LEAN PRINCIPLES AND ENGINEERING TOOLS IN MAINTENANCE ORGANIZATIONS – A SURVEY STUDY

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Abstract: This paper presents a questionnaire survey mapping how Lean principles and engineering tools are applied in a maintenance context in Swedish industry, based on a high-level strategic view from 76 respondents representing 71 companies. Results from the study cover different work practices according to Lean principles, to what extent risk assessment tools and software are used, to what degree companies are employing reliability engineers to conduct risk and reliability analysis, and how this relates to the safety of maintenance operations. The results indicate a gap between applying Lean in production and maintenance, and low use of valuable engineering tools.

Keywords: Lean, Maintenance, Production, Risk, Reliability.

1. INTRODUCTION

Manufacturing companies are faced with increased demands on extreme flexibility and speed in operations in order to stay competitive in today's fast-changing market. To manage this challenge, companies are searching for new ways to improve their manufacturing practices. During the past decade, adopting Lean production principles has been widely popularized in order to allow for increased profitability and productivity.

A result of striving for more streamlined processes is that the consequences of failures are increasing (Ericsson, 1997), and Lean principles such as Just-In-Time (JIT) and aggressive inventory reduction makes the production flow more sensitive to disturbances and equipment failures (Faria & Nunes, 2012). Therefore, a transition towards a Lean production system also requires fundamental changes in the maintenance operations (Baluch et al, 2012; Moyaed & Shed, 2009). However, most companies are solely focusing on manufacturing efficiency through the use of Lean production tools, but a prerequisite for the success of a Lean manufacturer is the concurrent adoption of Lean maintenance (Baluch et al, 2012). Moreover, the maintenance function is often underdeveloped and has low status, and there is a great improvement potential for more effective maintenance in the average Swedish manufacturing firm (Jonsson, 1999).

An industrial survey study conducted by Ylipää & Harlin (2007) highlights that Production Disturbance Handling (PDH) strives to create sustainable and reliable production systems. High reliability is essential for a Lean production system (Faria & Nunes, 2012), but this requires effective maintenance and a systematic approach to avoiding failures and managing uncertainties (Johannesson et al, 2013). Reliability is often neglected during the design phase of the production system, which could be due to the absence of ground engineering methodologies and tools to perform reliability analysis (Faria & Nunes, 2012). There are however several available tools for reliability analysis and risk assessment, such as Failure Mode Effect Analysis (FMEA) and Variation Mode and Effect Analysis (VMEA) (Johannesson et al, 2013), and some of the most commonly used analysis tools are risk probability assessment, risk impact assessment, and risk classification (Raz &

Michael, 1999). Nonetheless, Ylipää & Harlin (2007) concludes that PDH tools and methodologies lack integration and have low user satisfaction amongst Swedish companies.

Risk assessment during the design of production systems and planning of maintenance activities is furthermore of vital importance in order to ensure the safety and health of maintenance workers. In fact, EUSOHA (2010) reports that 10-15% of all fatal accidents associated with 'working process' activities are related to maintenance operations, and occupational diseases and work-related health problems such as cancer, hearing problems and musculoskeletal disorders, are more prevalent amongst maintenance workers. Furthermore, Lind & Nenonen (2008) describes several risk-increasing factors for maintenance operators such as working under the pressure of time, working while machines are in motion, and carrying out independent maintenance work during night shifts, and the Swedish Emergency Services Authority (2007) state that one of the most common causes for work place injuries in Sweden is in fact due to machine accidents.

Moreover, there is little research on the collaborative use of Lean and reliability concepts (Keyser & Sawhney, 2013). Therefore, the aim of this paper is to investigate to what extent Swedish companies are adopting Lean maintenance as well as using various tools and software for PDH, reliability analysis and risk assessment. This is performed through a questionnaire study where an online questionnaire is distributed by email, resulting in responses from 71 Swedish industrial companies.

2. THEORETICAL FRAMEWORK

2.1 Risk assessment and reliability analysis

Risk assessment is an elaborative method that consists of several steps, starting with hazard identification and development of incident scenarios, and finalized by preparing strategies for risk reduction and control of damage. As a tool, risk analysis is about identification and evaluation of losses in order to predict future risks, and the results from the analyses are used in making decisions to determine the most cost-effective way to reduce the risks and uncertainties (Shahriari, 2011).

Hazard identification can be used to identify possible risks that can lead to unwanted consequences, such as injuries to employees or damage to property. Furthermore, the fundamental goal of reliability analysis is to manage the uncertainty in the occurrences and consequences of failures (Zio, 2009), and risk assessment tools can in fact be used to also analyse factors influencing reliability. Furthermore, there are today plenty of software solutions that are developed to conduct advanced risk analysis, as well as to collect different risk assessment tools and reliability analysis features, such as failure mode and frequency analysis, in order to enable a collaborative use of them.

Reliability performance is to a large extent determined during the development phase, and by facing the consequences of failures and uncertainties early, the future cost of lack of reliability can be avoided (Johannesson et al, 2013). In fact, Gulati & Smith (2009) argue that up to 60% of failure and safety issues can be prevented by making changes during the design phase. Addressing maintainability and reliability during the design phase of new equipment are emphasised by several authors (see for example Almgren, 1999; Bellgran & Säftsen, 2009; Jonsson, 1999; Tsang et al, 1999; Ylipää, 2000).

2.2 Lean Maintenance

According to Ylipää (2000), there is synergism in integration of Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM), and this is what Smith & Hawkins (2004) defines as Lean maintenance: "fine-tuning" TPM with elements of RCM. In essence, Lean maintenance is a proactive maintenance strategy using planned and scheduled maintenance activities in a TPM manner, developed through application of RCM decision logic and practiced by self-directed teams using 5S, improvement events and operator maintenance together with multi-skilled maintenance-technicians performed maintenance. This is supported by a maintenance storeroom supplying parts and materials JIT, and backed up by reliability engineering teams performing Root Cause Analysis (RCA) and failure analysis (Baluch et al, 2012). In order to effectively combine TPM and RCM, two actions are required: assessing equipment criticality and establishing maintenance task priority codes. Criticality assessment quantifies how important an item or system function is in relation to the indented mission, and maintenance task prioritization is used to assign the priority of maintenance work orders based on the equipment criticality. Several of the previously mentioned risk assessment tools are in fact emphasised in RCM and TPM. RCM analysis is based on a detailed FMEA and also utilizes Logic Tree Analysis (LTA), and RCA is used to evaluate the major TPM losses (Smith & Hawkins 2004).

Although the core of Lean principles is a commitment to continuous improvements and customer satisfaction by striving towards perfection and elimination of waste, it is best known for its tools such as 5S, Standardized Work, Kaizen, Poka-Yoke and Value Stream Mapping (VSM) (Baluch et al, 2012). These are most commonly applied in the production environment towards targets such as reduced lead-time or cost, but they can also be applied for maintenance operations. Examples of this are Standardized Work for maintenance operators, Andon-signals to initiate corrective maintenance, and using VSM to identify and eliminate waste in maintenance operations (Levitt, 2008). Note however that the fundamental elements of Lean, and TPM in particular, must be in place before approaches such as specific tools can be applied (Baluch et al, 2012).

3. METHODOLOGY OF THE SURVEY

The overall method used was an online questionnaire distributed by email, as well through an open invitation listed publicly on the web and included in a newsletter. The primary target group for the questionnaire were maintenance or production experts. The questions in the questionnaire were derived from the survey conducted by Ylipää & Harlin (2007) as well as from additional literature review.

The full questionnaire, a description of the respondents and the participating companies, together with an extended methodology, has been reported in Bokrantz (2014).

Respondents of the questionnaire represent an expert view at a high strategic level within maintenance or production management at the different companies. This selection was made as these respondents were considered to possess specific knowledge of the production area, as well as play a central role in achieving high system reliability and maintenance performance at the company. In addition, maintenance and production managers and other actors with a central role related to maintenance operations and risk management were included in the survey.

82 selected respondents received an invitation to the questionnaire, out of which 62 answered, resulting in a response rate of 75 percent. The open invitation resulted in 22 additional responses. Out of the total 84 submitted responses, the respondents with the highest management level were chosen at plant-level for each company, resulting in the final selection of 76 responses from 71 companies. 62 percent of the respondents can be regarded as maintenance department, 25 percent production department, and 13 percent as equally maintenance and production department. The companies represent various production contexts, i.e. both discrete and continuous production, such as manufacturing, energy, nuclear, paper and food industries.

4. RESULTS

Results from the survey cover the use of various tools and software for performing risk and reliability analysis, and to what extent reliability engineers are carrying out various analysis and improvement work. Moreover, the extent to which Lean principles are adopted in both a production and maintenance context is covered, as well as the use of specific Lean maintenance tools and methodologies.

4.1 Tools and software

As shown in table 1, the two most common tools are RCA and Fishbone diagrams, indicated by 55 and 40 respondents respectively. Thereafter, 25 respondents stated that their company use FMEA, and 16-19 respondents indicated they use HAZOP, What-if analysis, or FTA. Moreover, almost no respondents indicated that they use LTA, VMEA, or Event Tree Analysis (ETA).

Regarding software, one respondent indicated that Discrete Event Simulation (DES) is used in the maintenance department, and one stated to use Risk-Based Work Selection (RBWS). None of the 76 respondents indicated that any of the software Relex, Reliasoft, or @Risk, are utilized at their company. However, 37 respondents instead answered that they use another type of software, out of which 6 clarified that they do not use any of the suggested software, or that they do not have that type of software in the maintenance department. The remaining 31 respondents clarified that they used other types of software from different providers than the ones suggested, this by referring to their maintenance planning software, i.e. “API”, “SAP”, “IFS”, or “Tekla” etc. Moreover, 35 out of 72[1] respondents were absolutely or to a certain extent satisfied with how the tools work, and 8 stated to be scarcely or not at all satisfied. In addition, 30 were absolutely or to a certain extent satisfied with the software, whilst 4 indicated to be scarcely or not at all satisfied.

[1] Of those that answered the question

Performing safety analysis in form of Job Safety Analysis (JSA) is regarding corrective maintenance activities done to a relatively high degree according to 27 respondents, and to a very high degree by an additional 4. Similarly, 25 respondents indicate that JSA for preventive maintenance operations is performed to a relatively high degree, and 6 state it to a very high degree. In addition, 15 respondents indicated that they are not at all performing JSA for corrective maintenance at their company, and 13 not all for preventive maintenance.

Table 1 Risk assessment tools and software, JSA for maintenance activities.

Which of the following tools are used by the maintenance department in your company?	What-if	RCA	HAZ-OP	FTA	ETA	LTA	Fish-bone diag-rams	VMEA	FMEA
Number of checked answers:	16	55	17	19	5	2	40	2	25
Which of the following software are used by the maintenance department in your company?	DES	@Risk	Relex	Relia-soft	RBWS	Other			
Number of checked answers:	1	0	0	0	1	37			
Do you consider that the use of these...	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	Do not know	Not appl-icable	Missing answer		
… tools are working in a satisfactory way?	3	32	7	1	5	24	4		
… software are working in a satisfactory way?	3	27	3	1	7	31	4		
To what extent do you at the company work with…	To a very large extent	To a relati-vely large extent	To a relati-vely low extent	Not at all	Do not know	Not appl-icable	Missing answer		
… JSA for corrective maintenance?	4	27	19	15	9	1	1		
… JSA for preventive maintenance?	6	25	22	13	10	0	0		

4.2 Reliability engineers

The data in table 2 shows to what extent the companies have reliability engineers in the maintenance department carrying out risk and reliability analysis in practice. Fifty-eight respondents indicated that their company absolutely or to a certain extent have engineers who develops and improves preventive maintenance activities, 48 state the same for RCA analysis, and an additional 47 regarding risk analysis. According to 41 respondents, their company to a certain extent have engineers working with improving maintainability and reliability during the design phase, and 5 absolutely have it. However, Life Cycle Cost analysis (LCC), failure mode, and failure frequency analysis are only absolutely performed by engineers according to 5, 6 and 4 respondents respectively.

Table 2 Reliability engineers

Does your company have maintenance engineers who work with…	Yes, absol-utely	Yes, to a certain extent	No, scar-cely	No, not at all	Do not know	Not appl-icable	Missing answer
… RCA of stoppages, failures or other disturbances?	19	28	8	15	0	5	1
… risk analysis and risk handling?	17	30	10	12	0	5	2
… failure frequency analysis?(e.g. using Weibull plot)	4	13	17	30	1	6	5
… failure mode analysis? (e.g. using FMEA)	6	18	21	19	2	7	3
… Life Cycle Cost analysis? (LCC)	5	19	20	22	4	5	1
… improving maintainability and reliability of processes, equipment or machines during the design phase?	5	41	8	14	1	6	1
… developing and improving methods and work practices for preventive maintenance activities?	19	39	6	7	0	4	1

4.3 Lean Maintenance

Table 3 displays that working with Lean principles in production is by 36 out of 76 respondents done to a relatively high or very high degree at their company. In addition, 26 indicated that they to a relatively low degree work with Lean in production, and 14 answered that it is not done at all. Furthermore, Lean in maintenance is adopted to a relatively high or very high degree according to 19 respondents. However, thirty-five stated that they work with Lean maintenance to a relatively low degree, 21 not at all, and one respondent did not know whether it is used at the company. The 22 respondents that answered "Not at all" or "Do not know" were instead asked whether they had discussed to start working with Lean maintenance, out of which 5 confirmed that it had been discussed.

When asked whether the respondent feel that they have knowledge about the concept of Lean maintenance, 42 considered that they had it to a relatively high or very high degree. The remaining 34 respondents indicated that they had relatively low or non-existing knowledge of Lean maintenance.

To combine TPM and RCM into Lean maintenance, criticality assessment of equipment and priority-based maintenance scheduling is required. 27 out of 76 respondents stated that their company are to a high degree establishing criticality levels of equipment, and 21 indicated that criticality levels are continuously updated. Moreover, the number of respondents who indicated that maintenance work tasks are to a high degree scheduled based on priority was 51 out of 75.

Regarding the application of specific Lean tools in a maintenance context, as shown in table 4, the 3 most popular are to have daily morning meetings for maintenance personnel, indicated by 60 respondents. Thereafter, 42 respondents indicated that they are working with 5S in maintenance areas, and 39 that they visualize maintenance work orders using monitors, whiteboards etc. Regarding the 6 remaining tools that are used to a lower extent, eight or less respondents claimed to apply any of these tools to a very high degree. Thirty-one respondents stated that they standardize the range of spare parts and maintenance tools, 28 works with reducing the inventory levels of maintenance storage areas, and twenty-three respondents indicated that they apply standardized work for maintenance operators. Very few companies are using Andon-signals to initiate corrective maintenance or utilizing Poka-Yoke techniques to prevent maintenance errors, and almost none are performing VSM for maintenance activities. In fact, merely one company maps the flow of maintenance activities using VSM to a very high degree.

Table 3 Lean principles

To what extent do you consider that…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	Do not know	Not applicable	Missing answer
… your company is working with Lean production?	13	23	26	14	0	0	0
… your company is working with Lean maintenance?	7	12	35	21	1	0	0
… you have knowledge about Lean maintenance?	9	33	23	11	0	0	0
To what extent do you at the company work with…	To a very large extent	To a relatively large extent	To a relatively low extent	Not at all	Do not know	Not applicable	Missing answer
… establishing criticality levels for maintenance of production processes, equipment or components?	7	20	26	16	6	1	0
… continuously updating the criticality levels of production processes, equipment or components?	6	15	27	22	5	1	0
… scheduling of maintenance work orders based on the priority of the maintenance activity?	16	35	15	4	2	3	1

Table 4 Lean maintenance tools

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

5. DISCUSSION

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

To effectively combine TPM and RCM into Lean Maintenance, Smith & Hawkins (2004) describes how to integrate criticality assessment with priority-based scheduling of maintenance work tasks. The gap between the extent the companies in this survey are establishing and updating criticality levels and to what degree maintenance tasks are scheduled based on priority, indicate that companies are often prioritizing the execution of work orders based on other criteria than the criticality of equipment. It is however unclear whether the companies who are not using criticality are instead scheduling based on a first-come-first-serve basis etc., but this indicates a possible improvement potential in scheduling maintenance based on the basic goal of high reliability.

Operating according the demands on short lead times and low production costs found in JIT supply chains increases the sensitivity of the production system and the severity of consequences (Faria & Nunes, 2012). Therefore, a reliable Lean system is essential (Keyser & Rapinder, 2012), and companies that are truly successful with Lean production are a logical result of effective PDH (Ericsson, 1997), rapid responses to breakdowns and rigorous problem-solving when a re-occurring cause is detected (Liker, 2014). To achieve the high reliability necessary for a Lean production system, a systematic approach to avoiding failures and managing uncertainties is required (Johannesson et al, 2013). However, despite that several of the tools in this survey are emphasised in such maintenance concepts as RCM, TPM and Lean Maintenance (Smith & Hawkins, 2004), few companies are using FMEA, VMEA HAZOP, FTA, LTA or What-if analysis. Moreover, there is still an improvement potential for using simple problem-solving tools such as RCA and Fishbone diagrams to identify root causes to failures or accidents. Noteworthy is however that the majority of the respondents are satisfied with how the tools and the software works.

To support a maintenance department operating in a JIT manner, reliability engineering teams performing failure analysis is emphasised by Baluch et al (2012). The results in this survey however show that absolutely having engineers in the maintenance department conducting failure frequency and failure mode analysis is fairly uncommon.

Faria & Nunes (2012) hypothesise that reliability analysis during the development phase is neglected due to the absence of ground engineering tools to perform the analysis work, but this is contradicted by the presentation of a wide array of available tools and software in this survey. However, the low use of these resources, in combination with the scarce employment of reliability engineers working with maintainability and reliability during the design phase, supports the view that reliability analysis is often ignored at an early stage. This calls for further research in order to assess what factors that counteracts and prevents companies from either using tools and software, or employing dedicated reliability engineers to carry out this type of work.

Furthermore, Idhammar (2014) describes that applying a variety of the Lean tools in a maintenance context can result in such effects as reduced over-maintenance, general waste-reduction in maintenance activities, and a 10-20% reduction in inventory cost without sacrificing reliability. In addition, several of the tools promote operator involvement in improvement activities, which are an important feature of the PDH work emphasised in TPM (Nakajima, 1998). In particular, Ericsson (1997) suggests that visualization systems are in fact one of the most important tools for minimizing production losses. The results in this survey show that few companies are making extensive use of these tools, indicating a large source of untapped potential for waste-reduction of maintenance activities. However, the fundamental elements of Lean, and TPM in particular, must be in place before approaches such as specific tools can be applied (Baluch et al, 2012). The fact that fairly few companies in this survey are working with Lean production and Lean maintenance can therefore also explain the low use of specific Lean maintenance tools.

In a case study, Toulouse (2002) showed that production disturbances could result in direct accident risk and reduced safety for the maintenance operators. In combination with the added sensitivity to disturbances caused by Lean principles such as JIT (Faria & Nunes, 2012), a particular need for safety awareness and active work with safety in Lean companies can be identified. Lind & Nenonen (2008) and EU-OSHA (2010) advocates for appropriate risk assessment in order to avoid accidents to maintenance operators. However, several companies in this survey are making little use of risk assessment tools, JSA for corrective and preventive maintenance, as well as risk analysis performed by engineers. This indicates a large improvement potential for safer maintenance operations in Swedish industry, especially in combination with a transformation towards a Lean production system more sensitive to disturbances. In particular, safety issues should be addressed at the earliest stage possible, preferably by making changes during the design phase of equipment and processes (Gulati & Smith, 2009).

6. CONCLUSION

This questionnaire study has indicated a large improvement potential in using tools and software for conducting risk and reliability analysis in Swedish industry. In addition, the study has shown that there is a gap between employing Lean principles in production and maintenance, and that there is untapped potential in utilizing Lean tools in a maintenance context. Moreover, despite that reliability aspects are especially important to consider for companies operating in a Lean production system, few companies are absolutely having reliability engineers performing reliability analysis. Finally, the study indicated that there is a call for improved work with safety awareness and development of safer maintenance operations in Swedish industry. Making better use of engineering tools, and employing engineers to carry out risk and reliability analysis in a maintenance context, can contribute to achieving the high level of reliability that is necessary for the success of a Lean manufacturer. Furthermore, applying the tools and principles highlighted in this study enables the development of safer and more effective maintenance operations.

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