Types and sources of fatal and severe non-fatal accidents in industrial maintenance

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A R T I C L E  I N F O

Article history:
Received 24 October 2006
Received in revised form 27 February 2008
Accepted 13 March 2008
Available online 5 May 2008

Keywords:
Industrial maintenance
Accident types
Sources of accidents
Accident prevention

A B S T R A C T

Due to the various work phases in disassembly and assembly, coupled with, for example, the pressure of time and working in close contact with machinery, industrial maintenance operations include several occupational risks. This article presents the results of an analysis based on real accident data. The data consisted of public Finnish accident reports describing fatal and severe non-fatal accidents in Finnish industry. The examination was limited to those accidents that involved full-time maintenance workers executing industrial maintenance operations. In the case of fatal accidents, the examination included the reports that were published during the years 1985–2004. The analysis of severe non-fatal accidents included the publication years 1994–2004. The accident types as well as their sources were examined in the light of Reason’s theory on organizational accidents. During the reference periods, a total of 37 maintenance workers died in 33 accident cases. The respective number of victims among severe non-fatal accidents is 90. The findings indicate that the most typical accident types in both fatal and severe non-fatal accidents are crushing, falling, and accidents involving falling objects. The most frequently identified unsafe act leading to fatal accidents is dangerous working method (including conscious risk-taking), while the severe non-fatal accidents occur most often due to working at a running process. Within both types of accidents the most typical latent causes are defects in work instructions and machinery safety equipment. Based on the findings, the most essential roles in accident prevention are played by organizational factors, such as safety management and operations planning.

Relevance to industry

Analyzing accidents creates a basis for more effective safety and risk management, which can be expected to face new challenges as more and more maintenance operations become subcontracted. It also provides valuable information regarding machine and process design, and the planning of maintenance operations.

1. Introduction

The consequences of an accident in high-risk industries may be catastrophic. This sets high requirements on technology and management (e.g. Kjellén, 2000). It is also reflected in maintenance, which must be kept at a high standard to ensure reliability. In addition, maintenance operations must be carried out in a cost-effective way to minimize the economic losses that result from production disturbances.

From the occupational safety viewpoint, maintenance operations are challenging. In addition to risks that are connected with the industrial working environments, maintenance operations include several maintenance-specific risks. Such risk factors are, for example, working at a running process, complicated machinery, and the pressure of time. In contrast to many other areas of technology and industry, the direct contact between the operator and machine in maintenance activities cannot be reduced substantially. Typically, distancing people from processes diminishes the likelihood of the occurrence of human errors and other chains of events that can lead to accidents. However, maintenance is, and probably always will be, that area in the use of technology where humans will be in direct contact with processes (Reason, 1997). Maintenance is also a good example of work that is performed in exceptional conditions, such as the time of day, especially when high-priority repairs are involved (c.f. Nag and Patel, 1998). A maintenance operation may also be exceptional work in itself, depending on the frequency with which it is performed. Maintenance operations typically include both assembly and disassembly, which can be considered to increase the number of risks of injury. Subcontracting maintenance services,
which is currently becoming more and more typical, may also raise new challenges.

1.1. Maintenance and “safety”

According to the Federation of Accident Insurance Institutions in Finland (FAII), the most typical accident type in Finnish industry is crushing (24% of all accidents) and impact with solid/static structures (17% of all accidents) (FAII, 2006a). During the years 1996–2004, the three most typical types of fatal and severe non-fatal accidents in industry were caused by being trapped in or between components, persons jumping/falling from heights, and accidents caused by falling or tumbling objects (FAII, 2006b). The total number of maintenance professionals in Finnish industry is currently approximately 50,000, while in 2004 the total number of workers in industry was 418,298 (Finnish Maintenance Society, 2006; Statistics Finland, 2006).

In general, studies on maintenance-related risks can be divided into two groups, examining either: (1) human performance as a risk to the maintained process, or (2) maintenance operations as a risk to humans (Lind, 2004). The first group includes studies that have concentrated on post-maintenance safety and reliability (e.g. Hobbs and Williamson, 2002; Holmgren, 2005; Jo and Park, 2003; Rankin et al., 2000; Taylor, 2000; Thomaidis and Pistikopoulos, 1995; Torizuka, 2001). Most of the studies concerning maintenance-related risks discuss human performance as a cause of the accident. A finding whereby a significant proportion of equipment failures occur shortly after a maintenance operation (Reason and Hobbs, 2003) supports this viewpoint. The approach is based on the increased possibility of human error during disassembly and assembly. The problem has been clarified by Reason (1997) with the nuts-and-bolts example. The basic idea is in all the possible variations in which a process or a machine can be re-assembled in an incorrect way. Studies connecting human errors with the reliability of the maintained object have been carried out, especially within nuclear power production and commercial aviation, which have obviously been the pioneering branches in assessing the role of human error in post-maintenance safety and reliability (Dhillon and Liu, 2006; Lind, 2004).

The second group of studies on maintenance-related risks examines maintenance operations as a risk to humans. Occupational safety in industrial maintenance operations has previously not been examined systematically. However, maintenance is often identified as a risky operation from the perspective of occupational safety (e.g. Kelly and McDermid, 2001; Lin and Cohen, 1997; Reason, 1997; Su et al., 2000). Both the management and the physical working conditions play important roles in developing safety in risky environments (e.g. Rasmussen, 1997; Sasou and Reason, 1999; Williamson et al., 1996). Maintenance can be considered to include the same risks as other operations in industrial working environments, and also boasts some certain specific risks. Such maintenance-related risk factors (e.g. working alone or during nights) especially arise from the need for urgent repairs and disturbance controls. Other typical risk factors are, for example, frequency of tasks, lack of tidiness and order of the working environment, as well as defects in the equipment and tools. These factors can also increase the risk of human error (Reason and Hobbs, 2003), although they are often considered to increase the probability of any occupational accident.

To conclude, the typical basis for earlier studies has been the consideration of human performance as a threat to the post-maintenance reliability. However, it can be presumed that industrial maintenance operations also include several risks for the maintenance workers that should be particularly examined and managed. Reason (1997) has examined how the chains of events leading to organizational accidents are formed. According to Reason, the causes of an organizational accident are the combined result of various factors at different organizational levels. The accident causes can be grouped into “active errors” and “latent conditions”. The latent conditions are based on organizational and local workplace factors, while the actual worker makes the active errors. Basically, the active errors (unsafe acts) appear only if the organizational and local workplace factors enable them. An accident occurs if the accident causes manage to pass through the defenses protecting the object (e.g. a human) from danger (Reason, 1997).

Although Reason’s theory is particularly related to organizational accidents leading to catastrophic consequences, the concept may also be applicable in the case of individual accidents. This article aims to utilize the theory of organizational accidents in examining a group of individual accidents (i.e. fatal and severe non-fatal accidents) that have occurred in industrial maintenance operations.

1.2. The scope and aim of this study

In practice, maintenance operations in industry can vary greatly depending on the actual working environment and/or the maintained object. In this article, the term “maintenance” complies with Reason’s (1997) definition of maintenance activities:

- unscheduled repairs;
- inspections;
- planned disturbance—and failure—preventive operations;
- calibration and testing.

Further, in this context, the terms “maintenance crew” and “maintenance worker” refer to full-time maintenance workers, while “maintenance operations” and “industrial maintenance” refer to tasks that are performed by full-time maintenance workers in various industrial workplaces. Building (property) maintenance was excluded from the study. The article is based on public accident reports describing fatal and severe non-fatal accidents in Finland. In the case of fatal accidents, the examination covers the publication years 1985–2004, while the examination of severe non-fatal accidents involves the publication years 1994–2004.

This article focuses on industrial maintenance, with an aim to examine: (1) what kind of fatal and severe non-fatal accidents have occurred during industrial maintenance operations in Finnish industrial workplaces and (2) how such accidents could be prevented. The findings are examined in the light of Reason’s theory of organizational accidents. Thus the first question concentrates on accident types together with their sources, i.e. latent conditions (including organizational and local workplace factors) and unsafe acts. The second question examines the role of unsafe acts, local workplace factors, and organizational factors in accident prevention. The examination in this article is based on the findings and preventive methods proposed by the accident investigators.

2. Materials and methods

2.1. Accident reports

In Finland, there are two types of publicly available accident reports. Thus the material used in this study consisted of: (1) investigation reports on fatal workplace accidents (IFWA) from the years 1985–2004 and (2) accident reports written by industrial safety inspectors concerning occupational accidents resulting in serious injuries, known as safety inspectors’ accident
(SIA) reports, from the years 1994–2004. The first group includes all relevant fatal workplace accidents. The second group includes reports on accidents that are serious but did not result in deaths.

In both groups, the examination was limited to cover only such accidents that have occurred during a maintenance operation, and where the victim was a full-time maintenance worker. Thus repairs carried out by machinists or operators (i.e. any workers other than maintenance workers) were excluded.

2.1.1. Investigation reports on fatal workplace accidents

In Finland, the FAII, in cooperation with labor market organizations, coordinates the investigation and reporting of fatal workplace accidents. The investigation system has been on stream since 1985. During the years 1985–2004, the FAII published 678 investigation reports (FAII, 2006a).

A group of experts carries out the actual investigation and reporting—the aim of which is to determine what happened, rather than to identify the people responsible for any accident. Upon completion, the results are delivered to other companies within the same industry, with the aim of preventing similar accidents from occurring. The reports are also made available on FAII’s website in PDF format.

The reports typically extend to five or six pages, and generally include some black-and-white pictures and a flow diagram summing up the chain of events. The text in the reports describes the accident in a precise way. The IFWA reports include a detailed description of the chain of events based on the findings of the accident investigation group. However, the actual injuries suffered are seldom mentioned. The reports give background information on the victim, accident scene, task execution, and fatal chain of events. They also give suggestions on how to prevent similar accidents.

2.1.2. Safety inspectors’ accident reports

Finland has been divided into eight industrial safety districts that operate under the supervision of the Finnish Ministry of Social Affairs and Health (Finnish Industrial Safety Administration, 2007). Industrial safety inspectors from the company’s local industrial safety district investigate and report on severe non-fatal accidents. Thus, the SIA reports are generally composed by a single author. The form and length of the report varies, but they are typically shorter and include fewer details than IFWA reports.

Like IFWA reports, the SIA reports also aim to promote safety in companies by providing external accident information accompanied by recommendations for preventing similar accidents. However, the SIA reports are available only on an Internet database that is administrated by the Finnish Industrial Safety Administration (2007). The database currently includes over 7000 accident cases, dating from 1987.

2.2. Methods

The relevant accident descriptions were examined with the aim of finding information concerning: (1) the characteristic features of fatal and severe non-fatal accidents in industrial maintenance and (2) the recommended corrective measures for preventing similar accidents listed in the IFWA and SIA reports. The charted features included:

- background information on a victim’s task and work experience, and on the circumstances at the accident scene;
- accident types (e.g. falling, being trapped between components);
- identified sources of accidents, including latent conditions and unsafe acts;
- causes of injuries (in the case of severe non-fatal accidents).

The findings were coded and the quantified data were analyzed. Furthermore, the collected recommendations for accident prevention were divided into three groups based on Reason’s (1997) theory of organizational accidents: unsafe acts, local workplace factors, and organizational factors. Grouping of the findings was based on the following criteria:

- organizational factors: executing recommendations is primarily the duty of the management (e.g. work planning, supervision);
- local workplace factors: recommendations primarily apply to workplace (e.g. machine/process) design;
- unsafe acts: recommendations primarily involve human (operator/user) performance.

The respective degree of involvement of each group was analyzed to identify which of them could be considered the most critical in preventing accidents in industrial maintenance in the future.

3. Results

3.1. Workplace fatalities

During the years 1985–2004, 33 accidents occurred, leading to fatalities in industrial maintenance, of which four accident cases involved two victims each. Thus the total number of victims was 37. On average, the victims had 14 years of work experience. Typically, fatal workplace accidents occurred during planned operations and unscheduled repairs (Table 1). The typical accident scenes for fatal accidents were indoors at a process (46%), while 19% of accidents occurred while executing maintenance operations outdoors (e.g. at a process pipeline). In addition, 15% of the accident cases occurred indoors in maintenance workshops.

3.1.1. Types and sources of fatal accidents

It appeared that close contact with machinery and working in industrial environments are reflected in maintenance-related fatalities. (Table 2).

Among the most common unsafe acts, the degree of involvement of “dangerous working methods” stood out clearly (Table 3a). In practice, “dangerous working methods” include conscious risk-taking as the task is executed in an unsafe way or without sufficient safety measures. Thus, the most important latent conditions were defects in planning or managing the work (Table 3b).

In examining the accident factors in Tables 3a and b, it must be noted that several factors can have appeared at the same time in one accident. Among unsafe acts, it is noteworthy that working at a running machine or process is a cause in 15% of fatalities.

Table 1

<table>
<thead>
<tr>
<th>Maintenance operation</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned disturbance—and failure—preventive operations</td>
<td>48</td>
</tr>
<tr>
<td>Unscheduled repairs</td>
<td>24</td>
</tr>
<tr>
<td>Changes (e.g. to processes and machinery)</td>
<td>18</td>
</tr>
<tr>
<td>Calibrations, testing, and inspections</td>
<td>9</td>
</tr>
<tr>
<td>Other/unknown</td>
<td>1</td>
</tr>
</tbody>
</table>
3.2. Severe non-fatal accidents

During the years 1994–2004, there were 90 severe non-fatal accidents in industrial maintenance involving full-time maintenance crew members. About 59% of accidents were associated with maintenance work indoors at a process. Maintenance workshops were an accident scene in 5% of the cases, while 6% of accidents occurred outside a building. The accident scene was not mentioned in 27% of the SIA reports.

3.2.1. Types and sources of accidents

Various categories of severe non-fatal accidents were defined, and the most typical accident type was crushing or being trapped between components (Table 4). The percentage of “Crushing or being trapped in or between components” was larger than the equivalent percentage in the case of fatal accidents.

In assessing the most common unsafe acts and latent conditions leading to accidents, it appeared that a large proportion of them involved working instructions (Tables 5a and b). Again, several factors might have been involved at the same time.

3.2.2. Causes and types of injury

Machines and devices were typical causes of injury in the case of severe non-fatal accidents, being involved in 76% of the cases (Table 6). Scaffolds, in addition to walking and working surfaces, were involved in 12% of severe non-fatal accident cases.

The most typical injury type was fracture, which occurred in 38% of severe non-fatal accidents (Table 7). Most injuries were caused to upper limbs (39%) or to several body parts at the same time (28%). The head or feet were injured in only 10% of accidents.

3.3. Accident reports: recommendations to prevent similar accidents

Both the IFWA and SIA reports list recommendations and measures for preventing accidents of similar types. When comparing the recommendations in both groups of fatal and severe non-fatal accidents, it appeared that recommendations after a fatal accident are more often directed towards organization than in the case of severe non-fatal accidents. The recommenda-

<table>
<thead>
<tr>
<th>Accident type</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing or being trapped between components</td>
<td>27</td>
</tr>
<tr>
<td>Persons falling</td>
<td>27</td>
</tr>
<tr>
<td>Accidents caused by falling/tumbling objects</td>
<td>15</td>
</tr>
<tr>
<td>Other</td>
<td>31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accident type</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing or being trapped between components</td>
<td>39</td>
</tr>
<tr>
<td>Jumping or falling</td>
<td>21</td>
</tr>
<tr>
<td>Accidents caused by falling objects</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
<td>28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cause of injury</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other machines and devices</td>
<td>30</td>
</tr>
<tr>
<td>Lifters, transmitters, and transport devices</td>
<td>22</td>
</tr>
<tr>
<td>Process equipment</td>
<td>14</td>
</tr>
<tr>
<td>Walking and working surfaces, scaffolds</td>
<td>12</td>
</tr>
<tr>
<td>Machining devices (e.g. lathes, cutters)</td>
<td>10</td>
</tr>
<tr>
<td>Electric devices and conductors</td>
<td>6</td>
</tr>
<tr>
<td>Hand tools and equipment</td>
<td>2</td>
</tr>
<tr>
<td>Structures under construction</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of injury</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture (broken bones)</td>
<td>38</td>
</tr>
<tr>
<td>Cuts and minor bruises</td>
<td>20</td>
</tr>
<tr>
<td>Burns</td>
<td>14</td>
</tr>
<tr>
<td>Crushing of limbs</td>
<td>14</td>
</tr>
<tr>
<td>Amputations</td>
<td>8</td>
</tr>
<tr>
<td>Other (e.g. eye injuries, skin damage, arrhythmia)</td>
<td>25</td>
</tr>
</tbody>
</table>

4. Discussion

This study charted the accident types and sources within the framework of reported severe non-fatal and fatal accidents in industrial maintenance in Finland. As incidents and minor accidents are investigated internally in companies, the results in this article reflect only the more serious cases that have been investigated and reported externally by safety authorities and experts. Still, it can be assumed that measures intended to prevent serious accidents will also affect the probability of minor accidents and incidents.
Table 8
Recommendations and suggestions for preventing accidents of similar types

<table>
<thead>
<tr>
<th>Group of recommendation</th>
<th>Most typical recommendations</th>
<th>Fatal accidents % (N = 33)</th>
<th>Severe non-fatal accidents % (N = 90)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational factors</td>
<td>Instructions and task planning</td>
<td>75</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Development of work planning</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td>Management and</td>
<td>Employer’s supervision of safe working methods (including acquiring and use of personal protective equipment)</td>
<td>39</td>
<td>15</td>
</tr>
<tr>
<td>supervision</td>
<td>Enhancement of safety management (including hazard identification)</td>
<td>60</td>
<td>21</td>
</tr>
<tr>
<td>Local workplace factors</td>
<td>Machine and process safety</td>
<td>27</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Adequacy and condition of machinery (including machine safety equipment)</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Workplace design</td>
<td>Prevention of unintended start-ups, switching off live parts reliably</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Development of workplace conditions (including occupational hygiene, walking and working surfaces)</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Unsafe acts</td>
<td>Human performance</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Use of safe working methods (including choosing proper tools, care)</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Following orders and instructions</td>
<td>12</td>
<td>6</td>
</tr>
</tbody>
</table>

This study adopted a quantitative approach, although the total number of cases was small—due to the strict focus on maintenance operations and maintenance crew-related incidents. However, the study involved all reported fatalities and severe non-fatal accidents over a 10-year time period. Thus, the results are strongly indicative of actual accident types and their latent and direct sources. The IFWA and SIA reports are in fact qualitative descriptions and partial interpretations of what occurred (e.g. often due to lack of eyewitnesses). Also, there have been many phases of investigation, analysis, and reporting after the actual accident events, and investigation- or author-based variation in the quality of reports may also occur. These aspects may have had an influence on the findings reported in this article.

4.1. Accident reports

In general, the accident reports avoid directly alluding to specific persons being responsible for an accident. This principle is highly emphasized, especially in the investigation and reporting of fatal accidents (IFWA cases), where the investigation and reporting is coordinated by FAII. The form of the SIA investigation and reporting is somewhat freer, and the same person describes the results and gives recommendations. On the other hand, this may also lead to subjective variations and interpretations regarding what happened and how such accidents could be prevented, whereas the IFWA reports give the joint results of an investigation and coordinating group. The differences in reporting practices may partially explain the differences in findings between the two groups. For example, when comparing the reported accident causes between the two types of reports, it appears that IFWA reports are more focused on the chain of events than on defining the direct causes of fatalities. In contrast, the SIA reports often leave some aspects of the chain of events open.

In the case of fatal accidents, most recommendations for accident prevention concern organizational factors (Table 8). The local factors, as well as unsafe acts, play only a minor role. In the case of severe non-fatal accidents, the recommendations are mainly directed at local workplace factors. These findings may partly result from the reporting practices, as previously described. An observation made by Rasmussen (1997) and supported by Körvers and Sonnemans (2007) applies also to the SIA and IFWA investigations: as the accidents are investigated by experts of safety and legal matters, the results often emphasize the violated rules, instructions, and laws, i.e. organizational matters.

The emphasis on organizational means in accident prevention supports the idea that accidents are manifestations of different organizational failures (c.f. Hollnagel, 2004; Körvers and Sonnemans, 2007; Little, 2004; Perrow, 1984; Reason, 1997). Such failures can be, for example, missing or defective barriers that enable the human to get in contact with the accident cause (Hollnagel, 2004, 2007). In the context of organizational accident prevention, an important issue is the issue of learning from accidents, which, in Finland, also includes accidents reported in the IFWA and SIA reporting systems. The internal and external accident information of companies could provide important input to accident prevention on different organizational levels, but in practice companies may have difficulties in learning from internal and/or external accidents (see e.g. Baram, 1997; Hale, 1997; Lind and Kivistö-Rahnasto, 2008). In order to support accident prevention in companies with accident reports, the critical points in safety management, as well as practical solutions (defining what can be done), should be clearly stated in the reports.

4.2. Findings

The types of fatal and severe non-fatal accidents in industrial maintenance seem to be in line with the accidents in Finnish industry in general (see also Jeong, 1999). For example, the three most typical types of fatal maintenance-related accidents (Table 2) are the same as accident types among all severe non-fatal and fatal accidents in Finnish industry (FAII, 2006b).

In the case of fatal and severe non-fatal accidents in industrial maintenance, latent conditions and unsafe acts tending to cause accidents are often different kinds of shortcomings in the planning or performance of work (Table 5b), although the victims appeared to have been relatively experienced workers. Thus it can be assumed that a planned maintenance operation does not automatically include systematic safety planning. On the other hand, sources of accidents may result from some typical problems in maintenance operations, such as the pressure of time, and changing projects and tasks. Such problems may also affect the workers’ choice of tools and working methods. Despite the
importance of organizational means, the role of workers should not be underestimated or neglected in accident prevention. On the contrary, the role of workers should be emphasized in safety management by finding ways to positively affect safe working. It also seems that the planning of maintenance operations requires some systematic approach towards integrated safety planning, including task-specific safety planning.

Working at running machinery and/or processes is a specific issue in maintenance safety. Executing maintenance tasks (e.g. unscheduled repairs) may require working at a running process. Such situations should be taken into account and avoided when planning the maintainability of the machine or process. Working at a running process or machine can also result from conscious or unconscious risk-taking, which can be a result of, for example, time pressure or a worker's defective hazard identification. Such factors should also be taken into account in the safety and risk management. To promote safety, it is essential to focus efforts on developing work instructions and ensuring they are followed. In the best case, the running parts can be turned off or safeguarded when executing a maintenance operation. If this is not possible, the planning of maintenance operations and/or working instructions should carefully account for such situations. The maintainability and maintenance of processes outdoors should be planned even more carefully, taking into account the seasonal variations in working conditions. For example, in Finland the wintertime can be very challenging due to darkness, ice, and snow. Again, supporting the hazard identification abilities of workers could help to make work performance safer.

It can be assumed that planned operations represent the biggest group in all maintenance operations, which would then be reflected in the number of working hours and even accident rates. On the one hand, the more infrequent (atypical) tasks, like unplanned repairs, may include unexpected hazards. However, the workers may be more careful and take more time to carry out some infrequent task. Also, the total risk exposure time is probably smaller in the case of infrequent tasks. From a company's viewpoint, the frequency and hazards of different tasks should be considered as a basis for safety management procedures and practical means of accident prevention. Thus, the different maintenance tasks should be charted and classified depending on their frequency and the associated risks. One option could involve listing all planned operations and charting also different kinds of unplanned/unexpected tasks that are allocated to maintenance personnel on customer sites. This could be a good basis for the instructions given to workers regarding maintenance tasks and safety. It would also help to estimate, for example, how much time and workforce is required in different situations.

Finally, due to increasing subcontracting of industrial maintenance, in the future it can be expected that maintenance operations will be increasingly carried out alone on customer sites, and/or without supervision (i.e. a supervisor may be far away from the actual site of the work). This means several safety-related decisions, such as the use of personal protective equipment, the choice of working methods, and the task-specific hazard identification, are decided by the worker. In addition, the increase in automation and more complicated machinery (e.g. remotely operated machinery), together with time pressures arising from customer demands, can also make safety management in maintenance more challenging. To tackle these new challenges, relevant measures for safety management could involve improving site- and task-specific safety planning and hazard identification. Again, safety planning, including adequate scheduling, should be a relevant part of maintenance operations planning and instruction, and not a separate procedure. Such aims could be supported through customer cooperation.

5. Conclusions

5.1. Types and sources of accidents in industrial maintenance

The most typical types of fatal accidents in industrial maintenance involve crushing, persons falling, and accidents caused by falling objects. In the case of severe non-fatal accidents, the types of accidents are the same. Thus, the types and rates of severe non-fatal and fatal accidents in the case of maintenance are similar to those for severe non-fatal and fatal accidents in Finnish industry in general. It appears that fatal accidents generally involve the working environment and structures, while severe non-fatal accidents also involve machinery or devices.

The most typical unsafe acts among fatal accidents are dangerous working methods, such as conscious or unconscious risk-taking in task execution. The most typical latent condition is defective work instructions. An essential unsafe act among severe non-fatal accidents is working at a running machine/process. Also in the case of severe non-fatal accidents, the most typical latent condition is defective work instructions. Practical differences in the utilized information sources may have affected these results to some degree.

5.2. The role of unsafe acts and latent conditions—prevention of accidents

In this study, the preventive methods were charted from the public Finnish accident reports. The identified sources of accidents involved both unsafe acts and latent conditions (local workplace factors and organizational factors). Although unsafe acts were more often identified as the sources of accidents, most of the accident preventive measures were directed at organizational and local workplace factors.

Accidents can be considered to demonstrate unsuccessful safety management and, for example, inappropriate supervision (organizational factors), although, in the end the decision to use unsafe working methods or not to use personal protective equipment is up to the workers (unsafe acts). To avoid such unsafe acts, the management, work supervision, and task planning should support and emphasize safe working, even when the job is executed in exceptional situations, such as with haste, alone, and/or during the night. Thus, the accident preventive measures should highlight the role of the workers in accident prevention, in addition to management and/or workplace design.

Machine design was only of minor importance in the assessment of the sources of accidents and suggested preventive methods. This may indicate advances in machine safety design, but it also underlines the essential role of management in accident prevention, as accidents can be a consequence of inappropriate use of machinery and/or defects in machine safety devices. To provide more information for accident prevention through machine design, a detailed technical examination of accident causes is required.

A significant issue for a worker engaged in a maintenance operation is tasks planning. In case maintenance, operations are carried out alone, in foreign working environments, without work supervision, or at short notice with no time for detailed job-specific planning, it is important that the worker assesses the risks arising from such conditions before starting a work operation. Such situations also emphasize the need of careful operations planning (by management and supervisors), which should include safety planning. In addition, the planning should take into account adequate scheduling so that the worker has time for task preparations, including an independent safety check at
the workplace. For such purposes, a brief checklist that enables independent hazard identification by workers is proposed.

A more detailed investigation is required to examine the challenges arising from the subcontracting of maintenance services. It may be assumed that subcontracting makes site-specific safety planning more important due to the differences in sites, varying practices in customer cooperation, and the greater distance between individual workers and the company management. In the long run, this may also be reflected in the accident rates of maintenance operations.

It appears that maintenance-related risks should be controlled by improving and strengthening safety management. On the basis of the findings in the literature, there are no specific tools for managing occupational safety in industrial maintenance. On the other hand, the special characteristics of industrial maintenance, such as increasing subcontracting, more complicated processes and machinery, and the various risks associated with disassembly and assembly clearly show the need to provide tailored organizational and technical tools for maintenance risk management. In addition, safety planning should be an integral part of maintenance operations planning.

Acknowledgements

Ms. Sanna Nenonen, M.Sc. (Eng., Stat.), is acknowledged for significant contribution in data processing. Ms. Marileena Koskela, M.Sc. (Eng.), is acknowledged for valuable comments and support during the writing process. Finally, the anonymous referees are acknowledged for their valuable comments and constructive feedback.

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