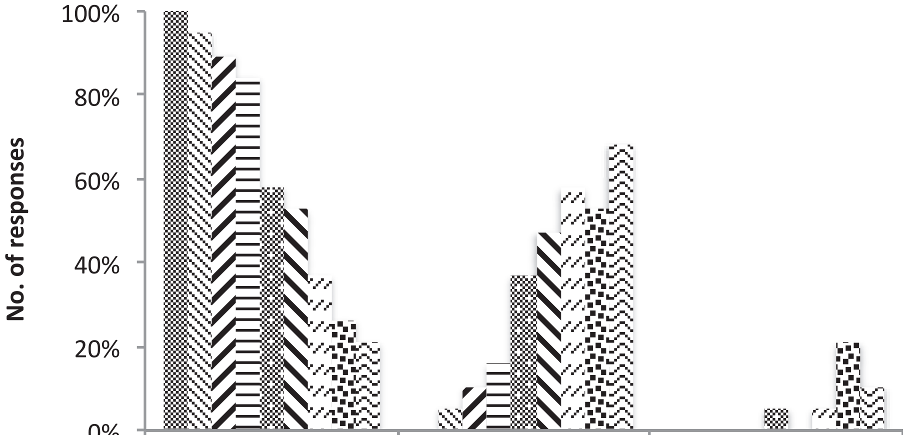
Lean Maintenance is defined as fine-tuning TPM by integrating influences of RCM, and in Figure 31 displays to what extent the Lean 19 Maintenance companies are in fact working with TPM and RCM. The data indicates that these companies do in fact work with TPM, where 5 and 12 state it to a relatively high and very high degree respectively. RCM is however not employed to the same extent, where merely 2 and 17 companies work with RCM to a relatively high or very high degree respectively.



	Yes	No	Do not know / not applicable / missing answer
Establish criticality levels	58%	32%	5%
Update criticality levels	37%	79%	5%
Schedule maintenance based on priority	79%	16%	5%

Figure 32 - Criticality assessment and maintenance scheduling

In order combine TPM and RCM, criticality assessment of equipment and scheduling maintenance work orders based on the priority of the maintenance requirement is necessary. The extent to which these principles are followed by the Lean Maintenance companies are displayed in Figure 32. The data suggests that these companies are both establishing and updating criticality levels to a slightly larger degree than the average presented in the overall analysis. Still, only 11 out of 19 are performing criticality assessment to a relatively high or very high degree, and only 7 are continuously updating their criticality levels. On the contrary, a vast majority of the Lean Maintenance companies are in fact scheduling maintenance work orders based on the priority of the maintenance requirement, indicated to a relatively high or very high degree by 15 respondents.



	Yes	No	Do not know / not applicable
Daily morning meetings	100%	0%	0%
Inventory reduction	95%	5%	0%
5S	89%	11%	0%
Visualization	84%	16%	0%
Standardization of parts and tools	58%	37%	5%
Standardized work	53%	47%	0%
Andon	37%	58%	5%
Poka-Yoke	26%	53%	21%
VSM	21%	68%	11%

Figure 33 - Lean Maintenance tools

The data in Figure 33 represents to what extent the Lean Maintenance companies have implemented the classic Lean tools in a maintenance context. It can be seen that almost all of these companies have daily morning meetings for maintenance personnel, employs inventory reduction for maintenance storage areas, have a 5S system implemented in maintenance areas and use visualize maintenance work orders using screens, whiteboards etc. In fact, none of the respondents answered these four questions with any of the alternatives "Not at all", "Do not know" or "Not applicable". Thereafter, standardizing the range of spare parts and tools for maintenance work as well as implementing standardized work for maintenance operators are prevalent in approximately half of the Lean Maintenance companies. Note however that only 2 out of 19 companies standardize parts and tools to a very high degree, and only 1 use standardized work to a very high degree. Lastly, using Andon-signals to initiate corrective maintenance, working with elimination of maintenance errors through Poka-Yoke and mapping the value stream of maintenance activities with VSM is rather uncommon. Note however that 5 companies does in fact work with Poka-Yoke to a very high degree, whereas only 2 and 1 companies use Andon-signals or performs VSM to a very high degree respectively.

If the data is compared to the average of the entire survey, it can bee seen that all of the tools are to a greater extent employed in Lean Maintenance companies. This is particularly seen for 5S and visualization with a difference of 33-34 absolute percent, as well as regarding inventory reduction of maintenance storage areas, which displays a difference of 58 absolute percent.

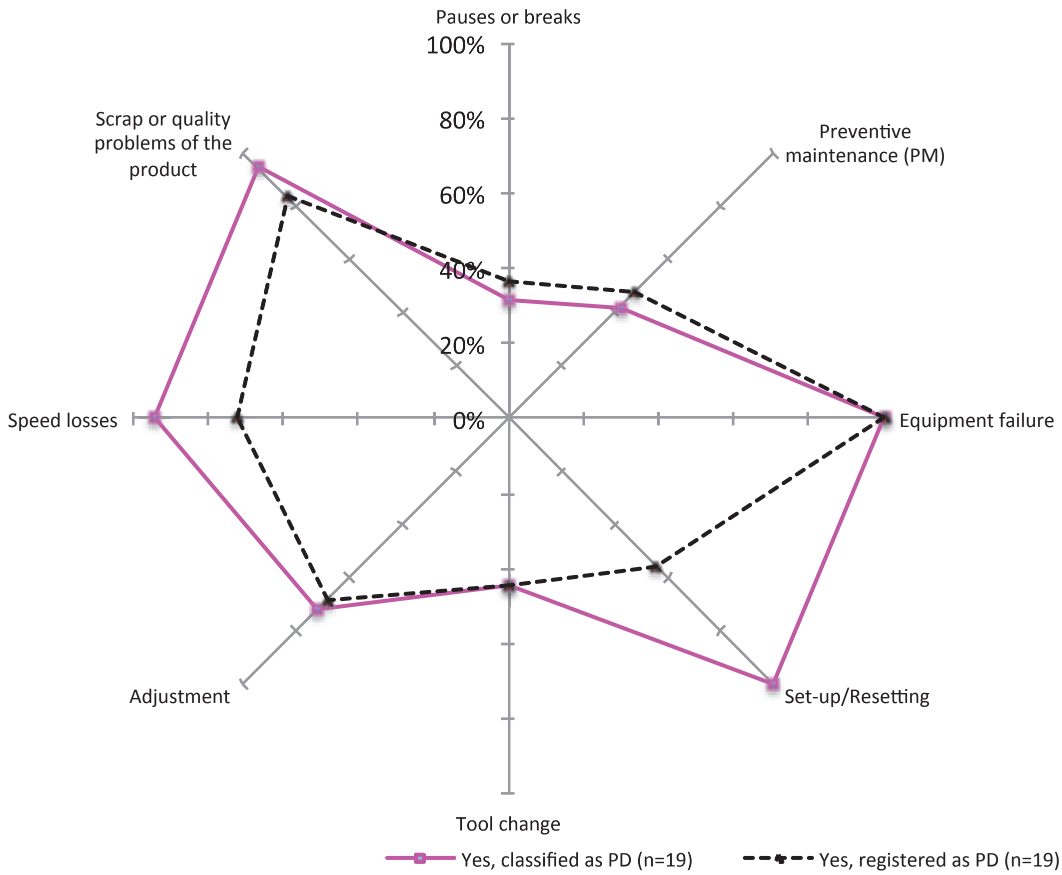
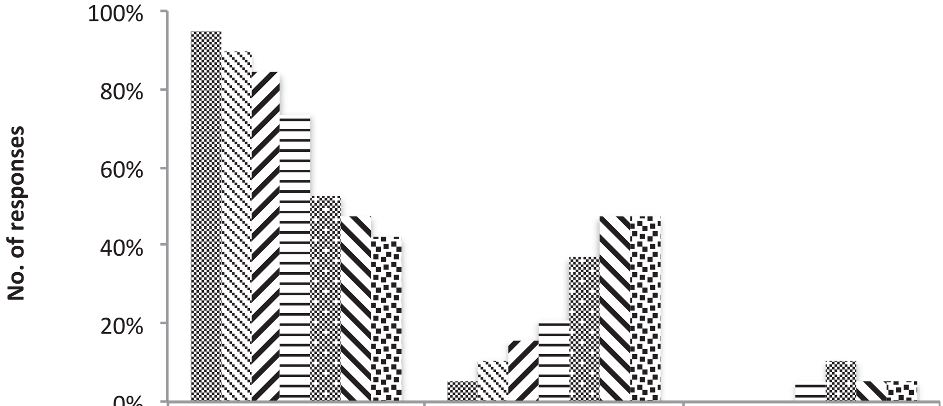


Figure 34 - Classification and registration of TPM losses

Figure 34 depicts to what extent the Lean Maintenance companies classify and register the factors that corresponds to the 11 major TPM losses as PD. Note however that the polar diagram only displays 8 PD factors, but they actually covers 10 of the TPM losses except *"minor stoppages"*. To account for this, the question regarding to what extent all stoppages in production (including minor stoppages) are measured and registered was also explored separately for the Lean Maintenance companies. This data revealed that all stoppages are according to 18 out of 19 respondents measures and registered to a relatively high or very high degree. Regarding the PD factors, it can bee seen that almost all of the respondents from the Lean Maintenance companies classify the factors *"equipment failure"*, *"set-up/resetting"*, *"speed losses"* and *"scrap or quality problems"* as PD. Moreover, 72 percent of the respondents classify *"adjustments"* as PD, but *"tool change"*, *"preventive maintenance"*, and *"pauses or breaks"* are classified as PD by less than 44 percent.

The only factor that is registered as PD in all 19 Lean Maintenance companies is *"equipment failure".* Thereafter, 68-83 percent of the companies register *"scrap or quality problems"*, *"speed losses"*, and *"adjustments"* as PD, and the remaining four factors is registered in 37-56 percent of the companies.



	Yes	No	Do not know / not applicable / missing answer
Development and improvement of PM	95%	5%	0%
RCA analysis	89%	11%	0%
Reliability and maintainability during design phase	84%	16%	0%
Risk analysis	74%	21%	5%
Failure mode analysis	53%	37%	11%
LCC analysis	47%	47%	5%
Failure frequency analysis	42%	47%	5%

Figure 35 - Reliability Engineering in Lean Maintenance companies

Since high reliability is essential for a Lean production system, reliability engineering is emphasized in the concept of Lean Maintenance. The data in Figure 35 shows to what extent the Lean Maintenance companies have reliability engineers in the maintenance department carrying out various analyses and engineering improvement work. In particular, development and improvement of PM activities, RCA analysis, and improving reliability and maintainability during the design phase of new equipment or processes is prevalent in a vast majority of the companies. In detail, 18 out of 19 absolutely or do a certain extent improves PM, 17 absolutely or to a certain extent does RCA analysis, and 16 improves reliability and maintainability during design phase. Slightly less frequent, but still prevalent in a majority of the Lean Maintenance companies, is having engineers doing risk analysis, indicated by 14 out of 19 respondents. Thereafter, the least common analysis methods used by these types of engineers are failure mode, LCC and failure frequency analysis, which is absolute or to a certain extent performed in 10,9 and 8 Lean Maintenance companies respectively.

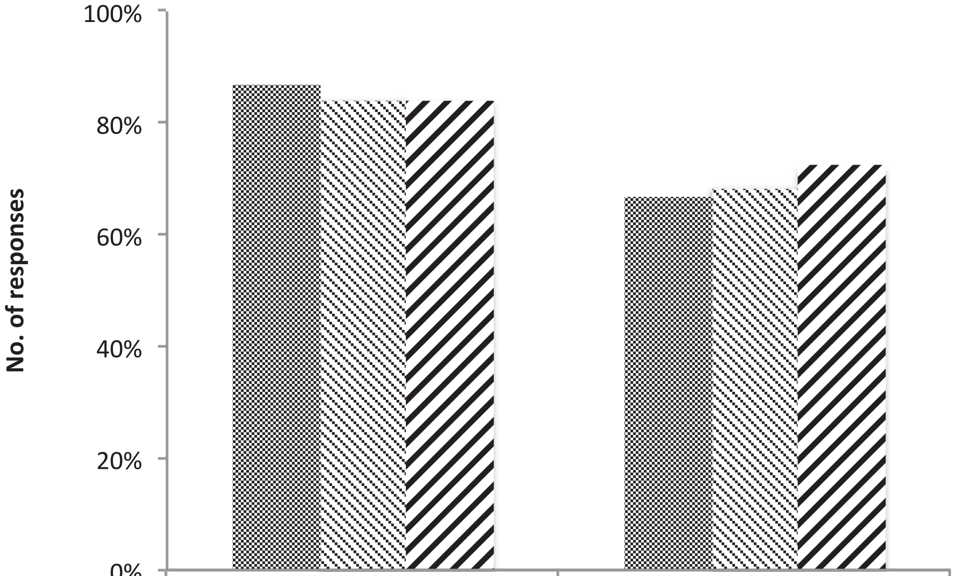
If compared to the average in the entire survey, the Lean Maintenance companies have engineers carrying out all of these types of work to a higher degree. In detail, 6 of the 7 types displays a difference of 15-26 absolute percent compared to the average, and the largest difference of 23 and 26 absolute percent is found for improving maintainability and reliability during the design phase and RCA analysis respectively.

On a final note regarding the analysis of the Lean Maintenance companies, it can be found that only half of these companies, i.e. 8 out of 19, are working with set-up reduction using a method like SMED to a relatively high or very high degree.

4.5.3 Maintenance performance of TPM and Lean Maintenance companies

As the data suggests that both the TPM and the Lean Maintenance group of companies are to a slightly larger extent employing various principles, practices and tools in order to achieve effective maintenance operations, it is of interest to see whether they are performing better in terms of PDH, maintenance effectiveness and safety. A note worth pointing out regarding these results is that since TPM is the basis for Lean Maintenance, almost all the companies in the Lean Maintenance group is also included in the TPM companies.

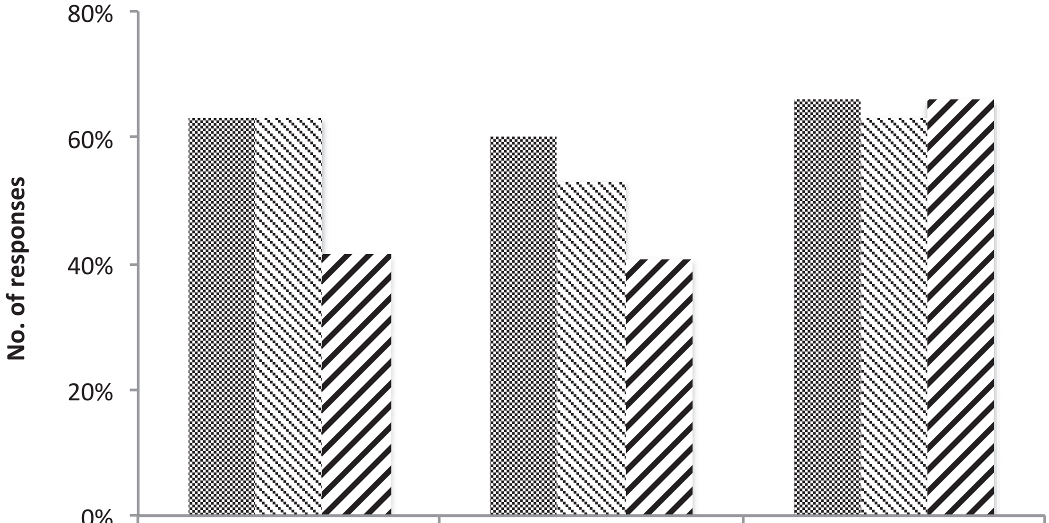
In terms of the ratio between corrective maintenance and PM, the data indicates that the both the TPM and Lean Maintenance companies have slightly larger amount of PM compared to the average in this survey. In detail, 12 out of the 30 TPM companies, i.e. 40 percent, and 8 out of 19 Lean Maintenance companies, i.e. 42 percent, claim to have more than 50 percent PM, compared to the average of 21 out of 76, i.e. 28 percent.



	Yes, frequent PD	Yes, PD during running-in
TPM companies	87%	67%
Lean Maintenance companies	84%	68%
Average	84%	72%

Figure 36 - PD in TPM and Lean Maintenance companies

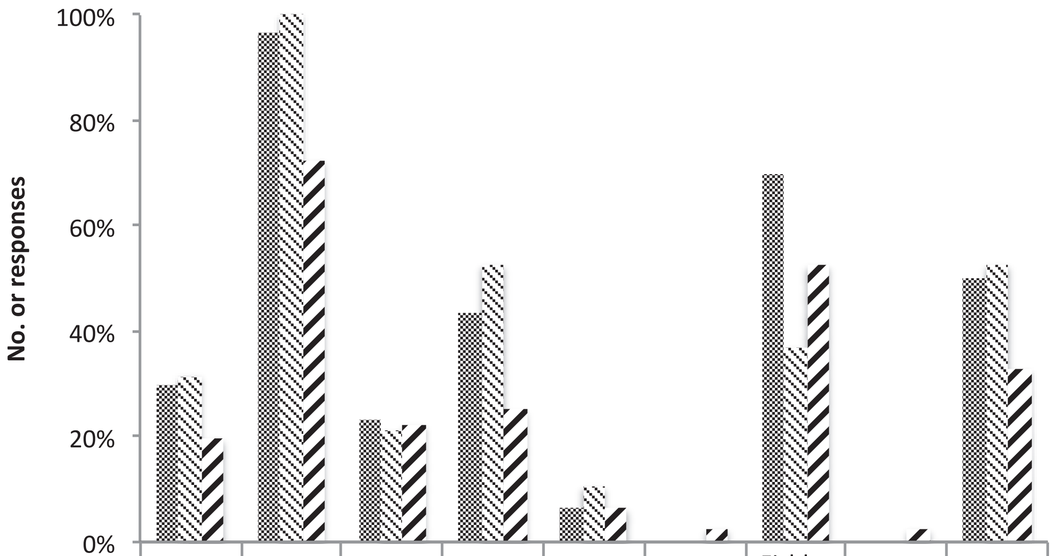
The data in Figure 36 shows that frequent and unsolved PD in production as well as increased PD during running-in of new equipment, processes or products is also to a very high degree prevalent in the TPM and Lean Maintenance companies. In fact, neither frequent PD or increased PD during running-in displays more than a 5 absolute percent difference compared to the overall average in the survey.



	Yes, JSA for corrective maintenance	Yes, JSA for PM	Yes, registering "incidents/near misses" as PD
TPM	63%	60%	66%
Lean M	63%	53%	63%
Average	41%	41%	66%

Figure 37 - Safety in TPM and Lean Maintenance companies

The data in 37 compares to what extent the TPM and Lean Maintenance companies are doing JSA for corrective maintenance and PM as well as registering *"incidents / near misses"* as PD compared to the average for all responses. It indicates that the companies working with TPM and Lean maintenance are performing JSA to a slightly higher degree, where especially he TPM companies show a difference of 19 percent compared to average regarding JSA for PM. However, there are no differences concerning the registration of *"incidents / near misses"* as PD.



	What-if	RCA	HAZOP	FTA	ETA	LTA	Fishbone	VMEA	FMEA
TPM	30%	97%	23%	43%	7%	0%	70%	0%	50%
Lean	32%	100%	21%	53%	11%	0%	37%	0%	53%
Average	20%	72%	22%	25%	7%	3%	53%	3%	33%

Figure 38 - Risk assessment tools in TPM and Lean Maintenance companies

Figure 38 displays the data of the use of risk assessment tools in the TPM and Lean Maintenance companies. It indicates that primarily RCA is employed to a very high extent in these companies, where in fact 29 out of 30 TPM companies and 19 out of 19 Lean Maintenance companies use it. Furthermore, FMEA is used by half of these companies, which is slightly higher than average. However, the data indicates that despite RCA, the TPM and Lean Maintenance companies in general utilize risk assessment tools to a fairly low degree.

If the same interpretation is based regarding software, it is indicated that the one company working with RBWS is also working with TPM. Moreover, 12 out of the 30 TPM companies, and 8 out of the 19 Lean Maintenance companies, are using other types of software for maintenance planning.

5 Discussion

5.1 Results discussion

In this section, the results from the questionnaire are discussed in relation to literature in order to explain, validate or disregard the findings.

5.1.1 Classification and registration of PD factors

The results in this questionnaire study shows that almost all respondents classify the factors *"equipment failure"*, *"failure of software in production equipment"*, and *"media error"* as PD. More than 75 percent also classified *"human error", "failure of peripheral", "planning error", "subsequent stop in output flow", "shortage of staff", "speed loss"*, and "*scrap or quality problems"* as PD, but factors concerning planned activities such as *"preventive maintenance"*, *"cleaning"*, *"work meetings"* and *"pauses or breaks"* was classified as PD by less than 45 percent of the respondents. These results supports the conclusion made by Ljungberg (1998) that companies are in general primarily focusing on downtime losses, and especially breakdowns, and that planned stoppages are instead not emphasized enough. In relation to Ylipää's (2000) model for sustainable PDH, it is naturally the breakdowns that result in the biggest visual effect in terms of PD, and they also require a restart of the system after they have been resolved. However, some of the less emphasised planned activities are aimed at managing the important PPD. Such PPD could be dirt and dust that can in fact cause major breakdowns (Nakajima, 1998), or deficiencies in interventions and violations that has an ability to propagate towards a PD (Ylipää, 2000).

Interesting to note here is also that there are in fact differences between factors that are rather similar, shown through that *"shortage of staff"* is clearly classified as a PD to a greater extent than *"work meetings"* or *"pauses or breaks"*. In addition, it is important to note that none of the factors was completely rejected as PD, as even the factors that was classified and registered as PD to the lowest degree, i.e. the two planned activities *"work meetings"* and *"pauses or breaks",* had an affirmative response by more than 20 percent of the respondents

Moreover, several events that are defined as TPM losses and are topics for continuous improvements and waste elimination in Lean such as *"set-up/resetting", "tool change"*, *"adjustments",* and *"time for changing/refilling of material"* was classified as PD by less than half of the respondents. A possible explanation to why these factors are not perceived as disturbances could be that they are not directly concerning technical failures and instead seen as are a natural part of the production process. Their contribution to decreased availability could thus easily be overlooked, and they are not covered by the fundamental purpose of maintenance; to ensure the functioning of technical equipment (SIS, 2000). However, as Jonsson & Lesshammar (1999b) points out, if actions that are a part of the production process, as well as the previously discussed planned stoppages, are in fact registered and included in calculations of availability, the low figures would create an incentive for decreasing planned downtime by more effective set-ups and PM, as well as highlight the importance of plant-wide waste elimination.

Williamsen (2013) describes how approximately 600 leads to one severe accident. By analyzing near misses and conduct appropriate risk assessment, actions to prevent accidents can be taken. In this survey, *"incidents/near misses"*, was classified as PD by 69 percent of the respondents, and registered in 61 percent of the companies.

The results furthermore indicate that 18 out of the 21 factors are to a greater extent classified by the respondents as PD compared to what is registered in the follow-up systems. Detailed data collection can however be very resource demanding and result in unmotivated personnel (Jonsson & Lesshammar, 1998b). Interestingly enough, the 3 factors that are instead to a greater extent registered as PD are in fact the planned activities *"preventive maintenance"*, *"cleaning"*, and *"work meetings"*, although the two latter only show a difference of 6 and 3 absolute percent respectively. It is probably not surprising that *"preventive maintenance"* displays the largest difference of 13 absolute percent as it is widely debated within literature whether PM should be treated as a PD or not (see for example Dal et al, 2000; Ericsson, 1997; Nakajima, 1998; Jonsson & Lesshammar. 1998b; Ljungberg, 1998). Ylipää (2000) sees PM as a kind of paradox: it can be a disruption if it is carried out during production even though it is also aimed at avoiding failures. In addition, PM can in fact be a cause of failure due to the probability of introducing failures during the maintenance activity.

Moreover, maintenance concepts like TPM and Lean Maintenance stresses the importance of close co-operation between the production and maintenance department (Nakajima, 1988; Smith & Hawkins, 2004). In order to prevent sub-optimization and enable collaboration towards achieving high reliability through prevention and elimination of disturbances, a shared view upon the PD factors is a necessity. The results in this study shows that production and maintenance people in general share a similar view on the subject, where the average of which factors that are classified as PD lies within 63-66 percent for the three groups of maintenance and production personnel. The same scenario was in fact also found in the previous survey as described in Ylipää et al (2007), signifying that a uniform view on PD factors between the production and maintenance department has been prominent in Swedish industry for many years.

The results that are based on discrete versus continuous production companies show that the groups on average register the PD factors to the same extent, but that there are differences concerning specific factors. The factors "*planning error", "speed loss"*, and *"cleaning"* is more frequently registered as PD in continuous production companies. The first two could correlate to the high consequences of rework and delays due to large batch sizes particularly found in process industry. The latter connects to addressing the PPD, or the "hidden effects" such as dirt, dust and scratches that seem insignificant on their own but can in fact cause major breakdowns (Nakajima, 1988; Ylipää, 2000). On the contrary, *"work meetings", "subsequent stop in the output flow"* and *"incidents/near misses"* is to a greater extent registered by discrete manufacturing companies.

In the data that is based on company size, it was found that the larger the company is, the more factors are both classified and registered as PD. The larger companies are especially prone to register the factors regarding reduced production flow in form of *"waiting time for incoming product or material"* and *"speed loss"*, changes in production in form of *"set-up", "tool change",* and *"time for changing/refilling of material"*, as well as downtime due to *"preventive maintenance".* The larger production volume naturally results in larger economical losses from disturbances, and there are likely more resources to be found for investing in data collection equipment compared to smaller companies. However, the opposite is found for *"incidents/near misses"* which is more often registered as a PD in the companies with less than 100 employees. Reporting these types of disturbances does not require any particular equipment and could be done in a more ad-hoc manner, possibly favoring smaller companies.

5.1.2 Development of PD factors since the previous survey

If the results from this survey are directly compared with the previous survey, it can be found that all factors are more or less classified as PD to the same extent today as in the previous survey, with a difference average of 63 versus 65 percent. However, larger differences is found regarding the registration, where in average, 49 percent of the factors was registered as PD in the previous survey, whereas 56 percent is registered as PD today. The factors "*preventive maintenance", "cleaning", "scrap or quality problems"*, and *"incidents / near misses"* displays the largest difference with 17-28 absolute percent.

If the data based on industry type is compared between the two surveys, it can be shown that both discrete manufacturing and continuous production companies are registering more factors as PD today. For discrete manufacturing, there is difference in average of 47 versus 57 percent, and for continuous production a difference of 44 versus 58 percent. In detail, a difference of 37-41 percent can be found in discrete manufacturing companies for the factors *"preventive maintenance", "subsequent stop in output flow"*, and *"incidents/near misses"*. For continuous production, 8 of the 21 factors have a difference of 17-21 absolute percent, and the factors *"failure of peripheral"*, *"cleaning"* and *"speed loss"* display a difference of 28-32 absolute percent.

Moreover, if the scenario based on company size is compared between the two surveys, one can identify that the companies with either <100 or >500 employees are today clearly registering more factors as PD. On average, the smallest companies are today registering 46 percent of the factors, compared to 27 percent in the previous survey. The largest difference can be found for *"incidents/near misses"* with a difference of 53 absolute percent, followed by *"failure of peripheral*" and *"set-up/resetting"* with 40 and 38 percent respectively. Regarding the largest companies, there is a difference in average of 65 versus 47 percent. In this scenario, the most significant is regarding *"waiting time for incoming product or material",* which displays a difference of 61 absolute percent. Moreover, *"preventive maintenance"* and *"speed loss"* are also more often registered as PD today, with a difference of 31-33 absolute percent.

Note however that the companies with 101-500 employees are showing no significant difference in average (i.e. 56 versus 52 percent), but *"incidents/near misses"* have increased by 40 absolute percent, and *"failure or peripheral"* and *"adjustments"* with 22 and 26 absolute percent respectively. A likely explanation for that this group of companies shows less difference in average is that it was the largest sample of companies in both surveys.

This general increase of registering PD factors indicate a positive trend towards that companies are nowadays paying more concrete attention to the influence of PD on production performance, possibly in line with a clearer view on the connection between effective maintenance and improved productivity and profitability (Alsyouf, 2007).

However, it is still possible to highlight a large improvement potential since about half of the 21 suggested factors in this questionnaire study are on average registered as PD. Besides, there are naturally plenty of other events that potentially could cause costly and resource-intensive disruptions in production, as indicated by several respondents.

Finally, the noted tendency towards more attention to *"incidents/near misses"* found in both discrete manufacturing and smaller companies follows S.E.S.A.'s (2007) suggestion that despite machine injuries are still one of the most common causes for work place injuries in Sweden, the severity of these accidents have decreased most likely due to better awareness of safety risks. However, one should also note that within the largest group of companies, registering *"incidents/near misses"* as PD have however slightly decreased with a difference of 14 absolute percent, and it also the group of companies that in this survey register this safety factor to the lowest degree. This is obviously an alarming indication since larger companies in general have bigger production areas and more machines and equipment that require maintenance. Thus, they need more personnel to carry out the maintenance work, which means being exposed to the many work hazards highlighted by EU-OSHA (2010). However, it is possible that near misses are instead measured by other means than registering it as a PD. Furthermore, possible explanations to this inconsistency of registering *"incidents/near misses"* could be the barriers mentioned by Williamsen's (2013). In terms of PD, the "desire to avoid work interruption" can most certainly influence to what extent these events are registered.

5.1.3 Running-in and chronic PD

Today's manufacturing situation is characterized by much more dynamic conditions, where PDH is crucial for companies' competitiveness (Ylipää, 2000). Despite this, most research on PD are based on stable conditions, and a situation that has increased during recent years as an effect of shorter product life-cycles is that of running-in of new products or equipment (Ylipää & Harlin, 2007). The data from the previous survey indicated that a vast majority of the respondents experienced increased PD during the latest running-in, and the results in this survey suggest that there has been no development towards improved PDH during these conditions. The fact that approximately 75 percent of the respondents in both surveys agreed to have experienced an increase of PD during the latest running-in highlights that this is still a major issue today. Naturally, the introduction of new technology or running-in often leads to some sort of production losses and in general poor OEE figures (Ljungberg 1988). However, if the PD are not eliminated during the start-up phase, they can remain as chronic and unsolved PD and threaten the whole life-cycle revenue of the product (Almgren, 1999).

The reason for neglecting PD during running-in could be that that they are put aside in favour for such measures as technical availability (Almgren, 1999). The results reported in Ylipää & Harlin (2007) indicated that most respondents considered that the goals for the running-in was met in terms of time-to-quality and time-to-volume, and approximately half claimed to have achieved time-to-cost according to plan. In this survey, 33 out of 76 respondents considered that the goals for cost, quality and production volume was met to some extent, and only 6 claimed that they where absolutely achieved, suggesting that many companies still struggles with achieving the goals of the running-in according to plan. Continuous production companies does however seem to be better in reaching the goals of the running-in, which is likely an effect of the added pressure from large batch sizes, limited possibility and large costs to make changes after production has been initiated. These results impose a dilemma for the scenario of running-in of new products or equipment. It is not unlikely that the pressure on short lead times and low production costs characterized in today's JIT supply chains (Faria & Nunes, 2012) requires focus to be put towards reaching the targets for the running-in instead of spending time on resolving PD, but the results suggests that most companies neither fully achieves the goals according to plan, nor manage to avoid an increase of PD.

On the positive note however, a comparison of the results from both surveys indicates an increase in both the satisfaction regarding how experiences from PD during running-in have been documented, as well as whether these experiences have been taken are of in improvement work in a satisfactory way. In detail, 21 out of 57 was to a certain extent or absolutely satisfied with how PD had been documented in the previous survey, compared to 45 out of 76 in this survey. In addition, 27 out of 57 respondents in the previous survey was satisfied with how the experiences had been taken care of in improvement work, compared to 50 out of 76 in this survey. These two factors are a prerequisite for permanent elimination of PD, and this positive trend can be a brick in developing more effective PDH.

Moreover, the results from the previous survey indicated that chronic PD that never gets attended, which could be a consequence of PD that occurred during running-in (Almgren, 1999), was prevalent in 69 out of 80 companies. The results from this survey implies that this issue is just as widespread today as it was 10 years ago since frequent PD in production was indicated by 64 out of 76 respondents. The difficulty with chronic PD is that they are hard to detect and can often be seen the natural state of the process (Ljungberg, 1998), and it is in fact the chronic PD that causes low utilization of equipment (Jonsson & Lesshammar, 1999b), Despite that many authors strongly advocates to address PD during the design phase (Almgren 1999; Bellgran & Säftsten, 2009; Jonson, 1999a; Tsang et al, 1999; Ylipää, 2000), most companies seem to struggle with PDH during running-in and in general achieving disturbance-free production conditions. The lack of development towards a reduction of both PD during running-in and chronic PD in production, in combination with the fact that consequences of failures are steadily increasing as an effect of more streamline production processes (Ericsson, 1997) indicates a definitive improvement potential for more effective PDH and maintenance in Swedish industry. As pointed out by Nakajima (1998) and Ericsson (1997), the main reason for the occurrence of PD is lack of proper maintenance, and Ericsson (1997) stresses that the most important factor that determines the magnitude of these losses are in fact how much emphasis that is put on minimizing PD. A reduction of PD does not only enable increased production efficiency, but also promotes a safer workplace since PD can result in direct accident risk and reduced safety for maintenance operators (Toulouse, 2002).

5.1.4 Performance measures

Regarding measurements in production and calculation of performance metrics, the results in this survey show that a majority of the companies, 54 out of 76 to be precise, are measuring and registering all stoppages in production, including minor stoppages. Identifying the stoppages through measurements is naturally a prerequisite to be able to establish magnitude of the losses and calculate production efficiency, but regular measurements of cycle time or production speed is required to identify minor losses (Ljungberg, 1998). The results in this survey show however that continuous measurement of cycle time is not employed to the same extent at the recording of stoppages in production, as only 42 out of 74 respondents indicated this. This yet again goes in line with Ljungberg's (1998) conclusion that cycle time losses and minor stoppages are not emphasised to the same extent as breakdowns and other downtime losses, despite that both minor stoppages and reduced speed or cycle time is a defined as losses in TPM. The data furthermore shows that continuous production companies and companies with >500 employees are especially prone to measure all stoppages, which as previously discussed most likely is a result of that the consequences of stoppages in such terms as cost and deliverability are higher.

In TPM, the purpose of OEE is to identify the losses from PD in terms of availability, performance rate and quality (Nakajima, 1998), but the results in this survey shows that only half of the respondents, i.e. 38 out of 75, claim that OEE is to a relatively high or very high degree calculated at their company. The same goes for calculation of TA, which is indicated by 39 out of 76 respondents. It is however shown that continuous production companies calculate both OEE and TA to a higher degree than discrete manufacturing companies. An argument for having a structured approach like OEE to measure and calculate the magnitude of PD losses is that ad-hoc measurements of downtime often neither shows an appropriate nor comprehensive picture of the losses (Ljungberg, 1998). An unstructured approach to measurements of downtime is probably especially deceiving in continuous production companies since the complexity of the production process is in general higher and stoppages are much harder to visually detect, which could explain the higher use of performance measured in these companies. However, authors also direct criticism towards OEE as a measure due to large data collecting requirements (Ljungberg 19998), that can cause unmotivated employees (Jonsson & Lesshammar, 1999b), that it aggregates so much and is hard to act upon, and is in most cases inappropriate for benchmarking (Liker, 2014). This displays that there are several potential drawbacks with OEE that could be the reasons for its low use by many companies in this survey.

The real value of OEE is if it is applied in some context of operational improvement, and the results in this survey shows that it is most commonly used for development and follow-up of KPIs in production, to identify critical equipment such as bottlenecks, to identify and direct improvement work as well as a way of monitoring and controlling processes and equipment. The results indicate however that using OEE for internal or external benchmarking as suggested by Jonsson & Lesshammar (1999b) is uncommon, which supports Liker's (2014) clarification that OEE is relative to a baseline for specific equipment and thus disabled from being used for benchmarking against other types of machines or processes. The results moreover show that primarily larger companies are using OEE in relation to KPI's, which could indicate that smaller companies in general have a less structured approach to follow-up of production performance.

The low usage of OEE in general, and for benchmarking purposes in particular, indicate a need for more structured approaches to measuring maintenance performance as suggested by Van Hoorenbeek & Pintelton (2014). The benefits of such a system could overcome the drawbacks of the OEE figure and enable an approach to measuring maintenance performance that is aligned with the corporate strategy, allowing for a company-wide integration of maintenance as stressed by Jonsson, (1999a). In addition, such a system can in contrast to OEE be used for benchmarking and thus enables a clear link for maintenance performance between departments, plants and even business sectors (Van Hoorenbeek & Pintelton, 2014). This could enable companies to directly measure themselves against competitors and find incentives for improved maintenance and prevent unnecessary resources to be spent on calculating OEE figures in isolation on the production floor.

5.1.5 PDH and maintenance in the organization

Formulation of maintenance goals and planning of maintenance activities are absolutely or to a certain extent synchronized with production in most companies, as indicated by 59 out of 76 respondents in this survey. This co-operative structure between the maintenance and the production department is for example emphasised in TPM and Lean Maintenance as a prerequisite for effective maintenance operations (Nakajima, 1988; Smith & Hawkins, 2004), and these results supports Jonsson's (1999a) observation that a company-wide integration of maintenance has been emphasised during the past decades.

Moreover, the results in this survey also indicated that a majority of the respondents, i.e. 56 out of 76, are absolutely or to a certain extent satisfied with how PD are handled and prioritized by management. If compared to the results in the previous survey, where 47 out of 79 was satisfied in this regard, one can see a trend towards larger dedication to PD by management. This involvement from top management is included in the strict definition of the 5 steps towards TPM (Nakajima, 1998) and is an absolute necessity for improved PDH as these people are primarily in charge of distributing the available resources for improvement work. In fact, it is in countless of modern literature strongly stressed that practically all improvement projects and change initiatives are doomed before they are even launched unless top management show their complete and utter support and belief.

Yet again, the respondents who represent continuous production companies are identified to be both more satisfied with how PD are handled by management and to the extent maintenance is synchronized with production, shedding further light on the tendency that maintenance is more evolved in this type of industry.

The same high level of satisfaction was however not indicated in this survey regarding several other factors of PDH and improvement work. 49 out of 76 respondents stated to be to a certain extent or absolutely satisfied with how experienced from PD are documented, and 40 out of 76 with how these experiences are tied back to development departments. On the positive note, the level of satisfaction seem to have increased since the previous survey, where 45 and 28 out of 80 was satisfied with documentation of PD and the feedback of PD to development respectively. A prerequisite for being able to eliminate PD during the design phase and reduce the start-up problems, ramp-up time and number of PD during operation (Bellgran & Säfsten, 2009) is naturally that the experiences are properly documented and made available for the people in the development department. A possible explanation to the particularly increased satisfaction of tying back PD experiences to development departments could be that this type of development work has in general become more prioritized. However, this trend would mean that at least the basic conditions to enable PD to be addressed during the design phase seem to have improved. However, the fact that increased PD during running-in is still a major issue questions whether these experiences are in fact utilized in the work towards elimination of PD during the development phase of new products, process or equipment.

A small positive trend can also be found regarding the satisfaction of improvement teams, which actually follows the results in the previous survey that showed a strong future belief in improvements teams for PDH. The data reported in Ylipää & Harlin (2007) showed that 36 out of 72 respondents was scarcely or not at all satisfied with improvements teams, and only 3 was absolutely satisfied. The results in this survey indicate however that fewer respondents, 26 out of 76, are scarcely or not at all satisfied, but still only 6 are absolutely satisfied. Although fewer respondents seem to be dissatisfied, the fact remains that very few are absolutely satisfied. In addition, the production people are in this survey identified to be more satisfied with improvement teams compared to maintenance people. Despite that these small group activities to promote improved maintenance are absolutely fundamental in TPM, RCM and Lean Maintenance principles, these results highlight that there are still many obstacles to overcome in order to achieve well-functioning improvement teams with the involvement of maintenance representatives in Swedish industry.

Directly connected to the functioning of the improvement teams are how well completed improvement activities are being followed up, and the results in this survey correspondingly shows that very few respondents are absolutely satisfied with the follow-up of improvements. In detail, 40 out of 76 respondents are to a certain extent satisfied, and merely 6 are absolutely satisfied. In TPM, the small improvement teams are not just the engine in the PDH work, but also a forum for analysis, problem-solving, learning and competence development (Ylipää, 2000). If completed improvement activities are not followed up, a large part of the opportunities for learning goes to waste. In fact, it is not always the actual practical benefits of the implemented improvement that is the real value, it is instead the gained knowledge, the practice of problem-solving skills and a step towards continuous organizational learning. These intangible effects can easily remain untapped if implemented improvement work is not evaluated and reflected upon.

A prerequisite for effective PDH is naturally that the people involved have adequate education and knowledge about the subject area of PD. The results however indicate that 38 out of 76 respondents are to some extent satisfied with how education and competence development regarding PD works, and 6 are absolutely satisfied. This indicates a need for an in general increase of knowledge and education of maintenance, which could possibly be enabled through a stronger collaboration between academia and industry.

5.1.6 Structure of maintenance operations

A definitive improvement potential is found regarding the ratio of corrective maintenance and PM. Out of all the 76 companies in this survey, two thirds indicated to have less than 50 percent PM, and merely 21 stated to have more than 50 percent PM. However, continuous production companies were shown to in general have slightly larger amount of PM, but the fact remains that the majority of all maintenance activities are carried out as corrective maintenance. In contexts of purely random breakdowns and low maintenance costs, corrective maintenance might be the most appropriate strategy (Jonsson, 1999a). However, as the results in this survey also show that most respondents are experiencing re-occurring chronic PD and report high estimated cost of stoppages, most companies seem to have a production environment that does not call for high amounts of corrective maintenance. But even more important is the fact that corrective maintenance does not only result in higher maintenance costs and decreased availability (Mobley, 2004) but it is also a severe safety issue as it is the situation where most accidents occur to maintenance operators (EU-OSHA, 2010). The results in this survey thus indicate that a shift towards increased PM and reduced corrective maintenance is an urgent issue that needs to be addressed in order to achieve more effective, efficient and safer maintenance in Swedish industry.

It is not easy to transform ones entire approach to maintenance operations without clear principles, guidelines and implementing instructions. This is where the maintenance concepts like TPM and RCM comes to play. The results do however indicate that few companies are to a high degree following the principles and work practices preached in these concepts. In detail, 30 companies work with TPM to a high or very high degree, and merely 19 with RCM. Moreover, 32 companies state to be employing work practices and techniques according to the CBM approach. A large improvement potential in increasing the popularisation these maintenance concepts in Swedish industry can thus be identified. This yet again calls for closer collaboration between the industry and the academic world since the high level of education and knowledge of the concepts can be found in academia, whilst the value of putting them to practice is naturally at the shop floors in companies.

The data also shows that larger companies are to a much greater extent working with these concepts. This is likely an effect of both having a much more defined and developed maintenance department, but also more available resources for investing in the development of maintenance operations. On the other hand, one can argue that characteristics such as the closer communication and a flatter organization found in smaller companies can enhance the possibility to achieve high involvement and company-wide integration of maintenance. In addition, a transformation towards TPM can also be achieved with little resources as many of the principles is based on simple and cheap solutions such as operator maintenance and continuous improvements through small team activities (Nakajima, 1998). Nevertheless, a necessity for long-term success with any maintenance concept, regardless of company size, is yet again the full support from top management and the stipulation of a clear maintenance strategy (Nakajima, 1998; Ylipää, 2000).

A deeper look into the application of work practices emphasised in the various maintenance concepts indicated a large improvement potential in utilizing the fundamental TPM feature of autonomous operator maintenance. In detail, 22 respondents indicated that operator maintenance is utilized to a relatively high degree in their company, and 9 stated it to a very high degree. There are likely many and varied social aspects to overcome in order to develop more flexible shop floor employees where the work content includes both production and maintenance tasks. A reason for the opposition amongst production operators to carry out maintenance could be due to the long tradition of viewing operators to be responsible for running the system, and maintenance to be responsible for keeping up the availability of the machinery (Ylipää, 2000). This unfortunately also prevents companies to utilize cheap and simple predictive techniques such as visual inspection or oil sample testing carried out by operators (Alsyouf, 2007). Instead the results in this survey show that many companies hire external personnel to carry out maintenance, indicated to a relatively high or very high degree by 41 out of 76 respondents. Especially continuous production companies are found to utilize external personnel, but this is likely an effect of that major overhaul and maintenance of advanced equipment found in these industries often require specially trained repairers. Nevertheless, one cannot deny the unexploited potential of more in-house autonomous operator maintenance.

The results in this survey did however imply that production operators are to a large extent involved in improvement teams, indicated to a relatively high or very high degree by 57 out of 76 respondents. However, having maintenance personnel involved in improvement teams is slightly less common, and it is rare that production and maintenance operators collaborate to plan and carry out maintenance. These findings combined with the results that indicated low satisfaction with how the teams are working, signals a definitive improvement potential for small-group continuous improvement activities in a maintenance context in Swedish industry. Not only can cross-trained teams with maintenance representatives reduce PD, improve overall production performance and achieve much more efficient maintenance (Jonsson, 1999a; Smith & Hawkins, 2004), but striving for cross-training of maintenance and production operators and applying a team-based approach to maintenance can also build a base for a learning organization (Smith & Hawkins, 2004).

These findings also impose a dilemma for the gap between the situation in top management and what actually happens on the shop floor. As discussed, the results in this survey show that most respondents (who are primarily representing an expert view from a high management level) consider maintenance to be synchronized with production, but there are fairly low level of collaboration between maintenance and production on the shop floor. This situation call for more holistic approaches to measurements of maintenance performance that can concretize top level maintenance objectives to an operative level and make maintenance more prioritized throughout the entire organization (Van Hoorenbeek & Pintelton, 2014).

Looking closer into work methods and techniques found in RCM and CBM, the results indicate that bottleneck analysis, CM and criticality assessment is employed to a fairly low degree. CM is stated to be used to a relatively high or very degree by 31 out of 76 respondents and also found to be more common in both larger and continuous production companies. A reason for this could be that CM is assumed to only consist of techniques such as vibration or thermography analysis that require expensive and advanced equipment to be effective. However, as pointed out by Alsyouf (2007) and Idhammar (1992), one of the most profitable applications of CM techniques is to utilize cheap and simple methods such as visual inspection, oil samples or to have operator use their human senses to monitor equipment and prevent problems by lubrication or routine cleaning.

To find bottlenecks in production means to find the equipment that strangles the production rate and limits capacity. Proper maintenance of the bottlenecks is of extreme importance since disturbances on this equipment will affect the entire production flow.

In this survey, 43 out of 76 respondents indicated that bottleneck analysis is performed to a relatively high or very high degree at their company. A way of utilizing the bottleneck analysis to ensure adequate maintenance is to incorporate it with the establishment of criticality assessment of equipment. Criticality assessment quantifies how important an item or system function is in relation to production, and the purpose of establishing the criticality levels is to schedule maintenance based on the equipment with the highest criticality (Smith & Hawkins, 2004). In this survey, only 27 out of 76 respondents indicated that their company established criticality levels to a relatively high or very high degree. An effect of not knowing the criticality of the equipment is that the *preservation of the intended function* in not put in focus and all functional failures are treated equally from a maintenance perspective (Hinchcliff & Smith, 2003).

Moreover, the results in this survey also show that criticality levels of equipment are seldom updated. An issue with this is that in today's manufacturing environment characterized by both tightly coupled flows and frequent changes, it is not only the production itself that is dynamic, but also the critically of the equipment. For example, as bottlenecks are resolved and capacity is freed up, another part of the production process becomes the bottleneck. This means that the equipment that is most critical from a maintenance perspective has changed, showcasing the fact that that criticality assessment of equipment can easily present a deceiving view unless a dynamic approach to updating them is also employed. This survey also covered on what basis criticality levels are established, and the results indicated that ABC-classification is the most commonly applied method, indicating an improvement potential for developing and popularizing more dynamic approaches to criticality assessment.

5.1.7 Risk assessment

The questionnaire also surveyed the use of various tools for risk identification and reliability analysis. The results showed that RCA is by far the most frequently utilized tool as indicated by 55 out of 76 respondents, followed by Fishbone diagrams as stated by 40 respondents. All the other 7 tools were found to be utilized to a fairly low degree, and several was almost not used at all. Furthermore, as Fishbone diagrams can be in incorporated in RCA to construct the cause chain and identify the possible root causes, one can definitely state that finding the underlying reasons to failures or incidents is what the companies in this survey are primarily focusing on.

Moreover, the results in this survey indicate that risk assessment and reliability software is used to a low degree in the maintenance department. In fact, the three suggested alternatives Relex, Reliasoft, or @Risk, are not used by any of the companies in this survey. Although several companies use other types of software, they did in fact refer to their maintenance planning software, which cannot be equated to the risk and reliability analysis functions found in Relex, Reliasoft, or @Risk. Larger companies are furthermore identified to use both tools and software to a higher degree, which is not surprising since some of them require investment in form of specific training and education, and the licensing of the software must naturally be paid for. However, many of the tools are easy to use and do not require more equipment than pen and paper, which suggest that other factors such as lack of time or insufficient education to conduct the analysis is the constraining factor. This could in turn be due to the low status and underdeveloped situation of maintenance in Swedish industry (Jonsson, 1999a). Furthermore, Strömgren & Andersson's (2010) hypothesis that tools such as risk analysis and risk inventoried can be of great value, is supported by the results in this survey, which shows that the companies that do in fact use the tools and software seem to be satisfied with how they work. This should be seen by other companies as an incentive to explore these tools further.

Since RCA is a tool that aims at isolating the facts that surrounds an event or a failure that has already occurred (Mobley, 1999), it is a reactive tool by nature. On the other hand, tools such as HAZOP and What-if, and software like Relex or Reliasoft, are instead proactive by nature and intended to identify possible risks, hazards or causes for failure prior to that the event has occurred. Being able to identify risks and eliminate them before they lead to failures or accidents naturally means that extremely costly failures or accidents can be avoided, easily overshadowing the investment cost for starting to use these tools and software.

The proactive tools are especially valuable for identifying safety hazards. Since injuries to employees cannot be tolerated in any scenario, companies cannot wait until an accident has occurred in order to analyse the possible root causes. The results in this survey however indicate that few companies are conducting JSA in order to improve the safety of maintenance operations. In fact, only 4 respondents indicated that JSA is to a very high degree performed for corrective maintenance, and 6 stated that it is to a very high degree done for PM. Strömgren & Andersson (2010) observed that safety management tools are put to broad use amongst Swedish municipalities. However, the results in this survey indicate that these tools are not put to the extensive use by maintenance departments in industry.

Moreover, although S.A.S.A (2007) propose that the reduction in severity of work place accidents in Sweden is a result of increased safety awareness and improved work with safety, the results in this survey indicate that there are still room for major improvement. The low use of proactive tools and JSA show a particularly large potential in increasing the use of structured analysis methods for improving the safety conditions of maintenance operators. Putting it all together, the many and varied hazards that maintenance operators are exposed to (EU-OSHA, 2010), in combination with poor risk assessment (Lind & Nenonen, 2008) and low use of analysis tools stresses an urgent need for continued work towards increased safety awareness and improved work with safety in Swedish industry.

5.1.8 Reliability engineering

In addition to low use of risk assessment tools, the results in this survey also indicate a large improvement potential for employing reliability engineers in the maintenance department. The most common work tasks for these types of engineers today seem to be development and improvement to PM activities, risk analysis and RCA analysis. However, only 19 respondents indicated that they absolutely have engineers who does RCA analysis or develops and improves PM, and 17 absolutely have people doing risk analysis. In addition, the results indicate that these types of engineers is primarily found in continuous production companies and companies with >500 employees, suggesting that a certain level of production complexity or company maturity is required before reliability engineers becomes a viable investment.

The fifth pillar of TPM, *"Manage equipment in order to prevent maintenance"*, is according to Wireman (2000) often neglected. By the use of Maintenance Prevention or EEM, the amount of maintenance required can be influenced during the design phase, resulting in reduced overall life-cycle cost of the equipment and increased profitability. The results in this survey supports Wireman's (2000) conclusion that this pillar is overlooked, shown through that only 6 respondents indicated that their company absolutely has a structured method like EEM or Maintenance prevention to address reliability and maintainability during the design phase. In addition, only 5 respondents indicated that they absolutely have reliability engineers that work with improving maintainability and reliability during the design phase. This related to the re-occurring discussion regarding safety since not addressing maintainability of equipment during the design phase imposes an increased safety risk throughout the life-cycle of the machinery (EU-OSHA, 2010; Lind & Nenonen, 2008).

Moreover, the principle of Maintenance Prevention is based on data analysis to identify root causes, failure frequency and failure modes (Wireman, 2000). The results in this survey show that only 6 and 4 respondents indicated that they absolutely have engineers doing failure mode and failure frequency analysis. This implies that very few companies meet the prerequisite to even be able to work effectively with Maintenance Prevention, contributing to the evidence for that this TPM pillar is in fact neglected.

Similarly, only 5 respondents claimed that their company absolutely have reliability engineers performing LCC analysis, indicating an improvement potential in developing a more long-term perspective on maintenance. LCC can be a way of overcoming short-sighted mind-sets and instead realize that even though a certain alternative displays increased initial cost, it can lead to dramatic reduction in operation and maintenance seen over the entire life-cycle (Dell'isosa & Kirk, 2003).

Faria & Nunes (2012) argues that systematic reliability analysis is neglected during the design phase due to absence of ground engineering tools and methodologies, but the literature research conducted in this thesis indicated that there are in fact a large number of available tools and software to perform this type of analysis. However, the low use of tools and software, in combination with that few reliability engineers are conducting failure analysis or addresses maintainability and reliability during the design phase, supports the view that reliability analysis is often ignored at an early stage. This naturally raises the questions whether industrial companies are unaware of the availability of tools and software, or if there are other counteracting factors that prevent them to be utilized. This calls for further research in order to assess what factors that counteracts and prevents companies from either using tools and software, or employing dedicated reliability engineers to carry out this type of work.

5.1.9 Lean Maintenance

The results in this survey show that working with Lean principles is much more common in production than in maintenance, indicated by that 36 out of 76 respondents claim that their company are working with Lean Production to a relatively high or very high degree, whilst only 19 are working with Lean Maintenance to a relatively high or very high degree. This indicates that there a gap between applying Lean in production and maintenance, and a possible missing link when it comes to also fundamentally change the maintenance operations during a transformation towards a Lean production system (Baluch et al, 2012; Moayed & Shell, 2009). However, Moayed & Shell (2009) describes that changing from a non-Lean to a Lean production system is a matter of transforming the maintenance from unplanned to planned, then to preventive maintenance, and eventually TPM (2009). This could possibly explaining the lag between Lean in production and maintenance due to the fact that the maintenance function is often underdeveloped and has low status in the average Swedish manufacturing firm (Jonsson, 1999).

The case implementation conducted by Shamsuddin et al (2005) showed that the addition of 5S and ecology oriented manufacturing to a TPM program can result in an increase of capacity and a reduction of capital cost. This implies that whether or not a complete transformation towards Lean Maintenance is pursued, the classic Lean tools applied in a maintenance context offer plenty of effective solutions for improved maintenance. Furthermore, Idhammar (2014) describes that applying a variety of the Lean tools in a maintenance context can result in such effects as reduced over-maintenance, waste-reduction in maintenance activities and a 10-20% reduction in inventory cost without sacrificing reliability. In addition, several of the tools promote operator involvement in improvement activities, which are an important feature of the PDH work emphasized in TPM (Nakajima, 1998).

However, the results in this survey show that the only two approaches that are widely employed is that of daily morning meetings for maintenance personnel and scheduling of work orders based on priority. In detail, morning meetings is indicated to be utilized to a relatively high or very high degree by 60 out of 75 respondents, and priority-based maintenance scheduling by 51 respondents. Thereafter, 5S in maintenance areas and visualization of maintenance work orders is claimed to be utilized to a high degree by approximately half the respondents. Standardization of spare parts and maintenance tools, inventory reduction of maintenance storage areas and standardized work for maintenance operators is used to a high degree according to 23-31 respondents respectively, but Andon signals to initiate corrective maintenance, Poka-Yoke to prevent maintenance errors and VSM to map maintenance activities is almost not used at all. Idhammar (2014a) describes that applying a variety of these tools can result in such effects as reduced over-maintenance, waste-reduction in maintenance activities and a 10-20% reduction in inventory cost without sacrificing reliability. In addition, several of the tools promote operator involvement in improvement activities, which is in previous discussion clearly established as highly valuable. In particular, Ericsson (1997) suggests that visualization systems are in fact one of the most important tools for minimizing PD losses. Mapping of the production flow using VSM is often reported to result in tremendous amount of waste reduction, freed up capital and increased production performance, and this could definitely be a useful tool to clearly visualize the improvement potential in maintenance activities.

The results also indicate that both Lean Maintenance in general, as well as Lean Maintenance tools, is almost exclusively utilized by large companies, indicating that a certain level of maturity has to be met before companies starts to explore the possibilities of Lean Maintenance. This follows Baluch et al's (2012) notion that the fundamental elements of Lean, and TPM in particular, must be in place before approaches such as specific tools can be applied. Nonetheless, there is still a large untapped potential for Lean Maintenance in Swedish industry.

5.1.10 In-depth view of TPM and Lean Maintenance companies

If a company is claiming to be working to a high degree with TPM or Lean Maintenance, one could expect them to not only apply the principles, but also be able to display that they do in fact have more developed and efficient maintenance operations. Bergman & Klefsjö (2010) explains that The Swedish Institute for Quality (ISQ) has developed an assessment tool to evaluate the characteristics of successful organizations. The assessment was originally based on the three criteria *Approach, Deployment*, and *Results. Approach* refers to *"how?"*, deployment describes *"to what extent?"*, and results are often described as *"trends and levels".* The *Approach* does in this case mean the principles of the TPM or Lean Maintenance concepts, and the *Deployment* and *Results* criteria can thus be used in order to assess the TPM and Lean Maintenance companies.

The results in this survey show that the respondents representing TPM companies are especially experiencing that maintenance is synchronized with production and that PD are prioritized by management, as well as have a fairly high degree of production and maintenance operators involved in improvement teams. This goes in line with the TPM definition of a co-operative structure between production and maintenance, involving all staff members from top management to shop floor workers, and promote improvement work though small-group activities (Nakajima, 1988).

However, there are still several aspects of the TPM concept that are not being fully met. The absolutely fundamental pillar of operator maintenance is surprisingly not utilized to a high level in the TPM companies. In addition, the emphasised approach of having a cross-trained and team-based approach to maintenance seems to be lacking since the results indicate that collaboration between production and maintenance operators is not prevalent to a large degree. This connects back to the previous discussion regarding whether there are social factors or a strong tradition of the views upon divided responsibilities of production and maintenance that prevents companies from integrating the scope and the work content of production and maintenance operators.

Moreover, one third of the TPM companies do not calculate OEE to a very high degree, and very few absolutely have a systematic method for EEM or Maintenance Prevention. If OEE is not calculated by the companies who work with a concept that is built around that type of performance measures, it is very likely that the previously discussed drawbacks of OEE calls for new and improved approaches to measurements of maintenance performance. In addiction, the fact that even the TPM companies neglect the fifth pillar of TPM sheds further light on the difficulty with collecting accurate equipment data in order to reduce or eliminate future maintenance requirement during the design phase (Wireman, 2000).

Similarly, the Lean Maintenance companies are utilizing the tools and work practices preached in the concept larger degree than average, but there are still room for major improvements. To effectively combine TPM and RCM into Lean Maintenance, Smith & Hawkins (2004) describes how to integrate criticality assessment with priority-based scheduling of maintenance work tasks. The results in this survey show that 15 out of the 19 Lean Maintenance companies schedule their maintenance work order based on priority, but merely 5 are to a high degree establishing criticality levels of equipment, and only 3 are continuously updating their criticality levels. This gap between the extent the Lean Maintenance companies are establishing and updating criticality levels and to what degree maintenance tasks are scheduled based on priority indicate that these companies are often prioritizing the execution of work orders based on other criteria than the criticality of equipment.

Operating according the demands on short lead times and low production costs found in JIT supply chains increases the sensitivity of the production system and the severity of consequences (Faria & Nunes, 2012), and due to the high impact on reliability that comes with a Lean production system, Reliability Engineering is emphasised in Lean Maintenance (Smith & Hawkins, 2004). In addition, to support a maintenance department operating in a JIT manner, reliability engineering teams performing failure analysis is emphasized by Baluch et al (2012). Positively, the results indicate that the Lean Maintenance companies to a fairly high degree have reliability engineers in the maintenance department who develops and improves PM, does RCA and risk analysis and considered improves to maintainability and reliability during the design phase. However, failure mode and failure frequency analysis as well as LCC is performed to a much lower extent.

Moreover, the results in this survey show that several of the 11 major TPM losses as described by Smith & Hawkins (2004) are in fact not registered to a high degree in the Lean Maintenance companies. The PD factor *"set-up/resetting"* is classified as PD in 100 percent of the responding Lean Maintenance companies, but only registered as PD in 56 percent of them. In addition, the results also indicate that working with set-up reduction is fairly uncommon even in the Lean Maintenance companies. This relates to that companies that are truly successful with Lean Production is a logical result of effective PDH (Ericsson, 2014), and a large part of the explanation for Toyota's well-functioning equipment is because of rapid responses to breakdowns (Liker, 2014), indicating a clear improvement potential for Swedish companies aiming to achieve a Lean production systems.

In theory, it is possible that the absence of simultaneous change of the maintenance operations during a Lean transformation, and in general inadequate PDH and maintenance, is a major contributing factor to the high rate of failures of Lean implementations (Pay, 2008).

This discussion chapter highlights how the *Deployment* criteria of the ISQ assessment tool is not fully met by neither the TPM nor the Lean Maintenance companies. Although these companies utilize most of the work practices and principles to a higher degree than average, several of the fundamental building blocks of the concepts are not fulfilled, and several of the emphasised tools and work practices are scarcely applied.

5.1.11 Performance of the TPM and Lean Maintenance companies

The in-depth view of the performance of TPM and Lean Maintenance companies in terms of amount of PM, PD during running-in, frequent PD and safety indicates that these companies are not performing considerably better than the average in this survey. The fact that even these companies are to a very high degree experiencing PD in various forms shows that this is an issue that is very difficult to tackle. Whether nor this is a result from not truly applying the principles of the concepts as previously discussed is hard to tell, but it is clear that even the companies that can be considered to be in the forefront of maintenance development are having issues achieving effective PDH.

The results also indicate that they are only marginally performing JSA to a higher extent, and are not registering *"incidents/near misses"* as PD to larger degree in average, displaying a large improvement potential for improved work with safety also in this group of companies.

Principally all the TPM and Lean Maintenance companies are found to use RCA, and they are performing FMEA to a slightly larger degree than average. They are however neither using these tools to a much larger extent than the average of the survey, nor to a very large degree in general.

If yet again referring to the ISQ assessment tool, this discussion indicates that neither the *Results* criteria seems to be fulfilled by the TPM or Lean Maintenance companies. They are in some aspects utilizing the principles of the concepts to a larger degree, but are on most levels of comparison not performing significantly better than the average.

5.1.12 Summarizing results discussion

According the PDH model by Ylipää (2000), PD and PPD are to be handled before, during, and after a PD has occurred. The goal of sustainable PDH is to preserve the system's ideal state, which is possible if PPD are controlled and if PD symptoms are detected, diagnosed and actions are taken, prior to the PD occurs. In order to reach a long-term reduction of PD, improvement efforts should focus on the underlying reasons instead of merely trying to address the symptoms (Ylipää, 2000).

This results in this survey has shown a positive indication that RCA, both as a tool and analysis method, is widely employed. Root cause analysis in any form is highly effective and shifts the focus from the symptom to the underlying reasons for the occurrence of disturbances. However, this study has also shown an enormous improvement potential when it comes to the use of proactive tools that can allow for PD symptoms to be controlled, and PPD to be identified, prior to the PD occurs.

Ericsson (1997) moreover explains that when PD occurs, it is most commonly due to a series of events that eventually results in a visual disturbance. This study has highlighted the possible connection between PD during-running in and chronic PD in production, further stressing the need for addressing PD at an early stage. In addition, it has been shown that there is a low use of holistic and comprehensive approaches to risk and reliability analysis, and few reliability engineers are employed to conduct failure analysis in the companies in this survey. Such analytical tools have a large potential in improving the work towards preventing the occurrence of PD by detailed and accurate analysis of failure patterns. Moreover, considering the cost of maintenance throughout the entire life-cycle of equipment, as well as addressing maintainability and reliability during the design phase, has in this survey shown to be largely neglected.

This raises the question regarding to what extent people in decision-making positions are aware of the relationship between cost of changes and degrees of freedom during the life-cycle of equipment as described by Bellgran & Säfsten (2009). If more companies would fully embrace the fact that the largest possibility, to the lowest cost, to affect the final results is during the development phase, and that the cost of changes increases almost exponentially when they are carried out later on in the life-cycle, a more proactive approach to maintenance is much more likely to be employed.

Finally, several safety issues in relation to PD and maintenance operators has been discussed. On one end, there is a wide array of factors that contribute to that PD should be treated with greater concern regarding safety. PD are in itself a safety hazard, and the situation is aggravated by increased PD during running-in, high amounts of frequent PD, a trend towards production systems more sensitive to PD, and large amounts of corrective maintenance. On the other hand, the actions that are supposed to prevent PD from resulting in accidents are largely absent: inconsistent registration of *"incidents/near misses"* as PD, low use of risk assessment tools, neglecting maintainability and reliability during the design phase, and sporadic use of JSA to assess the safety of maintenance activities. This illustrates a situation where the aggravating factors clearly seem to outweigh the preventive actions, calling for an urgent need of more work with safety and a stronger emphasis on proactive, effective and efficient PDH.

The most important question to answer is *why* PDH and maintenance in so many aspects appears to be underdeveloped in Sweden, and that little improvement seem to have occurred during the past decade. There are naturally thousands of possible explanations and contributing factors to this scenario, but one of the major underlying reasons must be that the traditional perception of maintenance is still largely prevalent today; that maintenance is seen as a necessary evil without a clear connection to productivity and profitability. This is probably aggravated by the experiences from companies where maintenance is in fact viewed as an operating expense to be minimized, in which it actually decreases their competitiveness through reduced throughput, increased inventory and poor delivery performance (Patterson et al, 1996). So, in order to enable a future achievement of both sustainable production in general, and sustainable PDH in particular, a fundamental change in the perception of maintenance is required. Maintenance must be seen as an active provider to efficiency and profitability, not merely as a required but undesired organizational function that is overshadowed by production. This would also help change the traditional view of maintenance personnel being responsible for keeping up the availability of machinery whilst operators are responsible for running the system (Ylipää, 2000).

5.2 Methodology discussion

As described by Lauer et al (2013), pre-packaged survey tools have its limitations. This resulted in that some questions from the previous had to be slightly revised in order to be included in this questionnaire, which could influence the possibility to study these subjects in a strictly repeated manner.

Regarding the 21 PD factors, it is important to mention that this is not a complete list of factors, which can easily be seen through the diverging views regarding production losses in literature. However, in order to study this subject in a repeated manner, the same factors as used in Ylipää & Harlin (2007) were chosen, which in turn were derived from previous studies in combination with extensive literature studies. Unlike the previous survey, the questionnaire used in this study did in fact offer the possibility for the respondents to add further factors that they classified or registered as PD, which resulted in the detection of several other potential PD factors. This shows that the list of

PD factors can easily be extended beyond these the 21 factors used in this questionnaire, but they can still be seen as the key factors in the types of industries surveyed in this study.

The different PD factors can also have a diverging level of impact depending on the specific characteristics of the production processes in each company. Incorporating actual performance data in relation to the PD factors could aid in describing which of these factors that are in fact most critical to measure and direct improvement work towards. However, collecting detailed, comprehensive and relevant numerical data in a questionnaire is very difficult and involves large margins of error.

Moreover, a methodological flaw was detected regarding the questions concerning the use of software in the maintenance department. Instead of listing specific software, a much more comprehensive view could have been obtained if the respondents would have answered to what extent they used various types of software in the maintenance department (i.e. software for maintenance planning, risk assessment, reliability analysis etc.). This calls for further research regarding the extent to which software is used, as well as an assessment of the possible benefits of using software for maintenance purposes. It is also likely that other parts of the questionnaire can be a subject for this type of discussion, and some respondents did in fact comment that several questions was rather difficult to answer. More comprehensive and detailed pre-testing of the questionnaire would have helped in this regard, which unfortunately was a consequence of the limited time span of the thesis work.

The questionnaire was primarily designed around the use of Likert-scales, which to a certain extent results in subjective answers. Naturally, the perception of one individual cannot be equated with that of the entire organization. There can also be large differences between the perceived situation from a top management position and what actually happens on the shop floor. In addition, it is impossible to assess the honesty of the responses in a large-scale questionnaire, meaning that there is a possibility that what the respondents indicate does not actually reflect the reality at their company.

The high level of detail and wide array of subject areas in the questionnaire required the respondents to be specifically interested in order to participate in this rather demanding survey. In addition, the selection of respondents with an expert view from a high management level further affects what companies that are included in the survey. However, the high response rate from the selected participants indicate that there is in fact a possibility to use long and demanding questionnaires if the respondents have a vested interest in contributing. Undoubtedly, a shorter and simpler questionnaire in combination with including respondents from lower levels of the organization could have resulted in a much higher level of participation. This results in that the selected companies can not been seen as representative for all types of branches and industries, nor depicting a comprehensive view of Swedish industry. A survey with a much larger sample size and broader array of industries is required to make general conclusions on a countrywide basis, but this would require enormous amounts of resources if an equivalent level of detail to this survey is to be used.

This also relates to the exclusion of conducting statistical tests. By performing such tests, the strength of the correlation between variables could have been assessed and thus help in assessing the validity of the results. However, the actual benefits from proving the statistical significance of the correlations are still argued to be minor in the context of this survey. The only real benefit from validating the strength of correlations is if this can prove causation. In fact, it is of uttermost importance to stress that correlation does not equal causation. For this survey, it is in most cases not relevant to try to prove causation since there are enormous amounts of variables that affect the outcome. For example, suppose that the correlation between the use of a specific tool and the difference between industry types was to be proven statistically significant. This does not automatically mean that for instance *being* a company that operates in the process industry *causes* you to use this particular tool. This is instead dependent on such variables such as the specific characteristics of the production process, the level of education, interest from top management, available resources, etc.

However, these methodological weaknesses are in accordance with the purpose of this study. This survey has not been indented to assess any exact numbers or definitive answers, but primarily aimed at establishing a general picture of aspects concerning PDH and maintenance, and identify possible generalizations between various company-dependent characteristics.

6 Conclusions

In this section, the conclusions of the thesis are presented in form of answers to the stipulated research questions.

What factors are regarded as PD?

In this study, it has been shown that the factors that are to the greatest extent classified and registered as PD are concerning downtime losses, and especially equipment breakdowns or failures. Planned activities are instead regarded as PD to a lower extent. During the past decade, a trend towards increased registration of PD factors has been identified. There are however clearly contextual factors that influence the perception and the handling of PD, in this survey shown to be especially prevalent between discrete and continuous production companies and companies of different sizes.

How is PDH applied in industry?

Applying work practices according to well-known maintenance concepts such as TPM and RCM has shown a large improvement potential in this survey, especially that of operator maintenance, improvement teams, collaboration between production and maintenance operators on the shop floor, and using criticality assessment of equipment for maintenance planning.

Measurements and calculations of production performance is in this survey found to be fairly scarce, indicating a need for both more effective use of such figures as OEE and TA, but also more holistic approaches to measurements of maintenance performance that can translate and connect maintenance objectives throughout the organization and establish a clear maintenance strategy.

This study has also shown that running-in of new products, machines, lines or other equipment often results in an increase of PD, and that many are struggling with reaching the goals according to plan. The combination of these two can potentially result in large losses of profitability. If not both the symptoms and the underlying reasons of PD during running-in is resolved immediately, this can result in that the PD remain in production as unsolved and chronic disturbances, causing large reductions of the availability of equipment.

Furthermore, reliability engineers has been shown to be scarcely employed, indicating yet another large source of improvement potential, especially regarding detailed failure analysis for resolving PD, and analysis of maintenance aspects at an early stage, and from a long-term perspective.

In general, the current state of maintenance can be characterized as primarily reactive and rather underdeveloped, with an emphasis on resolving PD during, or after, an event has occurred. Moreover, this survey has shown a need for more PM, and presented support for the neglecting of maintenance aspects at an early stage, especially during the design and development phase.

A positive finding in this study is a tendency towards improved status of maintenance at top management level, in form of well-functioning synchronization between maintenance and production, and high level of prioritization of PD from management.

What risk assessment tools are used in relation to PDH?

This survey has shown that RCA is the most widely applicable tool and analysis method in relation to PDH. Thereafter, an enormous amount of untapped potential has been identified regarding the use of proactive tools that aims to identify possible risks, hazards and causes for failures prior them leading to an unwanted consequence.

To what extent is Lean Maintenance principles used?

Lean Maintenance as a concept has been adopted to a fairly low extent amongst the companies participating in this survey, and a gap between applying Lean principles in production and maintenance has been identified. In addition, several aspects of the concept such as the connection between criticality assessment and priority-based maintenance scheduling seem to be overlooked. Moreover, the application of specific Lean tools in a maintenance concept is utilized to a fairly low degree, yet again indicating a large source of untapped potential for more effective maintenance operations.

In addition to the findings in accordance to the stipulated research question, the importance of reliability in Lean production systems has been stressed, a more proactive approach to maintenance has been requested, and an urgent need a more sustainable and long-term perspective of PDH and maintenance has been highlighted. Moreover, a strong need for increased safety awareness and continuously improved work with safety has been identified in order to achieve a safer working environment for maintenance operators in Swedish industry.

As a final note, the hope is that this thesis can inspire companies to find incentives for investing in the development of more effective PDH, to urgently and drastically change the perception and status of maintenance within Swedish industry, and tirelessly work towards sustainable production in the future.

6.1 Suggestions for further research

Despite the extensive data analysis carried out in this study, there are in fact further subject areas and scenarios that would be of interest to investigate. In particular, no direct analytical comparison was made regarding the 36 companies who participated in both surveys. A separate analysis of only the responses from these companies would have been a way to directly display the development of PDH, maintenance, and the perception of PD during the past decade in a stricter longitudinal manner.

Moreover, the connection between PD, maintenance and quality has not been extensively addressed in this study. Quality has not only a direct impact on production efficiency due to scrap etc., but also a strong connection to maintenance and PDH. PD cannot only result in stoppages or increased cycle time, but also quality deviations of products. Events such as failures in machine tolerances or tool exchange problems can result in quality errors, and the detection of quality deviations can thus be a way of identifying the occurrence of PD. In this case, the gap in time between the detection of the quality deviation and the occurrence of the PD is of particular interest. In addition, inadequate maintenance also has an impact on product quality. Old and worn cutting tools can cause surface damages, and broken details such as chucks or drills can both result in quality errors but also larger machine failures.

On a final note, in order to capitalize on the improvement potential for PDH and maintenance indicated in this study, further research is required. Of particular interest would be to assess the direct effects of more extensive use of risk assessment and reliability tools and software, as well as applying the principles and work practices preached in the maintenance concepts.

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Appendix A

A full presentation of the results from the questionnaire is shown in this section, and the tables include all the data that the results section refers to. The tables are divided into the 6 different sections of the questionnaire, and each section of appendix displays the results from the various cross-tabulated groups. In Appendix, *"N/A"* refers to the number of missing or omitted answers of the question, and *"?"* refers to the answer alternative *"Do not know".*

Appendix A displays the overall results, Appendix B the cross-tabulation based on industry type, Appendix C based on company size, Appendix D based on production vs. maintenance, and Appendix E the in-depth view of TPM and Lean Maintenance companies.

Table 1 – Measurements and work practices

Measurements and work practices							
	Yes	No	?				
Have you at the company estimated the cost of stoppages in production?	43	26	7				
	< 10%	11-20%	21-30%	31-40%	41-50%	>50%	?
How much of the total amount of maintenance is carried out as preventive maintenance?	8	8	13	10	13	21	3
To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… regularly measure cycle-time in production?	18	24	16	8	0	8	2
… work with set-up reduction (e.g. using SMED)?	7	20	33	10	1	5	0
… perform JSA for corrective maintenance?	4	27	19	15	9	1	1
… perform JSA for preventive maintenance?	6	25	22	13	10	0	0
… have operators performing maintenance?	9	22	38	5	0	2	0
… have external personnel performing maintenance?	12	29	33	2	0	0	0
… have operators and repairers collaborate in the planning and execution of maintenance?	6	23	36	9	0	2	0
… have operators involved in improvement teams?	19	38	17	1	0	1	0
… have repairers involved in improvement teams?	16	29	22	5	2	2	0

Table 2 – Classification and registration of PD

Proposed PD factors	Classified as PD (n=76)					Registered as PD (n=76)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	73	2	97%	0	1	67	6	92%	0	3
Human error	63	9	88%	2	2	51	17	75%	7	1
Failure of peripheral, e.g. external transport system	63	8	89%	3	2	51	20	72%	3	2
Failure of software, in production equipment	69	3	96%	3	1	62	8	89%	4	2
Reprogramming	36	35	51%	4	1	32	35	48%	7	2
Planning error	58	16	78%	0	2	32	37	46%	4	3
Tool change	26	43	38%	2	5	27	39	41%	5	5
Time for changing/ refilling of material	34	35	49%	3	4	25	43	37%	4	4
Set-up/Resetting	36	36	50%	0	4	35	36	49%	1	4
Adjustment	49	21	70%	2	4	41	26	59%	4	2
Preventive maintenance	27	48	36%	0	1	36	36	50%	2	2
Cleaning	29	45	39%	0	2	33	38	46%	2	3
Work meeting	17	54	24%	2	3	19	51	27%	3	3
Pauses or breaks	17	56	23%	1	2	17	52	25%	4	3
Waiting time for incoming product / material	59	14	81%	1	2	45	25	64%	3	3
Subsequent stop in output flow from station / machine	57	14	80%	1	4	48	23	68%	2	3
Shortage of staff	57	17	77%	0	2	36	34	51%	3	3
Media error	70	3	96%	0	3	57	10	85%	4	5
Speed loss	55	13	81%	3	5	43	26	62%	3	4
Scrap or quality problems of the product	61	9	87%	2	4	55	15	79%	1	5
Incidents / near misses	51	22	70%	1	2	48	19	72%	6	3
μ:			**67%**					**59%**		

Table 3 – Performance measures and running-in

Performance measures and running-in							
To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… measure and register all stops in production? (including minor stoppages)	33	21	19	3	0	0	0
… calculate Technical Availability?	26	13	21	13	3	0	0
… calculate Overall Equipment Effectiveness?	26	12	19	17	2	0	0
To what extent is OEE used for…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… monitoring and control of production processes, machines, or other equipment?	17	15	25	12	3	4	0
… identification and development of improvement actions?	17	18	24	10	3	4	0
… identification of critical equipment? (e.g. bottlenecks)	15	21	21	11	3	5	0
… follow-up and development of KPI's in production?	18	21	18	12	3	4	0
… internal benchmarking? (e.g. between stations/machines)	6	17	28	16	3	6	0
… external benchmarking? (e.g. against other companies / targets)	5	13	29	21	4	4	0
During the latest running-in of a new product, machine, or line, do you consider that…	Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A
… you reached the goals for production cost, quality and volume according to plan?	6	33	20	5	6	6	0
… the running-in caused an increase of production disturbances?	15	40	7	6	4	4	0
… experiences from the running-in have been documented in a satisfactory way?	13	32	21	4	3	3	0
… experiences from the running-in have been taken care of in improvement work in a satisfactory way?	10	40	18	1	4	3	0

Table 4 – Organization

Organization							
In your company, do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… formulation of goals and planning of maintenance is synchronized with production?	25	34	14	0	2	1	0
… production disturbances are prioritized by management in a satisfactory way?	24	32	19	1	0	0	0
… education and competence development regarding production disturbances are working in a satisfactory way?	6	38	28	3	1	0	0
… documentation of production disturbances are working in a satisfactory way?	13	36	23	3	1	0	0
… improvement teams regarding production disturbances are working in a satisfactory way?	6	40	22	4	0	4	0
… the follow-up of completed improvement actions is working in a satisfactory way?	6	40	24	5	1	0	0
… there are frequent disturbances in production? (e.g. re-occurring disturbances that are not being resolved)	15	49	11	1	0	0	0
… experiences of production disturbances are tied back to development departments?	11	29	19	7	1	9	0
… you have a systematic method (e.g. EEM/Maintenance prevention) for improving maintainability and reliability during the design- and development phase of new production processes, machines, or other equipment?	6	21	29	15	4	1	0

Table 5 – Risk assessment tools and software, reliability engineers

Risk assessment tools and software, reliability engineers									
Which of the following tools are used by the maintenance department in your company?	What-if	RCA	HAZ-OP	FTA	ETA	LTA	Fish-bone diag-rams	VMEA	FMEA
Number of checked answers:	16	55	17	19	5	2	40	2	25
Which of the following software are used by the maintenance department in your company?	DES	@Risk	Relex	Relia-soft	RBWS	Other			
Number of checked answers:	1	0	0	0	1	37			
Do you consider that the use of these...	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A		
… tools are working in a satisfactory way?	3	32	7	1	5	24	4		
… software are working in a satisfactory way?	3	27	3	1	7	31	4		
Do your company have engineers in the maintenance department who work with…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A		
… RCA of stoppages, failures or other disturbances?	19	28	8	15	0	5	1		
… risk analysis and risk handling?	17	30	10	12	0	5	2		
… failure frequency analysis? (e.g. using Weibull plot)	4	13	17	30	1	6	5		
… failure mode analysis? (e.g. using FMEA)	6	18	21	19	2	7	3		
… Life Cycle Cost analysis? (LCC)	5	19	20	22	4	5	1		
… improving maintainability and reliability of processes, equipment or machines during the design phase?	5	41	8	14	1	6	1		
… developing and improving methods and work practices for preventive maintenance activities?	19	39	6	7	0	4	1		

Table 6 – Other software

Clarification of "Other" category of software:
"AM Underhåll" *(AM Maintenance)*
"API"
"API PRO"
"Aretics"
"ARPI"
"Axxos"
"Bi-Cycle RCM"
"Proprietary risk system"
"IDUS"
"IFS"
"IFS + ODIN + Excel"
"IFS UH System"
"None"
"None of these"
"Internal system"
"Movex"
"The binder"
"RBUS (RCM)"
"Rejus"
"SAP"
"SAP R3, P2 Production"
"Sologica"
"T7, SISTEMA, OBI"
"Tekla"
"TEKLA"
"Do not know"
"Do not know / I don't think we have it"
"We don't have any software for that yet"

Table 7 – Lean Maintenance

Lean Maintenance							
To what extent do you at the company work with…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… methods and work practices according to Total Productive Maintenance (TPM) ?	17	13	26	13	4	2	1
… Reliability-Centered Maintenance (RCM) ?	4	13	26	25	4	2	2
… Condition-Based Maintenance (CBM) ?	10	22	29	7	4	2	2
To what extent do you consider that…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… your company is working with Lean production?	13	23	26	14	0	0	0
… your company is working with Lean maintenance?	7	12	35	21	1	0	0
… you have knowledge about Lean maintenance?	9	33	23	11	0	0	0
To what extent do you at the company work with…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… Condition Monitoring of equipment?	8	23	31	11	0	2	0
… identification and analysis of bottlenecks in production?	13	30	25	6	0	2	0
… establishing criticality levels for maintenance of production processes, equipment or components?	7	20	26	16	6	1	0
… continuously updating the criticality levels of production processes, equipment or components?	6	15	27	22	5	1	0
… scheduling of maintenance work orders based on the priority of the maintenance activity?	16	35	15	4	2	3	1

Table 8 – Criticality assessment of equipment

Criticality assessment			
On which primary basis do you establish criticality levels of equipment?	No. of checked answers		No. of checked answers
Cost-based priority	5	At the point of purchase	4
ABC-classification	23	Other	9
Bottleneck analysis	7	Do not know	9
Operator influence	8	Not applicable	10
Missing answer	1		

Clarification of "Other" category:
"demand-controlled", "enterprise system", "cost of root cause category", "product mix", "similar to ABC but 1-5 classification where 5 is the highest", "reactor safety", "safety", "equipment with importance for nuclear safety", "RCM/FMECA",

Table 9 - Lean Maintenance tools

Lean Maintenance tools							
To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… 5S in maintenance areas (e.g. Inventory of parts and tools, workshop, office)?	17	25	23	9	0	2	0
… standardized work for maintenance operators?	4	19	43	7	1	2	0
… visualization of the scheduling and status of maintenance work orders (e.g. using boards for work cards, whiteboard, monitors)?	10	29	24	11	0	2	0
… automatic signals for initiation of corrective maintenance (Andon-signals, e.g. lamps or sound alarms during machine failures)?	8	9	19	32	0	8	9
… inventory reduction of maintenance material (e.g. spare parts, tools, consumables)?	6	22	31	11	1	4	1
… standardization of the range of components, spare parts, tools for maintenance?	2	29	29	12	1	3	0
… Value Stream Mapping for maintenance activities?	1	7	24	37	3	4	0
… daily morning meetings for maintenance personnel?	37	23	8	5	0	2	1
… error proofing of machines or equipment to prevent maintenance errors (Poka-Yoke)?	2	14	41	13	4	2	0

Table 10-13 – General information

Lean Maintenance	Yes	No	?	Total
Have you at the company discussed to start working with Lean Maintenance?	5	13	4	22

How long have you worked within your position?	
<1 year	4
2-3 years	8
4-5 years	8
6-10 years	13
11-15 years	12
16-20 years	13
>21 years	18

Industrial branches	**No. of respondents:**
Engineering industry	28
Automotive industry	6
Process industry	11
Food industry	8
Paper industry	4
Energy industry	3
Nuclear industry	2
Transport industry	1
Other	13
Clarification of "Other" category: *(each category represents one respondent)* Packaging, real estate, paint and coatings, graphical industry, infrastructure, power transmission, air filters, pulp industry, pulp process industry, medicine technology, carpentry, surface treatment, recycling	

How many employees do you have at the company?	**No. of companies:**
11-50 employees	9
51-100 employees	7
101-500 employees	37
501-1000 employees	6
1001-5000 employees	16
>5000 employees	1

Table 14-15 – General information

Capital turnover per year	No. of companies:
< 200 MSEK	11
201-500 MSEK	11
501-1000 MSEK	13
1001-5000 MSEK	12
5001-10000 MSEK	5
> 10000 MSEK	16
Missing answer	8

Which primary roles and responsibilities do you have?	No. of checked answers:
CEO/company-wide strategic level, management, planning etc.	24
Production management	19
Maintenance management	49
Production engineering	15
Maintenance engineering	19
Operative maintenance (e.g. service technician)	3
Construction	2
Preparation	5
Planning	10
Purchasing	3
Human resources	11
Marketing / sales	1

Note: A mistake was made regarding how this question was asked. Due to the fact that checkboxes was used, the respondents indicated several of the alternatives as a part of their roles and responsibilities. However, the responses was further analysed and then categorized into "maintenance", "production" or "maintenance / production" as described in the Methodology chapter.

Appendix B

In this section, the results based on the cross-tabulation of industry type (i.e. discrete manufacturing vs. continuous production) are presented.

Table 1-3 – Measurements and work practices

Measurements and work practices							
Have you at the company estimated the cost of stoppages in production?	Yes	No	?				
Discrete manufacturing companies	*25*	*20*	*7*				
Continuous production companies	**18**	**6**	**0**				
How much of the total amount of maintenance is carried out as preventive maintenance?	< 10%	11-20%	21-30%	31-40%	41-50%	>50%	?
Discrete manufacturing companies	*7*	*5*	*10*	*5*	*10*	*12*	*3*
Continuous production companies	**1**	**3**	**3**	**5**	**3**	**9**	**0**

To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… regularly measure cycle-time in production?							
Discrete manufacturing companies	*12*	*17*	*14*	*5*	*3*	*3*	*1*
Continuous production companies	**6**	**7**	**2**	**3**	**5**	**5**	**1**
… work with set-up reduction (e.g. using SMED)?							
Discrete manufacturing companies	*4*	*16*	*24*	*6*	*1*	*1*	*0*
Continuous production companies	**3**	**4**	**9**	**4**	**0**	**4**	**0**
… perform JSA for corrective maintenance?							
Discrete manufacturing companies	*4*	*17*	*11*	*11*	*7*	*1*	*1*
Continuous production companies	**0**	**10**	**8**	**4**	**2**	**0**	**0**
… perform JSA for preventive maintenance?							
Discrete manufacturing companies	*5*	*15*	*14*	*10*	*8*	*0*	*0*
Continuous production companies	**1**	**10**	**8**	**3**	**2**	**0**	**0**

To what extent do you at the company…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… have operators performing maintenance?							
Discrete manufacturing companies	*8*	*14*	*26*	*4*	*0*	*0*	*0*
Continuous production companies	**1**	**8**	**12**	**1**	**0**	**2**	**0**
… have external personnel performing maintenance?							
Discrete manufacturing companies	*6*	*18*	*26*	*2*	*0*	*0*	*0*
Continuous production companies	**6**	**11**	**7**	**0**	**0**	**0**	**0**
… have operators and repairers collaborate in the planning and execution of maintenance?							
Discrete manufacturing companies	*5*	*14*	*23*	*9*	*0*	*1*	*0*
Continuous production companies	**1**	**9**	**13**	**0**	**0**	**1**	**0**
… have operators involved in improvement teams?							
Discrete manufacturing companies	*14*	*27*	*11*	*0*	*0*	*0*	*0*
Continuous production companies	**5**	**11**	**6**	**1**	**0**	**1**	**0**
… have repairers involved in improvement teams?							
Discrete manufacturing companies	*12*	*20*	*13*	*4*	*2*	*1*	*0*
Continuous production companies	**4**	**9**	**9**	**1**	**0**	**1**	**0**

Table 4 – Classification and registration of PD in continuous production companies

Proposed PD factors	Classified as PD (n=24)					Registered as PD (n=24)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	21	2	91%	0	1	20	2	91%	0	2
Human error	18	3	86%	2	1	17	3	85%	3	1
Failure of peripheral, e.g. external transport system	19	2	90%	2	1	17	4	81%	2	1
Failure of software, in production equipment	21	1	95%	1	1	19	2	90%	2	1
Reprogramming	11	11	50%	1	1	10	11	45%	2	0
Planning error	23	0	100%	0	1	14	8	64%	1	1
Tool change	9	12	43%	1	2	9	12	43%	1	2
Time for changing/ refilling of material	10	10	50%	2	2	9	11	45%	2	2
Set-up/Resetting	12	10	55%	0	2	11	11	50%	0	2
Adjustment	15	7	68%	1	1	13	9	59%	1	1
Preventive maintenance	9	14	39%	0	1	10	13	43%	0	1
Cleaning	12	11	52%	0	1	14	9	61%	0	1
Work meeting	3	19	14%	1	1	4	18	18%	1	1
Pauses or breaks	5	17	23%	1	1	5	17	23%	1	1
Waiting time for incoming product / material	17	5	77%	1	1	13	9	59%	1	1
Subsequent stop in output flow from station / machine	17	4	81%	1	2	15	6	71%	1	2
Shortage of staff	18	5	78%	0	1	12	10	55%	1	1
Media error	21	1	95%	0	2	18	2	90%	2	2
Speed loss	19	1	95%	1	3	16	4	80%	1	3
Scrap or quality problems of the product	17	3	85%	1	3	15	5	75%	1	3
Incidents / near misses	15	8	65%	0	1	13	8	62%	2	1
μ:			**68%**					**61%**		

Table 5 – Classification and registration of PD in discrete manufacturing companies

Proposed PD factors	Classified as PD (n=52)					Registered as PD (n=52)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	52	0	100%	0	0	47	4	92%	0	1
Human error	45	6	88%	0	1	34	14	71%	4	0
Failure of peripheral, e.g. external transport system	44	6	88%	1	1	34	16	68%	1	1
Failure of software, in production equipment	48	2	96%	2	0	43	6	88%	2	1
Reprogramming	25	24	51%	3	0	22	24	48%	5	1
Planning error	35	16	69%	0	1	18	29	38%	3	2
Tool change	17	31	35%	1	3	18	27	40%	4	3
Time for changing/ refilling of material	24	25	49%	1	2	16	32	33%	2	2
Set-up/Resetting	24	26	48%	0	2	24	25	49%	1	2
Adjustment	34	14	71%	1	3	28	20	58%	3	1
Preventive maintenance	27	48	53%	0	1	26	23	53%	2	1
Cleaning	17	34	33%	0	1	19	29	40%	2	2
Work meeting	14	35	29%	1	2	15	33	31%	2	2
Pauses or breaks	12	39	24%	0	1	12	35	26%	3	2
Waiting time for incoming product / material	42	9	82%	0	1	32	16	67%	2	2
Subsequent stop in output flow from station / machine	40	10	80%	0	2	48	23	102%	2	3
Shortage of staff	39	12	76%	0	1	24	24	50%	2	2
Media error	49	2	96%	0	1	39	8	83%	2	3
Speed loss	36	12	75%	2	2	27	22	55%	2	1
Scrap or quality problems of the product	44	6	88%	1	1	40	10	80%	0	2
Incidents / near misses	36	14	72%	1	1	35	11	76%	4	2
µ:			**67%**					**59%**		

Table 6-8 Performance measures and running-in

Performance measures and running-in							
To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… measure and register all stops in production? (including minor stoppages)							
Discrete manufacturing companies	*21*	*13*	*15*	*3*	*0*	*0*	*0*
Continuous production companies	**12**	**8**	**4**	**0**	**0**	**0**	**0**
… calculate Technical Availability?							
Discrete manufacturing companies	*18*	*7*	*13*	*12*	*2*	*0*	*0*
Continuous production companies	**8**	**6**	**8**	**1**	**1**	**0**	**0**
… calculate Overall Equipment Effectiveness?							
Discrete manufacturing companies	*16*	*8*	*15*	*11*	*2*	*0*	*0*
Continuous production companies	**10**	**4**	**4**	**6**	**0**	**0**	**0**

To what extent is OEE used for…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… monitoring and control of production processes, machines, or other equipment?							
Discrete manufacturing companies	*12*	*10*	*16*	*7*	*3*	*4*	*0*
Continuous production companies	**5**	**5**	**9**	**5**	**0**	**0**	**0**
… identification and development of improvement actions?							
Discrete manufacturing companies	*11*	*11*	*17*	*6*	*3*	*4*	*0*
Continuous production companies	**6**	**7**	**7**	**4**	**0**	**0**	**0**
… identification of critical equipment? (e.g. bottlenecks)							
Discrete manufacturing companies	*8*	*14*	*15*	*7*	*3*	*5*	*0*
Continuous production companies	**7**	**7**	**6**	**4**	**0**	**0**	**0**
… follow-up and development of KPI's in production?							
Discrete manufacturing companies	*11*	*15*	*10*	*9*	*3*	*4*	*0*
Continuous production companies	**7**	**6**	**8**	**3**	**0**	**0**	**0**
… internal benchmarking? (e.g. between stations/machines)							
Discrete manufacturing companies	*5*	*11*	*16*	*12*	*3*	*5*	*0*
Continuous production companies	**1**	**6**	**12**	**4**	**0**	**1**	**0**
… external benchmarking? (e.g. against other companies / targets)							
Discrete manufacturing companies	*4*	*7*	*17*	*17*	*3*	*4*	*0*
Continuous production companies	**1**	**6**	**12**	**4**	**1**	**0**	**0**

During the latest running-in of a new product, machine, or line, do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… you reached the goals for production cost, quality and volume according to plan?							
Discrete manufacturing companies	*4*	*19*	*15*	*5*	*5*	*4*	*0*
Continuous production companies	**2**	**14**	**5**	**0**	**1**	**2**	**0**
… the running-in caused an increase of production disturbances?							
Discrete manufacturing companies	*13*	*25*	*3*	*4*	*3*	*4*	*0*
Continuous production companies	**2**	**15**	**4**	**2**	**1**	**0**	**0**
… experiences from the running-in have been documented in a satisfactory way?							
Discrete manufacturing companies	*8*	*20*	*16*	*3*	*2*	*3*	*0*
Continuous production companies	**5**	**12**	**5**	**1**	**1**	**0**	**0**
… experiences from the running-in have been taken care of in improvement work in a satisfactory way?							
Discrete manufacturing companies	*8*	*28*	*9*	*1*	*3*	*3*	*0*
Continuous production companies	**2**	**12**	**9**	**0**	**1**	**0**	**0**

Table 9 – Organization

Organization							
Do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… formulation of goals and planning of maintenance is synchronized with production?							
Discrete manufacturing companies	*15*	*22*	*13*	*0*	*2*	*1*	*0*
Continuous production companies	**10**	**12**	**1**	**0**	**0**	**0**	**0**
… production disturbances are prioritized by management in a satisfactory way?							
Discrete manufacturing companies	*16*	*19*	*16*	*1*	*0*	*0*	*0*
Continuous production companies	**8**	**13**	**3**	**0**	**0**	**0**	**0**
… education and competence development regarding production disturbances are working in a satisfactory way?							
Discrete manufacturing companies	*5*	*24*	*19*	*3*	*1*	*0*	*0*
Continuous production companies	**1**	**14**	**9**	**0**	**0**	**0**	**0**
… documentation of production disturbances are working in a satisfactory way?							
Discrete manufacturing companies	*7*	*28*	*13*	*3*	*1*	*0*	*0*
Continuous production companies	**6**	**8**	**10**	**0**	**0**	**0**	**0**
… improvement teams regarding production disturbances are working in a satisfactory way?							
Discrete manufacturing companies	*4*	*29*	*14*	*2*	*0*	*3*	*0*
Continuous production companies	**2**	**11**	**8**	**2**	**0**	**1**	**0**
… the follow-up of completed improvement actions is working in a satisfactory way?							
Discrete manufacturing companies	*4*	*28*	*16*	*4*	*0*	*0*	*0*
Continuous production companies	**2**	**12**	**8**	**1**	**1**	**0**	**0**
… there are frequent disturbances in production? (e.g. re-occuring disturbances that are not being resolved)							
Discrete manufacturing companies	*11*	*32*	*8*	*1*	*0*	*0*	*0*
Continuous production companies	**4**	**17**	**3**	**0**	**0**	**0**	**0**
… experiences of production disturbances are tied back to development departments?							
Discrete manufacturing companies	*7*	*19*	*16*	*4*	*1*	*5*	*0*
Continuous production companies	**4**	**10**	**3**	**3**	**0**	**4**	**0**
… you have a systematic method (e.g. EEM/Maintenance prevention) for improving maintainability and reliability during the design- and development phase of new production processes, machines, or other equipment?							
Discrete manufacturing companies	*5*	*11*	*21*	*11*	*3*	*1*	*0*
Continuous production companies	**1**	**10**	**8**	**4**	**1**	**0**	**0**

Table 10 – Risk assessment tools and software

Risk assessment tools and software									
Which of the following tools are used by the maintenance department in your company?	What-if	RCA	HAZ-OP	FTA	ETA	LTA	Fish-bone diag-rams	VMEA	FMEA
Discrete manufacturing companies	*8*	*32*	*9*	*12*	*2*	*2*	*26*	*2*	*18*
Continuous production companies	**8**	**23**	**8**	**7**	**3**	**0**	**14**	**0**	**7**
Which of the following software are used by the maintenance department in your company?	DES	@Risk	Relex	Relia-soft	RBWS	Other			
Discrete manufacturing companies	0	0	0	0	0	28			
Continuous production companies	1	0	0	0	1	9			
Do you consider that the use of these...	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A		
… tools are working in a satisfactory way?									
Discrete manufacturing companies	3	20	3	0	3	20	3		
Continuous production companies	0	12	4	1	2	4	1		
… software are working in a satisfactory way?	3	27	3	1	7	31	4		
Discrete manufacturing companies	3	17	2	0	5	22	3		
Continuous production companies	0	10	1	1	2	9	1		

Table 11 – Reliability engineers

Do your company have engineers in the maintenance department who work with…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… RCA of stoppages, failures or other disturbances?							
Discrete manufacturing companies	*11*	*15*	*8*	*13*	*0*	*4*	*1*
Continuous production companies	**8**	**13**	**0**	**2**	**0**	**1**	**0**
… risk analysis and risk handling?							
Discrete manufacturing companies	*9*	*20*	*7*	*10*	*0*	*4*	*2*
Continuous production companies	**8**	**10**	**3**	**2**	**0**	**1**	**0**
… failure frequency analysis? (e.g. using Weibull plot)							
Discrete manufacturing companies	*2*	*7*	*11*	*23*	*1*	*4*	*4*
Continuous production companies	**2**	**6**	**6**	**7**	**0**	**2**	**1**
… failure mode analysis? (e.g. using FMEA)							
Discrete manufacturing companies	*4*	*13*	*13*	*15*	*1*	*4*	*2*
Continuous production companies	**2**	**5**	**8**	**4**	**1**	**3**	**1**
… Life Cycle Cost analysis? (LCC)							
Discrete manufacturing companies	*3*	*10*	*11*	*20*	*3*	*4*	*1*
Continuous production companies	**2**	**9**	**9**	**2**	**1**	**1**	**0**
… improving maintainability and reliability of processes, equipment or machines during the design phase?							
Discrete manufacturing companies	*3*	*27*	*5*	*10*	*1*	*5*	*2*
Continuous production companies	**2**	**14**	**3**	**4**	**0**	**1**	**0**
… developing and improving methods and work practices for preventive maintenance activities?							
Discrete manufacturing companies	*13*	*23*	*5*	*7*	*0*	*3*	*1*
Continuous production companies	**6**	**16**	**1**	**0**	**0**	**1**	**0**

Table 12-13 – Lean Maintenance

Lean Maintenance							
To what extent do you at the company work with…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… methods and work practices according to Total Productive Maintenance (TPM) ?							
Discrete manufacturing companies	*11*	*9*	*17*	*8*	*4*	*2*	*1*
Continuous production companies	**6**	**4**	**9**	**5**	**0**	**0**	**0**
… Reliability-Centered Maintenance (RCM) ?							
Discrete manufacturing companies	*4*	*8*	*13*	*20*	*4*	*2*	*1*
Continuous production companies	**0**	**5**	**13**	**5**	**0**	**0**	**1**
… Condition-Based Maintenance (CBM) ?							
Discrete manufacturing companies	*8*	*12*	*19*	*5*	*4*	*2*	*2*
Continuous production companies	**2**	**10**	**10**	**2**	**0**	**0**	**0**
To what extent do you consider that…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… your company is working with Lean production?							
Discrete manufacturing companies	*9*	*15*	*19*	*9*	*0*	*0*	*0*
Continuous production companies	**4**	**8**	**7**	**5**	**0**	**0**	**0**
… your company is working with Lean maintenance?							
Discrete manufacturing companies	*4*	*9*	*22*	*16*	*1*	*0*	*0*
Continuous production companies	**3**	**3**	**13**	**5**	**0**	**0**	**0**
… you have knowledge about Lean maintenance?							
Discrete manufacturing companies	*7*	*19*	*17*	*9*	*0*	*0*	*0*
Continuous production companies	**2**	**14**	**6**	**2**	**0**	**0**	**0**

To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… Condition Monitoring of equipment?							
Discrete manufacturing companies	*4*	*13*	*23*	*9*	*1*	*2*	*0*
Continuous production companies	**4**	**10**	**8**	**2**	**0**	**0**	**0**
… identification and analysis of bottlenecks in production?							
Discrete manufacturing companies	*8*	*19*	*19*	*5*	*0*	*1*	*0*
Continuous production companies	**5**	**11**	**6**	**1**	**0**	**1**	**0**
… establishing criticality levels for maintenance of production processes, equipment or components?							
Discrete manufacturing companies	*5*	*9*	*18*	*13*	*6*	*1*	*0*
Continuous production companies	**2**	**11**	**8**	**3**	**0**	**0**	**0**
… continuously updating the criticality levels of production processes, equipment or components?							
Discrete manufacturing companies	*3*	*8*	*20*	*15*	*5*	*1*	*0*
Continuous production companies	**3**	**7**	**7**	**7**	**0**	**0**	**0**
… scheduling of maintenance work orders based on the priority of the maintenance activity?							
Discrete manufacturing companies	*11*	*22*	*13*	*2*	*1*	*3*	*0*
Continuous production companies	**5**	**13**	**2**	**2**	**1**	**0**	**1**

Table 14 – Criticality assessment

Criticality assessment, discrete manufacturing companies

On which primary basis do you establish criticality levels of equipment?

	No. of checked answers		*No. of checked answers*
Cost-based priority	3	At the point of purchase	4
ABC-classification	13	Other	6
Bottle neck analysis	2	Do not know	6
Operator influence	8	Not applicable	9
Missing answer	1		

Criticality assessment, continuous production companies

On which primary basis do you establish criticality levels of equipment?

	No. of checked answers		*No. of checked answers*
Cost-based priority	2	At the point of purchase	0
ABC-classification	10	Other	3
Bottle neck analysis	5	Do not know	3
Operator influence	0	Not applicable	1
Missing answer	0		

Table 15 – Lean Maintenance tools

Lean Maintenance tools							
To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… 5S in maintenance areas (e.g. Inventory of parts and tools, workshop, office)?							
Discrete manufacturing companies	*14*	*16*	*15*	*5*	*0*	*2*	*0*
Continuous production companies	**3**	**9**	**8**	**4**	**0**	**0**	**0**
… standardized work for maintenance operators?							
Discrete manufacturing companies	*4*	*11*	*28*	*6*	*1*	*2*	*0*
Continuous production companies	**0**	**8**	**15**	**1**	**0**	**0**	**0**
… visualization of the scheduling and status of maintenance work orders (e.g. using boards for work cards, whiteboard, monitors)?							
Discrete manufacturing companies	*9*	*19*	*16*	*6*	*0*	*2*	*0*
Continuous production companies	**1**	**10**	**8**	**5**	**0**	**0**	**0**
… automatic signals for initiation of corrective maintenance (Andon-signals, e.g. lamps or sound alarms during machine failures)?							
Discrete manufacturing companies	7	6	14	21	0	4	0
Continuous production companies	1	3	5	11	0	4	0
… inventory reduction of maintenance material (e.g. spare parts, tools, consumables)?							
Discrete manufacturing companies	4	17	18	8	1	3	1
Continuous production companies	2	5	13	3	0	1	0
… standardization of the range of components, spare parts, tools for maintenance?							
Discrete manufacturing companies	2	17	21	8	1	3	0
Continuous production companies	0	12	8	4	0	0	0
… Value Stream Mapping for maintenance activities?							
Discrete manufacturing companies	1	4	17	24	2	4	0
Continuous production companies	0	3	7	13	1	0	0
… daily morning meetings for maintenance personnel?							
Discrete manufacturing companies	25	16	7	2	0	2	0
Continuous production companies	12	7	1	3	0	0	1
… error proofing of machines or equipment to prevent maintenance errors (Poka-Yoke)?							
Discrete manufacturing companies	2	8	30	8	2	2	0
Continuous production companies	0	6	11	5	2	0	0

Appendix C

In this section, the cross-tabulation based on company size (<100, 101-500, and >500 employees) are presented.

Table 1-3 – Measurements and work practices

Measurements and work practices							
Have you at the company estimated the cost of stoppages in production?	Yes	No	?				
<100	*9*	*6*	*1*				
101-500	**17**	**15**	**5**				
>500	17	3	1				
How much of the total amount of maintenance is carried out as preventive maintenance?	< 10%	11-20%	21-30%	31-40%	41-50%	>50%	?
<100	*4*	*2*	*2*	*1*	*2*	*5*	*0*
101-500	**4**	**4**	**8**	**5**	**4**	**10**	**2**
>500	0	2	3	4	7	6	1

To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… regularly measure cycle-time in production?							
<100	*3*	*4*	*3*	*2*	*0*	*2*	*2*
101-500	***2***	***14***	***12***	***6***	***0***	***3***	***0***
>500	13	6	1	0	0	3	0
… work with set-up reduction (e.g. using SMED)?							
<100	*2*	*3*	*10*	*0*	*0*	*1*	*0*
101-500	**2**	**11**	**13**	**10**	**0**	**1**	**0**
>500	3	6	10	0	1	3	0
… perform JSA for corrective maintenance?							
<100	*1*	*3*	*3*	*6*	*2*	*1*	*0*
101-500	**1**	**10**	**10**	**9**	**6**	**0**	**1**
>500	2	14	6	0	1	0	0
… perform JSA for preventive maintenance?							
<100	*1*	*4*	*2*	*6*	*3*	*0*	*0*
101-500	**2**	**10**	**12**	**7**	**6**	**0**	**0**
>500	3	11	8	0	1	0	0

To what extent do you at the company…		To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… have operators performing maintenance?								
	<100	*2*	*4*	*9*	*1*	*0*	*0*	*0*
	101-500	**6**	**8**	**18**	**4**	**0**	**1**	**0**
	>500	1	10	13	0	0	1	0
… have external personnel performing maintenance?								
	<100	*5*	*6*	*5*	*0*	*0*	*0*	*0*
	101-500	**4**	**14**	**18**	**1**	**0**	**0**	**0**
	>500	3	9	10	1	0	0	0
… have operators and repairers collaborate in the planning and execution of maintenance?								
	<100	*1*	*3*	*11*	*1*	*0*	*0*	*0*
	101-500	**4**	**11**	**12**	**8**	**0**	**2**	**0**
	>500	1	9	13	0	0	0	0
… have operators involved in improvement teams?								
	<100	*6*	*5*	*4*	*1*	*0*	*0*	*0*
	101-500	**11**	**16**	**9**	**0**	**0**	**1**	**0**
	>500	2	17	4	0	0	0	0
… have repairers involved in improvement teams?								
	<100	*3*	*2*	*5*	*4*	*0*	*2*	*0*
	101-500	**11**	**12**	**12**	**1**	**1**	**0**	**0**
	>500	2	15	5	0	1	0	0

Table 4 - Classification and registration of PD in companies with <100 employees

Proposed PD factors	Classified as PD (n=16)					Registered as PD (n=16)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	15	1	94%	0	0	11	4	73%	0	1
Human error	13	1	93%	1	1	11	4	73%	1	0
Failure of peripheral, e.g. external transport system	14	2	88%	0	0	9	6	60%	0	1
Failure of software, in production equipment	13	2	87%	1	0	10	4	71%	1	1
Reprogramming	6	10	38%	0	0	4	11	27%	0	1
Planning error	12	4	75%	0	0	6	9	40%	0	1
Tool change	3	12	20%	0	1	6	10	38%	0	0
Time for changing/ refilling of material	3	12	20%	0	1	4	12	25%	0	0
Set-up/Resetting	3	12	20%	0	1	6	10	38%	0	0
Adjustment	9	6	60%	0	1	7	9	44%	0	0
Preventive maintenance	2	14	13%	0	0	3	12	20%	0	1
Cleaning	3	13	19%	0	0	5	10	33%	0	1
Work meeting	1	15	6%	0	0	2	13	13%	0	1
Pauses or breaks	2	14	13%	0	0	4	11	27%	0	1
Waiting time for incoming product / material	10	6	63%	0	0	6	9	40%	0	1
Subsequent stop in output flow from station / machine	8	6	57%	1	1	8	7	53%	1	0
Shortage of staff	9	7	56%	0	0	5	10	33%	0	1
Media error	15	1	94%	0	0	11	4	73%	0	1
Speed loss	7	7	50%	1	1	7	8	47%	1	0
Scrap or quality problems of the product	11	5	69%	0	0	11	4	73%	0	1
Incidents / near misses	11	4	73%	1	0	11	3	79%	1	1
μ:			**53%**					**47%**		

Table 5 - Classification and registration of PD in companies with 101-500 employees

Proposed PD factors	Classified as PD (n=37)					Registered as PD (n=37)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	36	0	100%	0	1	34	2	94%	0	1
Human error	31	5	86%	0	1	23	10	70%	3	1
Failure of peripheral, e.g. external transport system	29	4	88%	2	2	28	11	85%	3	1
Failure of software, in production equipment	35	0	100%	1	1	31	4	89%	1	1
Reprogramming	19	16	54%	1	1	18	16	53%	2	1
Planning error	28	7	80%	2	0	15	18	45%	2	2
Tool change	10	22	31%	2	3	9	21	30%	3	4
Time for changing/ refilling of material	14	17	45%	3	3	9	22	29%	2	4
Set-up/Resetting	18	17	51%	0	2	15	18	45%	1	3
Adjustment	22	11	67%	2	2	19	12	61%	4	2
Preventive maintenance	13	23	36%	0	1	20	15	57%	1	1
Cleaning	13	22	37%	0	2	16	19	46%	0	2
Work meeting	8	24	25%	2	3	9	25	26%	2	1
Pauses or breaks	6	28	18%	1	2	5	29	15%	1	2
Waiting time for incoming product / material	30	4	88%	1	2	21	12	64%	2	2
Subsequent stop in output flow from station / machine	31	4	89%	0	2	23	11	68%	1	2
Shortage of staff	30	5	86%	0	2	19	14	58%	2	2
Media error	34	1	97%	0	2	27	5	84%	3	2
Speed loss	27	5	84%	2	3	19	14	58%	1	3
Scrap or quality problems of the product	31	2	94%	1	3	27	6	82%	1	3
Incidents / near misses	24	11	69%	0	2	25	7	78%	3	2
μ:			**68%**					**59%**		

Table 5 - Classification and registration of PD in companies with >500 employees

Proposed PD factors	Classified as PD (n=23)					Registered as PD (n=23)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	22	1	96%	0	0	22	0	100%	0	1
Human error	19	3	86%	1	0	17	3	85%	3	0
Failure of peripheral, e.g. external transport system	20	2	91%	1	0	19	3	86%	1	0
Failure of software, in production equipment	21	1	95%	1	0	21	0	100%	2	0
Reprogramming	11	9	55%	3	0	10	8	56%	5	0
Planning error	18	5	78%	0	0	11	10	52%	2	0
Tool change	13	9	59%	0	1	12	8	60%	2	1
Time for changing/ refilling of material	17	6	74%	0	0	12	9	57%	2	0
Set-up/Resetting	15	7	68%	0	1	14	8	64%	0	1
Adjustment	18	4	82%	0	1	15	8	65%	0	0
Preventive maintenance	12	11	52%	0	0	13	9	59%	1	0
Cleaning	13	10	57%	0	0	12	9	57%	2	0
Work meeting	8	15	35%	0	0	8	13	38%	2	0
Pauses or breaks	9	14	39%	0	0	8	12	40%	3	0
Waiting time for incoming product / material	19	4	83%	0	0	18	4	82%	1	0
Subsequent stop in output flow from station / machine	18	4	82%	0	1	17	5	77%	0	1
Shortage of staff	18	5	78%	0	0	12	10	55%	1	0
Media error	21	1	95%	0	1	19	1	95%	1	2
Speed loss	21	1	95%	0	1	17	4	81%	1	1
Scrap or quality problems of the product	19	2	90%	1	1	17	7	77%	0	1
Incidents / near misses	16	7	70%	0	0	12	9	57%	2	0
µ:			**74%**					**69%**		

Table 6-8 – Performance measures and running-in

Performance measures and running-in							
To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… measure and register all stops in production? (including minor stoppages)							
<100	*3*	*5*	*5*	*1*	*0*	*0*	*0*
101-500	**15**	**7**	**13**	**2**	**0**	**0**	**0**
>500	13	9	1	0	0	0	0
… calculate Technical Availability?							
<100	*2*	*4*	*4*	*6*	*0*	*0*	*0*
101-500	**11**	**6**	**12**	**7**	**3**	**0**	**0**
>500	13	5	5	0	0	0	0
… calculate Overall Equipment Effectiveness?							
<100	*2*	*4*	*4*	*6*	*0*	*0*	*0*
101-500	**13**	**4**	**9**	**9**	**2**	**0**	**0**
>500	11	4	6	2	0	0	0

To what extent is OEE used for…		To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… monitoring and control of production processes, machines, or other equipment?								
	<100	*2*	*2*	*6*	*2*	*1*	*3*	*0*
	101-500	**8**	**6**	**11**	**9**	**2**	**1**	**0**
	>500	7	7	8	1	0	0	0
… identification and development of improvement actions?								
	<100	*4*	*3*	*3*	*2*	*1*	*3*	*0*
	101-500	**6**	**8**	**13**	**7**	**2**	**1**	**0**
	>500	7	7	8	1	0	0	0
… identification of critical equipment? (e.g. bottlenecks)								
	<100	*3*	*4*	*2*	*2*	*1*	*4*	*0*
	101-500	**5**	**10**	**11**	**8**	**2**	**1**	**0**
	>500	7	7	8	1	0	0	0
… follow-up and development of KPI's in production?								
	<100	3	3	2	4	1	3	0
	101-500	9	8	10	7	2	1	0
	>500	6	10	6	1	0	0	0
… internal benchmarking? (e.g. between stations/machines)								
	<100	0	3	5	4	1	3	0
	101-500	3	7	14	10	2	1	0
	>500	3	7	8	2	0	2	0
… external benchmarking? (e.g. against other companies / targets)								
	<100	*0*	*1*	*3*	*8*	*1*	*3*	*0*
	101-500	**3**	**4**	**16**	**10**	**3**	**1**	**0**
	>500	2	8	10	3	0	0	0

During the latest running-in of a new product, machine, or line, do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… you reached the goals for production cost, quality and volume according to plan?							
<100	*0*	*7*	*6*	*0*	*1*	*2*	*0*
101-500	**3**	**16**	**8**	**4**	**2**	**4**	**0**
>500	3	10	6	1	3	0	0
… the running-in caused an increase of production disturbances?							
<100	*2*	*8*	*2*	*2*	*0*	*2*	*0*
101-500	**8**	**19**	**2**	**3**	**3**	**2**	**0**
>500	5	13	3	1	1	0	0
… experiences from the running-in have been documented in a satisfactory way?							
<100	*3*	*5*	*4*	*2*	*0*	*2*	*0*
101-500	**7**	**14**	**11**	**2**	**2**	**1**	**0**
>500	3	13	6	0	1	0	0
… experiences from the running-in have been taken care of in improvement work in a satisfactory way?							
<100	*1*	*8*	*4*	*0*	*1*	*2*	*0*
101-500	**7**	**17**	**9**	**1**	**2**	**1**	**0**
>500	2	15	5	0	1	0	0

Table 9 – Organization

Organization							
Do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… formulation of goals and planning of maintenance is synchronized with production?							
<100	*4*	*8*	*3*	*0*	*1*	*0*	*0*
101-500	**11**	**17**	**8**	**1**	**0**	**0**	**0**
>500	10	9	3	0	0	1	0
… production disturbances are prioritized by management in a satisfactory way?							
<100	*4*	*8*	*4*	*0*	*0*	*0*	*0*
101-500	**10**	**17**	**9**	**1**	**0**	**0**	**0**
>500	10	7	6	0	0	0	0
… education and competence development regarding production disturbances are working in a satisfactory way?							
<100	*2*	*7*	*7*	*0*	*0*	*0*	*0*
101-500	**1**	**18**	**14**	**3**	**1**	**0**	**0**
>500	3	13	7	0	0	0	0
… documentation of production disturbances are working in a satisfactory way?							
<100	*3*	*6*	*7*	*0*	*0*	*0*	*0*
101-500	**5**	**18**	**11**	**2**	**1**	**0**	**0**
>500	5	12	5	1	0	0	0
… improvement teams regarding production disturbances are working in a satisfactory way?							
<100	*1*	*8*	*3*	*2*	*0*	*2*	*0*
101-500	**3**	**19**	**12**	**1**	**0**	**2**	**0**
>500	2	13	7	1	0	0	0
… the follow-up of completed improvement actions is working in a satisfactory way?							
<100	*1*	*8*	*5*	*1*	*1*	*0*	*0*
101-500	**3**	**18**	**13**	**3**	**0**	**0**	**0**
>500	2	14	6	1	0	0	0
… there are frequent disturbances in production? (e.g. re-occuring disturbances that are not being resolved)							
<100	*2*	*8*	*5*	*1*	*0*	*0*	*0*
101-500	**6**	**26**	**5**	**0**	**0**	**0**	**0**
>500	7	15	1	0	0	0	0
… experiences of production disturbances are tied back to development departments?							
<100	*3*	*3*	*3*	*3*	*0*	*4*	*0*
101-500	**5**	**16**	**7**	**3**	**1**	**5**	**0**
>500	3	10	10	1	0	0	0

… you have a systematic method (e.g. EEM/Maintenance prevention) for improving maintainability and reliability during the design- and development phase of new production processes, machines, or other equipment?		Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A
	<100	*0*	*3*	*6*	*6*	*1*	*0*	*0*
	101-500	**2**	**11**	**12**	**8**	**3**	**1**	**0**
	>500	4	7	11	1	0	0	0

Table 10 – Risk assessment tools and software

Risk assessment tools and software										
Which of the following tools are used by the maintenance department in your company?		What-if	RCA	HAZ-OP	FTA	ETA	LTA	Fish-bone diag-rams	VMEA	FMEA
	<100	*2*	*9*	*3*	*1*	*0*	*1*	*6*	*0*	*3*
	101-500	**8**	**23**	**7**	**8**	**3**	**0**	**18**	**1**	**10**
	>500	6	24	7	10	2	1	16	1	12
Which of the following software are used by the maintenance department in your company?		DES	@Risk	Relex	Relia-soft	RBWS	Other			
	<100	*0*	*0*	*0*	*0*	*0*	*6*			
	101-500	**1**	**0**	**0**	**0**	**0**	**18**			
	>500	0	0	0	0	1	13			
Do you consider that the use of these...		Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A		
… tools are working in a satisfactory way?										
	<100	*1*	*4*	*1*	*0*	*1*	*7*	*2*		
	101-500	**0**	**16**	**5**	**0**	**3**	**13**	**0**		
	>500	2	12	1	1	1	4	2		
… software are working in a satisfactory way?										
	<100	*0*	*4*	*1*	*0*	*1*	*8*	*2*		
	101-500	**2**	**11**	**2**	**0**	**5**	**17**	**0**		
	>500	1	12	0	1	1	6	2		

Table 11 – Reliability engineers

Do your company have engineers in the maintenance department who work with…		Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… RCA of stoppages, failures or other disturbances?								
	<100	*2*	*7*	*2*	*1*	*0*	*3*	*1*
	101-500	**6**	**10**	**6**	**13**	**0**	**2**	**0**
	>500	11	11	0	1	0	0	0
… risk analysis and risk handling?								
	<100	*3*	*6*	*0*	*3*	*0*	*3*	*1*
	101-500	**7**	**12**	**8**	**8**	**0**	**2**	**0**
	>500	7	12	2	1	0	0	1
… failure frequency analysis? (e.g. using Weibull plot)								
	<100	*1*	*0*	*4*	*6*	*0*	*3*	*2*
	101-500	**0**	**5**	**6**	**20**	**1**	**3**	**2**
	>500	3	8	7	4	0	0	1
… failure mode analysis? (e.g. using FMEA)								
	<100	*1*	*3*	*5*	*2*	*0*	*4*	*1*
	101-500	**1**	***6***	***8***	***16***	***2***	***3***	***1***
	>500	4	9	8	1	0	0	1
… Life Cycle Cost analysis? (LCC)								
	<100	*1*	*3*	*3*	*5*	*0*	*3*	*1*
	101-500	**2**	**5**	**9**	**15**	**4**	**2**	**0**
	>500	2	11	8	2	0	0	0
… improving maintainability and reliability of processes, equipment or machines during the design phase?								
	<100	*0*	*6*	*1*	*5*	*0*	*3*	*1*
	101-500	**2**	**17**	**5**	**9**	**1**	**3**	**0**
	>500	3	18	2	0	0	0	0
… developing and improving methods and work practices for preventive maintenance activities?								
	<100	*3*	*8*	*1*	*0*	*0*	*3*	*1*
	101-500	**7**	**17**	**5**	**7**	**0**	**1**	**0**
	>500	9	14	0	0	0	0	0

Table 12-13 Lean Maintenance

Lean Maintenance								
To what extent do you at the company work with…		To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… methods and work practices according to Total Productive Maintenance (TPM) ?								
	<100	*1*	*1*	*8*	*4*	*0*	*1*	*1*
	101-500	**8**	**5**	**10**	**9**	**4**	**1**	**0**
	>500	8	7	8	0	0	0	0
… Reliability-Centered Maintenance (RCM) ?								
	<100	*0*	*1*	*5*	*8*	*0*	*1*	*1*
	101-500	**1**	**5**	**11**	**14**	**4**	**1**	**1**
	>500	3	7	10	3	0	0	0
… Condition-Based Maintenance (CBM) ?								
	<100	*1*	*3*	*6*	*3*	*0*	*1*	*2*
	101-500	**2**	**12**	**14**	**4**	**4**	**1**	**0**
	>500	7	7	9	0	0	0	0
To what extent do you consider that…		To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… your company is working with Lean production?								
	<100	*3*	*6*	*4*	*3*	*0*	*0*	*0*
	101-500	**5**	**9**	**13**	**10**	**0**	**0**	**0**
	>500	5	8	9	1	0	0	0
… your company is working with Lean maintenance?								
	<100	*0*	*1*	*8*	*7*	*0*	*0*	*0*
	101-500	**4**	**3**	**15**	**14**	**1**	**0**	**0**
	>500	3	8	12	0	0	0	0
… you have knowledge about Lean maintenance?								
	<100	*2*	*4*	*9*	*1*	*0*	*0*	*0*
	101-500	**2**	**18**	**7**	**10**	**0**	**0**	**0**
	>500	5	11	7	0	0	0	0

To what extent do you at the company work with…		To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… Condition Monitoring of equipment?								
	<100	*0*	*3*	*7*	*5*	*0*	*1*	*0*
	101-500	**1**	**12**	**17**	**5**	**1**	**1**	**0**
	>500	7	8	7	1	0	0	0
… identification and analysis of bottlenecks in production?								
	<100	*2*	*8*	*5*	*0*	*0*	*1*	*0*
	101-500	**6**	**12**	**13**	**6**	**0**	**0**	**0**
	>500	5	10	7	0	0	1	0
… establishing criticality levels for maintenance of production processes, equipment or components?								
	<100	*0*	*2*	*5*	*7*	*1*	*1*	*0*
	101-500	**2**	**9**	**14**	**9**	**3**	**0**	**0**
	>500	2	5	9	7	2	0	0
… continuously updating the criticality levels of production processes, equipment or components?								
	<100	*1*	*2*	*4*	*7*	*1*	*1*	*0*
	101-500	**2**	**8**	**13**	**12**	**2**	**0**	**0**
	>500	3	5	10	3	2	0	0
… scheduling of maintenance work orders based on the priority of the maintenance activity?								
	<100	*2*	*3*	*5*	*2*	*2*	*2*	*0*
	101-500	**5**	**23**	**8**	**0**	**0**	**1**	**0**
	>500	9	9	2	2	0	0	1

Table 14-16 Criticality assessment

Criticality assessment, <100 employees			
On which primary basis do you establish criticality levels of equipment?			
	No. of checked answers		*No. of checked answers*
Cost-based priority	2	At the point of purchase	1
ABC-classification	0	Other	2
Bottle neck analysis	2	Do not know	3
Operator influence	3	Not applicable	2
Missing answer	1		

Criticality assessment, 101-500 employees			
On which primary basis do you establish criticality levels of equipment?			
	No. of checked answers		*No. of checked answers*
Cost-based priority	2	At the point of purchase	3
ABC-classification	9	Other	2
Bottle neck analysis	4	Do not know	5
Operator influence	5	Not applicable	7
Missing answer	0		

Criticality assessment, >500 employees			
On which primary basis do you establish criticality levels of equipment?			
	No. of checked answers		*No. of checked answers*
Cost-based priority	1	At the point of purchase	0
ABC-classification	14	Other	5
Bottle neck analysis	1	Do not know	1
Operator influence	0	Not applicable	1
Missing answer	0		

Table 17 – Lean Maintenance tools

Lean Maintenance tools							
To what extent do you at the company work with…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… 5S in maintenance areas (e.g. Inventory of parts and tools, workshop, office)?							
<100	*3*	*1*	*7*	*3*	*0*	*2*	*0*
101-500	**7**	**14**	**10**	**6**	**0**	**0**	**0**
>500	7	10	6	0	0	0	0
… standardized work for maintenance operators?							
<100	*2*	*2*	*7*	*3*	*0*	*2*	*0*
101-500	**0**	**10**	**22**	**4**	**1**	**0**	**0**
>500	2	7	14	0	0	0	0
… visualization of the scheduling and status of maintenance work orders (e.g. using boards for work cards, whiteboard, monitors)?							
<100	*1*	*6*	*5*	*2*	*0*	*2*	*0*
101-500	**5**	**14**	**11**	**7**	**0**	**0**	**0**
>500	4	9	8	2	0	0	0
… automatic signals for initiation of corrective maintenance (Andon-signals, e.g. lamps or sound alarms during machine failures)?							
<100	*1*	*0*	*3*	*8*	*0*	*4*	*0*
101-500	**3**	**5**	**8**	**17**	**0**	**4**	**0**
>500	4	4	8	7	0	0	0
… inventory reduction of maintenance material (e.g. spare parts, tools, consumables)?							
<100	*0*	*3*	*4*	*6*	*0*	*3*	*0*
101-500	**2**	**12**	**16**	**4**	**1**	**1**	**1**
>500	4	7	11	1	0	0	0
… standardization of the range of components, spare parts, tools for maintenance?							
<100	*0*	*4*	*4*	*6*	*0*	*2*	*0*
101-500	**0**	**15**	**16**	**5**	**0**	**1**	**0**
>500	2	10	9	1	1	0	0
… Value Stream Mapping for maintenance activities?							
<100	*0*	*1*	*2*	*9*	*0*	*4*	*0*
101-500	**1**	**4**	**10**	**19**	**3**	**0**	**0**
>500	0	2	12	9	0	0	0

… daily morning meetings for maintenance personnel?							
<100	*5*	*6*	*0*	*3*	*0*	*2*	*0*
101-500	**17**	**10**	**8**	**2**	**0**	**0**	**0**
>500	15	7	0	0	0	0	1
… error proofing of machines or equipment to prevent maintenance errors (Poka-Yoke)?							
<100	*0*	*1*	*8*	*5*	*0*	*2*	*0*
101-500	**1**	**8**	**21**	**6**	**1**	**0**	**0**
>500	1	5	12	2	3	0	0

Appendix D

In this section, the cross-tabulation based on management position (i.e production, maintenance, maintenance/production) is presented.

Table 1 – Running-in

Running-in							
During the latest running-in of a new product, machine, or line, do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… you reached the goals for production cost, quality and volume according to plan?							
Production	*0*	*10*	*7*	*0*	*1*	*1*	*0*
Maintenance	**6**	**18**	**10**	**5**	**4**	**4**	**0**
Maintenance/Production	0	5	3	0	1	1	0
… the running-in caused an increase of production disturbances?							
Production	*5*	*11*	*1*	*1*	*0*	*1*	*0*
Maintenance	**10**	**24**	**5**	**4**	**2**	**2**	**0**
Maintenance/Production	0	5	1	1	2	1	0
… experiences from the running-in have been documented in a satisfactory way?							
Production	*6*	*8*	*3*	*1*	*0*	*1*	*0*
Maintenance	**5**	**21**	**15**	**2**	**2**	**2**	**0**
Maintenance/Production	2	3	3	1	1	0	0
… experiences from the running-in have been taken care of in improvement work in a satisfactory way?							
Production	*5*	*10*	*3*	*0*	*0*	*1*	*0*
Maintenance	**4**	**26**	**12**	**1**	**2**	**2**	**0**
Maintenance/Production	1	4	3	0	2	0	0

Table 2 - Organization

Organization							
Do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… formulation of goals and planning of maintenance is synchronized with production?							
Production	*6*	*9*	*2*	*0*	*2*	*0*	*0*
Maintenance	**17**	**21**	**8**	**0**	**0**	**1**	**0**
Maintenance/Production	2	4	4	0	0	0	0
… production disturbances are prioritized by management in a satisfactory way?							
Production	*7*	*6*	*6*	*0*	*0*	*0*	*0*
Maintenance	**16**	**20**	**10**	**1**	**0**	**0**	**0**
Maintenance/Production	1	6	3	0	0	0	0
… education and competence development regarding production disturbances are working in a satisfactory way?							
Production	*0*	*11*	*7*	*0*	*1*	*0*	*0*
Maintenance	**5**	**23**	**16**	**3**	**0**	**0**	**0**
Maintenance/Production	1	4	5	0	0	0	0
… documentation of production disturbances are working in a satisfactory way?							
Production	*1*	*10*	*7*	*1*	*0*	*0*	*0*
Maintenance	**12**	**20**	**13**	**2**	**0**	**0**	**0**
Maintenance/Production	0	6	3	0	1	0	0
… improvement teams regarding production disturbances are working in a satisfactory way?							
Production	*4*	*10*	*2*	*1*	*0*	*2*	*0*
Maintenance	**2**	**24**	**17**	**3**	**0**	**1**	**0**
Maintenance/Production	0	6	3	0	0	1	0
… the follow-up of completed improvement actions is working in a satisfactory way?							
Production	*3*	*10*	*6*	*0*	*0*	*0*	*0*
Maintenance	**3**	**24**	**14**	**5**	**1**	**0**	**0**
Maintenance/Production	0	6	4	0	0	0	0
… there are frequent disturbances in production? (e.g. re-occuring disturbances that are not being resolved)							
Production	*4*	*13*	*1*	*1*	*0*	*0*	*0*
Maintenance	**10**	**32**	**5**	**0**	**0**	**0**	**0**
Maintenance/Production	1	4	5	0	0	0	0
… experiences of production disturbances are tied back to development departments?							
Production	*4*	*10*	*3*	*0*	*1*	*1*	*0*
Maintenance	**7**	**16**	**12**	**6**	**0**	**6**	**0**
Maintenance/Production	0	3	4	1	0	2	0

… you have a systematic method (e.g. EEM/Maintenance prevention) for improving maintainability and reliability during the design- and development phase of new production processes, machines, or other equipment?	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
Production	*0*	*7*	*5*	*3*	*4*	*0*	*0*
Maintenance	**5**	**10**	**22**	**9**	**0**	**1**	**0**
Maintenance/Production	1	4	2	3	0	0	0

Table 3-4 Classification of PD factors

Proposed PD factors	Production					Maintenance				
	Classified as PD (n=19)					Registered as PD (n=47)				
	Yes	No	Yes %	?	N/A	Yes	No	Yes %	?	N/A
Equipment failure	19	0	100%	0	0	44	2	96%	0	1
Human error	18	0	100%	1	0	37	8	82%	1	1
Failure of peripheral, e.g. external transport system	18	1	95%	0	0	38	5	88%	2	2
Failure of software, in production equipment	17	1	94%	1	0	45	1	98%	0	1
Reprogramming	7	11	39%	1	0	23	20	53%	3	1
Planning error	16	3	84%	0	0	33	12	73%	0	2
Tool change	6	13	32%	0	0	18	23	44%	2	4
Time for changing/ refilling of material	6	11	35%	2	0	25	19	57%	1	2
Set-up/Resetting	9	10	47%	0	0	24	20	55%	0	3
Adjustment	13	5	72%	1	0	31	12	72%	1	3
Preventive maintenance	4	15	21%	0	0	20	26	43%	0	1
Cleaning	9	10	47%	0	0	17	28	38%	0	2
Work meeting	4	13	24%	2	0	13	31	30%	0	3
Pauses or breaks	4	14	22%	1	0	10	35	22%	0	2
Waiting time for incoming product / material	15	4	79%	0	0	35	9	80%	1	2
Subsequent stop in output flow from station / machine	14	4	78%	1	0	35	9	80%	0	3
Shortage of staff	15	4	79%	0	0	34	11	76%	0	2
Media error	16	2	89%	0	1	44	1	98%	0	2
Speed loss	12	6	67%	1	0	35	7	83%	1	4
Scrap or quality problems of the product	18	1	95%	0	0	34	7	83%	2	4
Incidents / near misses	14	5	74%	0	0	29	16	64%	0	2
μ:			**65%**					**67%**		

Proposed PD factors	Maintenance/Production Classified as PD (n=10)				
	Yes	No	Yes %	?	N/A
Equipment failure	10	0	100%	0	0
Human error	8	1	89%	0	1
Failure of peripheral, e.g. external transport system	7	2	78%	1	0
Failure of software, in production equipment	7	1	88%	2	0
Reprogramming	6	4	60%	0	0
Planning error	9	1	90%	0	0
Tool change	2	7	22%	0	1
Time for changing/ refilling of material	3	5	38%	0	2
Set-up/Resetting	3	6	33%	0	1
Adjustment	5	4	56%	0	1
Preventive maintenance	2	8	20%	0	0
Cleaning	3	7	30%	0	0
Work meeting	0	10	0%	0	0
Pauses or breaks	3	7	30%	0	0
Waiting time for incoming product / material	9	1	90%	0	0
Subsequent stop in output flow from station / machine	8	1	89%	0	1
Shortage of staff	8	2	80%	0	0
Media error	10	0	100%	0	0
Speed loss	8	0	100%	1	1
Scrap or quality problems of the product	9	1	90%	0	0
Incidents / near misses	8	1	89%	1	0
μ:			**65%**		

Appendix E

In this section, the results of the in-depth view of the TPM and Lean Maintenance companies are presented.

Table 1 – Operator maintenance and improvement teams in TPM companies

Operator maintenance and improvement teams							
To what extent do you at the company…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… have operators performing maintenance?	4	12	11	2	0	1	0
… have operators and repairers collaborate in the planning and execution of maintenance?	4	10	14	2	0	0	0
… have operators involved in improvement teams?	8	16	6	0	0	0	0
… have repairers involved in improvement teams?	8	13	8	0	1	0	0

Table 2 – Organization and OEE in TPM companies

Organization & OEE							
Do you consider that…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	?	Not appl-icable	N/A
… formulation of goals and planning of maintenance is synchronized with production?	12	15	2	0	0	1	0
… production disturbances are prioritized by management in a satisfactory way?	15	10	6	0	0	0	0
… the follow-up of completed improvement actions is working in a satisfactory way?	4	15	9	1	1	0	0
… you have a systematic method (e.g. EEM/Maintenance prevention) for improving maintainability and reliability during the design- and development phase of new production processes, machines, or other equipment?	5	12	10	2	1	0	0
To what extent do you at the company…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	?	Not appl-icable	N/A
… calculate Overall Equipment Effectiveness?	17	4	7	2	0	0	0

Table 3 – Lean Maintenance principles in Lean Maintenance companies

Lean Maintenance principles							
To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… methods and work practices according to Total Productive Maintenance (TPM) ?	12	5	2	0	0	0	0
… Reliability-Centered Maintenance (RCM) ?	2	7	8	1	0	0	1
… establishing criticality levels for maintenance of production processes, equipment or components?	5	6	4	2	2	0	0
… continuously updating the criticality levels of production processes, equipment or components?	4	2	8	3	2	0	0
… scheduling of maintenance work orders based on the priority of the maintenance activity?	7	8	2	1	0	0	1

Table 4 – Reliability engineers in Lean Maintenance companies

Reliability engineers							
Do your company have engineers in the maintenance department who work with…	Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A
… RCA of stoppages, failures or other disturbances?	11	6	1	1	0	0	0
… risk analysis and risk handling?	8	6	2	2	0	0	1
… failure frequency analysis? (e.g. using Weibull plot)	2	6	4	5	0	0	2
… failure mode analysis? (e.g. using FMEA)	4	6	4	2	1	0	1
… Life Cycle Cost analysis? (LCC)	3	6	5	4	1	0	0
… improving maintainability and reliability of processes, equipment or machines during the design phase?	3	13	2	1	0	0	0
… developing and improving methods and work practices for preventive maintenance activities?	12	6	0	1	0	0	0

Table 5 – Lean Maintenance tools in Lean Maintenance companies

Lean Maintenance tools							
To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… 5S in maintenance areas (e.g. Inventory of parts and tools, workshop, office)?	8	9	2	0	0	0	0
… standardized work for maintenance operators?	1	9	9	0	0	0	0
… visualization of the scheduling and status of maintenance work orders (e.g. using boards for work cards, whiteboard, monitors)?	7	9	3	0	0	0	0
… automatic signals for initiation of corrective maintenance (Andon-signals, e.g. lamps or sound alarms during machine failures)?	5	2	4	7	0	1	0
… inventory reduction of maintenance material (e.g. spare parts, tools, consumables)?	5	8	5	1	0	0	0
… standardization of the range of components, spare parts, tools for maintenance?	2	9	6	1	1	0	0
… Value Stream Mapping for maintenance activities?	1	3	8	5	1	1	0
… daily morning meetings for maintenance personnel?	14	5	0	0	0	0	0
… error proofing of machines or equipment to prevent maintenance errors (Poka-Yoke)?	2	3	10	0	4	0	0

Table 6 – Classification of PD in Lean Maintenance companies (TPM/Lean losses)

Proposed PD factors	Classified as PD (n=19)					Registered as PD (n=19)				
	Yes	**No**	**Yes %**	**?**	**N/A**	**Yes**	**No**	**Yes %**	**?**	**N/A**
Tool change	8	10	44%	0	1	8	8	50%	2	1
Set-up/Resetting	18	0	100%	0	1	10	8	56%	0	1
Adjustment	13	5	72%	0	1	13	6	68%	0	0
Preventive maintenance	8	11	42%	0	0	9	9	50%	1	0
Pauses or breaks	6	12	33%	1	0	7	11	39%	1	0
Speed loss	17	1	94%	0	1	13	5	72%	0	1
Scrap or quality problems of the product	17	0	100%	1	1	15	3	83%	0	1
μ:			**70%**					**60%**		

Table 7 – Minor stoppages in Lean Maintenance companies

To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… measure and register all stops in production? (including minor stoppages)	12	6	1	0	0	0	

Table 8 – Running-in and frequent PD in TPM and Lean Maintenance companies

Running-in and frequent PD							
During the latest running-in of a new product, machine, or line, do you consider that…	Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A
… the running-in caused an increase of production disturbances?							
TPM companies	*5*	*15*	*2*	*4*	*2*	*2*	*0*
Lean Maintenance companies	**6**	**7**	**3**	**2**	**1**	**0**	**0**
Do you consider that…	Yes, absolutely	Yes, to a certain extent	No, scarcely	No, not at all	?	Not applicable	N/A
… there are frequent disturbances in production? (e.g. re-occuring disturbances that are not being resolved)							
TPM companies	*8*	*18*	*4*	*0*	*0*	*0*	*0*
Lean Maintenance companies	**4**	**12**	**3**	**0**	**0**	**0**	**0**

Table 9 – JSA and classification of incidents/near misses in TPM and Lean Maintenance companies

JSA and classification of incidents/near misses							
To what extent do you at the company…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	?	Not applicable	N/A
… perform JSA for corrective maintenance?							
TPM companies	*3*	*16*	*7*	*2*	*2*	*0*	*0*
Lean Maintenance companies	**3**	**9**	**4**	**1**	**2**	**0**	**0**
… perform JSA for preventive maintenance?							
TPM companies	*5*	*13*	*8*	*1*	*3*	*0*	*0*
Lean Maintenance companies	**3**	**7**	**6**	**0**	**3**	**0**	**0**
Classify "incidents/near misses" as PD	Yes	No	?	N/A			
TPM companies	*22*	*7*	*0*	*1*			
Lean Maintenance companies	**13**	**6**	**0**	**0**			

Table 10 – Risk assessment tools and software in TPM and Lean Maintenance companies

Risk assessment tools and software									
Which of the following tools are used by the maintenance department in your company?	What-if	RCA	HAZ-OP	FTA	ETA	LTA	Fish-bone diag-rams	VMEA	FMEA
TPM companies	*9*	*29*	*7*	*13*	*2*	*0*	*21*	*0*	*15*
Lean Maintenance companies	**6**	**19**	**4**	**10**	**2**	**0**	**14**	**0**	**10**
Which of the following software are used by the maintenance department in your company?	DES	@Risk	Relex	Relia-soft	RBWS	Other			
TPM companies	0	0	0	0	1	17			
Lean Maintenance companies	0	0	0	0	0	12			