Industrial Maintenance Performance Analysis Routine – IMPART

- A methodology evaluating the risk of human error during maintenance

Master thesis
by

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Preface

This report is the result from the master thesis within Risk Management and Safety Engineering carried out by Oscar Lindén in cooperation with the *Department of Chemical Engineering* as well as the *Department of Risk Management and Safety Engineering*, both at the Faculty of Engineering, Lund University.

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Abstract

When discussing industrial maintenance, human error is a topic that easily comes to mind. Slips, lapses and mistakes due to hazardous settings of critical conditions referred to as Performing Shaping Factors (PSFs) introduce unforeseen and unanticipated risks. Unlike several tools to date, the methodology presented in this master thesis is thought to serve as an easy and fast way to identify risks related to this issue, thereby highlighting fallacies, which the company can look into further. The methodology called "Industrial Maintenance Performance Analysis RouTine" or just "IMPART", uses a questionnaire-based, semi-quantitative approach by revealing the operators' and maintenance mechanics' view of the settings of the PSFs. As the name implies, it imparts information to the company, this by combining up-to-date research in the field of human reliability and behavior with the very core of the maintenance industry

The IMPART backbone is built up from five PSFs which are (1) stress, (2) ergonomics, (3) expertise, (4) maintenance strategy, and (5) types of maintenance works. Each of the five originates from various number of dimensions, which are elucidated with the questionnaires. In order to exemplify the IMPART methodology, it was tested on a chemical plant within a successful multinational company in the south parts of Sweden. The concluding results showed evident shortfalls in several dimensions in three of the five PSFs, the most prominent being lacking communication skills, the occurrence of harassments as well as deficiencies in the maintenance strategies. A discussion is also held regarding validity, reliability as well as advantages and limitations of the methodology.

Sammanfattning

När man pratar om industriellt underhållsarbete är mänskliga fel ett viktigt ämne att hantera. Olika typer av mänskliga misstag till följd av farliga tillstånd i vissa speciella parametrar, s.k. Performance Shaping Factors (PSFs) introducerar nya och oförutsägbara risker. Detta examensarbete presenterar en metod som, till skillnad från många metoder som finns tillhands idag, är tänkt som en enkel och snabb metod för att adressera detta. Metoden, "Industrial Maintenance Performance Analysis Routine" (IMPART) för ljus på brister i dessa faktorer genom att använda sig av en enkätbaserad, semikvantitativ metodik. Genom att ställa frågor som visar operatörers och underhållsmekanikers syn på tillståndet för faktorerna kopplas den senaste forskningen inom mänsklig tillförlitlighet till själva kärnan för underhållsarbetet.

IMPART – metodiken är uppbyggd från fem PSFs, nämligen (1) stress, (2) ergonomi, (3) skicklighet, (4) underhållstrategi, och (5) typer av underhållsarbete som genomförs. De fem faktorerna har sedan ett antal dimensioner som bedöms med hjälp av enkätsvaren. IMPART – metodiken exemplifierades på en industri ingående i ett framgångsrikt multinationellt kemiföretag i södra Sverige. Resultaten visade på uppenbara brister i tre av de fem faktorerna. De mest slående uppfattningarna var de interna kommunikations-svårigheterna, förekomsten av trakasserier samt brister i strategierna för underhållsarbete. En diskussion förs sedan angående validitet, reliabilitet samt för- och nackdelar med metoden.

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1. Introduction

Maintenance is of great importance in the industry. Not only is it a necessary evil regulated with laws and requirements, but it also generates great economic loss in terms of production downtime as well as repair and labor costs. However, industrial maintenance is still an indispensable feature since an obsolete, risky and insufficient approach to maintenance may cause capacity fluctuation, loss of market shares as well as induce incident and accident frequencies (Eti, et al., 2006). In high reliability organizations, like chemical or nuclear plants, there is a big need for maintenance in order to manage technological risks. For instance, in the Swedish stealth industry, the annual cost for industrial maintenance is about 13-14 % of the total revenue (Gillberg & Brodd, 2004). When discussing industrial maintenance, human performance is a subject that easily comes to mind. A report by Fredström (2014) which analyzed incident and accident reports in Sweden between 2006 and 2014 reveals several notes that motivates this master thesis out of an industrial perspective. For instance:

- The most common reason for the incidents and accidents was worn out process equipment due to fallacies in precautionary maintenance. The same conclusion was also found by Doyle (1969).
- The ability of managing temporary changes reasoned several events during proactive maintenance during preplanned downtime.
- Insufficient instructions, documentation and risk awareness caused events linked to human error.

Hence, there is use for a strategic methodology, making use of the information at the very core of maintenance performance, i.e. the mechanists and operators, and linking it to up-to-date research within human reliability assessment.

1.1. Purpose

The main purpose for the master thesis is to develop an overarching, semi-quantitative, questionnaire-based tool that evaluates the risk of human error during maintenance. The methodology aims to gather diverse and interdisciplinary science and to couple it to information derived from the core of the industry, namely the plant mechanists and operators. The data obtained is presented in an illustrative way enabling an easy interpretation, hence, reducing the chance of unintended misconceptions, which is believed to enable a more standardized view of the diverse field of human error assessment.

1.2. Delimitations

The aim of the tool is not to be an in-depth analysis tool but rather to function as an easy way to identify unsafe settings of critical conditions referred to as Performance Shaping Factors (PSFs). Thus, the methodology merely intends to serve as an eye-opener for the company and find areas that may be improved or further evaluated, not rendering in detailed instructions of maintenance performance.

The term "risk for human error" is defined in this methodology as "*the probability of one or more malfunctions during task performance, due to human slips, lapses or mistakes, which could be traced to unfavorable settings of performance shaping factors*". Thus, the definition does not include the amplitude of the consequences, but only the probability of human error. The reason for this is that the methodology has to be held rather general in order to be used in a diverse set of industries.

Another delimitation is that only five PSFs are analyzed. A greater number of PSFs requires a vast increase of questions, which likely reduces the number of respondents. Five PSFs seems to give a reasonable number of questions and is still thorough enough for the application.

1.3. Theory

The probability of human error during maintenance increases existing risks as well as introduce new and temporary risks. Furthermore, human error during maintenance could also create diverse and unanticipated risks generating hazards later on when the conditions are restored to normal. In this section, relevant literature is introduced. Different perspectives on human cognition and the three different maintenance strategies, which are viewed in the methodology, are explained. After this, background theory on the five Performing Shaping Factors (PSFs) considered in the methodology are declared. But first is the role of human error in industrial accidents clarified.

1.3.1. The role of human error in industrial accidents

Human error has played a big role in several industrial incidents, accidents and disasters throughout history, for instance: Chernobyl, Seveso, The Three Mile Island and Oyster Creek. These are all accidents that include operator malfunction in one way or another. The 1993 Newport accident was a direct consequence of maintenance deficiency. Despite this, human fallacies rarely trigger large-scale catastrophes by themselves. However, they often interact with so called latent conditions to cause incidents or accidents (Reason, 1990). The latent conditions are comprised of hard-to-detect, built-in organizational conditions, derived from well-founded, legitimate decision making. These conditions require certain circumstances to be contributing factors in the causation of an accident. It could for example be physical factors like the construction and organization of a chemical plant, or conceptual factors like manufacturing routines or budget allocation (Akselsson, 2014). These kind of factors may be part of a problem that contributes when other factors line up in a bad way. A famous model for the interaction between human error and latent conditions is the Swiss-cheese metaphor (Reason, 1990).

1.3.2. Cognition

To be able to understand the diverse and fine-tuned aspects of how human error occurs, a short introduction to human cognition and perception is given. Also the perspective of expertise and different ways to error, are presented.

1.3.2.1. Perception

A basic definition of perception is the mental interpretation of an object or idea. How a person perceives a situation or a piece of information is dependent on external factors like stimuli via the sensory organs, and internal factors such as expectations, individual decision making and problem solving and other mental processes like long- and short term memory (Goldstein, 2009). Hence, knowledge is very important since it lays the groundwork for how the information is perceived. Sometimes however, it contributes to misunderstandings and misinterpretations because the person for instance, “heard” what he expected to hear and not what was actually told (Akselsson, 2014).

Understanding the concept of perception require some prior knowledge of the difference of long- and short term memory as well as the sensory memory. Essentially one can say that the sensory memory possess iconic, acoustic and tactile memory which are active less than two seconds after the contact with the corresponding stimuli. After this, the signal is basically transferred to the short term memory where one become aware of the information. Nevertheless, in order to remember the information for a longer period of time, the information needs to be repeated and eventually, it will be placed in the long term memory (Akselsson, 2014). These three different types of memories all enable different ways to error which will be described after an introduction to what is meant by expertise.

1.3.2.2. What is expertise?

A workers level of expertise highly influence both the frequency of errors and the type of errors being made. The model by Rasmussen, illustrating information processing, is often used to explain the basics of the concept. This model consist of three different layers in which the human mind process information depending on the level of expertise (Rasmussen, 1982). The three layers are skill-, rule- and knowledge-based performance, hence, it is often referred to as the SRK-model.

If a person is an expert, the performance is at the skill-based level which means that he has experienced the situation several times before and does not have to think about how to solve the problem. If a person on the other hand acts at the rule-based level, he has to follow rules which he has learned are matching certain situations. If a person is at the knowledge-based level, he has never experienced the type of information before and has to process the information in a laborious way, via for instance, calculations and logic reasoning. In general, Rasmussen concludes that human beings have great potential at working at the skill-based level. We can, without thinking, and if we have encountered the task several times before, process and conduct plenty of tasks at the same time. However, when it comes to knowledge-based performances, it requires a tremendous effort and we are very restricted in what we can achieve. A definition of an expert, stated by the author could then be:

A person that have a lot of knowledge and experience in the type of work carried out, so that he can perform several difficult activities on a skill-based level and can therefore allocate his knowledge-based level to even more difficult subjects.

Regarding the frequency of errors, humans conduct much more work on skill- and rule-based levels than on the knowledge-based level. As a result, the absolute frequency of errors is a lot higher at these levels. However, when working at the knowledge-based level, the risk of human error is much higher than that of the skill- and rule-based levels, hence, the relative frequency of errors are much higher at the knowledge based-level. In the following section, the different types of error are presented and linked to the different levels of performance.

1.3.2.3. Different ways to error

As mentioned, the different types of memories as well as the different levels of expertise highly effects how prone for human error a certain situation is. In general, one can say that the types of errors reflects the level of expertise. Hence, there are three main groups of errors, skill- rule- and knowledge based errors.

Skill-based errors

These types of errors comprise, in the daily work, a vast majority of the human errors. The kinds of errors made here are typically inattention errors in monitoring or in similar types of work which does not require very hard focus. The errors are most often made when a task very similar to a standard routine is supposed to be performed. A slip of inattention may cause the worker to subconsciously end up doing the routine work instead of the task he was supposed to do. These kinds of effects are often referred to as “Strong-but-wrong”-routines. The temporary inattention may be caused by either situational factors or Performing Shaping Factors (PSFs), which will be described in chapter 1.3.4.

Rule-based errors

These are rather common errors and typically “Strong-but-wrong”-routines where an individual is selecting a rule, or set of rules, which previously have been seen to work. It does, however not, necessarily suit the current situation and may therefore cause an error. The likelihood for these kind of mistakes increases if, for instance, signal background noise is frequent. This may cause plant operators to dismiss signals that are against the use of the rule. The “first exception” is a big reason for rule-based errors. When operators are faced to a new type of information, it is not uncommon that the regular set of rules are used anyway. The Oyster Creek accident is an example of when a rule-based error partially caused an accident.

Knowledge-based errors

Knowledge-based errors consist typically of errors in advanced problem solving and are therefore often hard to predict. They usually arise from an exaggerated self-trust or by putting focus on wrong information, or a too small part of it. The short term memory also has a restricting impact which usually is very critical. Knowledge-based errors are especially induced if a lot of information has to be dealt with simultaneously (Akselsson, 2014).

1.3.3. Three maintenance strategies

When it comes to safety, efficiency and economy in the chemical process industry, maintenance strategies is a key aspect. Worn out process equipment, from safety valves, alarms, level-, flow-, heat- and pressure indicators to filters, bulks, heat exchangers, pumps, stirring devices, tanks, pipes, etc. have to be maintained from time to time to ensure their function and safety. However, not all maintenance work require the plant to be shut down. In the literature to date, one finds several different maintenance strategies and concepts. In order to keep the methodology at a reasonable scope, three main strategies are considered. These are Corrective Maintenance (CM) (Paz & Leigh, 1994), Proactive Maintenance (PM) (Gits, 1992) and Total Productive Maintenance (TPM) (Nakajima, 1988).

1.3.3.1. Corrective maintenance (CM)

Corrective Maintenance (CM) is performed as an immediate measure when a component fails. For this type of maintenance, the equipment is said to have run to failure. The need for this inevitable type of maintenance is more often than not, crucial, sudden and urgent, and can be seen as a "firefighting" type of maintenance (Paz & Leigh, 1994). Since component failure never can be 100 % accurately predicted, CM is never to be ruled out completely. Although it should, in most cases, be held as low as possible (Swanson, 2001), a successful approach to CM is very important. An inefficient approach to CM may not only be the causation of manufacturing downtime, but could also increase task related pressure and the degree of emergency potential for the maintenance workers, which in turn increase the risk for human error.

1.3.3.2. Proactive maintenance (PM)

The preferred definition of Proactive Maintenance (PM) is found in Swanson (2001). It is a strategy designated to predict at what time components will fail. PM is sometimes subdivided into preventive (condition based) and predictive (time based) maintenance. Both subcategories have the same intention, but differ in the criterion when maintenance is supposed to be taking place. In preventive maintenance (Gits, 1992), component lifetime statistics are used to calculate the time of maintenance, whereas predictive maintenance (Vanzile & Otis, 1992) focuses on measuring process parameters and perform maintenance only when the parameter fluctuation is unacceptable. The big drawback with PM is still considered to be the necessity of costly manufacturing downtime. Yet, the advantages e.g. reduced risk of component breakdown and prolonged equipment lifetime, are to be appreciated. Studies reveal correlations between a healthy approach to PM and successful industrial performance (Swanson, 2001).

1.3.3.3. Total Productive Maintenance (TPM)

In the late 1980s, the paradigm of industrial maintenance began to include a more aggressive attitude towards maintenance. Where CM and PM are concepts focused directly at industrial maintenance, the Total Productive Maintenance (TPM) strategy uses a more holistic point of view. The notion of the concept is founded in teamwork among different groups of workers (Maggard, 1989). Involving production employees in the maintenance tasks, normally carried out by maintenance mechanists, is thought to teach the plant operators to do quick-fixes, clean-ups and inspections, thereby enhancing continuous improvement (Nakajima, 1988). If the operators increase their knowledge regarding how equipment, machines and measuring devices ought to function and grasp the idea of the design, there is a greater chance they notice and fix imperfections during their daily work. Although production employees may execute maintenance tasks they can handle, maintenance mechanists are still required for critical tasks. Furthermore, the informational trade is mutual. This means that, during the collaboration including different staffs, the production employee meanwhile teach the maintenance personal about the plant peculiarities, what to do, and what not to do.

According to Maggard & Rhyne (1992), a pilot study made on a Tennessee Eastman Company plant showed that operators, with just some additional training, could perform 80 % of all maintenance. The same source also claims that 75 % of all maintenance related problems can be prevented at an early stage using the TPM strategy. Although TPM may not entirely prevent unforeseen and surprising events, it is a seemingly good approach to maintenance and yet another study revealed well-defined correlations between TPM and industrial performance (Swanson, 2001).

1.3.3.4. Concluding remarks on maintenance strategies

Traditionally it has been easy for plant managers to recognize the short term economic perks of CM. About 60 years ago, focus switched towards more precautionary measures like PM and in the late 1980s

TPM was introduced in order to reduce the amount of CM as much as possible (Dunn, 1998). The general idea was that a safe and steady production is better than high risk and capacity fluctuations, even though it comes with higher costs for maintenance.

CM, PM and TPM are each thought to be used as one part of the total and successful maintenance approach, hence, using only one of them is either very risky and irresponsible or plain insufficient. The authors' belief is that a successful overall maintenance policy should include successful approaches to all the three strategies. This will be described more in the chapter 2.4 "Maintenance strategies".

1.3.4. Performing Shaping Factors (PSFs)

The human mind and internal processing is not always seen as a risk factor. In fact, in many systems the flexibility that is human decision making and behavior, it is seen as one of the most crucial factors to why incidents are avoided (Akselsson, 2014). On the contrary, there are numerous studies made in the fields of psychology and psychosocial aspects on human behavior which address human failure and its role in industrial accidents, for instance (Rasmussen, 1982), (Bello & Colombari, 1980), (Mackieh & Cilingir, 1998) and (Boring, 2010). In the studies mentioned, a number of so called Performing Shaping Factors (PSFs) are discussed thoroughly. Unfavorable "settings" of these factors have been found inducing human error, hence, increasing the frequency of these kind of fallacies. Depending on the level of detail, the number of PSFs discussed in papers varies between "single factor models up to 50 or more PSFs" (Boring, 2010). To keep the master thesis at a reasonable level of difficulty, five PSFs are chosen. These are: (1) mental stress, (2) ergonomics, (3) worker competence, (4) degree of emergency potential and (5) degree of attention required. Measuring and analyzing these five PSFs are the major part of this questionnaire-based, semi-quantitative methodology. Below some theory and the way of measuring the PSFs are presented.

1.3.4.1. Mental pressure – level of stress

The interdisciplinary research field of mental well-behavior and stress are of interest in several applications, for instance, (Cohen, et al., 1983), (Smith, 2003), (Foa & Meadows, 1997) and (Nater, et al., 2005). There exist numerous models and methods that address to explain and simplify the notion of stress. Frequently used models to view stress are for instance, (Karasek, et al., 1981) and (Yerkes & Dodson, 1908). What every paper, model and description of stress seem to agree on, is that stress is a perceived loss of control, following the feeling of demands exceeding the coping ability. Here, the “demands” are referring to the mental load due to the task to be performed, but also due to individual- and work related psychosocial aspects, which both could be further characterized. The “coping ability” is referring to the individuals’ perceived ability to handle the situation. This includes features such as, knowing one have managed the task before, self-confidence and social support. Rubenowitz (2004) concentrates a successful psychosocial work environment into five items, namely:

- High individual job decision latitude/control
- Positive company management attitude
- Stimulating tasks
- Positive working climate among colleagues
- Reasonable level of demand

Several papers have attempted to measure stress, some of these are reviewed by Kopp, et al. (2010). The nature of the concept “stress” makes it highly notional which leads to weaknesses and pitfalls in some of these methods. The validity and reliability of some of these instruments appear to be questioned (Kopp, et al., 2010). Thus, the reader ought to keep in mind the difficulties in measuring the level of stress. Out of the reviewed tools to measure stress, Cohen, et al. (1983) stands out to fit the purpose for this application the best. Also, it does not deviate much from the model design for measuring the other PSFs. Moreover, it is also appraised by the Cohen, et al. (1983) to be both valid and reliable. With some slight changes, the design of the questions elucidating the level of mental stress in this methodology is based on the principles used by Cohen, et al. (1983) as well as the items defined by Rubenowitz (2004). The questions can be seen in the appendix and the outline of the assessment and answer evaluation is described further in the chapter “Methodology”.

1.3.4.2. Ergonomics – level of workspace suitability

It is a well-founded fact that ergonomics, work environment factors, affect the quality of the worker performance in several different fields (Lin, et al., 2001) and (Robertson, et al., 2008). In this application, ergonomics is defined as the definition stated by the International Ergonomics Association (IEA) as “*The scientific discipline concerned with the interaction between humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.*” (IEA, 2011). This includes physical features like lighting, noise, posture and vibrations (Akselsson, 2014). However, when discussing ergonomics, intricate factors such as the outline of the user interface of man-machine systems are sometimes left out. In the maintenance industry, the man-machine system is, as later will be declared, of outmost importance. Consequently, this feature is included in this methodology.

The physical features disturb cognitive processes and thereby increase the difficulties of a task. For instance, a loud work environment may be the root to problems in the instant and indispensable communication between two or more maintenance workers. On the other hand, the design of the user interface of a man-machine system is a more complex and unpredictable source of error. To be successful, the interface design, including both hardware and software design, should create and enhance logic reasoning by the user. This would facilitate and increase the performance of the operator. It could for instance be the outline of information indicators or control devices, but also a display showing only the necessary information in order to prevent misinterpretations.

There are plenty of tools aiming to measure ergonomics, for instance, (Reynolds, et al., 1994), (Bello & Colombari, 1980) and (Keyserling, 1986). The RAMP-methodology (Rose, 2014) is a very detailed method focused on elucidating the health risks in the working environment to prevent an unhealthy and unsafe workspace. The method gave inspiration since it contains features which are valid for this application even though some aspects are left out. In this methodology the following aspects are going to be semi-quantitatively evaluated:

- Noise
- Lighting
- Vibrations
- Man-machine interface
- Posture

The questions can be seen in the appendix and the outline of the assessment and answer evaluation is described further in the chapter "Methodology".

1.3.4.3. Worker competence – level of expertise

As previously mentioned, the level of expertise affects both the frequency of human errors as well as the types of errors made. Rasmussens SRK-model illustrates the outlines of the concept (Rasmussen, 1982). A high level of expertise is in general favorable. This master thesis view expertise as a combination of education and experience in the current field of work. For instance, if the worker performing maintenance has some theoretical knowledge of the background hazards and the chemistry taking place it would appear as they would take more precautionary measures than they would have done otherwise. Greater experience in the work field would enable the worker to perform more tasks at a skill-based level which would improve efficiency but also give the worker a bigger set of tools to handle surprising and obscure turn of events (Rasmussen, 1982). The questions can be seen in the appendix and the outline of the assessment and answer evaluation is described further in the chapter "Methodology".

1.3.4.4. Maintenance strategies – degree of emergency potential

As described in the section regarding maintenance strategies, the degree of emergency potential will be evaluated by analyzing the company approach to three different maintenance strategies; corrective maintenance (CM), proactive maintenance (PM) and total productive maintenance (TPM). The questionnaire-based model will address this by asking questions aimed to reveal the average degree of emergency potential. A healthy and successful approach to CM, rendering in a high Grading Point (GP) for the CM strategy, would for instance, require good preparedness for unforeseen events, but also that such events (giving short periods of downtime) are very infrequent and that there is a well-established policy for replacing process equipment before it is worn out. Successful PM is characterized by the frequency of preplanned downtime, that downtime is announced far in advance (to increase personal awareness) and that the task-related pressure is minimized. A high grade in TPM strategy requires five different dimensions to be obtained, namely, training in simpler maintenance tasks for process operators, high overall maintenance awareness, instructions of maintenance during production uptime and an implemented company maintenance policy. The questions can be seen in the appendix and the outline of the assessment and answer evaluation is described further in the chapter "Methodology".

1.3.4.5. Type of maintenance work – degree of attention required

As mentioned, the fifth PSF is the degree of attention required. Along with the theory of the SRK - model by Rasmussen (1982) as presented above, a high degree of attention required implies greater risk for human error. A way to view the "Degree of attention required" is to examine the composition of different types of maintenance works. This was partially done in a recent report by Berntsson, et al. (2013). Four different characteristic maintenance events was considered to induce the task complexity differently, and thus also the risk for human error differently. These are (A) heavy lifting (such as stealth construction works), (B) hot maintenance works (works requiring flames or very hot temperaturs, like welding and, to some extent, assembling), (C) inspection works and (D) “cold” maintenance works (works not requiring hot temperatures, for instance, installation of instruments and electric components). The report denoted complexity factors according to table (1) below. These are used in order to calculate the grading point. The questions can be seen in the appendix and the grade scoring system can be viewed in the chapter “Methodology”.

Table 1. The different maintenance works and their denoted complexity factors by Berntsson, et al. (2013).

Type of work	**Heavy lifting**	**Hot works**	**Inspections**	**“Cold” works**
Denoted complexity factors by Berntsson, et al. (2013)	3	2	1.5	1

2. Methodology

As mentioned, the master thesis aims to present a questionnaire-based methodology evaluating the risk of human error during industrial maintenance using a semi-quantitative Grading Point-system. The five Performing Shaping Factors (PSFs) that are to be measured constitute various numbers of dimensions. In this section, the use of the questions as well as the semi-quantitative grading point system awarding each PSF with a Grading Point (GP), are declared. The two questionnaires can be seen in the appendix.

2.1. Level of stress

The level of stress can obviously be viewed in several different perspectives. In the IMPART – methodology, the level of stress is measured by elucidating five work related dimensions (A-E) as well as one individual dimension (F). These are (A) decision latitude (question 18; 27), (B) stimulating tasks/reward system (question 19; 23; 24), (C) working climate (question 21; 25; 26), (D) experienced workload/demand (question 20; 22; 29; 30), (E) company communication (question 28) and (F) individual psychosocial stress (question 31; 32; 33). To which extent the workers feel these statements to be correct will give the answers to these questions as a number (1-5). This will give the GP for each dimension according to equation 1.

$$GP_i = \overline{x_i} \qquad \text{(eq. 1)},$$

where $\overline{x}_i$ is the average response of the questions evaluating dimension i.

The overall grade of "Level of stress" will be given according to equation 2.

$$GP_{stress} = \frac{\sum_1^5 GP_i}{5} \qquad \text{(eq. 2)}$$

2.2. Ergonomics

The level of ergonomic suitability is also measured in five dimensions, namely (A) lighting (question 12; 13), (B) noise (question 9; 10), (C) posture (question 7), (D) vibrations (question 11) and (E) man-machine interface (question 14). Question 8 is used in order to evaluate the validity of the overall ergonomics questionnaire. If question 8 receives a high grade, there should also be a high grade on at least one of the measured dimensions. If not, this PFS should be measured in a different way. Question 15-17 are used in a similar way to validate the scoring system in the PSF "Types of maintenance work".

Note that the grading system in the ergonomics section is reversed, meaning that, in this section the questions were asked in a way that the answer "1" is the best answer and "5" is the worst. In order to reduce confusion when presenting the results of the study, the answers will be transposed to Grading Points according to equation 3 so that this PSF follows the same outline as the other PSFs.

$GP_i = 6 - \overline{x}_i$ (eq. 3),

where $\overline{x}_i$ is the average response of the questions evaluating dimension i.

The overall grade of "Level of ergonomics" will be given according to equation 4.

$GP_{ergonomics} = \frac{\sum_1^5 GP_i}{5}$ (eq. 4)

2.3. Worker competence

In the IMPART – methodology, the level of competence is comprised of two dimensions only. These are the working experience, which is estimated by the number of years in the current profession (question 2) and educational level (question 3). The individual workers' level of experience will be graded as follows:

- 0 – 2 years = 1 GP
- 2.5 – 5 years = 2 GP
- 5.5 – 10 years = 3 GP
- 10.5 – 20 years = 4 GP
- 20.5 < … = 5 GP

The educational level will be evaluated by stating six levels of education, for each level passed, one point will be received in the semi-quantitative scoring system. Noteworthy is that only five educations will have to be fulfilled in order to achieve the top grade. The educational level "choices" will be as follows:

- Elementary school or similar
- High school or similar
- Bachelor degree in chemistry, mechanics or related field
- Vocational training
- In-house training at the company
- Other:

The Grading Point of the PSF "worker competence" is estimated by calculating the average responses for the two dimensions presented above.

2.4. Maintenance strategies

As described in the background theory, the questions elucidating the overall maintenance strategy aim to reveal the degree of emergency potential. These questions compose a separate questionnaire, which is to be answered by the employees responsible for maintenance. As mentioned, three strategies are evaluated, corrective maintenance (CM, question 3; 4; 5 and 11), proactive maintenance (PM, question 2; 10 and 11) and total productive maintenance (TPM, question 5-9). The questions aim to reveal the company strategy with respect to these three types of maintenance.

CM consist of four dimensions, (A) the frequency of short periods of downtime, (B) preparedness, (C) company policy and (D) task related pressure. (D) is not to be confused with the PSF "Level of stress", which not measure the same kind of pressure.

Three dimensions comprise PM, (A) the frequency of extensive, preplanned downtime, (B) far in advance announcement of preplanned downtime in order to increase personal awareness and, (C) minimization of task-related pressure.

The TPM strategy is measured in four dimensions, (A) company policy, (B) maintenance training for process operators, (C) overall maintenance awareness within company and, (D) instructions of maintenance performance during production uptime.

Each of the three strategies will receive a GP by calculating the average answers of the relevant questions. The overall GP will be received from equation 5.

$$GP_{strategy} = \frac{\sum_1^3 GP_i}{3} \qquad \text{eq. (5),}$$

where i is the three strategies

2.5. Type of maintenance work

The questions evaluating the types of maintenance work are used to reveal the degree of attention required. The answers are given as a number (1-5), “5” being “very frequent” and “1” being “almost never occurring”. As described in the theory section, the answers will be weighted with the denoted complexity factors presented by Berntsson (2013) showing in table 1. Equation (6) is used to calculate the grading point. Question 15-17 in “Questionnaire 1” are used to validate the complexity factors.

$$GP = 6 - \frac{\sum_1^4 CF_i * X_i}{\sum_1^4 CF_i} \qquad \text{eq. (6),}$$

where CF is the complexity factor, i is the type of work carried out and X is the average answer (in the range of 1-5) given by the workers.

3. Results and discussion

In this section, the resulting Grading Points (GP) of the PSFs will be presented and discussed. First all PSFs are presented together to give an overview of the results. After that, the results for each dimension measured of the PSFs will be presented. Differences between different groups of maintenance workers will be identified. But first a short introduction to the company examined.

3.1. Company examined

The company examined is a multinational, successful company, meeting high requirements of maintenance. Partially active within the petro industry and with more than 200 employees as well as various chemical reactants and products, the site has to follow the Seveso-directives.

Out of the 16 respondents of Questionnaire 1, six were non-specified maintenance workers (MW) including one “inspection manager”, five were electricians (E), two were maintenance mechanists (MM), and three were instrument engineers (IE).

As instructed, all (seven) respondents of Questionnaire 2 were managers with slightly different areas of focus. All however, with insight into maintenance.

3.2. Overview of all PSFs

In figure (1) the overall results of the investigation are shown. By the looks of this figure, no PSF is clearly distinguished and the settings of the PSFs seems to be around average, between level three and level four. The overall mean value of the PSFs is 3.4 which means there is most definitely room for improvement, even though the company seems to be fairly well aware of these matters already. In order to be able to know how to achieve higher levels of the different PSFs a more in depth analysis is performed. The results from the different categories of workers are shown separately in figure 2. Here it is evident that the degree of attention required as well as the levels of ergonomics and worker competence vary among the groups. These graphs are merely thought to be an overview, in the following sections it will be a more detailed comparison.

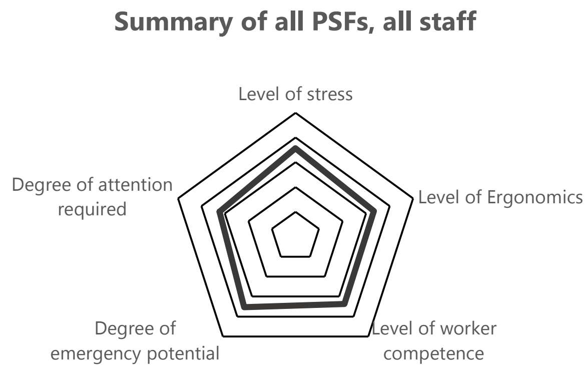

Figure 1. Summary of the PSFs (mean value 3.4) as an average of each of their specific dimensions. In the graph all four categories of workers were included to see their overall experience of the situation. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

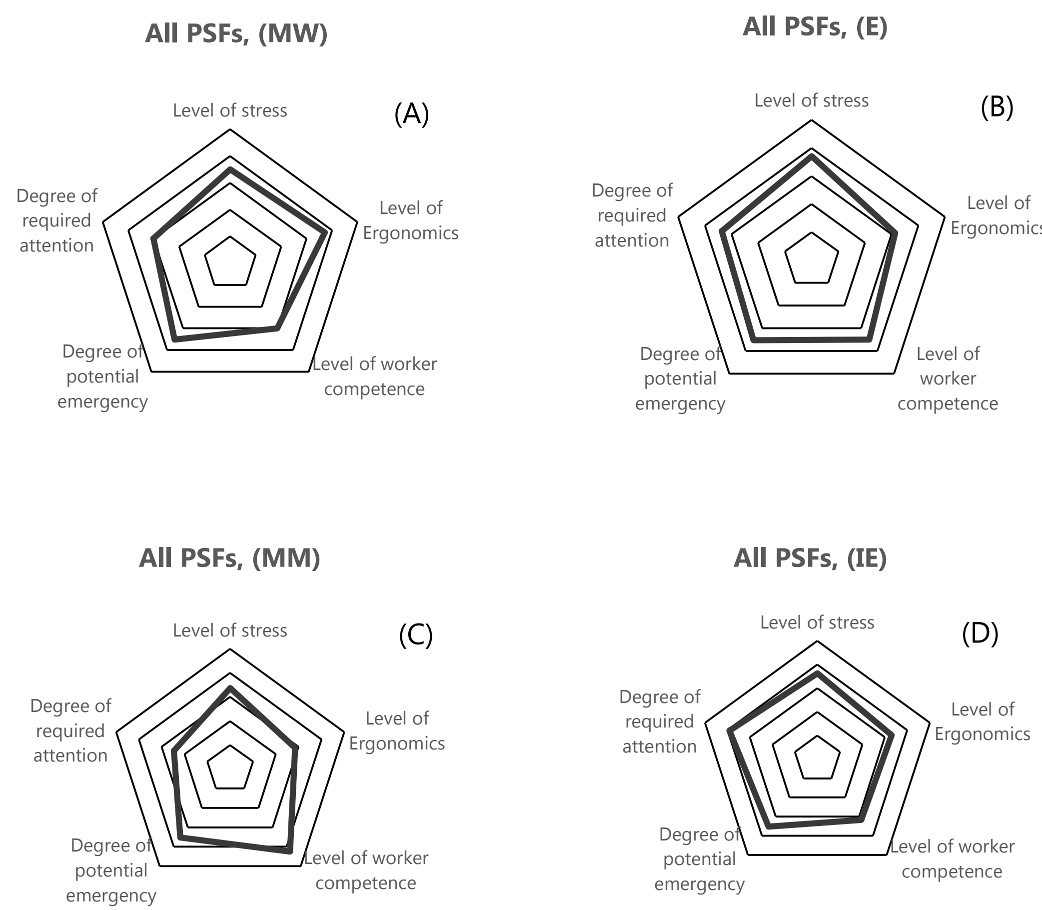

Figure 2. Summary of each PSF for the four different categories of workers. Non-specified maintenance workers (A), electricians (B), maintenance mechanists (C) and instrument engineers (D). Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

3.3. Mental pressure – level of stress

The results of the different dimensions of the workers level of stress are presented in figure 3 below. Note that in all cases, the higher the GP the better. Looking only at the overview graphs presented above, no interesting data are found on the level of stress. However, the results on the different dimensions of stress reveals several notes.

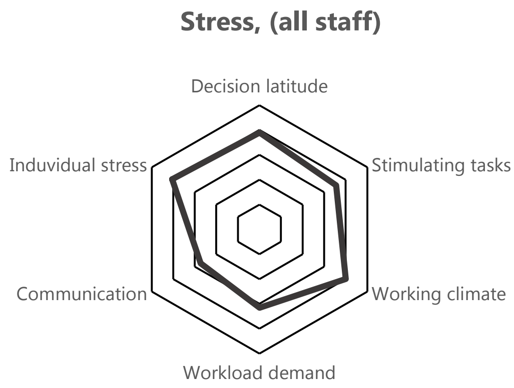

Figure 3. Summary of the PSF stress for all of the four categories of workers. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

As seen in figure (4), there are indications that all groups of workers experience the dimensions of individual stress, decision latitude and stimulating tasks in a rather successful way. This means that there is little impact of the workers personal stressors during their daily work and that they experience a healthy level of stimulation and self-control when performing their work. Nevertheless, the three remaining dimensions are topics for discussion.

There seem to be complications unfolding due to communication problems. The electricians, being the most prominent group, merely surpasses the average GP with a small margin. The non-specified maintenance workers (2.4) and the maintenance mechanists (2.5) are contributing the most to the low GP. Described in the questionnaire as "*company communication, reducing the risk of misunderstandings*" it would have you believe that these kind of problems are not at all rare. Maybe even that events or incidents have occurred at the company due to this reason. Where and when these kind of misunderstandings occur are not revealed. One possibility is that lacking information in top-down communication within the company when introducing new rules or regulations, presents new uncertainties at the sharp end. Another possibility is that the misconceptions occur internal, within the different groups of workers, in that case it is most likely immediate, direct communication difficulties when performing tasks requiring focus from several actors. This problem has to be investigated further by the company.

The level of workload demand is also an area where the answers are not completely satisfying. Once again, the group of electricians stands out. Although, this time as the far lowest of the groups. While the three remaining groups show rather positive results the electricians seem to experience a high level of workload demand, thereby increasing stress and the risk to fail when performing maintenance tasks. One suggestion that could solve the issue would be to increase the electrician manpower, most likely reducing the experienced workload demand and thus, increasing the GP.

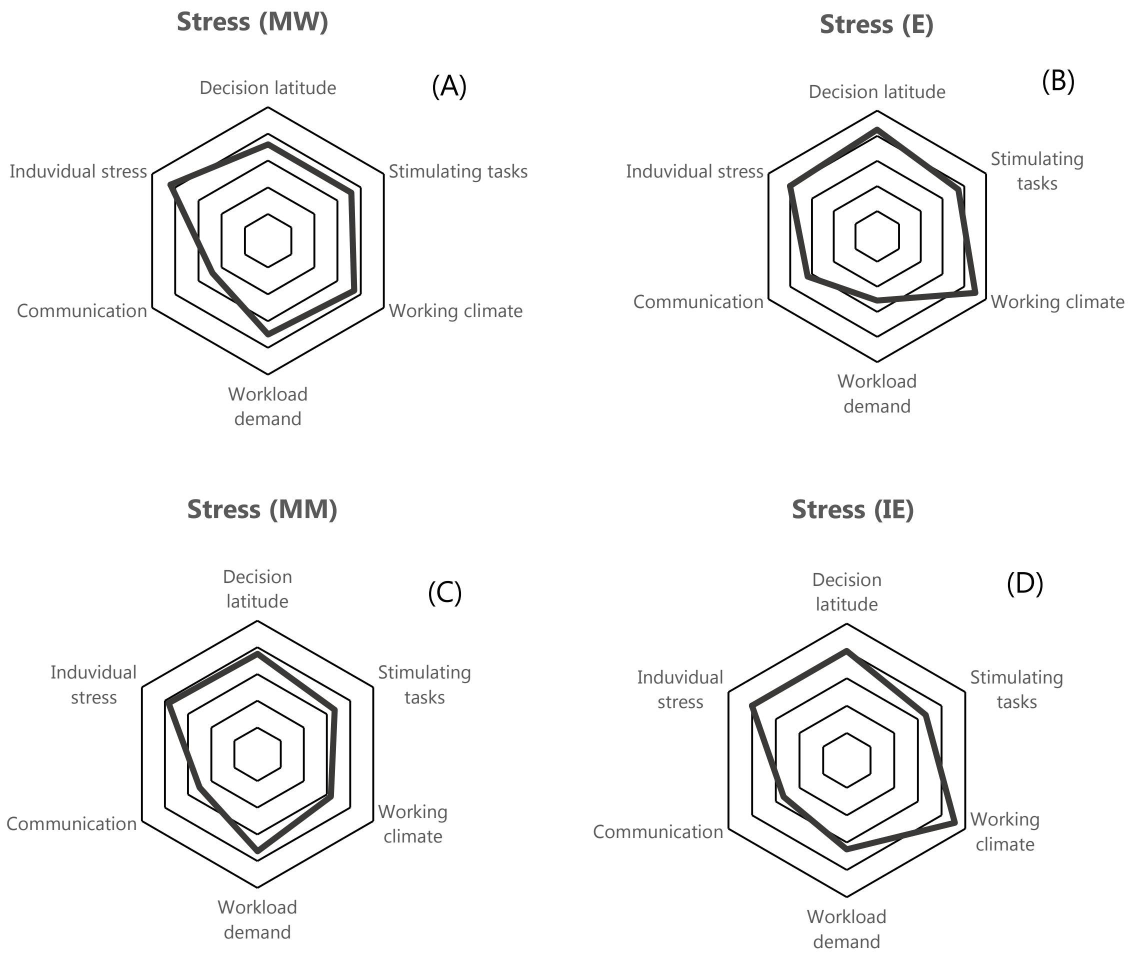

Figure 4. Summary of stress, separating the four different categories of workers. (A) Non-specified maintenance workers, (B) electricians, (C) maintenance mechanists, and (D) instrument engineers. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

Additionally, there is one more worrisome piece of information revealed regarding the level of stress. Although, the dimension of working climate receives high GPs, the highest value of standard deviation

(1.3) make the answers conspicuous. The questions elucidating this dimension bring especially up the frequencies of harassments and conflicts. Regarding harassments, three workers claim this is, or has been, experienced. If this is the case, it strongly contributes with a negative impact on the working climate as well as the level of stress. This matter is, for several obvious reasons, clearly worth looking into by the company. Moreover, regarding conflicts, the highest standard deviation for any single question (1.5) reveals the workers diverse view in this area. This could mean that certain employees are more prone to engage in conflicts than others, the severity and consequences of these conflicts are however not clarified or revealed. This is also a suggested area for the company to address with further investigation.

3.4. Ergonomics – level of workspace suitability

The results of the workspace suitability is shown in figure 5-6 below. The greatest overall ergonomic risks for human error at this company seem to be exhausting postures and loud workspace environments. On a brighter note, hassles caused by lighting, vibrations and man-machine interfaces seem limited. These three factors are able to interplay, though it appears to be no trouble at this company.

Long hours, requiring awkward postures, tear both physically as well as psychologically on the performer, no matter the task. Due to the very nature of the task that is to be performed, such intricate, yet very direct sources of error, are not always easy to take measures against. However, if the problem is anthropometric aspects influencing the postures of workers, adjustable equipment that can suit or fit various sizes or heights of people could be suggested (Akselsson, 2014). Another way to diminish the posture-related problems is to ask the workers about what measures they would recommend. Not only could this help to solve the very problem, but could also recover the workers experience of their employer (which currently seems to be at average) as well as increase the overall acceptance of tasks requiring exhausting postures and thus, improving the quality of the performance (Lin, et al., 2001).

Physical ergonomic factors such as a noisy workspace environment, as all groups of workers seem to experience, disturb the cognitive processes and may give rise to misconceptions or incorrect interpretations of information (Akselsson, 2014). In a treacherous interplay with factors such as stress and difficult tasks, loud workspace environment may contribute to increased risk for human error. Keeping in mind the apparent communication deficiencies discussed in the previous section, the loud workspace environment could perhaps be a root cause to the problem. Since the noise of working machines or welder machines could be hard to extinct, combined earmuffs and headsets could serve as an improvement to these factors, if not already in use. Whichever the case, this matter is still worth looking into by the company.

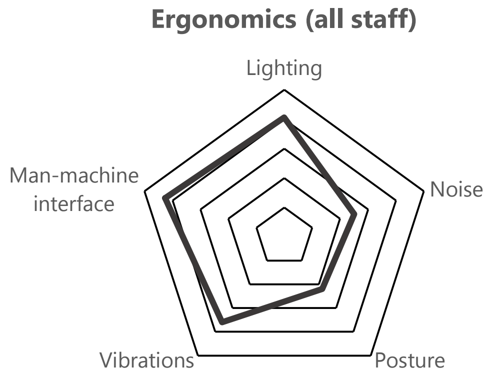

Figure 5. Summary of the PSF ergonomics for all of the four categories of workers. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

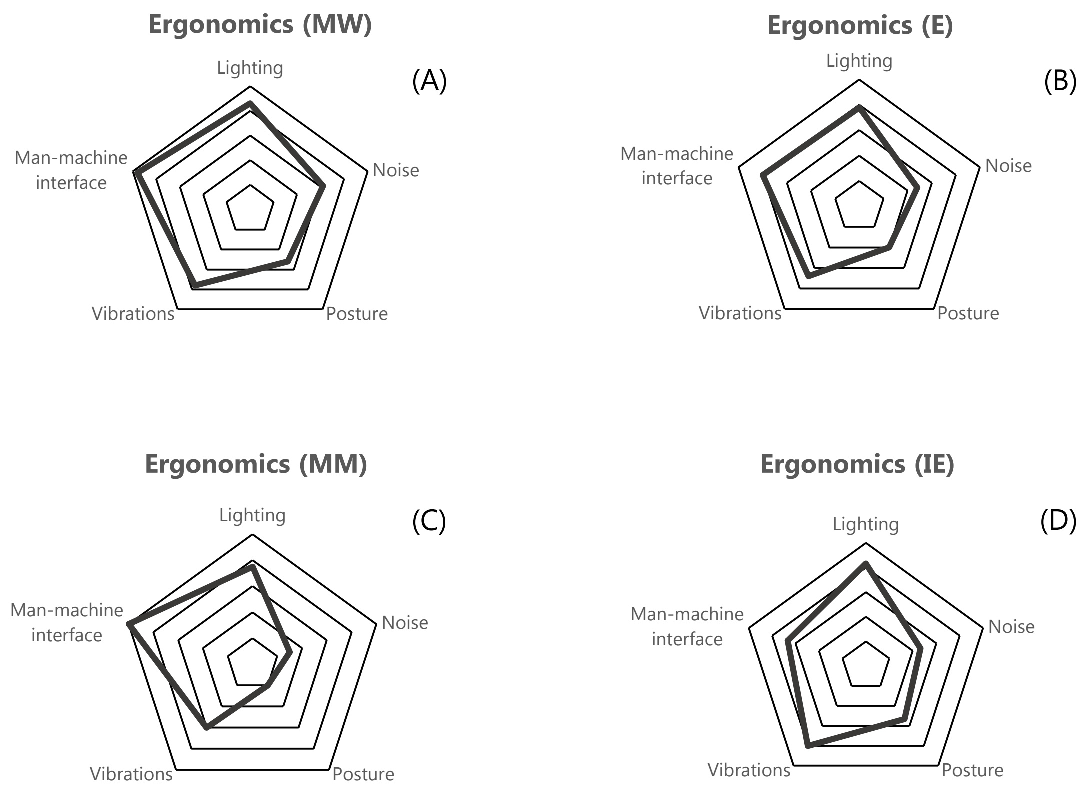

Figure 6. Summary of ergonomics, separating the four different categories of workers. (A) Non-specified maintenance workers, (B) electricians, (C) maintenance mechanists, and (D) instrument engineers. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

3.5. Worker competence – level of expertise

The results of the level of expertise and its' two dimensions (experience and education) are shown in table (2). The answers show that the workers have great experience including several years at the position or a similar position based at a different company. This experience entails capacity to handle obscure, uncommon events in a more calm and reasonable fashion (Rasmussen, 1982). Although the level of experience is high, the general level of education of the workers is low which also affects the level of competence. A measure to increase the level of education, and thus also the level of competence, is for example to provide the workers with "in-house, company-based" training (internutbildning). When recruiting, another measure is to hire workers with prior knowledge from one or two years of vocational training (yrkesutbildning). This is recommended since the answers reveal that only three out of the 16 workers possess this level of education.

Evidently, the workers were not fully aware of how to answer the question of education. The outcome may therefore be somewhat influenced by the confusion even though the GP was adjusted to diminish the effect. This was done by adjusting the answer to what was unmistakably the intended answer. For instance, if only the level of "highschool" was marked, the level of "elementary school" was added to the GP since the highschool-level only would have been possible if the elementary-level was completed.

Table 2. Showing the Grading Point for the level of competence as an average of the level of experience and the level of education.

Worker category	Level of experience	Level of education	**Level of competence**
GP, all staff	4.3	2.5	**3.4**
MW	4.0	2.0	**3.0**
E	4.6	2.4	**3.5**
MM	5.0	3.5	**4.3**
IE	3.7	2.7	**3.2**

3.6. Maintenance strategy – degree of emergency potential

As seen in figure (7A), the approaches to all three maintenance strategies considered in this methodology, are graded between three and four GP, with the approach to CM barely being more prominent than the two others.

Outlining the four dimensions evaluated within CM (figure 7B), the experienced preparedness is undoubtedly experienced by the company to be very good. From the bosses' perspective, the overall manpower is said to be trained for critical situations. That is in line with the frequency of unplanned production downtime. Since this is stated to occur every now and then, the workers gets to practice these kind of events, thus increasing the preparedness. The reasons behind the unplanned periods of downtime are not revealed, however, those situations can never really be ruled out even though the company surly strives to keep the frequency at a low number. What is suggested is to increase the company ability to learn from these kind of events in order to prevent future incidents to occur (Jacobsson, 2012). The third dimension, company policy, also shows signs of opportunities for improvement. Most of the respondents give answers indicating that there is a policy for replacing parts and equipment before they fail or are broken, but that the policy is not very well implemented. This also goes in line with the frequency of unplanned downtime, assuming unplanned downtime occurs when a part fails. Thus, clarifying, and implementing the maintenance policy regarding precautionary measures, may give effects on both these dimensions. The fourth dimension aims to measure the task related pressure (not to be confused with the PSF "stress"). With a GP at about average, the answers uncover that fluctuations and insufficient production capacity are factors partially decisive for announcing preplanned downtime. Knowing about this arguably induces momentary pressure for the worker performing the tasks.

Discussing the dimensions of PM (figure 7C), it should be stated that there are no distinct lines separating the three dimensions. Rather, they should be viewed as three intercorrelated variables. Altering the settings of one of them will, to some extent, affect the two others. It can be concluded that the frequency of preplanned downtime is certain occur once every three years since every respondent gave the same answer. Given the fact that *unplanned* downtime is experienced from time to time, the frequency of *preplanned* downtime could perhaps be increased even though those kind of problems are not necessarily avoided completely. The same goes for the dimension of task related pressure, which is shared between CM and PM. This dimension is strongly affected by the frequency of preplanned downtime. For example, if preplanned downtime was to be done, let us say every second year, this would entail that announcement of downtime was less dependent on production capacity and therefore avoid some of the task-related pressure. This, of course, has to be weighed against the costs for production downtime. Regarding announcement of preplanned downtime, the company seems to be good at announcing far in advance. This, to some extent, increases awareness (dimension of TPM) and preparedness (dimension of CM), which also is reflected in the GP of these dimensions.

As mentioned, TPM (figure 7D) is no strict maintenance concept in the sense of CM and PM. It should rather be contemplated as a holistic strategy where the company team spirit, and cooperation among different groups of workers help to increase the overall knowledge, awareness and desire to assist each other in maintaining the plant during production uptime (Nakajima, 1988). The dimension of company maintenance policy, as already has been discussed, shows some opportunities for improvement. The striking shortfall of the TPM-approach however, appears to be the maintenance training of process-operators.

Improvement of the TPM-approach could be done by introducing explicit instructions of how maintenance is supposed to be performed during production uptime. Examples of these instructions could be what maintenance tasks that may be executed and by which groups of workers as well as how to perform the tasks. This could be accompanied by implementing (and perhaps, slightly altering) the company maintenance policy in a way that also enhances maintenance awareness. The policy could also include sessions of maintenance training for the process operators. These kind of implementations have been seen successful in previous studies (Maggard & Rhyne, 1992).

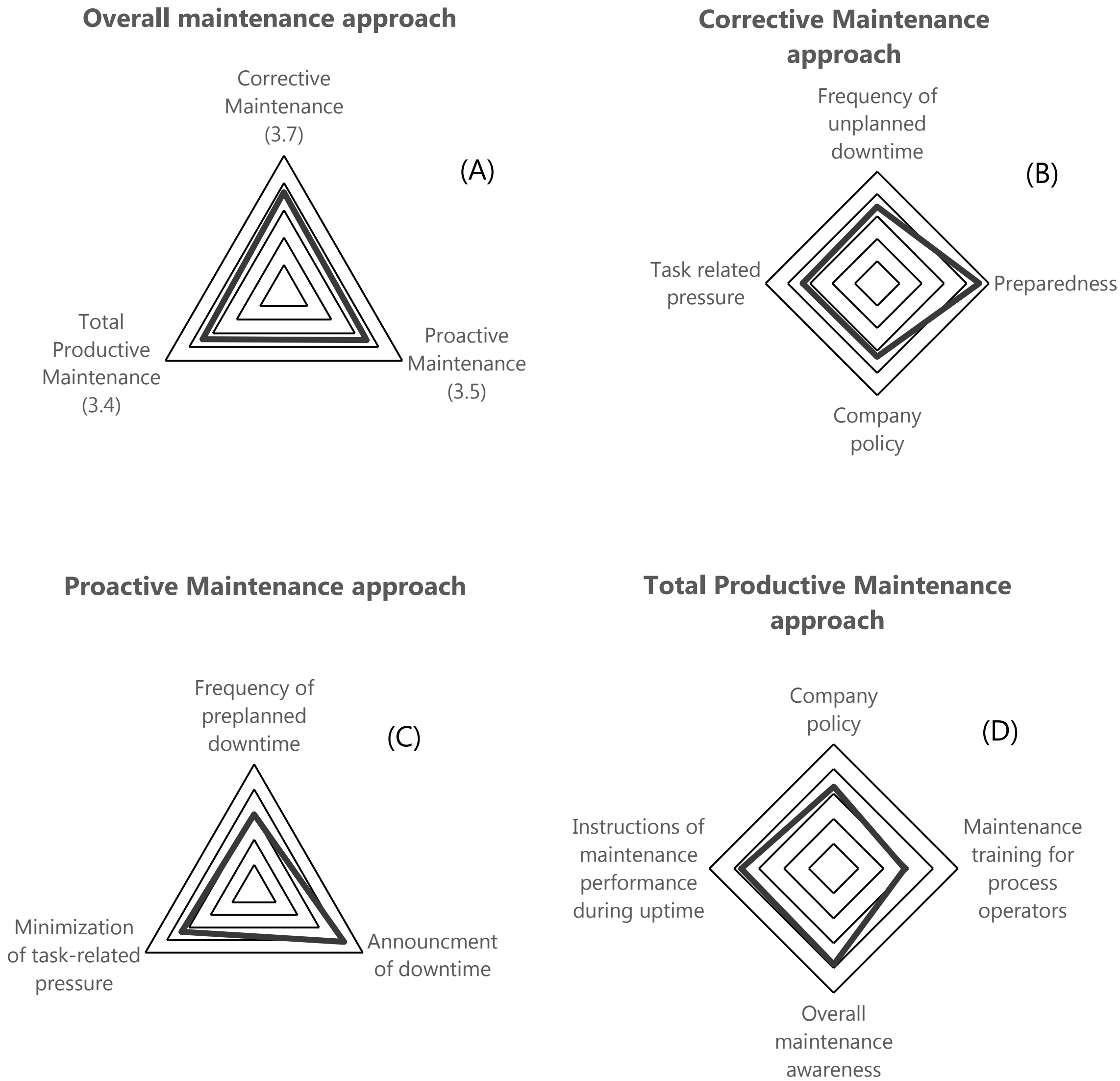

Figure 7. (A) Summary of the approach to the three different maintenance strategies CM, PM and TPM. (B-D) The dimensions of each strategy separate. Note that in all cases, the higher the number the better. Each line represents a Grading Point, 1 is the line in the center and 5 in the outskirt of the graph.

3.7. Maintenance works – degree of attention required

Initially it should be declared that it, of course, is somewhat impossible to alter the kind of maintenance works performed at a given plant. Requirements and legislations of safety have to be met, and in order to do so, the type of maintenance work is in most cases not the variable to change. In this methodology the degree of attention required is merely included in order to see the bigger picture and to enhance awareness in the matter, no actual measures will be suggested in this specific area.

As seen in table (3), cold works are the most frequent type of maintenance work for all groups of workers. From a safety point of view, this is favorable since these kinds of work have the lowest degree of attention required. Not to say that these tasks are done more easily, but the complexity factor (CF) and overall contribution to the risk for human error is more limited than any other category of maintenance work. Works in the category of "heavy lifting" is performed rather often which, on the contrary to cold works, have the highest CF. Especially the maintenance mechanists seem to have the highest degree of attention required in their daily work. The overall Grading Point lies at 3.2 when including all workers. As mentioned, this number is hard to increase but could serve as a comparison with the other four PSFs.

Table 3. The four categories of maintenance work considered in this methodology, their complexity factors, results and resulting grading points.

Type of work	Complexity factor	All staff	MW	E	MM	IE
Heavy lifting (X_1)	$CF_1 = 3$	2.9	3.2	2.5	4.0	2.0
Hot-works (X_2)	$CF_2 = 2$	2.4	2.6	2.3	2.5	2.0
Inspections (X_3)	$CF_3 = 1.5$	2.1	2.4	2.0	3.0	1.3
Cold works (X_4)	$CF_4 = 1$	4.3	4.0	4.8	5.0	3.7
$\sum_{1}^{4} CF_i * X_i$		20.8	22.4	19.8	26.5	15.7
$GP = 6 - \frac{\sum_1^4 CF_i * X_i}{\sum_1^4 CF_i}$		**3.2**	**3.0**	**3.4**	**2.5**	**3.9**

3.8. Concluding remarks

When concluding the semi-quantitatively estimated risk for human error during maintenance, the analysis can be concentrated to the following seven marks for improvement:

- Improve communication skills at all levels of the company and/or introduce measures that enable easier communication during task performance.
- Consider releasing some of the workload demand for electricians.
- Look into the worrisome information regarding harassments and conflicts.
- Increasing the overall ergonomic status for the workers by introducing favorable equipment and/or by asking the workers for recommendations or necessary equipment for releasing pressure from noise and exhausting postures.
- Enhance "learning efficiency" from incidents causing unplanned downtime to prevent these incidents in the future.
- Introduce the concept of TPM in the maintenance policy and establish instructions of how maintenance can be performed during production uptime.
- Give the process operators' in-house, company-based training in easier maintenance tasks.

4. Methodology evaluation

In this master thesis, the IMPART – methodology, a questionnaire-based tool for quick-scan use, has been developed to address the risk of human error during industrial maintenance. Asking questions revealing the view and state of maintenance workers, the methodology combines up-to-date research with the very core of the maintenance industry. In this section, the methodology will be evaluated and discussed with respect to validity, limitations, advantages, as well as possible further development.

4.1. Methodology validation

As mentioned, some of the questions in the questionnaire function as control of validation. Question eight in “Questionnaire 1” asked if there are any “general physical factors that are found annoying”. The answers were above average, giving the answer “Yes”. Since the methodology revealed that there, in fact, were two annoying physical factors, the answers of question eight validates what the methodology revealed regarding ergonomics.

Question 15, 16 and 17 were also used for validation. These validate the scoring of the complexity factors regarding the different types of maintenance works. The questions asked about the degree of attention required for (15) heavy lifting compared with cold works, (16) hot works compared with cold works and (17) inspection works. The answers were 3.5, 2.7 and 1.5 respectively. These answers are in line with the used complexity factors suggested by Berntsson, et al. (2013).

When it comes to the measurement of stress, the methodology used by (Cohen, et al., 1983) was found successful not only by themselves but also in a review article (Kopp, et al., 2010). Together with the items defined by (Rubenowitz, 2004), the measurement of stress is strongly connected to up-to-date, prominent research in the field.

4.2. Advantages and limitations of the IMPART – methodology

Using this semi-quantitative, questionnaire-based approach in an attempt to identify and assess the risk for human error during maintenance entails several advantages.

- The information obtained is derived from the very core of the plant, namely the maintenance mechanists and process operators.
- Munn & Drever (1990) state that questionnaire-based approaches in general generate descriptive information, rather than information explaining the situational factors. This they view as a limitation. However, for this application the descriptive information is actually an advantage since the aim is to identify critical settings of the PSFs as well as assessing them, rather than explaining them.
- Anonymity for the respondents is yet another advantage (Munn & Drever, 1990). The hypothesis being more truthful answers, which in turn, are thought to better represent the current state of the risks.
- The questionnaire-based approach entails standardized questions, hence, there is no chance of an interviewer distorting the questions. However, this requires the questions to be very clear to minimize respondent misconceptions.
- Declaring a semi-quantitative scale linked to a grade suppresses interpretational errors that textual or quantitative tools may impose.
- It does not require an advanced mathematical model or rigorous data as does the quantitative strategy, nor does it result in a too vague measure of the risk concept as does the textual estimation for this application.
- An additional benefit is that the data collected in the methodology is presented in an illustrative polar diagram, which is easily interpreted. Presenting the semi-quantitative data in such a way give the user himself an easy way to read out the results and to see where the opportunities for improvement are.
- Short time of responding.

Although there are several advantages using this methodology, there still limitations to be aware of.

- The severity of the potential consequences is not included in the definition of risk.
- Munn & Drever (1990) claims that responses in questionnaire-based methodologies may be of a superficial nature and that too little information is obtained. However, the problem related to lack of information is limited since the intended purpose of the tool is to be used as a quick-scan, identifing and assessing hazardous and unsafe settings of five perfoming shaping factors.
- Besides putting focus on areas of potential improvement, no exact measures can be suggested. Being an eye-opener and make the industry aware of hidden or neglected flaws, and if needed, to encourage further investigation on the matter is the overall use.

- As all questionnaire-based methodologies, the number of respondents has to be large enough to make the results reliable and representative.

4.3. Further development

As mentioned, the methodology is held rather general in order to fit a diverse set of industries. Since maintenance requirements are vastly different between different industries, further development could focus on specialized markets.

Another area of focus could be to adjust or alter the choice or number of PSFs, some type of industries may meet another set of requirements than what this general methodology can achieve.

Since this methodology was developed as a master thesis and thereby during a strict time schedule, further research could put effort in refining the questions to better suit and represent their dimension and PSF.

4.4. Similar methods

The researchers' strive to predict and quantify human error has brought forth several methodologies related to this work, e.g. Swain (1963), Hollnagel (1998) and Toriizuka, (2001). Presenting THERP as somewhat of a pioneer work, Swain (1963) introduced a structured method for quantifying human error, which opened up possibilities for several similar techniques. The kind of tools that THERP gave inspiration to is mostly for quantitative analysis. This requires, not only, much knowledge to execute, but also implies a severe amount of workload in order to obtain data and perform the calculations. Even when performed, one of the biggest drawbacks is the vast uncertainty, giving a questionable and dubious outcome. The same goes for the method CREAM (Hollnagel, 1998), which also requires a tremendous amount of time, resources and expertise to complete.

Where the two extensive methods mentioned above are rather general, Toriizuka (2001) on the other hand, specifies on elucidating Performing Shaping Factors during industrial maintenance, which also is the topic for this methodology. Nontheless, the methodology presented by Toriizuka (2001) is aiming to be an in-depth tool for analysis of improvement of maintenance tasks. This is not to say that the methodology is not to good use, which it probably is. Yet, the different aim also implicates several different strengths and weaknesses. In order to provide detailed information of how to improve maintenance tasks; resources, time as well extensive knowledge is required. Not only of the performer, but also of the receiver in order to interpret the analysis in a correct way. Since the methodology presented in this master thesis is thought to serve as a tool for quick-scanning the current state of the PSFs in order to identify any critical settings, the time and knowledge required to perform this analysis is very limited. Also it gives the company information of what factors are especially worth looking into and as the information is derived directly from the very core of the plant, namely the operators and maintenance workers, it is very reliable.

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6. Appendix

Questions about maintenance, stress and ergonomics

In this questionnaire, 33 short questions are treated. The purpose of these is to evaluate the types of maintenance works carried out, the level of stress as well as the level of the ergonomic suitability in order to see fields of improvement and suggest change of actions. The questionnaire is completely anonymous and in order to obtain as representative information as possible, I kindly ask you to answer as you are experiencing the current situation.

Thank you in advance!

1. What is your title? (For instance process operator, maintenance worker etc.)

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2. How many years have you been working in the current position at the current company or previous companies? Mark one of the following.

0 – 2 years

2.5 – 5 years

5.5 – 10 years

10.5 – 20 years

More than 20 years

3. What is your education? You may choose more than one of the following.

Studies at university within chemistry, assembling, maintenance or equivalent

Elementary school or equivalent

1-2 years of vocational training

In-house (company based) training

High school or equivalent

None

Other: ______________________________

Type of maintenance work

4. How would you rate the frequency of the following types of maintenance work? Appoint a number (1-5) to each of the alternatives.

   1 = Very seldom or never

   2 = Seldom

   3 = Average

   4 = Often

   5 = Very often

- Heavy lifting (with or without a trolley): ____
- Hot works (such as welding or other works requiring high temperature): ____
- Inspections (such as analyzing rust or damages of equipment): ____
- Cold works (such as installations or assembling): ____

5. Are you a part of risk assessments in a way that you can have your say regarding safety?

   Yes No

6. Do you read, follow and obey new instructions such as safety regulations?

   Yes No

For each of the following statements, choose *one* of the characters (1-5) as you are experiencing them. Even though some of the questions are similar, there are differences between them and you should preferably view each question individually.

1 = definitely not agreed

2 = not agreed

3 = neutral

4 = partially agreed

5 = definitely agreed

Ergonomic factors

7. When performing maintenance works, difficult and exhausting postures (for instance bent or twisted back and/or neck, slippery floor or no room for the feet when performing tasks.

Definitely not agreed 1 2 3 4 5 definitely agreed

8. There are physical factors in the work environment which I find annoys me when performing my work tasks.

Definitely not agreed 1 2 3 4 5 definitely agreed

9. During maintenance, there is in general a lot of noise which sometimes obstructs communication efforts during task performance.

Definitely not agreed 1 2 3 4 5 definitely agreed

10. During the daily work, the noise levels could be troublesome.

Definitely not agreed 1 2 3 4 5 definitely agreed

11. Some of the machines we use makes vibrations which could be irritating.

Definitely not agreed 1 2 3 4 5 definitely agreed

12. Headache due to the lighting in the plant occurs.

Definitely not agreed 1 2 3 4 5 definitely agreed

13. Blinding by the lights in the plant occurs.

Definitely not agreed 1 2 3 4 5 definitely agreed

14. It is not unusual to misinterpret the display of some machines which may lead you to press the wrong button.

Definitely not agreed 1 2 3 4 5 definitely agreed

15. I am more focused on work requiring heavy lifting than more routine-based tasks. Write "0" if heavy lifting not occurs.

Definitely not agreed 1 2 3 4 5 definitely agreed

16. I am more concentrated when performing welding than assembling or installations. Write “0” if welding or assembling not occurs.

Definitely not agreed	1	2	3	4	5	definitely agreed

17. Inspections do not require much focus. Write “0” if inspections not occurs.

Definitely not agreed	1	2	3	4	5	definitely agreed

Level of stress

18. In the last month, I have felt that I have been coping with sudden, work related changes in an efficient way. Write “0” if no changes were made.

Definitely not agreed	1	2	3	4	5	definitely agreed

19. In the last month, I have felt satisfied about my performed work.

Definitely not agreed	1	2	3	4	5	definitely agreed

20. In the last month, I have felt that I could spend my spare time as I wish without having to worry about my work in any way.

Definitely not agreed	1	2	3	4	5	definitely agreed

21. In the last month, there has *never* occurred conflicts at work.

Definitely not agreed	1	2	3	4	5	definitely agreed

22. In the last month, I have felt that we have had coffee breaks on regular, specific times.

Definitely not agreed	1	2	3	4	5	definitely agreed

23. In the last month, I have *never* become angry, upset or frustrated due to things that occurred in the company, beyond my control.

Definitely not agreed	1	2	3	4	5	definitely agreed

24. In the last month, I have felt that I have been coping with bothersome work situations in a successful way.

Definitely not agreed	1	2	3	4	5	definitely agreed

25. In the last month, I have *never* experienced myself or any colleague to be harassed.

Definitely not agreed 1 2 3 4 5 definitely agreed

26. In the last month, I have felt that I have had a good relation to my bosses.

Definitely not agreed 1 2 3 4 5 definitely agreed

27. In the last month, I have felt secure on my role at work.

Definitely not agreed 1 2 3 4 5 definitely agreed

28. In the last month, I have felt that we have had a clear, distinct communication within the company to reduce the risk of misunderstanding.

Definitely not agreed 1 2 3 4 5 definitely agreed

29. In the last month, I have *never* hesitated on managing to complete my tasks due to a work overload.

Definitely not agreed 1 2 3 4 5 definitely agreed

30. In the last month, I have *never* felt stressed out at work.

Definitely not agreed 1 2 3 4 5 definitely agreed

31. In the last month, I have felt confident in general.

Definitely not agreed 1 2 3 4 5 definitely agreed

32. In the last month, I have felt an ability to successfully manage everything I try to do.

Definitely not agreed 1 2 3 4 5 definitely agreed

33. In the last month, I have successfully been coping with personal problems.

Definitely not agreed 1 2 3 4 5 definitely agreed

If you have any thoughts or ideas, you are most welcome to write the below:

Thank you for your participation!

Questionnaire 2

Questions about maintenance strategy

In this questionnaire, 12 questions are treated. The purpose of these is to evaluate the overall maintenance strategy in order to identify improvement possibilities. The questionnaire is completely anonymous and in order to obtain as representative information as possible, I kindly ask you to answer as you are experiencing the current situation.

1. What is your title? (For instance, CEO, maintenance manager, production manager etc.)

2. How often do you have preplanned downtime in order to perform extensive maintenance work?

   ~ each year

   ~ every second year

   ~ every third year

   ~ every fifth year

   < once every five years

For each of the following statements, choose *one* of the characters (1-5) as you are experiencing them. Even though some of the questions are similar, there are differences between them and you should preferably view each question individually.

1 = definitely not agreed

2 = not agreed

3 = neutral

4 = partially agreed

5 = definitely agreed

3. In the production, we rarely see any kind of "short interruptions" on times up to 8 hours.

Definitely not agreed 1 2 3 4 5 definitely agreed

4. Our staff is trained to handle sudden, unforeseen and urgent errors on the equipment.

Definitely not agreed 1 2 3 4 5 definitely agreed

5. To exchange plant- and safety equipment on a regular basis before they are no longer functional, is a policy of ours. This policy is well implemented.

Definitely not agreed 1 2 3 4 5 definitely agreed

6. Our *process operators* are trained or educated in overall maintenance performance, which can be performed during production uptime.

Definitely not agreed 1 2 3 4 5 definitely agreed

7. To increase maintenance awareness, our *process operators* are encouraged to learn from mechanists/maintenance workers during maintenance performance.

Definitely not agreed 1 2 3 4 5 definitely agreed

8. From my position, I experience that there is a great awareness about maintenance requirement among our employees.

Definitely not agreed 1 2 3 4 5 definitely agreed

9. We have clear instructions regarding how "easier" maintenance tasks are to be performed. These are in systematic way incorporated in our business.

Definitely not agreed 1 2 3 4 5 definitely agreed

10. Me, or someone else responsible, warn far in advance before production shutdown due to maintenance.

Definitely not agreed 1 2 3 4 5 definitely agreed

11. In order to increase the time between shutdowns, we only announce planned shutdowns when we see production fluctuation or insufficient capacity.

Definitely not agreed 1 2 3 4 5 definitely agreed

12. Are risk assessments performed before each preplanned production shutdown?

    Always Sometimes Never

    If "always" or "sometimes", what methods for risk assessment are used?

Thank You for your participation!