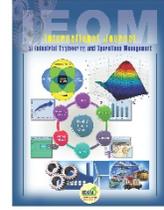




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A Combined VSM and Kaizen Approach for Sustainable Continuous Process Improvement

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ABSTRACT

The issues related to setup downtime, raw material waste, and the quality defects are inevitable in the flexographic printing business. To enable sustainable continuous process improvements within the printing process, lean manufacturing methodologies, such as Value Stream Mapping, (VSM), can be a competitive management approach. Therefore, this study explores how the systematic application of VSM in a flexographic printing process can foster further the process improvement when combined with other lean activities, such as, 5S, single minute exchange of die (SMED), and kaizen etc. To assess the contribution of this lean approach, the Overall Equipment Effectiveness, (OEE), and manufacturing costs are taken as performance metrics. The results demonstrate that when integrated with 5-why root cause analysis and kaizen, VSM improved OEE by 24.31% and reduced manufacturing costs from US\$0.762 million to US\$0.6 million. Hence, the significance of the proposed combined lean approach for continuous improvement is reached.

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1. Introduction

This paper addresses a case study involving a flexographic printing process, which is an important and widely used printing method. In spite of its widespread usage, this process is still of concern to researchers and practitioners alike, as it is prone to setup downtime, the quality issues and the raw material waste. While published works address these issues partially, there is still a need to a more thorough undertake where different lean tools can be combined for the detailed analysis and identification of the problem areas and the formulation of a well-studied implementation plan to remedy and eliminate the causes of these problems. This approach is in agreement with two key objectives for all organizations: high quality and low-cost products. To attain these objectives, the traditional approach of doing business has been replaced by "lean manufacturing concept"; (Zahoor et al. 2017). It is called "lean" because this helps organizations to continuously improve their processes by eliminating waste; thus, producing a cost-effective quality

product for both manufacturers and consumers. A variety of lean tools can be used to improve productivity by eliminating wastes within the process; (Abdualmalek et al. 2007).

Nowadays, the main difficulty in the successful implementation of lean tools and concepts in any organization would be the proper identification of problem area which needs improvements. So, an implementation based on inadequate or improper visualization of the process may lead to an inconclusive lean journey. The studies of, (Ali-Asghar and Changiz 2019; Zahoor et al. 2018, Yuvamitra et al. 2017; Alaya 2016, Edtmayr and Sunk 2016; Muzni and Ku Munirah 2015; Klabusayova 2014; Shook and Rother 2009; and Lasa et al. 2008), argued that value stream mapping while working within a lean paradigm helps to improve the process by eliminating wastes. Furthermore, these authors mutually agreed that VSM being the most promising among the other lean tools is capable to optimize the manufacturing organization as a whole.

In this research work, a VSM approach combined with kaizen lean tool will be used to address the concerns raised by a flexographic printing industry with the aim to eliminate waste and increase the efficiency. This combined lean approach is supported by the use of 5-why for a thorough root cause examination of the problem areas needing improvements. More importantly, the overall equipment effectiveness metric is periodically measured during the study to ensure that the intended improvement is on track. The careful examination of the published works reveals that this comprehensive undertaking to combine VSM, kaizen, 5-why, and OEE, has not appeared in the literature, and it is a step forward in the quest for continuous and sustainable improvement. More details will be provided and discussed in the next section about the state-of-the-art of lean tools and applications.

2. Literature Review

This section addresses the published literature on lean approach and continuous improvement. It includes papers that apply lean concepts in various industries. The focus is on the concepts using VSM, VSM with other techniques, and more importantly, on those papers that tackle the flexographic printing process. At this time, it is good to mention that the survival of any organization depends on its proficiency towards continuous process improvement in order to produce value-added products and services for consumers. To achieve this goal, VSM has been employed by numerous industrial sectors from manufacturing organizations; (Tomes et al. 2015, Kuhlant et al. 2013, Tabassum and Khan 2016) to various other industries such as process companies; (Zahoor et al. 2018; Rohani and Zahraee 2015; and Sattarova et al. 2016), maintenance departments; (Kasava et al. 2014), quality assurance; (Haefner et al. 2014), and materials flow; (Li et al. 2017).

Among others, Alvandi et al. (2012) emphasized on the importance of VSM application in the industry through comparing losses as icebergs and company itself as a ship. They argued that very small part of the iceberg is apparent while most of them are invisible under the sea. The real challenge is to identify them and VSM helps in this regards for almost every industry via giving a top-down and a bottom-up survey of the process. As well, Sattarova et al. (2016), improved product cycle time when they utilized VSM as a lean tool in a manufacturing industry. They reduced the cycle time by 42.28% and costs by 57.71%. The authors further added that future work related to VSM can improve the process further. Klimecka-Tatar (2017), applied VSM to cardboard packaging production and made process improvements after identifying three major losses from the current state map. The study recommended that integration of lean principles with VSM could be a good start for future improvements. Alternately, Yuvamitra et al. (2017), achieved continuous process improvements in a rope manufacturing industry through VSM integrated with the lean principles. The authors revealed that the modifications in the current state map made the process more efficient by reducing the manufacturing time from thirty-six days to nine days only. The published literature also illustrates the significance of the VSM in the other fields as well. For instance, Kasava et al. (2015), demonstrated the application of the conceptual framework of VSM as a sustainable manufacturing concept in an aircraft maintenance process. The operation was improved after categorizing the activities into "value-added" and "non-value-added" and they suggested an integration of other improvement tool with VSM for the future improvements of the process. In separate work, Haefner et al. (2014), used VSM in the context of quality assurance issues. They called this a quality value stream mapping (QVSM). This tool is ideal for 1) visualization, 2) analysis and 3) quality assurance design.

There are various researches that demonstrate the enhanced competency of VSM for sustainable improvements when used with other lean tools as a joint approach to suggest improvement changes. Among these efforts, Tabassum and Khan (2016), presented a case study on the effective utilization of VSM to identify the bottlenecks in the assembly process of an automotive manufacturing unit. These authors, thereafter used the 5S technique to organize a poorly designed workspace, which consequently brought a 62% improvement in the assembly line efficiency. Similarly, Rohani and Zahraee (2015), improved the production line of a colour manufacturing industry after differentiating the "value-added"

and the “non-value-added” activities through VSM. Furthermore, “non-value added” events were eliminated by using 5S and Kanban which led to the reduction of the production lead time by 6 days from 8.5 days.

In another work, Azizi and Manoharam (2015), employed an integrated lean approach to improve the machine set-up time for a printed circuit board (PCB) assembly line. These authors, after identifying the hidden losses in the current state map of the process, applied kaizen and SMED, as a lean concept. This approach resulted in the reduction of set-up time from 145 seconds to 54 seconds. Likewise, in one of our work, Zahoor et al. (2018), analyzed the current state of a gear manufacturing unit using VSM. It helped when joined with kaizen to improve the lead time from 528 minutes to 132 minutes. Similarly, Batra et al. (2016) made an attempt to reduce the waste within a tool room of an automotive industry using VSM. The authors argued that VSM correctly identified the areas for the improvements and bridged the gap between the current and the future state of the process using a lean approach: Jishuken (self-learning).

There is a literature pertaining to the use of computer simulation to take into accounts of all VSM outcomes (Alvandi et al. 2012; Li et al. 2017; Chukukere et al. 2014; and Standnicka and Antonelli 2015). While working for an aluminum recycling facility, Li et al. (2017), utilized a Sanky diagram for VSM to evaluate and visualize the complex flow of energy and materials in the manufacturing system. They embedded this diagram with the existing ERP software for the continuous analysis. Similarly, Stadnicka and Antonelli (2015), employed FlexSim™ simulation software to map current and future state of a sleeve manufacturing process. The authors argued that computer simulation could provide an opportunity to get a deeper insight of the process but preparing the model for the software is itself a time and cost consuming process. So, decision regarding the use of software simulation for a particular case would be a critical step. Although, these researches provide clear evidence to support the significance of VSM and its integration with other lean techniques in many manufacturing sectors, one of the major inadequacy that can be observed in almost all the reviewed papers, is the absence of using a common performance metric to benchmark any process performance such as OEE and use of an additional root cause analysis to strengthen the VSM effectiveness; (Dadashnejad et al. 2019; Zarwan 2017). In another attempt, Munyai et al. (2019), employed simulation-based VSM to enhance the productivity for a shaft manufacturing industry. The results revealed an increment in the throughput of two identified bottleneck operations by 27% and 60.74%, respectively.

Of the work, fewer case studies are found related to the lean application to improve the flexographic printing process. It includes Bodolay (2010), who presented a case study of this printing method. Bodolay employed two different lean tools, i. e., 5S and single minute exchange of die, to reduce the downtime and improve the throughput of the process. These improvements resulted in an additional 70 hours of productivity, saving more than \$3 million annually. In a different effort, Zahoor et al. (2017), improved the OEE from 34% to 40.2% using pareto and 5-why root cause analysis as a lean approach. Lipiak (2017), in his work, attempted to enhance the process effectiveness through the use of SMED and quality function deployment. The author further recommended the use of other available lean methodologies, which can identify the opportunities for the improvements within the existing process. Unfortunately, no one has employed VSM as a lean approach to improve the flexographic printing operation. Therefore, this work seeks to contribute to the literature about a widely applied concept of VSM integrated with kaizen and 5-why analysis with the focus to improve the OEE of this process along with the production cost.

The remainder of the paper is organized as follows: Section 3 describes the flexographic printing process and presents details about the various steps that constitute the printing process. Section 4 covers the combined lean manufacturing approach where value stream mapping, 5-why, and kaizen activities are featured and used. Lastly, the conclusion and recommendations for future research are stated.

3. Flexographic Printing Process Description and Related Problems

A flexographic printing machine used in a renowned packaging organization is considered as a case study. The paragraphs below present a detailed description of this widely used printing method. The machine specifications and the production capacity are listed in Table 1.

Table 1: Flexographic printing machine specifications

Machine name	Key raw material	Machine speed (meters/min)	Type of printing process	Actual production (meters/ year)
Cerruti Green	PET, Polyester, PVC and BOPP	220	In-line flexographic printing	80 million

The schematic of the various components of the printing machine under study is shown in Figure 1. There are nine basic steps involved in the flexographic printing process explained below:

1. Unwinding of poly film and passing through the plate cylinder and the impression cylinder.
2. Filling of the mixture of ink and the solvent in the ink tray.
3. Extraction of ink from the tray by the fountain cylinder.
4. Transfer of ink from fountain cylinder to the anilox cylinder.
5. Distribution of ink across the emerged areas of the plate cylinder that causes printing.
6. Pasting of a uniform layer of the ink from the anilox cylinder to the soft plate/flexible plate cylinder.
7. Uniform distribution and removal of the excessive ink by the doctor blade on the anilox roller.
8. Printing on the substrate by the plate cylinder against the impression cylinder.
9. Finally, the printing will be completed by the impression cylinder through exerting the pressure.

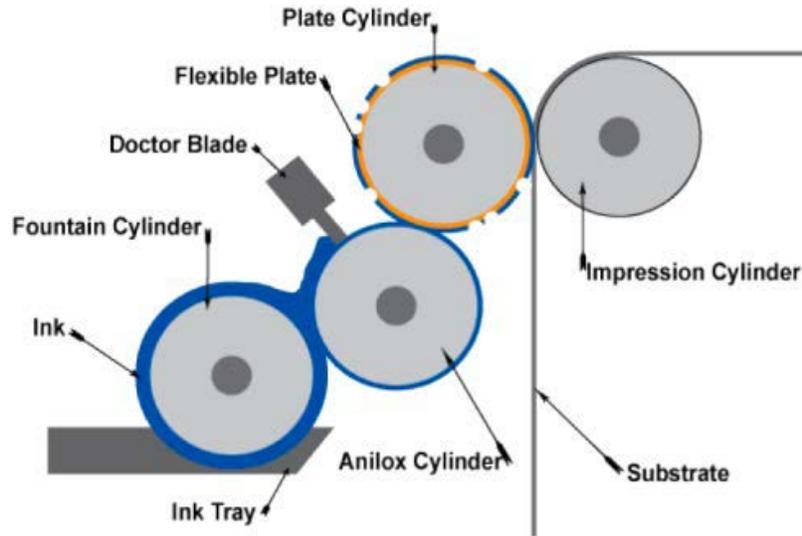


Figure 1: Schematic of the flexographic printing process

The following section will be dedicated to the approach tackling the above-indicated process shortcoming where details, explanations, and different metric measurements will be carried as per the proposed combined lean approach.

4. Methodology

To accomplish the objectives of this research, direct data collection method was used for the better understanding of the existing process; (Dadashnejad et al. 2019; Alaya 2016; and Thomas 1994). While using this method, thorough information related to the process downtime was gathered after the careful examination of the printing operation, and collected data was utilized to map the current state and identify the problem areas. Furthermore, semi-structured interviews with the production manager, the supervisor, and the operators were carried out in order to answer the questions for the root cause analysis of identified areas. The respondents were questioned to indicate the issues and possible causes related to the process stoppages and the other losses. Additionally, suggestions were invited from the staff in order to design appropriate kaizen routines. Moreover, the VSM awareness talks and workshops were organized in the company under consideration. Upon the compilation of the data, the following two main concerns were noted: machine downtime and final print quality. These two concerns have a direct impact, and negatively affect the metric OEE.

To address these process's weaknesses, the VSM as a lean approach is employed methodically to assess its impact on the OEE. During the first step, the flexographic printing machine was selected and the OEE of the current situation was evaluated as follows:

$$\text{OEE} = \text{Quality} \times \text{Availability} \times \text{Performance}$$

In the second step, the current state map was formulated based on the acquired data. In order to ensure the best VSM performance, it is advisable to conduct an additional root cause analysis. Therefore, upon recognizing the problem areas from the current state map, the 5-why analysis was performed to identify the root cause of these problems. It facilitates and strengthens the diagnostic of the process by identifying the exact cause of the problem. The work plan for the

improvement was then proposed in the third step using kaizen. Kaizen is used for the continuous improvement by focusing on the impactful small incremental changes and sustaining them for a long period of time by involving everyone in the organization; (Nguyen 2019; Akhter et al. 2015). It is a simple and inexpensive approach which can improve the efficiency and the productivity of the process. The fourth step involved the mapping of the future state incorporating each improvement routine. Improved OEE measurement based on the future state map was calculated followed by the production cost estimation. Lastly, the fifth step comprised of successful implementation of the work plan. To confine the kaizen practices during the implementation phase, a unit-functional team was established which worked together with the quality circle that already existed in the company. The schematic of the combined lean journey is shown in Figure 2.

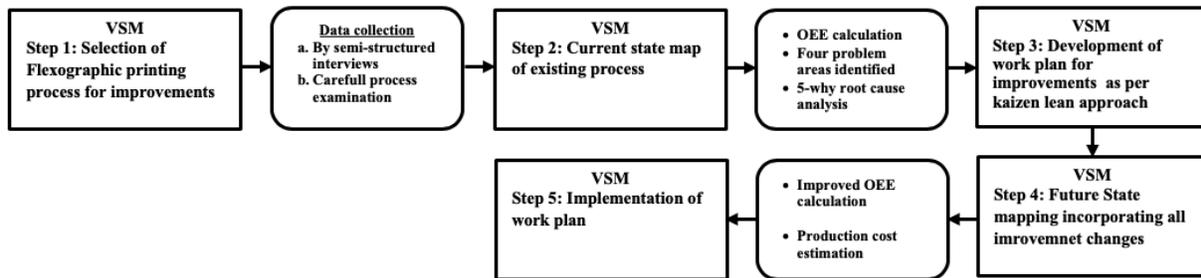


Figure 2: The combined lean journey

5 Results and Discussion

5.1 Current State Map

A current state of the process was mapped based on the collected data and is shown in Figure 3. It includes the production flow of the printing operation starting from the customer order to the finished product. From the map, four process steps were marked as experiencing stoppage losses. The summary of these process steps with recorded downtime is given in Table 2 below.

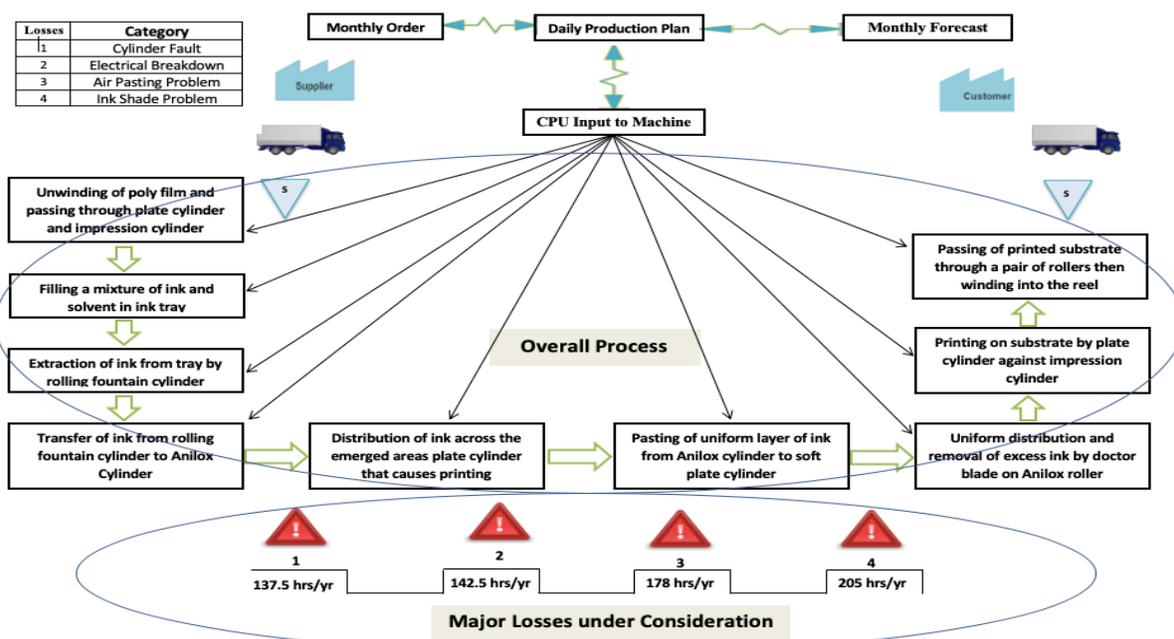


Figure 3: Current state map

Table 2: Summary of printing steps experiencing stoppage losses

Process step	Total downtime (hours/year)
Cylinder fault	137.5
Electrical breakdown	142.5
Air pasting problem	178.0
Ink shade problem	205.0

On the basis of the available downtime data, the OEE for the existing process (current situation) was calculated and is presented in Figure 4.

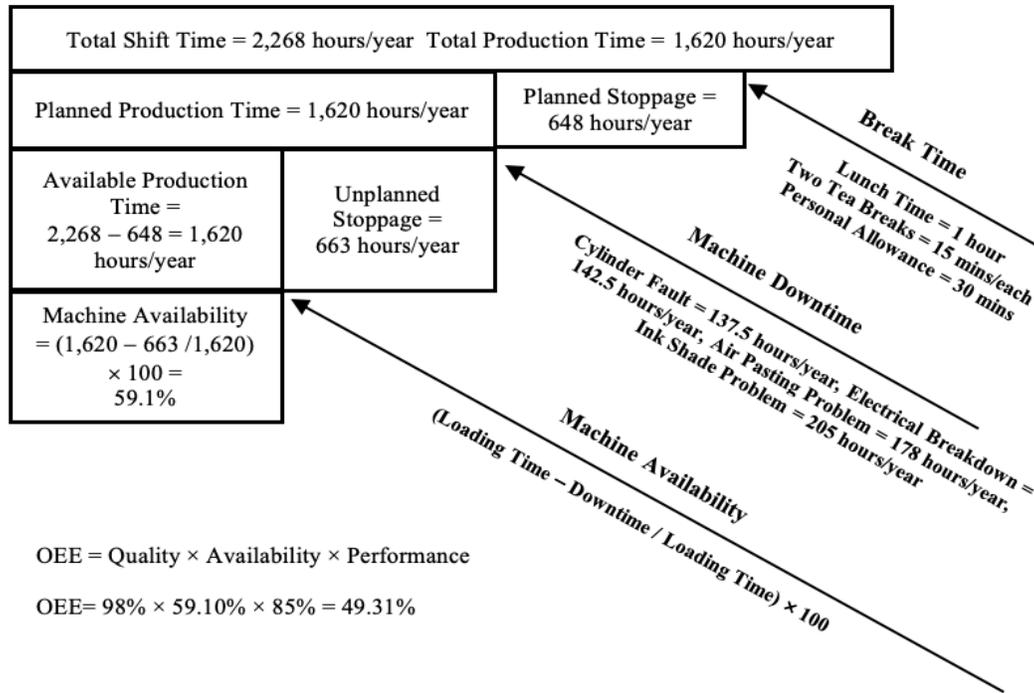
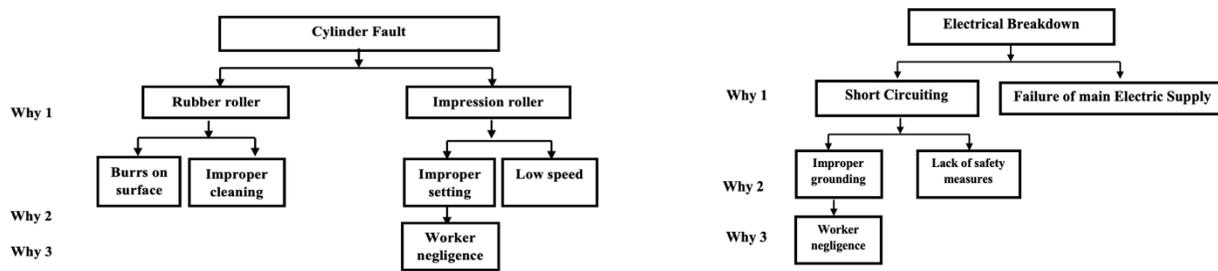


Figure 4: OEE calculation based on the current state

These printing steps were made out as problem areas which negatively impact the equipment availability. To diagnose the root cause of these identified problem areas, the 5-why analysis was carried out as shown in Figure 5. In this paper, the asking of "why" question was stopped after the third time because the root cause was clearly identified. The literature also confirms the same; (Zahoor et al. 2017; Alukal 2007; and Benjamin et al. 2010) that there is no need to further ask the "why" question if the root cause has been identified earlier. The results obtained after the 5-why analysis are given in Table 3.



(a) 5-why analysis for cylinder fault

(b) 5-why analysis for electrical breakdown

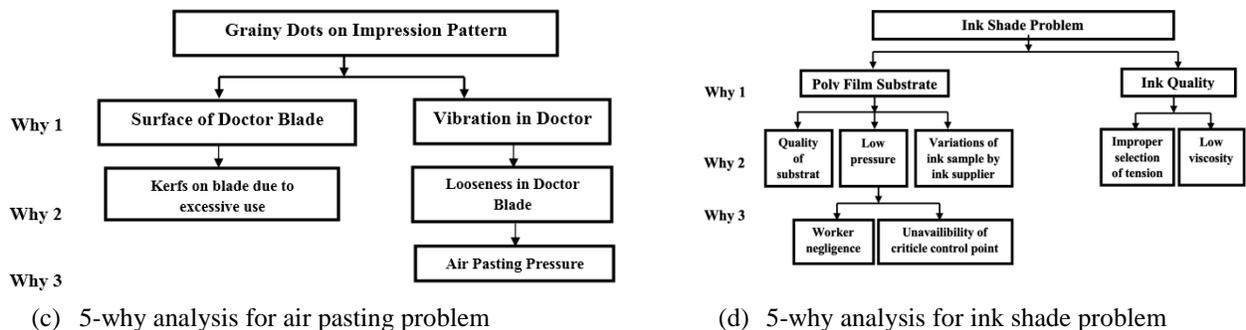


Figure 5: 5-why analysis of identified problem areas

Table 3: 5-why analysis results

Problem area	Cause and effects
Cylinder Fault	Cause: Improper setting/alignment of impression roller cylinder due to worker negligence Effect: Duplicate printing
Electrical Breakdown	Cause: Short-circuiting at the workplace Effect: Process breakdown
Air Pasting Problem	Cause: Looseness in the doctor blade Effect: Grainy dots on impression patterns
Ink Shade Problem	Cause: Reducing ink sticky effects Effect: Fade printing

To eliminate these issues which were causing process downtime; a work plan for improvements will be proposed in the subsequent section.

5.2 Proposed Work Plan

Upon identifying the root cause of these problem areas, different strategies for their improvement were proposed, (Table 4) to reduce the machine downtime. Kaizen was adopted to further elaborate the action plan for the comprehensive implementation of these routines.

Table 4: Strategies for improvements

Problem areas	Improvement strategies			
	Operation standardization	Housekeeping	Capital investment in modern equipment	Staff training
Cylinder fault	√			√
Electrical breakdown	√	√		√
Air pasting problem	√		√	√
Ink shade problem	√		√	√

A detailed description of the improvement routines suggested by kaizen is presented below:

1. **Operation standardization and housekeeping:** The current state map, (Figure 3), and 5-why analysis, (Figure 5), show that downtime can be reduced by standardizing the work method. This should be done by implementing a preventive maintenance schedule. To avoid the cylinder fault, a weekly inspection of the polishing and the waxing of the impression roller was recommended. As far as the electrical breakdown concerned, dedicated wire grouting was advised to prevent short-circuiting within the working area. Daily inspection of electrically related housekeeping should be incorporated within the preventive maintenance plan. Similarly, the examination of the air pasting pressure problem to avoid the looseness in the blade was suggested as a prime section of the maintenance schedule. To standardize the ink shade mixing process, display of the colour composition and pattern charts for the proper mixing of ink shade was appreciated. Furthermore, to avoid the delays in the process due to ink shade variations, the usage of a uniform number of lines/inch of the anilox cylinder at the ink supplier and the packaging manufacturer end was recommended.

2. **Capital investment in modern equipment:** The use of modern technology can eliminate the process downtime. Therefore, the following new machine set-ups were suggested for these specific problems:
 - The installation of a new doctor blade was advised for the reason that when used in series with the old one, it can support the better wiping of ink and the uniform transfer of the ink on the substrate. This arrangement will not only improve the grainy dots issue on the samples but also extend the life of the doctor blade as well.
 - The difference in the material of the drawdown sample (the glass screen on which the shade sample is taken before the final printing) and the actual poly film substrate (on which the final printing is done) results in the ink shade variation in the final printing. These variations could be eliminated through purchasing a new dedicated equipment to take the drawdown sample. It uses the same poly film material instead of the glass screen.
 - Ethyl acetate is used as a solvent to clean the ink drums, from which the printing rollers take ink, and transfer it to the substrate. Previously, fresh ethyl acetate was used for this purpose which consumed a reasonable amount of capital. Moreover, the scarcity of the fresh solvent in the market caused further process delays. To reduce the consumption of the fresh solvent and ensure its continuous availability, a solvent recovery plant was proposed to recycle the solvent from the ink waste. Table 5 illustrates the cost that can be saved after installing the solvent recovery plant.
3. **Staff training:** The awareness and the training sessions for the workers were recommended to maintain sustainability in the improvement process. This enables the employees to take part in the lean implementation by providing a specific skill level; (Bhasin 2012).

Table 5: Cost based comparison of the solvent recovery plant

Before the solvent recovery plant						
Ethyl Acetate	Annual consumption (kg)	Price/kg (US\$)	Cost in million (US\$)	Amount of fresh solvent used	Amount of recycled solvent	Remarks
	140400	1.76	0.23	100%	0%	Completely dependent on the costly fresh solvent
After installation of the solvent recovery plant						
	106704	1.76	0.18	24%	76%	Saving US\$ 0.05 million

5.3 Future State Map

After incorporating all the kaizen activities, the future state of the process was mapped as shown in Figure 6. The improved state indicates a reduction in the downtime associated with all the marked operation steps. The comparison of the OEE metric between the improved state and the current state of the printing operation will be presented in the subsequent paragraph.

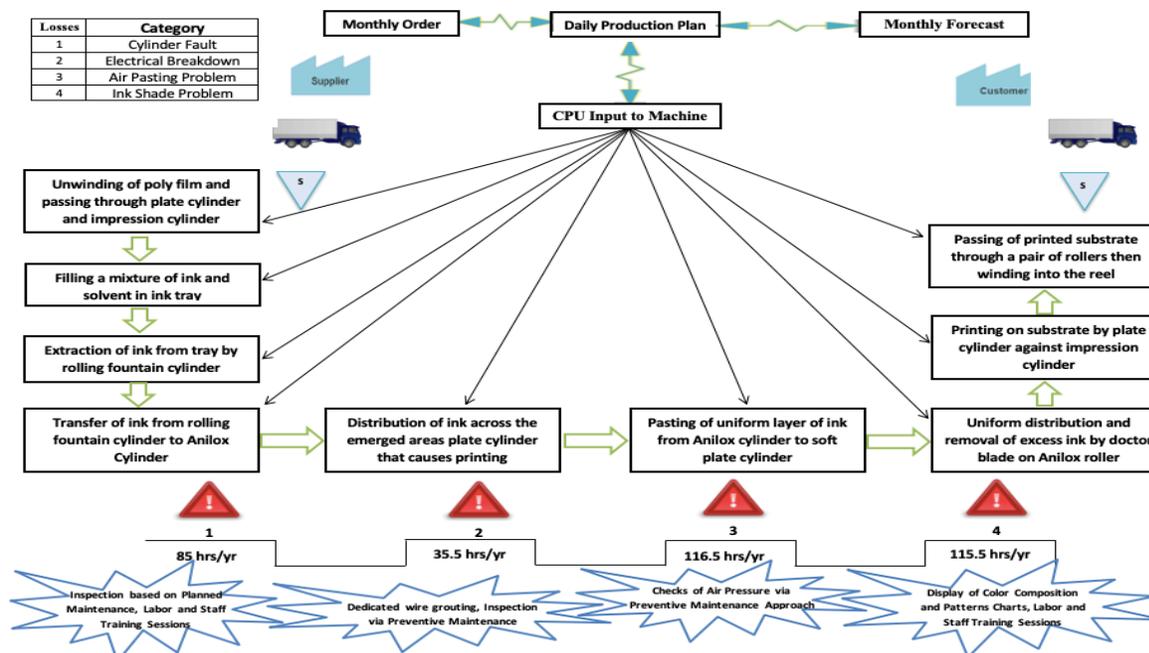


Figure 6: Future state map

The future state map shows the reduction in the downtime for all the identified issues, (see Table 6 below). The drop in the machine downtime is evidence of the success of this proposed combined lean approach. It also reveals that VSM is equally capable in targeting the specific areas for the improvement in case of the flexographic printing process, which is in agreement with the other published researches related to the different industrial sectors; (Tomes et al. 2015; Kuhlant et al. 2013; Tabassum and Khan 2016; Rohani and Zahraee 2015; and Sattarova et al. 2016). Moreover, it is noted that the VSM is well supported by the root cause analysis in revealing the exact cause of all these identified problems. As a result, this analysis facilitated the process in suggesting the improvements. The published works can be found in the sustenance of 5-why significance; (Zahoor et al. 2017; Benjamin et al. 2010). For example, Benjamin et al. (2010), used this approach to find out the main reasons for the waste in the Toyota production system. The authors referred to the 5-why analysis as a realistic approach for the identification of the prime cause of an issue to reduce and eliminate the defects.

The improvement in the downtime also proves that the kaizen, not only achieved the objectives with respect to the process downtime but also carved a path towards a sustainable continuous improvement. The achieved results are supported by several studies; (Nguyen 2019; Zahoor et al., 2018; Rahmanian and Rahmatinejad 2015; and Jamian et al. 2012). For instance, Nguyen (2019), proved that kaizen offered a competitive edge towards sustainable developments for the SMEs in Vietnam. Similarly, Rahmanian and Rahmatinejad (2015), concluded that manufacturing companies can use kaizen approach for their growth and survival.

Table 6: Downtime improvement in the flexographic printing process

Problem area	Current downtime (hours/year)	Improved downtime (hours/year)	Saved downtime (%)
Cylinder fault	137.5	85	38.2
Electrical breakdown	142.5	35.5	75
Air pasting problem	178	116.5	34.6
Ink shade problem	205	115.5	43.7

The corresponding improvement in the availability of the equipment and OEE followed by the production cost estimation is shown in Figure 7. As, the future state map showed a reduction in the process downtime (Table 6), followed by the improved OEE, (Figure 7), this combined lean approach was strongly recommended to ensure the continuous process improvement of this printing machine.

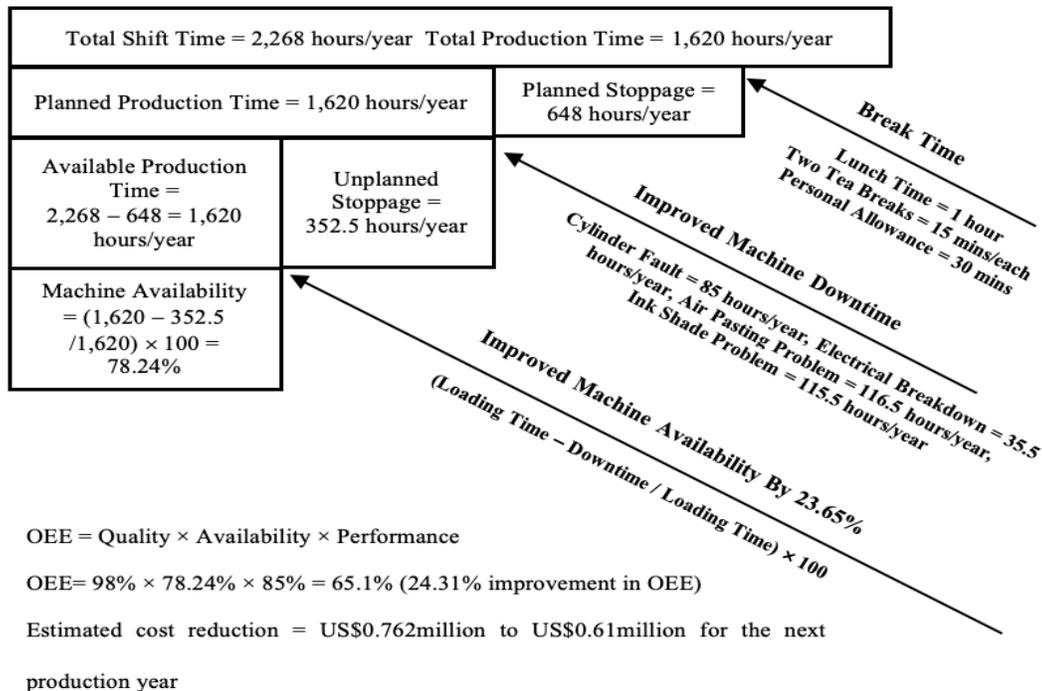


Figure 7: Improved OEE calculation

6. Conclusion and Recommendations for Future Research

This paper demonstrates the usefulness of lean manufacturing concepts and highlights how it can be utilized to improve the overall equipment effectiveness of a flexographic printing process. It also establishes the significance of the proposed combined lean approach using VSM, 5-why root cause analysis, and kaizen. This approach proved to be effective with regard to introducing improvement routines for the future state map and ensuring continuous process improvement.

In this study, the main practical objective was to improve the OEE with the focus to enhance the machine's availability by reducing the downtime. The following inferences were drawn:

1. The standardization of the machine operations work method led to a significant machine downtime reduction of 75% (electrical problems) and 38% (cylinder fault problems).
2. The results of the research also inferred that the capital investment for the suggested equipment set-up could cut downtime by 34.6% and 43.8% for air pasting and ink shade problems, respectively, thus, making the entire process more efficient and productive.
3. As stated earlier, lean manufacturing aims to bring a positive and continuous impact on the process. This study demonstrates the success of the lean approach applied to the production flow of a flexographic printing operation. The suggested kaizen improvements would enhance the availability of printing equipment by 23.65% through the reduction of downtimes. Consequently, the OEE would improve by 24.31%.
4. The cost saving based on the improved OEE for the next production year was estimated to be between US\$0.762 million to US\$0.60 million.

While the case study and its findings relate to a specific industry, flexographic printing, the combined and comprehensive approach used can be applied to other manufacturing industries. As future research undertake, one would consider the scheduling of jobs since a large variety of orders are normally processed in flexographic printing. This would add to the improvement in the overall performance of such processes.

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