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To cite this article: J P Marques *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1193** 012124

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Safety efficiency value stream mapping (SEVSM) - A new tool to support the implementation of Lean Safety

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Abstract: Occupational health and safety constitutes a topic of great importance in organizations nowadays, given the social and financial implications that arise. In addition to these problems, the manufacturing industry is greatly responsible for the number of accidents at work worldwide. In parallel, organizations focus on improving processes and eradicating waste from production flows. Therefore, there is a need to develop tools which are able to combine these two factors. Metalworking industry suffers of safety problems usually due to the great weight of the parts involved, as well as the processes used. The Safety Efficiency Value Stream Mapping (SEVSM) tool was developed to address these issues with the purpose of facilitating the identification of the risk level at each workstation, which is determined through risk assessment, as well as by verifying the type of risk which causes the security breach, and then indicating the most appropriate Lean tool to be applied for risk resolution. Besides these, it is also possible to obtain a diagnosis of the production flow, enabling an analysis of the most significant production indicators. The results obtained pointed to a 38% reduction in the risk level associated to job preparation activities through the introduction of Total Productive Maintenance, as well as a 31.8% reduction in compressor assembly process time, and 49.3% in the risk level related to the latter through Standard Work.

Keywords: Lean, Occupational health and safety, Lean safety, Safety efficiency value stream mapping.

1. Introduction

It is estimated that, on a global scale, there are 1000 daily deaths resulting from accidents at work, and 6500 workers suffering from occupational diseases. Indeed, 2.33 million work-related deaths were recorded in 2014 and 2.78 million deaths in 2017 [1].

The factors that most influence the occurrence of accidents at work are the demotivation of employees, a lack of clearly defined procedures, inadequate control, instructions and training, as well as low levels of commitment to safety by management. All of these aspects can be controlled and defined when an occupational health and safety system is correctly implemented [2,3].

Lean Safety resides in the creation of a safe and healthy work environment, in which risk management is carried out to reduce or eliminate hazards, while also seeking to motivate employees [4].



The use of Lean safety to improve occupational health and safety in the manufacturing industries additionally contributes to the reduction of waste, namely: in the time employees are absent from their activities, in costs arising from payments to employee insurance, as well as expenditure related to damaged tools or equipment [5]. Thus, employee safety constitutes a value adding proposal. Accordingly, through the implementation of improvements in the workplace safety process, the consequence will be the manufacture of faster, better, safer, and less expensive products or services [5, 6]. The relevance and importance of this study ensues from the need to explore and learn more about the impact and improvements produced by the implementation of Lean tools in the field of occupational health and safety, thus aiming to promote a culture of safety across the organization. In view of this, the objective of the article is to develop a new tool, which will be capable of providing the user with an overview of the organization, both in terms of productivity as well as health and safety. Furthermore, it also enables the easy identification of appropriate Lean tools to solve the problems encountered. In order to achieve this objective, a survey and analysis of the current state of working conditions must be carried out, assessing their impact on occupational safety, as well as verifying the existence of safety gaps and inefficiencies in the production process. Subsequently, one can then proceed with the implementation of the appropriate Lean tools.

2. Literature Review

In the first decades of the 20th century, issues related to Occupational Health and Safety (OHS) were addressed by states, with the support of inspections created specifically for this purpose. However, in real terms, little was done to solve these problems. The answer was provided by the mobilization and organization of workers, as well as the development of a body of regulatory experts, composed of public administrators and social security organizations. They were able to draw up a framework of regulatory controls, forcing organizations to safeguard workers from injuries or health problems, with financial compensation in the event of accidents [6,7].

The human social and economic costs arising from accidents and occupational diseases have long been a source of wear and tear in industries. In order to address these issues, health and safety management systems have sought to implement measures and strategies that accompany technological and economic changes, thus preventing, controlling, mitigating or eliminating occupational hazards and risks [8]. The way in which organizations attempt to manage occupational risks and guarantee workers' rights is considered to be a topic of great relevance by the International Labour Organization, World Health Organization, European Commission and national governments [9].

An important point in risk management is the definition of occupational health and safety indicators, which are numeric and provide information on the problems and difficulties encountered in the previous period. These indicators make it possible to measure progress in the management system and monitor the organization's activities in the area of safety [10].

A concept that aims to connect production with safety is Lean Safety. Not only does it aim to ensure that the working environment promotes safety, but it also enhances the productivity of employees [4]. Based on Lean thinking, the lack of safety in the workplace constitutes a source of waste for the company, which is specifically due to workers' compensation costs, lost productivity, and increased employee turnover. In order to improve safety conditions, production must be normalized and standardized through the introduction of Lean strategies in the company, which include incentives to keep the workplace clean and orderly, where materials are restricted to essential requirements and there is a flow of systematic work [11].

Thus, the implementation of Lean tools - normally used to enhance productivity and eliminate waste - is applied with a view to improving the work environment and reducing accidents and occupational diseases. The tools which are understood most easily by employees, and present better results regarding the work environment and ergonomics are: 5S, Value Stream Mapping (VSM), and Visual Management [12].

However, the great complexity of the different industrial sectors can make the implementation of traditional models of risk management unfeasible. In addition to this, the legislative mandatory

definition of these management systems is also of great influence [4]. Another point that negatively influences the implementation of a safety management system complemented by the Lean concept is related to organizations that manufacture a low volume of products, but which vary greatly. This is chiefly due to the diversity of processes and human resources involved in this context of production. In addition, there is evidence which indicates that Lean practices are not successful in some companies, more specifically because the human factor is not fully considered to be one of the fundamental factors in the implementation undertaken [13].

On the other hand, in a study linking Lean principles and the work practices associated with the social performance of employees at a large global clothing manufacturer, a significant improvement was found in the likelihood of product compliance. This result indicates that the implementation of the Lean concept is associated with the development of a standard work process. Through investment in training and education for employees, as well as the improvement of working conditions, employees are qualified and motivated [14; 15; 16] to produce goods of better quality [17; 18; 19].

In addition, a research study relating Lean tools with safety methods [20] was carried out with the objective of understanding if, by interconnecting the two concepts, the risks and accidents at work could be reduced. It was found that, in approximately 55% of the cases, Lean tools impacted positively on safety practices. Only in 8% of the cases did Lean tools present conflicts with such practices [21].

3. Method

The Safety Efficiency Value Stream Mapping (SVSM) tool was developed to address the problem areas detected and aims to facilitate the identification of the risk level presented by each job. This is determined through risk assessment, the verification of the type of risk as a cause of safety failure, and an indication of the most appropriate Lean tool to be applied to solve the risk. Furthermore, a diagnosis of the production flow can also be undertaken, thus obtaining the most significant production indicators for analysis.

Hence, the SEVSM aims to combine tools to analyse indicators from the productive perspective of the processes, as well as safety and efficiency. Table 1 presents some tools which contributed to the development of this new tool.

Table 1. Tool combination proposal

Tools	Perspective
Value Stream Mapping (VSM)	Productivity, by mapping the flow of information, material, and process.
Safety Stream Mapping (SSM)	Occupational safety, through the risk level of each production area.
Overall Equipment Effectiveness (OEE)	Efficiency through availability, performance and quality of the process.

4. Results

For the development of the Safety Efficiency Value Stream Mapping (SEVSM) tool, the criteria used as a basis were:

- The SEVSM can be incorporated into VSM, since users already master the tool, and the process is easy to view.
- The SEVSM must emphasize the perspective of occupational safety.
- The SEVSM must present the waste mentioned in Lean in its state map.

In order to ensure correct implementation, the application of SEVSM follows a defined procedure. The following steps must, therefore, be complied with:

1. Definition of the family of products or services that should be analysed, given the purpose of applying this tool. In order to emphasize occupational safety, one of the references obtained to define the family may be the product or service that involves a greater number of employees, but this will depend on each case. One should also highlight the importance of analysing historical data related to occupational accidents before the implementation of the tool.
2. Construction of a map of the organization's current state, drawing the entire process that occurs when documenting. Thus, data must be collected for pre-mapping, which is then divided into three steps:
 - Survey of data related to production, through observation, timing, and distance measurement.
 - Collection of data related to efficiency, through the analysis of equipment availability, as well as performance and product quality.
 - Conducting risk assessment, using a quantitative or semi-quantitative assessment method. The type of risk and the cause of failure (whether space, equipment or human error) must be included in the assessment.

Subsequently, the sequence of the processes must be mapped. This will include takt time, the cycle time of the entire process, the time during which an increase in value occurred, and the total distance covered.

3. Construction of a future state map. This must identify the problems found in the previous map and project opportunities for improvement. Thus, at this stage, the indicators should be analysed, paying greater attention to the risk level involved in each job, and applying the appropriate Lean tools to minimize these risks, as can be seen in Table 2.

Table 2. Lean tools to suit the type of risk associated and the Root Causes.

Risk Type	Root Causes	Lean Tools
Physical Risks	Space	Visual Management
	Equipment	Single Minute Exchange of Die (SMED)
Ergonomic Risk	Space	5 S, Visual Management
	Human	Poka-Yoke, Standard Work, Andon
	Equipment	Single Minute Exchange of Die (SMED)
Chemical Risk	Space	Visual Management
	Human	Poka-Yoke, Standard Work, Andon
Biological Risk	Space	Visual Management
	Human	Poka-Yoke, Standard Work, Andon
Mechanical Risk	Space	5 S, Visual Management
	Human	Poka-Yoke, Standard Work, Andon
	Equipment	Single Minute Exchange of Die (SMED)

In addition, one must analyse whether there is sufficient capacity to meet demand, and then act to balance the processes and the production line.

4. Creation of an action plan, which identifies and classifies the tools indicated in the future state map. This will prioritize the actions that generate the greatest impact on the organization's productivity and safety.
5. Implementation of the actions discussed above, carrying out changes and determining the defined objective.

In order to understand the functionality of the tool defined, one decided to implement it at a metalworking organization. Accordingly, the first step consisted of an analysis of the historical data related to accidents at work in the organization. As can be seen in Table 3, in the years during which the

study was undertaken, there were at least 2 occupational accidents per year, with the exception of 2017. Based on the classification of accident rates issued by the World Health Organization, it can be concluded that health and safety performance is good.

The first step of SEVSM methodology requires the family of products to be analysed and defined. Thus, as the objective of this tool is to link productivity with safety, the family of products that most relates to these themes, and which is also most connected to employees, must be verified; namely, the family of products involving a greater number of employees.

Table 3. Accident rate from 2015 to August 2020 at a metalworking organization.

Year	Number of employees	Accidents at Incidence		Frequency	Severity	Duration
		work	Index	Index	Index	Index
2015	49	2	40.82	22.16	0.14	6.50
2016	53	3	56.60	31.38	0.22	7.00
2017	55	0	0	0	0	0
2018	57	3	35.09	19.65	0.30	10.33
2019	59	2	33.90	19.01	0.35	18.50
2020	59	2	33.90	41.65	0.90	21.50

Subsequently, the flow of materials and information should be analysed, from the receipt of materials to the dispatch of the final product to the customer, given the production process involved in manufacturing the product family defined above. The workstations are related to activities such as: Reception of Materials, Bending and Stamping, Robotized Welding, 10 Pre-shaped Pressure Vessels, MIG-MAG (GMAW) Welding, Hydrostatic Testing, 10 Pre-shaped Pressure Vessels, PAINTING, ASSEMBLY AND PACKAGING, and EXPERTION.

The next step consists of the creation of maps for the current state (Figure 1) and the future state (figure 1), according to the second and third steps of the tool.

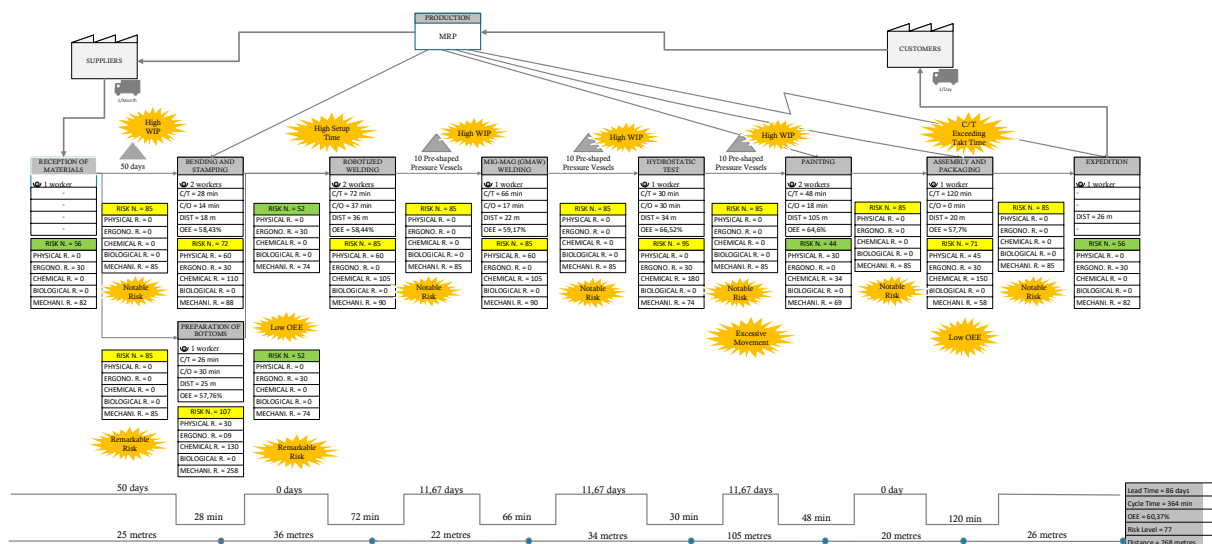


Figure 1. Current State Map.

In compliance with the fourth step of SEVSM methodology, the action plan must indicate all the opportunities for improvement reported in the previous maps, so as to address the problems encountered. In addition, the most critical aspects must be prioritized, according to the risk level, OEE, and productivity indicators. Thus, actions receive a score which reflects these safety and productivity priorities, as can be seen in table 4.

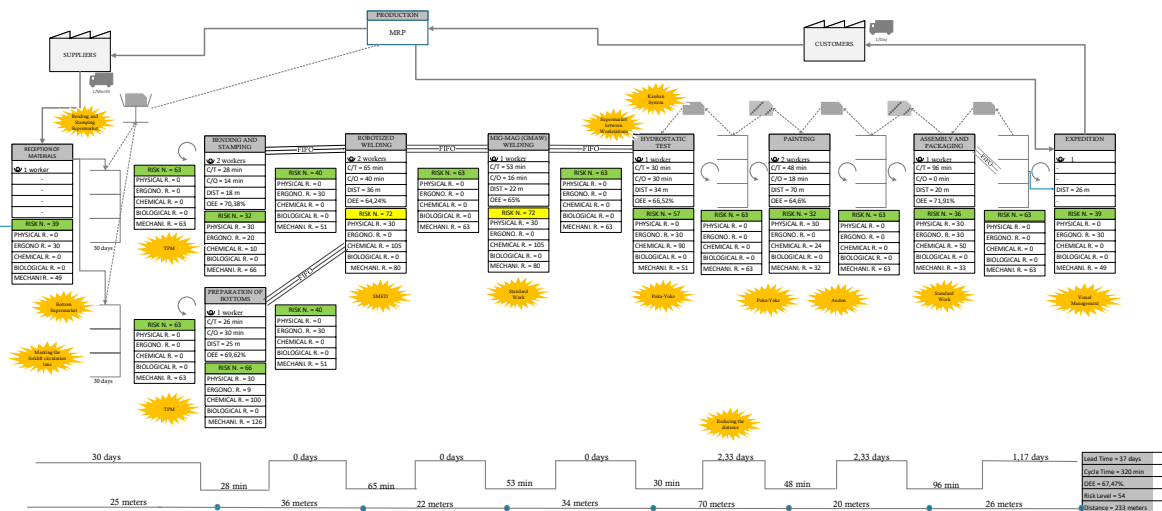


Figure 2. Future State Map.

Table 4. Action Plan according to safety and productivity priorities

Tools/ Method to use	Safety	Productivity	Total
Total Productive Maintenance (TPM) on Bottoms Preparation equipment (highest risk level)	5	4	20
Standard Work in Assembly and Packaging (Bottleneck Process)	3	5	15
TPM in the equipment of Bending and Stamping	3	4	12
SMED - Reduction of Robotized Welding setup	3	4	12
Standard Work in MIG/MAG (GMAW) Welding	3	4	12
Kanban system (following the metalworking process)	2	3	6
Visual Management - Marking of forklift routes	5	1	5
Reduction of lot size in the metalworking process	1	4	4
Poka-Yoke in the Hydrostatic Test	2	2	4
Layout change - Reduction of the distance between Hydrostatic Testing and Painting	2	2	4
Poka-Yoke in Painting	2	2	4
Visual Management in product dispatch	2	2	4
Supermarket between the Reception of Materials and Bending and Stamping	1	3	3
Supermarket between workstations (following the metalworking process)	1	3	3
Andon's System in Painting	3	1	3

The next step consists of presenting the results obtained from the comparison of the current state map with the future state map of the SEVSM methodology. Accordingly, Table 5 indicates the gains expected, once the implementation of the appropriate Lean tools for each step of the process has been concluded.

Table 5. Comparison of workstation indicators

Workstation	State Map.	Cycle Setup				OEE (%)	General Risk Level	Physi cal N. R.	Ergono mic N. R.	Chemi cal N. R.	Biologi cal N. R.	Mecha nical N. R.
		Time (min)	Time (min)	Distanc e (m)								
Reception of Materials	Current	-	-	-	-	56	0	30	0	0	82	
	Future	-	-	-	-	39	0	30	0	0	49	
Bending and Stamping	Current	28	14	18	58.4	72	60	30	110	0	88	
	Future	28	14	18	70.4	32	30	20	10	0	66	
Preparation	Current	26	30	25	57.8	107	30	09	130	0	258	
	Future	26	30	25	69.6	66	30	09	100	0	126	
Robotized Welding	Current	72	37	36	58.4	85	60	0	105	0	90	
	Future	65	40	36	64.2	72	30	0	105	0	80	
MIG-MAG (GMAW) Welding	Current	66	17	22	59.2	85	60	0	105	0	90	
	Future	53	16	22	65	72	30	0	105	0	80	
Hydrostatic Testing	Current	30	30	34	66.5	95	0	30	180	0	74	
	Future	30	30	34	66.5	57	0	30	90	0	51	
Painting	Current	48	18	105	64.6	44	30	0	34	0	69	
	Future	48	18	61	64.6	32	30	0	24	0	32	
Assembly and Packaging	Current	120	0	20	57.7	71	45	30	150	0	58	
	Future	96	0	20	71.9	36	30	30	50	0	33	
Expedition	Current	-	-	26	-	56	0	30	0	0	82	
	Future	-	-	26	-	39	0	30	0	0	44	

5. Discussion

The Safety Efficiency Value Stream Mapping tool serves as a complement to other tools, such as Value Stream Mapping, Safety Stream Mapping, and risk assessment. It enables the user to implement a single support tool at a manufacturing organization, thus facilitating the analysis of the more significant productivity and safety indicators.

Its advantage lies in: the quick and simple identification of the risk level at each workstation; the type of risk, depending on the cause of the security breach; and the most appropriate Lean tool to be applied in the resolution of the problem.

6. Conclusion

This article allowed one to connect the Lean concept, which has been widely discussed and proven by positive productive results, to the theme of occupational health and safety. Thus, the objective of the article focused on the analysis of the impact caused by the application of Lean tools in a metalworking organization, considering the risks associated with work accidents, occupational diseases in the workplace, and the productivity of processes.

Finally, it can be concluded that the implementation of SEVSM methodology, and the subsequent application of lean tools, generates benefits to employees' health and safety, as well as to the productivity of the process itself. However, the methodology must be carried out with the involvement and participation of all the employees, including those in top management positions. It is also essential to qualify and enable employees to be autonomous in the maintenance of equipment, ensuring that they perform work procedures correctly, and are able to make suggestions for improvements in the area of workplace safety.

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