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The changing role of shop-floor operators in zero defect manufacturing

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Abstract

In the journey towards zero defect manufacturing, digital technologies aiming to improve different aspects of production and quality control will be of high importance. This will not replace existing management approaches such as lean manufacturing, including continuous improvement at the shop-floor level. A single case study is performed, where we have examined various aspects that influence a successful continuous improvement for reducing scrap parts and prevent further propagation in interaction with new zero-defect solutions. The aim is to identify the changing roles of the shop-floor operators and we highlight that they still will remain a key part of the system.

Keywords: Zero defect manufacturing; continuous improvement, operators, case study

1. Introduction

Manufacturing enterprises continuously strive to sustain their competitive advantage worldwide. To remain competitive, it is important to have satisfied customers. This is directly related to the capability of an organization to deliver products on time and at required and expected levels of quality. Lean, based on the Toyota Production System and its Just-in-Time and Jidoka concepts [1], seeks to build this capability in organizations. With focus on quality and the elimination of defects, Zero Defect Manufacturing (ZDM) is an emerging strategy that promises to increase the competitiveness of firms by targeting near-zero defect levels of quality [2-4].

Undoubtedly, forthcoming industrial developments will be driven by the application of digital technologies [4]. As such, the level of complex manufacturing technologies is increasing. Simple production processes are being automated in addition to advanced production processes becoming more complex and integrated. As a result, the role of the operators at the shopfloor has changed from executing simple repetitive tasks to handling more complex tasks. Consequently, the operator's ability to fully understand the manufacturing technology will be more difficult and this will raise demands for technical support to help the shop-floor operators continue to work in the correct way.

Much research has been carried out to investigate how digital technologies support management strategies such as Lean Management and ZDM [6, 7], including a specific emphasis on quality [8, 9]. However, there appears to be little research exploring how the roles of the shop-floor operators is evolving in this digital transformation, especially in terms of the enhanced demands they face when working with continuous improvement (aiming for reduction of scrap parts and prevention of defect propagation) at a time when production processes are becoming more complex and integrated with new innovative digital technologies. Thus, the aim of this article is to identify the changing roles of shop-floor operator when working with continuous improvement in the age of digitalization and ZDM.

2. Theoretical background

2.1. Zero defect manufacturing

The most common approach to quality control is the use of end-of-line quality testing to assess the quality of finished

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products. However, this is a time consuming and cost intensive process for quality control. In additional, it does not support the in-line prevention and correction of defects [10]. An alternative approach is ZDM.

The goal of ZDM is to decrease and mitigate failures within manufacturing processes and '*to do things right first time*', with focus on both detection, prediction, prevention, and repair of defects [2,3]. ZDM is a way of thinking with regards to production processes and the product produced. This can be strengthened when applied in combination with other quality improvement method such as Total Quality Management, Lean and continuous improvement [2]. In an ideal state, ZDM-firms are able to produce products with zero defects, even with complex and autonomous production processes. This is, however, still very much a pseudo goal.

In modern manufacturing industry, manufacturing processes are being automated to a large extent, in addition to becoming more complex and integrated. Unfortunately, multi-stage production lines are error-prone and action to avoid failure in these processes must be taken [11]. The quality of a product is affected by the condition of manufacturing processes and machines, combined with the skills of the human operating these. When considering that the manufacturing industry today is becoming more and more complex with multistage production lines, there are many parameters which should be taken under control to ensure the quality of a final product.

There are many types of possible action to implement in a production line in order to reach zero defect products. Existing ZDM approaches are mainly based on advanced detection technology that requires significant investment in equipment and technical skills. One common approach is monitoring of manufacturing processes and machines [12]. Monitoring system can be used to improve both the performance of the machine and the quality of workpieces produced. The onset of industry 4.0 and mass digital transformation has led to technology solutions for monitoring of processes and machines to detect any abnormal variation of the sensed data. This includes the application of sensors. Retrofitting equipment and machines with sensors and sensor signal-processing systems have become an enabler for taking action in real time. One of the goals for this is to ensure that the manufacturing processes are performed within defined process limits to minimize the variation of the quality of the produced product. Another goal is to avoid degradation and damage to equipment and machines from collision, and overload, for example, as well as other problems that can cause variation of machine condition and performance.

Another strategy is to have in-line measurement after critical steps of the manufacturing process with the aim to autonomously detect and discard the workpiece if it does not meet the specified requirement. One example of this is use of vision cameras for automatic optical inspection, e.g. for analyzing surface and size of the workpieces.

Existing technological solutions for reaching ZDM is mainly based on application of local solution focused on optimization of a single process step independent of preceding or succeeding process step [13]. An important step further is to implement technical solutions to expands current single process boundaries towards a production line perspective, tailored on multistage and intertwined production lines.

Most manufacturing industry today operates in a data-rich environment with use of powerful data-acquisition systems. This includes large datasets related to individual production process parameters and machine parameters by means of sensor systems. The increasing availabilities of sensors and not least promising smart sensors provides the opportunity to collect more and other datasets.

For the future, it is important to be able to extract valuable information and knowledge from these datasets to continuously monitor condition of the processes [14]. Still, there is a challenge to find a proper solution to analyze all necessary and vast datasets and not least within identification of correlation within a multistage production system. In order to achieve this, the next step is to analyze large datasets for diagnosis and prognosing, decision making and feedback control. One possible output from this, is enabling to compensate defects from a previous process step in current or following step [13].

Eger et al. [15] have identified a methodology based on correlation analysis between process parameters to predict defects and enabling defects to be corrected in a later process step. As a result, defect can be corrected automatically, and it will avoid occurrence and propagation of defect in later process step.

2.2. Operators changing role in the digital area

As manufacturing technology advances, more and more complex technologies are installed in production lines on the shopfloor. As a result, there is a gap between the ability of today's shop-floor operators and the requirements for the operators of the future. Several authors describe the emergence of the *Operator 4.0* concept - a smart and skilled operator who performs not only 'cooperative work' with robots, but also 'work aided' by machines as and if needed - by means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation towards "human-automation symbiosis work systems" [16,17]. However, though these works explore the important relationship between humans and robots / machines, there is limited commentary regarding the changing role of shop-floor operators in the digital era.

Operators of the future will meet an increased level of technical solutions which again impacts on their daily duties, with an increasing level of new and more demanding tasks. This will influence the operators' discretion and scope of responsibilities. Thus, there exists a gap between knowledge to operate the production line efficiently and the current knowledge of the operators. A study by Holm [18] highlights the importance of development of knowledge and skills for the shop-floor operators to meet the future demand, not only the engineering department. This can be achieved by systematically transferring knowledge to the operators by providing greater integration between operators and technical function [19].

2.3. Continuous improvement

Continuous Improvement (CI) is a core principle regardless of which kind of management system the organization has chosen [20]. There exist several definitions of CI, two of which are: "*A continuous stream of high-involvement, incremental changes in products and processes for enhanced business performance*" [21], and "*A company-wide process of focused and continuous incremental innovation*" [22]. Both definitions emphasize involvement by everyone working together to make improvement. This is in accordance with the following definition of lean manufacturing: "*Systematic removal of waste by all member of the organization from all areas of the value stream*" [23]. Waste is further defined as non-necessary activities that do not add value to the customer. This includes all contributing activities from the extraction of raw material until a finished product is delivered to the customer [24].

CI may occur through incremental improvements or through radical change [25]. Incremental improvements refer to small and gradual improvements, while radical change refers to improvement based on innovative ideas ~~-~~or new technology that may require investments. Moreover, an extended period with several incremental improvements may result in major improvements or a radical change. Consequently, CI is a change process in which superior performance is attained [26].

Organizing for CI processes may take place on at least three levels: management level, team level and individual-oriented level. Firstly, CI at management level involves the organization's strategy. Secondly, CI at team level involves all kind of tasks, broadly defined. Finally, CI deals with improvements in day-to-day tasks at individual level [27]. Bhuiyan and Baghel [25] have exemplify that and it is a management responsibility to address CI at each of these levels. In a manufacturing organization, shop-floor operators may be involved both at team level and individual-oriented level. More specifically, a shop-floor team will be responsible for improving day-to-day operational activities, in addition to their own practices aiming improving the overall equipment efficiency [28].

Designing, executing, and achieving CI represents a variety of challenges [29]. Fortunately, there are several known factors that influence successful implementation of CI. Among the more important identified enablers are management commitment, leadership, cultural issues, a need to measure the progress, motivation of workers, resources, and working in cross-functional teams [30].

3. Research design

The investigation was carried out using a single case study. A case study is considered an appropriate approach when the area being studied is in progress or has recently been in carried out, and where research variables cannot be controlled [31]. The case company has an ongoing Lean program including CI processes which could be studied, and consequently met these requirements.

The aim of the case study was not to examine the technology used for targeting ZDM itself, but to focus on the anticipated changing role of the shop-floor operator when faced with increased use of digital technology in the context of ZDM. As such, the case study was carried out to better understand how to successfully involve shop-floor operators in continuous improvement activities aimed at eliminating the scrap rate in their production process. Specifically, to identify: How is the roles of the shop-floor operators evolving in this digital transformation, especially in terms of the enhanced demands they face when working with continuous improvement (aiming for reduction of scrap parts and prevention of defect propagation) at a time when production processes are becoming more complex and integrated with new innovative digital technologies.

A case study protocol describing area to study, research questions, method of data collection and data analyses technique was developed. To ensure quality of the research, triangulation of data was carried out [31]. The main data collection method used was semi structured in-depht interviews. In addition, observations and informal interviews were made on the shopfloor during company visits for three days, while one of the researchers followed operator while there were working. In additional, examination of written documentation was performed to allow for triangulation.

13 semi-structured interviews were carried out across shop-floor teams and technical support teams, as well as the management team. Operators working in different shop-floor teams, but within the same manufacturing department, were interviewed to identify success factors regarding involvement and active participation in the ongoing process aiming for reduction of scrap rate and prevent defect propagation. Question were formulated within the categories: leadership and facilitation, involvement of operators, decision making, process of problem solving and continuous improvement activities, teamwork at shop-floor level, working environment, and motivation factors. The goal was to gather their opinions and experience of what is function well and what could have been done differently within those categories. In additional, managers and technical support functions for the specific production lines were interviewed to understand their role in supporting shop-floor operators.

The collected data was analyzed in order to identify existing approach for CI at shopfloor regards to strategy of achieving ZDM. Transcribed interviews, results from observation and company documentation were coded and visualized in data displays to find patterns and recurring themes [33]. Findings were also discussed with company managers, adding respondent validation.

4. Case description

The case company has three production lines for producing its product. All the lines are fully automated and producing in total approximately 22 million parts, that are subsequently used in the final product before being sold to the consumer market.

The lines are fully automated, multi-stage production lines, designed with following in-line checks:

- In-line check with measurement of torques with 100% auto-reject function
- In-line check with use of vision camera with 100% auto-reject function

The production lines are operated in five shifts with 5 operators at each shift, which function as a team collaborating on running these three production lines together. One of the operators at each shift, also has the function as team leader with the responsibility of organizing the work at the production line. In each of the five shop-floor teams there is one expert operator with higher technical skills, supporting other operators on-the-job when required.

5. Results and discussion

5.1. Lean activities at the case company

The plant has been working systematically with lean as management approach since 2008 and admits that this is not a long period in terms of a lean journey. The management team admits that the plant still has much to improve within lean. One of the main purposes for adopting a lean approach is to systematically reduce waste in the workplace and to improve the manufacturing processes by working with CI. In order to address progress at shopfloor, they measure the scrap rate and the productivity each hour compared to budget numbers.

The company applies a standardized board for all of its production lines to allow for tracking and follow-up on overall equipment effectiveness (OEE) and improvement activities in a structured way. This was a standardized communication matrix from shop-floor level to top management level; referred to as Tiers 1 to 4. The aim for this was to show their management commitment and involvement to the companies Lean approach and to have a systematically approach to this in daily basis.

Tier 1: A meeting in the start of each shift is led by the team leader where all operators for the following shift are participating. In advance, all operators including the team leader have discussed production issues with the previous shift. A predefined board is used (named ComBoard – Communication Board) where, among other things, safety, available resources and skills, facts and numbers from the last shift, and improvement issues are discussed. The operators were mainly satisfied with this meeting, but they admitted that communication and information, especially between shifts, are a difficult area in which to achieve high quality. This was pointed out as an important issue to improve from most of the informants.

Tier 2: Every morning there is a ComBoard meeting at the shopfloor, in which the team leader of the morning shift, operators, assistant production manager and the technical support team participate. The core activity in the ComBoard meeting is information exchange regarding production performance for the last 24 hours, in addition to planning for the next 24 hours. Major outputs from these meetings are an identification of main production problems as well as identifying the necessary activities requiring support from the technical support team.

Tier 3: Each day after the Tier 2 meeting is finished, the assistant manager has a team meeting with the technical support team. Standardized team boards are again used, and the problems identified during the Tier 2 meeting and respective causes and countermeasures are discussed and recorded.

Tier 4: Once per week a team meeting is performed by the operation manager together with all production managers, also with use of a standardized team board. Among other things, problem description, causes and countermeasures are predefined using the ComBoard.

In addition, the technical support team has a ComBoard for an annual improvement program aiming to achieve the company's goals which includes improvement for the production lines. This shows that the management strategy has a clear link to performance and quality achieved within all processes, all of which contributes to the achievement of the main lean principles such as customer value, management of the value stream, creating flow in the production processes and striving for perfection [24].

Another focus was the deployment of best practices and the adoption of a standard way of working. There was also a minimal gap between the lean approach described by the management team and the practices observed at shopfloor in this respect. Interestingly, the operators experienced that standardization of tasks and the way of working helped them in a positive way at of working and highlighted that they couldn't imagine being without it. This is also a good starting point to achieve defined lean principles.

The operators on the production line are organized in shop-floor teams and the teams' content with different level in skills and knowledge. All the operators highlighted that an available expert operator was very important. This was due to more and more complex technologies were installed in their production lines with the goal to achieve ZDM. It could thereby be argued that it is necessary to increase their technical knowledge for the future. This view is supported by Holm [18], who claim that technical excellence knowledge is an enhanced demand to meet for the future shop-floor operators.

In addition, further competence from support functions is sourced when necessary. When to involve other functions in the team is highly structured and well known to all stakeholders. One example is the escalation process. When the line stops and the problem is still not solved by the operators after a specified period of time, then support function is invited into the team. At daytime, it is the dedicated technical team for the production line, and outside of daytime a common technical support team for the whole factory is available. This approach is in line with achievement of high performance with always getting availability of more skills and knowledge if you ask for it. It is apparently that the management see the necessary of using their intellectual capital fully to make the production output as best as possible.

5.2. CI activities on the production line

It was apparent that the operators were motivated to produce high quality parts, which is a good starting point for improvement activities. The focus is clearly *Quality over Quantity*, which also shows that the employees are taking care of customer value – an important principle and starting point in lean and CI [24].

Another interesting finding is that many of the respondents experienced the correlation with quality and number of produced parts. Low scrap rate means high output of the line. This indicates an ability to interpret processes and its relations, which is one of the "future" demand of shop-floor operator identified in a Swedish study [18].

Improvement tasks, involved by the operators, were mainly based on daily issues regarding keeping production running according to budget numbers for scrap rate and number of produced parts per hour. A warning lamp indicates when a production operation stops. When this happens, normally the operator checks the operator panel for failure mode and based on the description and their experience and knowledge about the process step, the operator figures out what to do in order to get the machine running well again. All the operators involved in this study were very satisfied with the usability and the information they receive from the operator panel. Often, they manage to figure out how to start the line again without the need of other expertise. When the dedicated operator at the specific line is unable to solve the issue stopping the line after a certain time, the escalation process starts. First, the expert operator and/or the team leader was asked to help to figure how to start the line again. This is described in their system who they shall get help from, but in practice it depends on who is available.

If they couldn't fix the problem either, then the one from the technical support team was invited for help. Who it was, depended on the problem to solve. At daytime it is the dedicated technical support team for production line, and outside of daytime a common technical support team for the whole factory is available. If a stop had been for more than one hour, then they used a predefined escalation board to figure out the root cause(s) and countermeasure(s). This process was based on the 8-disciplines of problem solving – 8D. By using this systematic approach correctly, it helps the team to stay focused on completing the improvement task. It emerged during the interviews that operators could have become a little more involved in this process. Not as expert help or as a goal to take over tasks form expert help, but knowledge transfer so that afterwards they are better equipped to understand how the machines operate.

What they focused on was improvement based on the scrap rate for each production hour. One screen per production line, which was easily visible for each of the lines, shows the scrap rate and produced number of parts regards to budget. In addition, it shows the last three main deviation for the scrap rate consecutive per last 30 minutes – number and name of the process step and the failure mode. This information was created from their MES (manufacturing execution system). If there is a deviation according to budget, the numbers were marked with red on the screen. When a deviation occurred, a countermeasure was decided by the operator at line to improve the numbers. This process was documented manually in a predefined form. It was apparently that the countermeasure was based on their existing knowledge and skills about the manufacturing process and not the root causes for the failure mode. From this, one could argue that there exists a gap between the knowledge to find the root causes and the actual knowledge of the operators.

Interestingly, all the operators tended to become impatient with the progress of digitalizing. Some of the younger operators commented on that it was time to spend more time on digital solution, which will be helping us to achieve better quality at the line. Their impatience indicates that they wanted CI to progress one step further. When asking for proposals for a digital solution which could help them in their daily work, they were undoubtedly impatient and missed more progress on this. One of the operators said, "*we are more digital at home than at work and we miss more effort on this at production line*." Another operator added *"I am very happy with pen and paper, but I would also like to see more digital solutions on the shop floor"*. One example mention was the manually form mention above where they followed up deviation regarding number of produced parts and scrap rate each production hour. The information and knowledge created in this process was a possibility to digitalize and to get an easier overview of action taken for similar problems.

Everyone is expected to contribute with improvements proposals covering all kinds of operational problems in their daily work. To a large extent, minor or large improvements are implemented every day in the production lines with regards to scrap rate and stop at the line. Still, they experience that the same type of problems and quality issues repeat themselves, often multiple times. This finding indicates that they struggle when it comes to identifying root causes and making preventive countermeasures. When observing the work at the shopfloor for three days, a lot of small stops occurred, each of under a few minutes' duration, which may indicate that failure modes tend to repeat themselves. This indicates that more knowledge and analytical skills is needed to find the root causes.

The company's current approach for reducing the scrap rate is mainly based on local solutions focused on single production stages. In order to achieve an approach dealing with multi-stage production processes, it is necessary to develop digital technologies enabling the detection of cause-and-effect relationships in the complex and intertwined manufacturing processes. In order to achieve this, data storage and communication standards as well as data analytics tools offer new opportunities for targeting ZDM. These digital technologies give the opportunity to reduce the generation of scrap parts and prevent stops in a multi-stage production process in a systematically and fact-based manner. Unfortunately, this is not a quick fix to implement.

6. Conclusion, limitations, and future research

This study indicates that the roles of shop-floor operators will change when working with continuous improvement in the age of digitalization and ZDM. In order to deal with the promising advances that digital manufacturing technologies offer for ZDM and Lean, where data analysis enables the prediction of what will happen and subsequently make autonomous decisions, the role of the human will become even more critical than before.

More specifically, the role of the shop-floor operator has evolved from single repetitive tasks to multiple complex tasks due to complex and intertwined technologies implemented in production lines. In order to face these challenges successfully, future shop-floor operators must expand their knowledge and skills simultaneously to successfully contribute with CI activities.

To meet the changing role for the shop-floor operators to successfully work with CI activities in the age of digitalization and ZDM, this study shows that they must meet at least following future demands:

- general knowledge and technical excellence
- accurate and logical approach to be able to interpret processes and their outcome
- analytical skills to be able to work on problem solving tasks including root cause analysis
- participate (and in some cases manage) autonomous shop-floor teams

- behave proactive, engaged, and motivated

These findings confirm the knowledge created from a study based on the Swedish manufacturing industry [18].

The results are based on a single quality case study and should be regarded as indicative and with limited generalizability. Hence, more research is needed to enhance the results and to increase the generalizability.

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