Ergonomic Value Stream Mapping: A Novel Approach to Reduce Subjective Mental Workload

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Abstract. Recently, companies have become more interested about well-being and satisfaction of human resources. There is an increased awareness that conditions on the marketplace such as high variety products, demand fluctuations and the high service levels required by customers make it necessary to develop methods and models to measure and predict human performance. As Lean Manufacturing is a popular method used at companies in order to foster productivity and innovation in the industrial environment, we proposed the application of the Ergonomic Value Stream Mapping, a novel tool that aims to improve ergonomic conditions while productive performance indicators are also in focus. This work aims to provide academics and practitioners with a novel tool capable to satisfy current needs in manufacturing environments, regarding cognitive ergonomics assurance at workplaces. The implementation of ErgoVSM on its cognitive modality is an effort for acknowledging the significance of assessing health risks within each workstation at companies.

Keywords: Cognitive ergonomics · Subjective mental workload · ErgoVSM · Lean manufacturing

1 Introduction

Over years, lean manufacturing has provided significant positive results in a wide range of companies, reducing waste and improving productivity; therefore, it is very likely that will continue to grow and become an important aspect for many industries [1]. However, current research recognize that rationalization tools such as lean generally have a negative effect on health, risk factor [2] and result in work intensification [3]. Yet, some authors have detected that the lean approach needs to detect situations where the ergonomic aspect is poor or exist potential improvements. Researchers are aware of the possible impacts on employee's productivity, reducing the efficiency on creating value during a formal job shift [4].

Current conditions in modern manufacturing, such as providing a wide range of product variety and the established short lead-times, require operators to use higher cognitive skills to complete a task successfully, which makes the Mental Workload much higher than assembling a single product, and therefore easily leading to an increase in human errors. On the other hand, when correctly acknowledged, Mental

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Workload can improve product quality and guarantee the efficiency simultaneously [5]. Subjective Mental Workload (SMWL) refers to the amount of effort done by the mind during an individual function, and is related to an individual's mental capacity [6]. Assessment of SMWL is one of the main goals of ergonomics aiming at investigate and improve the human–machine relationship and achieving convenience and satisfaction in the workplace [7].

Recent investigation aims to both, improve work conditions and reduce wastes, resulting on higher productivity and profits. A novel tool that attempts to integrate ergonomics and lean techniques is the so-called Ergonomic Value Stream Mapping (ErgoVSM), which has proved to be useful for engineers and experienced operators by estimating ergonomic improvements of proposed processes without any negative effects on the estimated production performance [8]. ErgoVSM incorporates aspects of the physical and psychosocial work environment into the lean tool VSM [9].

Previous works on this field analyzed the gains of considering the significant role of ergonomics in the rationalization of the work. However, none of them, to the best of our knowledge, comprises Mental Workload; even more, authors recognize that psychosocial factors of importance to health and well-being should be included in the tool [8]. This research presents a dual assessment of feasibility, taking into account both the performance metrics typically used in VSM, and the SMWL, which is valuable for both academics and practitioners to foster research in this field and improve current productive practices.

2 Literature Review

2.1 Overview of the Lean Approach

Lean manufacturing has its origins in the Toyota production system and it consists of a method to systematically reduce waste and maximize value in manufacturers [10]. The seven sources of waste that it identifies are: over-production, waiting time, transportation, over-processing, inventory, motion, and scrap [11, 12]. This approach has become very popular among manufacturers, services and large commercial areas [13]. Nowadays, it is so far the most widely known method for industrial improvement [14] and acts on improvement work through a set of group activities that pursue the benefit the organization [15].

Aiming to support and encourage the adoption of lean, many tools have been developed and adapted to different types of industries and manufacturing environments over time; this is possible due to its multi-dimensional perspective [16]. Some of the techniques and concepts commonly applied are: VSM, Gemba walks, JIT, kaizen events, production preparation process (3p), cellular manufacturing, single-minute exchange of dies, total productive maintenance, poka-yoke mechanisms, among others [17].

Lean tools and practices have provided companies with significant help at facing the waste challenge, thus, it has been possible to foster productivity and other key performance indicators. There are several cases where authors have reported positive results after implementation, such as shortening lead-times [18, 19], reduce work-in-process inventories [10, 20] increase of the value-added ratio [21] and many others. On the other hand, authors have perceived a negative side effect as product of the way in which lean manufacturing practices are applied. Among these impacts are the lack of capability of some of the tools to quantify and manage uncertainty, as well as to address the benefits of these tools under a dynamic perspective [16, 22]. Additionally, it has been found that lean methods affect the risk factors at workplaces, which might be dangerous for employees as it increases the repetitiveness and the mental workload [2, 3].

2.2 The Role of Ergonomics within Lean Manufacturing Systems

The lean manufacturing system is complex and benefic but the possible changes may cause ergonomical issues [23]. Human resources, the most important element in an organization, often feel the problems that arose in this regards. It is very important to consider that lean manufacturing system has more than one face and this makes the interpretation of its impact complex, therefore it is necessary to assess each of the important aspects before any transformation of the productive system, including ergonomics [24]. Ergonomic interventions attempt to improve physical and/or psychosocial working conditions for the individual while rationalization prioritizes creation of value at the facilities. Thus, ergonomists, working within a health paradigm, and production engineers, devoted to improving system performance, may have conflicting objectives [25].

Some authors have reported results as product of ergonomic assessments in after implementation of lean manufacturing techniques; these results include positive feedback such as an increase of workers autonomy [26, 27] and a decrease of hierarchical levels [28]. On the other hand, there have been found negative impacts along with the implementation of lean, including an increase of stress levels [29, 30], as well as work intensification [26, 31]. This available research allow us to see the importance of control and verify the well-being of the human resources has to be periodically.

2.3 ErgoVSM in Literature

ErgoVSM is based on the regular VSM methodology proposed by Rother and Shook [32]. While traditional VSM consists of drawing the current and future state of the productive system in order to eliminate sources of waste as much as possible [33], ErgoVSM it includes an ergonomic complement [3, 8]. Literature shows that the application of ErgoVSM is beneficial for improving ergonomic conditions without any negative effects on the estimated production performance [8]. However, even though ErgoVSM forces the employees to evaluate their work environment, a study states that it is not possible to conclude that those improvements are due the use of this tool [3]. Yet, there is another author, who suggest that ErgoVSM facilitates the development of an action plan that may result in higher organizational sustainability compared with VSM, based on preliminary data [9].

Available papers about ErgoVSM focus mainly on the assessment of physical issues, such as musculoskeletal disorders. Although some exemplary instructions are given on evaluation of mental demands, control/influence and communication, to the best of our knowledge available research has not specifically addressed the SMWL in previous case studies [34].

2.4 Subjective Perspective on Ergonomic Assessments

There are many subjective procedures and instruments to assess mental workload, three of the most outstanding among them are the NASA Task Load Index (TLX), the Subjective Workload Assessment Technique, and the Workload Profile [35]. The NASA Task Load Index [36] evaluates six dimensions in regads of mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. The Subjective Workload Assessment Technique uses three levels: (1) low, (2) medium, and (3) high, for each of three dimensions of time load, mental effort load, and psychological stress load to assess workload. Workload Profile tries to combine the advantages of secondary task performance based procedures (high diagnosticity), subjective techniques (high subject acceptability and low implementation requirements and intrusiveness [37].

The NASA-TLX instrument was selected for this study, after considering that it has been utilized in a wide range of areas, including military, government [38] and banking staff [7]. Additionally, it is very portable and can be used in operational experiments; it is reasonably easy to use [39] and reliably sensitive to experimentally important manipulations over the past 30 years [38].

2.5 Subjective Perspective on Ergonomic Assessments

The use of this instrument consists of two parts: ratings and weights. Ratings for each of the six subscales are obtained from the subjects following the completion of a task. A numerical rating ranging from 0 to 100 is assigned to each subscale. Then, weights are determined by the subjects' choices of the subscale most relevant to workload for them from a pair of choices. After that, the weights are calculated from the tally of these choices from 15 combinatorial pairs created from the six subscales. The weights range from 0 to 5 (least to most significant). The ratings and weights are then combined to calculate a weighted average for an overall workload score [39].

3 Methods

Even though it is possible to apply this study to any type of hazard, we focused on the SMWL, considering this of a great value because Ergo-VSM has not been previously applied to this kind of assessment. Moreover, we chose this evaluation due to the characteristics of the tasks performed at the workstations. This will be a bi-objective study with focus on fostering both productivity and ergonomic factors at the workplace. In this case, we selected a group of group lean tools that have proved to be resilient in the manufacturing environment along with the instrument NASA TLX to assess SMWL within the facilities.

Firstly, one designated person will create the Ergo-VSM, as the methodology of the traditional tool indicates, although this will include the values for the evaluation of the SMWL. The selected techniques will be used in the following order: Ergo-VSM, kaizen event, Gemba walk, 3p, aiming to propose a feasible option for redesigning the work area. During the elaboration of the Ergo-VSM, relevant information will be collected and depicted in the current state map. Then, the same information used for the creation of the future state of the Ergo-VSM.

Once the maps have been created, the team members of the project will met in form of a kaizen event in order to develop an improvement proposal collectively. As part of this event, the members will perform Gemba walks on the production floor to detect anomalies, and then, a 3p will be carried out by the members. The goal will be to redesign the workstation aiming to improve the key performance indicators such as inventories and productivity, while decreasing the SMWL.

To perform the SMWL evaluation of both current and future state, we will use the physical version of the NASA TLX instrument among the operators. After talking with employees in order to make them aware of the goals and the relevance of the project, they will be required to fill up the information in the form shown in Fig. 1, followed by some questions, as part of the instrument.

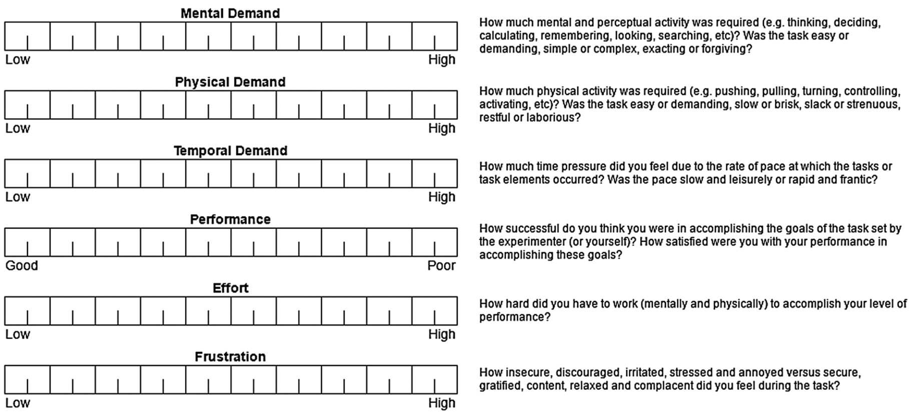

Fig. 1. Nasa-TLX rating scale.

Once the proposals obtained as result of the 3p methodology have been developed, the action plan will be presented to the management level for approval and the model will be implemented in the production floor, to verify that the previously simulated results correspond to reality, and adjust the physical distribution or production pace if necessary. The process herein present must be developed with a continuous improvement approach, in order to sustain and foster progress.

4 Case Study

Taking into account the ergonomic and lean manufacturing principles, we pursued a significant improvement aiming to potentiate wastage reduction and increase productivity, while reducing SMWL. This project was conducted at a real production system, where all the above techniques and tools were put into practice as part of one single project.

4.1 Company Background

The company considered for this project will be called XYZ due to confidentiality purposes. It is located in the north of Mexico. This is a global company certified in ISO 9000 with several departments and workstations, where it produces electronic components for industries such as defense, healthcare, and automotive, among others. We worked at a specific department with a single product family (a set of products sharing similar processes). According to the employees and manufacturing engineer of this area, it had productivity issues since approximately eleven years ago; these situations refer specifically the great amount of idle time perceived and ineffective work distribution among operators. Even though they knew the importance of provide solutions to the deficient productivity of the area, this recently became urgent due to new management strategies.

4.2 Implementation

The team the project was integrated by eight persons from different hierarchy levels, ranging from operators, shift leaders, process, production, quality and manufacturing engineers, as well as a manager and an external researcher. Firstly, the Ergo-VSM was developed with help of the external researcher, taking into account each of the significant indicators along the entire value stream at a door-to-door level of the selected product family. In order to perform the maps of both the current and future state, it was necessary the support and commitment of several areas, such as planning, purchasing and procurement of materials. Then, the SMWL evaluations were carried out preceded by an introductory talk about the goals and relevance of the project to all the operators of the area. The resulting maps including lean and ergonomic indicators can be observed in Figs. 2 and 3.

After the important information was available and ordered, it was presented to the team members and a kaizen event was arranged, with focus on generating ideas that could potentially achieve both objectives pursued. The team was divided into smaller groups in order to perform Gemba walks and remark possible areas of improvement; then, it was necessary to adjust the Ergo-VSM, since as the VSM methodology indicates, some important aspects became noticeable afterwards. Some of the problems observed were the accumulation of work-in-process inventories, the malfunction of the press and bad distribution of work content among operators.

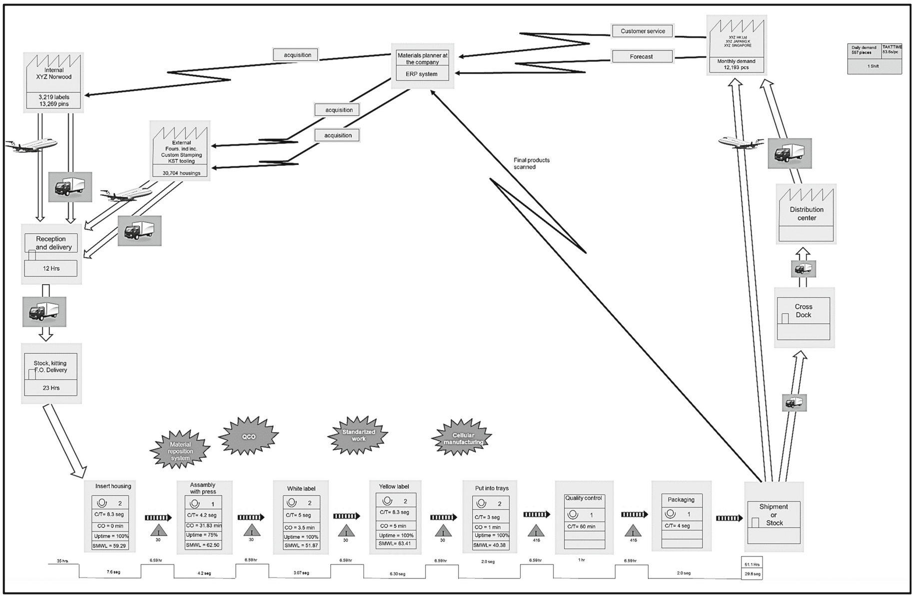

Fig. 2. Ergo-VSM on its current state.

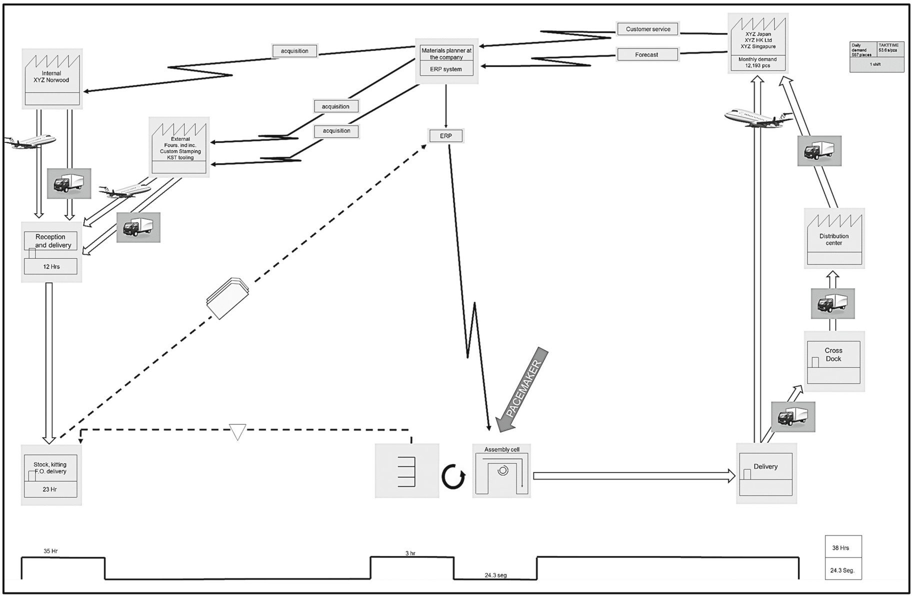

Fig. 3. Ergo-VSM on its future state.

Fig. 4. Engineer and operators implementing 3P tool (sketching examples).

The team followed the 3p technique aiming to propose a workstation redesign capable to deliver better results in both ergonomic and productive aspects. As part of the 3p methodology, the members collaborated in the construction of a prototype of the new workstation that included the potential improvements t. They first remarked the goal of the prototype and give keywords to achieve it, such as quality, order, safety, teamwork, among others. Then, each of the members sketched examples using paper and pencil, and shared their ideas with the rest of the team as shown in Fig. 4.

The stakeholders reached a common proposal, which acknowledge productivity, as well as ergonomic aspects. The selected design was then drawn by one of the members and verified by the rest of them. Right after, they constructed the prototype using recycled objects such as carton boxes available at the facilities, cardboard, sticky tape and similar materials. The redesigned the layout and distribution of work, aiming to

Fig. 5. Final 3p design prototyped

improve the flow of materials and reduce the SMWL indicator. This was tasted and adjusted, and several simulations of the assembly process were carried out, until the team approved the prototype (Fig. 5).

5 Results and Conclusions

The application of the selected lean tools showed us that all of the operators within the analyzed area have experienced excessive mental workload regularly during the performance of the tasks. The activity more demanding was press assembling, for which the NASA-TLX estimated weight of each of the factors that integrates SMWL. The highest scores were observed on Performance and Mental Demand scales with mean $\pm$ SD of 84.95 $\pm$ 7.18 and 75.71 $\pm$ 6.94, respectively.

After simulating the potential improvements approved by the team members, results showed a decrease on the SMWL from an average overall score of 59.29 in the current state, to 42.56 in the future state. The changes to be applied as part of the action plan include materials reposition system for reduction of inventory; layout redesign, with the transformation to a cell manufacturing system; and the redistribution of the work among operators according to the takt time. The results obtained after simulation can be observed in Table 1.

Table 1. Obtained results after 3p simulation

	Current	Proposed	Improvement (%)
Space (sq/ft)	240	80	67
Number of operators	7	1	86
Productivity (pcs/hr/op)	43	148	244
Work in process (pcs)	952	1	99.9
Overall SMWL	59.29	42.56	28.2

The conducted case study does not show any drawback derived from the consideration of ergonomic assessments as part of the lean activities. Although this type of additional analysis require a significant amount of time, it might result in future savings for companies, since it is much more feasible and useful to take into account ergonomic factors before applying physical transformations in productive systems. We would like to encourage future research on this field by conducting further works, which continue to evaluate the effects of performing sustainable improvement activities within companies.

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