Social Value Stream Mapping (Socio-VSM): Methodology to Societal Sustainability Visualization and Assessment in the Manufacturing System

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ABSTRACT The extended application of value stream mapping has more recently been clarified to fulfill the triple bottom line requirements in the manufacturing systems. Thus, there is a glaring lack of literature on this sustainable-oriented lean tool, among these minute studies, the research attention has mainly been given to the environmental issues, largely neglecting the societal aspects. To complement and support this narrow body of knowledge, this article is aimed at developing a social value stream mapping methodology, which we refer to as Socio-VSM, for visualizing and assessing the societal sustainability performance in the context of manufacturing. In doing so, it identified and incorporated crucial societal metrics into the proposed approach, which was made based on the conventional value stream mapping method. For validation purposes, a case study entailing a hard disc drive substrate manufacturing industry was applied for the documentation and reporting of results derived from the implementation of the proposed methodology and for testing and making conclusions about its effectiveness. It makes the valuable theoretical and practical contributions to narrow the gap on this long-neglected scope.

INDEX TERMS Social value stream mapping, (Socio-VSM), societal metrics, lean manufacturing, sustainability.

I. INTRODUCTION

Innovation has been regarded as a prerequisite for developing sustainability in the manufacturing systems. In this context, the design and development of strategic approaches/ methodologies can naturally be prompted by examining existing best practices and their possible adaptations that could fulfill the triple bottom line requirements [1]. Broad inquiries had been carried out on the utilization of lean practices for catalyzing improved strategies for green/environmentally-friendly manufacturing [2]–[4]. Studies were also undertaken to investigate the possible use of lean tools beyond green

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manufacturing to sustainable manufacturing [3], [5]. Such an approach necessitates a profound understanding of system wastes, beyond the time-based and green definitions of wastes (Muda) to involve Muda of the societal variety.

Out of the various lean tools available, value stream mapping (VSM) is held in high regard [6] with Womack [7] acknowledging it as "the most important tool lean thinkers will need to make sustainable progress in the war against Muda". As a straightforward and visual process-based tool, VSM documents, visualizes and conceives material and information flows in processes to enable the identification and thus the elimination of wastes [8]. Recent years have witnessed the increased usage of VSM in manufacturing plants and supply chains as well as in process industries and service

sectors [4]. Its aim is to identify wastes in a manufacturing system and ultimately realign production practices with lean philosophy towards establishing future improvement plans. Current-state VSM identifies all value-added and non-value-added activities that are performed in a sequence of manufacturing processes [9]. Waste could be inevitable in certain cases, and in such instances, VSM identifies the waste and assesses whether or not it can be minimized or removed [5].

Despite the growing attention on the use of VSM as a viable method for identifying waste, and with the necessary adaptations, for establishing green and sustainable manufacturing [1], its potentials in enhancing environmental and societal sustainability has not been thoroughly investigated [4]. Environmental and societal performance assessments have never been a part of the traditional VSM as the methodology focuses more on examining the economic aspects of manufacturing such as cycle time, lead time and change-out time. Enabling visual representations of environmental and societal performance using VSM will enhance its value as an assessment tool from the standpoint of sustainability. As a response to this call, [10] and [11] introduced the environmental value stream mapping (Environmental VSM) as a green methodology to visualize, assess and improve organizational environmental performance. This methodology is a combination of the value stream mapping from conventional lean manufacturing and green metrics for assessing environmental impacts. Although the likes of [12] and [13] refer to the use of Sustainable-VSM, the general focus remains only on integrating environmental performance in traditional VSMs.

To complement and support this narrow body of knowledge, this article is aimed at developing a Social VSM methodology or Socio-VSM henceforth, for visualizing and assessing the social sustainability performance in the context of manufacturing. The necessary criteria and metrics for the Socio-VSM are identified by examining the existing metrics for societal performance assessment in manufacturing. Having said that, however, very limited studies on this lean value stream were found in the related body of literature as the majority of it is more focused on Conventional VSM. Hence, to make up for the lack of evidence, a case study is used to validate the effectiveness of the proposed Socio-VSM, particularly to answer the main research question: *Can VSM be utilized to determine and reduce the negative societal impacts (hazards) of industrial operations?* Another contribution of this research is that it offers a guideline for future improvement efforts by operations managers apart from bridging the gap of limited academic evidence on Social VSM. This study also aims to motivate scholars and industry players to conduct more inquiries on this under-researched field.

II. LITERATURE REVIEW

Innovation is the key factor that ensures the successful development of sustainable manufacturing systems [1] which necessitate ''the creation of manufactured products which use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound'' [14]. Following the trailblazing publication of ''The Machine that Changed the World'', lean manufacturing experienced a substantial and exceptional evolution leading to it being highly regarded as a valuable practice [15].

There is a three-decade worth of well-documented benefits of lean manufacturing [16] including its positive impacts on operations performance, i.e. quality enhancement, inventory reduction, better delivery and productivity as well as reduced cost [17]–[19]; business performance, i.e. profitability, sales and customer satisfaction improvements [19], [20]; environmental performance [21]–[23]; social performance [24], [25]; and sustainable performance [26], [27]. This indicates the likelihood of employing lean tools for sustainable manufacturing.

In this regard, out of the wide range of lean tools available, value stream mapping (VSM) is deemed as one of the most significant ones [1], [5]. Hartini *et al.* [28] indicated that VSM has the ability to visualize the triple bottom lines better in sustainability performance assessment. The tremendous support for VSM is an expected outcome due to its growing reputation, effectiveness and ease-of-use in improving sustainable performance. Conventional VSM has been well developed and used industry-wide in the assessment of value added and non-value added operational activities [29]. Despite the numerous reviews available on the implementation of Conventional VSM, this study is more focused on examining efforts of its extension for revealing that proposed Socio-VSM methodology is missing in the existing literature.

To this end, sustainable VSM was proposed by [30] aimed at enhancing product manufacturing sustainability via the analysis of GHG gas emissions. Societal metrics are not directly incorporated in this framework as they are assumed to be incorporated indirectly via consequent economic or environmental benefits together with social benefits. A toolkit was developed by the US Environmental Protection Agency (EPA) to identify and eliminate environmental wastes via the tracking and visualization of environmental metrics, i.e. material and water consumption together with Conventional VSM metrics [31]. As energy use was not highlighted in VSMs, the US EPA hence developed a separate toolkit for mapping lean and energy consumption [32]. Nonetheless, the inclusion of societal metrics was neglected in both tools which focused more on environmental and energy consumption metrics. Simons and Mason's [30] Sustainable VSM method and Norton's [33] sustainability metrics were combined by Fearne and Norton [12] to establish a sustainable value chain map method that puts emphasis on the relationships and information flows between UK food retailers and manufacturers. Although this method incorporated numerous environmental metrics, societal metrics are once again neglected. Wills [34] developed a green value stream or Environmental VSM. Similarly, Torres and Gati [10] established an Environmental VSM using an expansion of the

TABLE 1. The recognized societal metrics.

Metrics	Measurement Techniques	Proposed Indicators	Source(s)	Conventional VSM	Environmental VSM	Social VSM
Physical Work	Rapid Entire Body Assessment	REBA:	[45]	-	-	+
	Rapid Upper Limb Assessment	RULA:	[46]	-	-	+
	Ovako Working Posture Analysing System	OWAS:	[47]	-	-	+
	Revised NIOSH Lifting Equation	RNLE:	[48]			
	Physical Load Index	PLI:	[1], [5], [28], [40], [43],[49], [51], [52]	-	-	+
Work Environment	Noise Level Inside Factory	Noise:	[1], [5], [40], [43], [50], [51], [52]	-	-	+
	EHPS Circle	E: H: P: S:	[1], [5], [40]	-	-	+

lean and environmental toolkit developed by the US EPA; this method was validated using a Brazilian case study on the country's sugar and alcohol manufacturing industry. Midzic-Kurtagic *et al.* [35] used a case study on the food and beverage industry in Bosnia and Herzegovina to validate a mapping tool for visualizing environmental and socio-economic indicators. Paju *et al.* [13] presented and demonstrated the VSM-based Sustainable Manufacturing Mapping which incorporates sustainability indicators, discrete-event simulation and life-cycle assessment. Kuriger *et al.* [36] proposed a lean sustainable production assessment tool based on the energy and environment VSM developed by [37], which incorporates energy consumption during a process but excluding that of transportation and specialty storage. Nevertheless, this inquiry too neglected societal metrics and the simultaneous visual presentation of various metrics. Kurdve *et al.* [11] used another developed Environmental VSM at Volvo Penta Vara and Volvo Construction Equipment Braås. Green VSM was applied by [38] on information technology functional areas of organizations. Folinas *et al.* [39] developed a systematic VSM-based approach to measure the environmental performance of the agrifood sector's supply chain. Faulkner and Badurdeen [1] established an all-inclusive method for developing Sustainable VSM via the identification of suitable metrics and methods as their visual representations. Brown *et al.* [5] scrutinised three case studies to validate the extent of the methodology's applicability as well as the tool's suitability and limitations in measuring and visualizing the sustainability performance of various manufacturing system configurations. Vinodh *et al.* [40] introduced a VSM method incorporated with life cycle assessment for ensuring sustainable manufacturing. Garza-Reyes *et al.* [41] also introduced a VSM-based Sustainable Transportation Values Stream Mapping for improving the transport operations of a globally renowned logistics company in the cosmopolitan area of Monterrey, Mexico. Garza-Reyes *et al.* [4]

used Deming's Plan-Do-Check-Act improvement cycle to propose an approach that implements and conducts Environmental VSM studies in a systematic manner.

The abovementioned innovative studies clearly indicated that extended VSMs have better capabilities in visualizing the triple bottom lines for the assessment and improvement of sustainability performance. However, there is a glaring lack of literature on the sustainable-based application as compared to that of Conventional VSM which had received a large attention from researchers. Additionally, the existing studies on the application only evaluated sustainable manufacturing performance from the environmental standpoint, largely neglecting the societal aspects. There is an urgent need to develop, test and assist in the multidisciplinary strategies/methodologies so as to develop a sustainable society [42]. The motivation for designing the methodologies/strategies is linked to the urgency exemplified in this paper.

III. METHODOLOGY

Despite indications that VSM can be extended and used to fulfill the triple bottom line requirements, a review on the extant literature reveals very little inquiry on the social aspect of this application. The criteria differences between conventional, environmental, and social VSM are shown in Table 1. Conventional VSM is prominently used for identifying prospective kaizen strategies for eliminating waste in a particular system, and it has the ability to illustrate the performance of a production line or system in a visually clear manner. Conventional VSM can potentially be extended into Environmental VSM where green metrics are integrated into the value stream mapping to measure environmental impacts in green manufacturing. Its extension and adaptation into Social VSM requires all the aforementioned features to be retained so it continues to be a beneficial and convenient tool. Such Social VSM can contribute organizations to addressing

the operational and societal challenges related to the existing risks to the employees' health and safety as well as the compliance with governmental societal regulations. Health and safety are deemed as a crucial factor in capturing the societal performance of a production line [43].

Societal assessment needs to be carried out from the standpoint of the stakeholder. The main stakeholders in a production line are the employees at each station; hence, it is the impacts on their health and safety that must be evaluated in the societal sustainability assessment. The development of an all-inclusive Social VSM, which we refer to as Socio-VSM, requires the identification of relevant societal metrics which is elaborated in this section. The methodology for constructing a Conventional VSM as proposed by Rother and Shook [29] is adapted in this study by integrating relevant societal metrics into the proposed Socio-VSM method. For validation purposes, a case study entailing a Malaysian hard disc drive substrate manufacturing industry is used, as explained in detail in the next section. However, according to [44], the action research/case study is a strategic approach for the documentation and reporting of results derived from the implementation of the proposed Socio-VSM and for testing and making conclusions about its effectiveness. It makes a valuable practical contribution to narrow the gap on this long-neglected scope.

A. SOCIETAL METRICS

Sustainability entails the assessment of social environment impacts that takes into account the interest of all stakeholders involved in the manufacturing phase. Employees were found to be the most affected group of stakeholders based on the examined scope of activities using Socio-VSM. This aspect is evaluated by measuring and monitoring the employee's health and safety risks on a continuous basis. The proposed societal metrics are further divided into two categories (see Table 1), as discussed in more detail below. Apart from assessing the working conditions and safety of the employees, these societal metrics also provide indicators of the need for further inquiries.

1) PHYSICAL WORK

This metric captures and presents the physical workplace ergonomics, measuring physical hazards that may impact the employees. Several ergonomics-related observational techniques are presented in the literature to assess the various aspects of physical work as described below:

- *Rapid Entire Body Assessment (REBA)* – This technique entails a postural analysis system assessing musculoskeletal risks in an assortment of tasks, particularly working postures prevalent in service industries including health care. The body part diagram is the basis for the posture classification system entailing the upper arms, lower arms, wrist, trunk, neck, and legs. REBA shows the degree of external load/force exertion; static-based muscle activity; dynamic, rapidly changing or unstable postures, and the coupling effect. This technique entails

five action levels in the evaluation of the corrective actions [45]. Scholars are recommended to refer to [45] for execution of this purpose.

- *Rapid Upper Limb Assessment (RULA)* – This technique provides a quick assessment of the musculoskeletal system loading caused by the neck, trunk, and upper limbs postures; muscle function, and exerted external loads. Hignett and McAtamney [45] suggested four action levels entailing the levels of necessary intervention for reducing injury risks on the workers caused by physical loading. Scholars are recommended to refer to [45] for the execution of this purpose.

- *Ovako Working Posture Analysing System (OWAS)* – This technique was the brainchild of a Finland-based steel company named Ovako Karhu *et al.* [47]. The method is grounded upon the working posture ratings derived from several divisions of a steel factory involving 32 skilled steel workers and international ergonomists. This technique entails four back postures, three arm postures, seven lower limb postures, and three categories of load handle weights or amount of exerted force. OWAS classifies the posture combinations for the four categories by the extent of their impact on the musculoskeletal system. These posture–load combinations are then divided into four action categories based on the extent of their impacts, indicating the urgency for workplace interventions. Scholars are recommended to refer to [47] for the execution of this purpose.

- *Revised NIOSH Lifting equation (RNLE)* – The National Institute for Occupational Safety and Health (NIOSH) developed this technique as a means of prevention or mitigation of the prevalence of lower back pain among workers caused by manual lifting. A multiplicative model provides the basis for weighting each of the six task variables. The weights or also termed as coefficients are utilized to reduce the load constant, i.e. the maximum suggested load weight for lifting under ideal circumstances. The suggested weight limit is derived from the equation and expressed as load weight [48]. Scholars are recommended to refer to [48] for the execution of this purpose.

- *Physical Load Index (PLI)* – The simple basic measure of this technique is derived from the responses to a questionnaire which underlines the occurrence frequency (from never to very often) of numerous body positions and management of different loads. The measurements of the body positions of a worker's trunk, arms, and legs as well as loads lifted at certain body positions are used to produce a PLI score ranging from 0 to 56 using the proposed equation by Hollman *et al.* [49]. Scholars are recommended to refer to [49] for the execution of this purpose.

Due to their practicality in assessing physical work, these techniques are deemed implementable in the Socio-VSM. Their visual symbols can be indicated in the Socio-VSM process box together with the other metrics (e.g. cycle time,

changeover time, uptime), under the 'proposed indicators', as shown in Table 1. Each technique possesses its own posture classification scheme, which may lead to the allocation of several postural load scores for a certain posture according to the techniques utilized. As these techniques were developed for various purposes, they should be employed based on the workplace conditions.

2) WORK ENVIRONMENT

Work environment is the second societal metric incorporated into the Socio-VSM which measures the potential work environment-related hazards on employees. In the manufacturing setting, the following measurement techniques have been identified in literature:

- *Noise Level Inside Factory* – Factory operators are at constant risk of factory-related noise levels. OSHA [50] indicated that any noise at a level of above 80 dBA pose risks to the operators, and more so the duration of the exposure. The operators' health and safety can be determined by mapping these levels of exposure at each process on the Socio-VSM, i.e. within the process box together with other metrics under the 'Noise' index (see Table 1). Scholars are recommended to refer to [50], [5], [1] for this purpose.

  EHPS Circle – This circle entails four risk categories namely risks caused by Electrical systems (E), Hazardous chemicals/materials used (H), Pressurized systems (P), and High-Speed components (S). Each category for a certain process is assigned with a rating system of 1-5 according to the occurrence probability and impact of the associated risk. To ensure employee safety, these hazards must be identified at each process. Considering that the EHPS circle can reasonably assess work environment-related risks, it can be implemented in the Socio-VSM with a visual representation under the form of a risk circle including four indicators, as presented in Table 1. Scholars are advised to refer to [5], [1] for this purpose.

IV. CASE STUDY: IMPLEMENTATION, RESULTS AND DISCUSSION

To validate the purposed Socio-VSM methodology, which is a potential extension of Conventional VSM method, a case study was carried out in a Malaysian hard disc drive substrate manufacturing industry, henceforth referred to as 'substrate'. Specifically, the application focused on the electro-less nickel plating (EN-Plating) process on aluminum discs, as shown in Fig. 1.

An EN-Plating process entails the depositing of a layer of Nickel-Phosphorus coating using an auto-catalytic reaction substrate without having to pass an electric current through the aqueous solution. Several main industries employ this electro-less technology including printed circuit boards and manufactured hard disk drives, which is able to give an atomically smooth coating to the aluminum disks and electroplated plastics. With its superb mechanical, physical, electrical, and
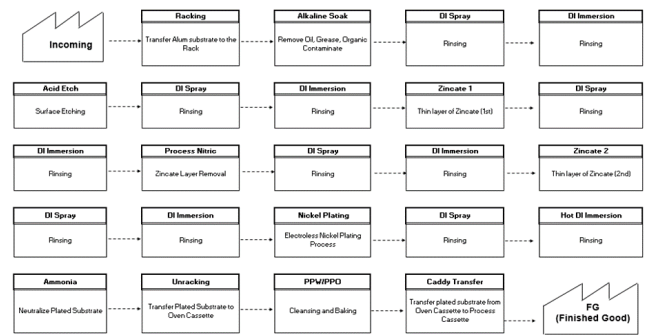

FIGURE 1. EN-Plating process flow.

corrosion- and wear-resistance properties, the EN-Plating process can be broadly applied across industries. Apart from that, EN-Plating is applicable on a wide range of substrate materials as well as having the capability to evenly plate intricate geometric parts.

Referring to Fig. 1, the EN-Plating process starts at the Racking station, where the incoming substrate arrives via conveyer, and subsequently put into a cassette box at 25 pieces each. Next, 4 cassette boxes which is equal to 100 pieces of substrate are moved to 1 spindle and subsequently into 1 rack. 1 rack contains 14 pieces of spindle which is equal to 1400 pieces of substrate. This final count of 1400 pieces of substrate makes up 1 batch of plated substrates. All the processes that take place at the Racking station are done automatically except for the handling of the spindle (i.e. pulling from the racking station and placing on the designated rack) which is conducted by a human operator. Each completed batch of substrate is pulled to the Loading station for the initiation of the pre-plating process. Pre-plate solutions are prepared for removing oxides and soils from the substrate's surface via immersion and to prepare it before undergoing the plating procedure. Five chemical tanks, i.e. Alkaline clean, Acid Etch, Nitric Acid and Zincate 1 & 2 are used in conditioning the aluminum substrate for nickel deposition and for improving the adhesive capability of the nickel onto the Aluminum. The next process entails the EN-Plating tank. A spray and rinse tank are placed in between each chemical tank to get rid of excess chemicals on the disks that may come from the previous process tank so as to avoid cross-contamination in the next process tank. Thorough removal of chemicals including from the fixtures and spindles are ensured with the overflows/dip rinse. The rack then undergoes pH neutralization with an Ammonia Hot dip rinse. Next is the Unloading station which requires a human operator to pull the rack to the Un-racking station. Once here, the spindles are moved to the conveyer before moving the substrate from the spindle back to the cassette. The contents of 1 spindle are distributed to 4 oven cassettes which are then transferred to the Post Plate Wash and oven. The oven cassette can withstand the high oven temperature, making it highly apt for this process. To remove all excess chemicals from the earlier EN-Plating process, the plated substrate is immersed into the boat tank and spray-rinsed. The plated substrate is

baked in the post-plate oven thus releasing pressure from the substrate molecules. Next, via the automated caddy transfer, the oven cassette changes to the process cassette for the next procedure.

A. DATA COLLECTION

A thorough and systematic manner of collecting data is a pre-requisite in VSM studies so as to enable proper identification of sources of waste and thereby methods of their elimination [29]. The same pre-requisite is imposed on Socio-VSM. In this study, a data collection plan is determined before-hand and abided by throughout. It involves gathering societal data of the value stream characteristics of the process under scrutiny namely: 1) the work-related physical hazards to the employees and 2) the potential hazards to the employees due to the work environment in each process, so as to determine the hazards and subsequently minimize them.

To assess the work-related physical hazards, data can be collected using one of the observational techniques – REBA, RULA, OWAS, RNLE, and PLI – as discussed in the section of Methodology. Each possesses a unique posture classification scheme, which may lead to the allocation of several postural load scores for a certain posture based on the techniques chosen. As these techniques had been developed for various purposes, they are hence applied under varying workplace circumstances. In the context of this study, the REBA technique is employed for the physical ergonomics assessment of the EN-Plating process as it is the most suitable technique for postural analysis entailing movement activities apart from being the most extensively used technique in Malaysia. The REBA employee worksheet shows the scoring guideline (see Fig. 2), which is based on body regions namely the wrists, forearms, elbows, shoulders, neck, trunk, back, legs, and knees. Based on the collected data and scoring of each body region, a single score is calculated to depict the MSD (musculoskeletal disorders) level. Hignett and McAtamney [45] defines the scoring of MSD risk to be from 1 to 11, i.e. from negligible risk to very high risk. A score above 11 indicates a 'very high' injury risk to the employee, necessitating a mandatory improvement action or 'necessary NOW' to assess the task in order to reduce its risk level.

In this case study, the Racking and Unracking process steps (see Fig.1) are carried out by two operators, who perform similar actions. Therefore, these two steps were taken into careful consideration to be evaluated based on the REBA technique. Fig. 2 shows the REBA employee worksheet for the Racking and Unracking steps in the EN-Plating process after assessment.

As previously discussed, the Noise level and work environment EHPS Circle were implemented to assess the prevailing hazards in the manufacturing setting. Industrial guidelines for regulating noise exposure to workers have been established by the Department of Occupational Safety and Health Malaysia [53] as hearing loss incidences among workers have been reported to be a serious global issue. In the current case study, the noise level distribution in the EN-Plating process
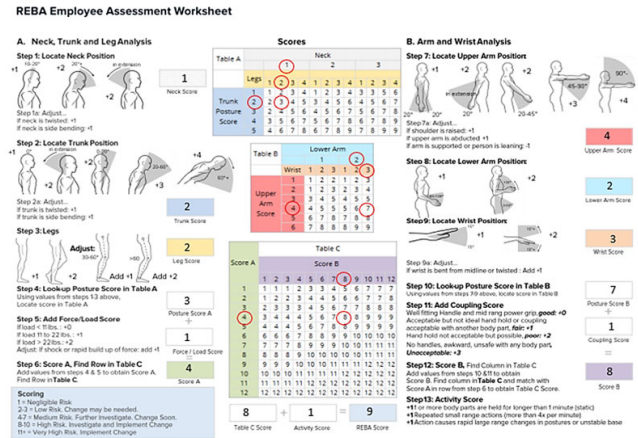

FIGURE 2. REBA score before improvement.

is illustrated by mapping the noise level (dB) in each process (Fig. 1). Each of the process is assigned with a particular measurement point so as to attain accurate noise level readings. OSHA [50] indicated that the maximum exposure to noise level is only 85dB for duration of not more than 8 hours. Noise level meter tools were accordingly used to easily and accurately measure industrial noise level.
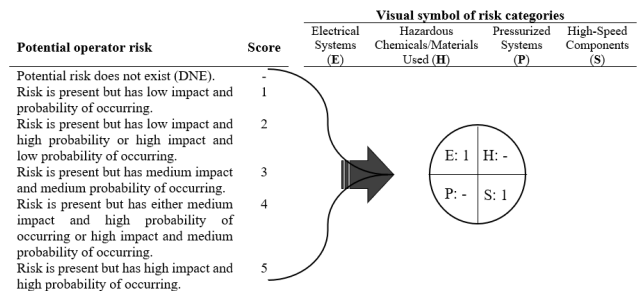

FIGURE 3. Work environment risk rating system.

The EN-Plating process is also assessed using the work environment EHPS circle which employs a rating system of 1-5 (Fig. 3), each assigned to a potential risk category related to a certain process according to the possibility and impact of that risk [1]. For instance, in the case study, at the Racking process step (see Fig.1), the potential risks exist due to the presence of electrical systems and high-speed components, but they have low impact and probability of occurring. Thus, the potential work environmental risk rating for the electrical systems (E) and high-speed components (S) metrics of the Racking process step would be both '1' in the visual symbol of EHPS circle (see Fig. 3). The rest of the work environment circle can be filled out accordingly for each process step. The visual symbol of the EHPS circle inclusive of this work environment metric status in Socio-VSM is shown in Fig. 3.

B. CREATION OF THE CURRENT-STATE SOCIO-VSM AND ANALYSIS

The current-state map is developed subsequent to identifying and measuring the societal metrics. The societal metrics are

incorporated into the current-state map using the adapted methodology for constructing a traditional VSM proposed by [29]. Resultantly, the value stream blueprint is developed where each process step is described in the data boxes (see Appendix A) with the matching societal metrics values. The sequence of the Socio-VSM is the same as that in Fig. 1.

The evaluation of the process operations is facilitated by the current-state Socio-VSM (Appendix A), but in this context, it is related to hazards instead of non-value added/lean wastes [54]. Prospective performance improvements are determinable via the identification of waste in the current state map which could include materials, information flows, or societal metrics (hazards). This hence facilitates the improvement team in developing and employing efficient hazard elimination/reduction strategies. After the current-state Socio-VSM is developed, the proposed approach moves on to the analysis, interpretation and proposal of the hazard elimination/reduction strategies.

C. DEVELOPMENT OF THE FUTURE-STATE SOCIO-VSM AND IMPROVEMENT

The current-state map depicts the operations and performance of the actual process 'as-is' [55], which aids in the identification of hazards and in turn prioritization and effective concentration of improvement efforts. Nevertheless, the ability to identify hazards and circumvent them is not the only mark of an effective VSM; it must also be able to come up with a vision and thereby a value stream that maps the best achievable state for the process [5]. This future-state map allows companies to define the best approach and performance for a process' prospective value stream. Hence, while current VSM portrays the 'as-is' state, future VSM represents the 'as-it-should-be' state [56]. For a Socio-VSM study, the future-state map depicts the best attainable improvements for a value stream via the integration of the societal metrics, i.e. hazard elimination/mitigation tactics developed in the current-state Socio-VSM.

Through the case study, REBA employee assessment has been conducted on the operators who work at the Racking and Unracking stations, and observed that the total score is 9. It indicates the high injury risk to the operators, alarming mandatory investigation and implement change (see Fig. 2). It is observed the operators have to pick the spindle that consists of 100pcs discs with both hands, bend the body in order to raise the spindle up, turn around and place the spindle to the rack. This activity may lead to wrist and back pain if repeated repetitively for long periods of time. Therefore, further analysis in the workstation layout, operator movement and work procedure should be wisely examined to identify problematic areas. The goal is to ensure the operators are able to pick and place the spindle with negligible risk. This will lead to a healthy and conducive workstation for the employees and directly provide a positive impact on the employee attrition rate and thus, organizational health. Therefore, a change of workstation layout was conducted to allow an easy and reachable access for the operators to the spindle within

lower risk. Since the implementation of the new layout where the rack has strategically been placed at the side area instead of behind, such health problems like twisting and wrist bents have been minimized. The operators are now able to pick and place spindle easily without turning their backs and bend their bodies, reducing the risk to suffer from shoulder, back and arm wrist pain. Figure 4 shows the REBA score assessment worksheet after improvement; the score was noticeably reduced to 5.
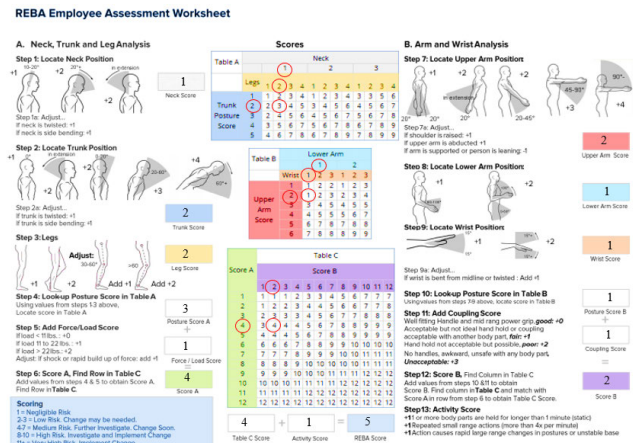

FIGURE 4. REBA score after improvement.

The current-state Socio-VSM (Appendix A) illustrates a noise level reading of 75.92dB for the EN-Plating process with a maximum value of 87.00dB at the back of plating tank area. However, in this particular area, no employee had been assigned to perform any task except for engineering specialists who are required to perform the necessary troubleshooting upon request, whom are well-equipped with personal protective equipment such as hearing aid. Hence, this social metric is not alarming to be improved.

The work environment EHPS circle was also used to assess societal sustainability performance in the EN-Plating process. On analyzing EHPS scores, the scores were found to be normal in general and were not critical.

Appendix B shows the future-state map of the EN-Plating process, depicting the best achievable improvements following the employment of the hazard elimination/mitigation tactics previously developed and measured in the earlier stage. The future-state Socio-VSM follows the same process used in the development of the current-state Socio-VSM. Here, the transcriptions of the prospective attainable hazard reductions as specified in the analyses (see Appendix B) are stated in the future-state map, i.e. in the header box of each process step. Additionally, the adjusted values, i.e. the amount after subtracting the possible hazard reduction amount from the current values are stated in the data boxes to portray the ideal future-state. This step is vital as the future-state map predicts the achievable societal improvements after the elimination or reduction of the identified hazards in the current-state map.
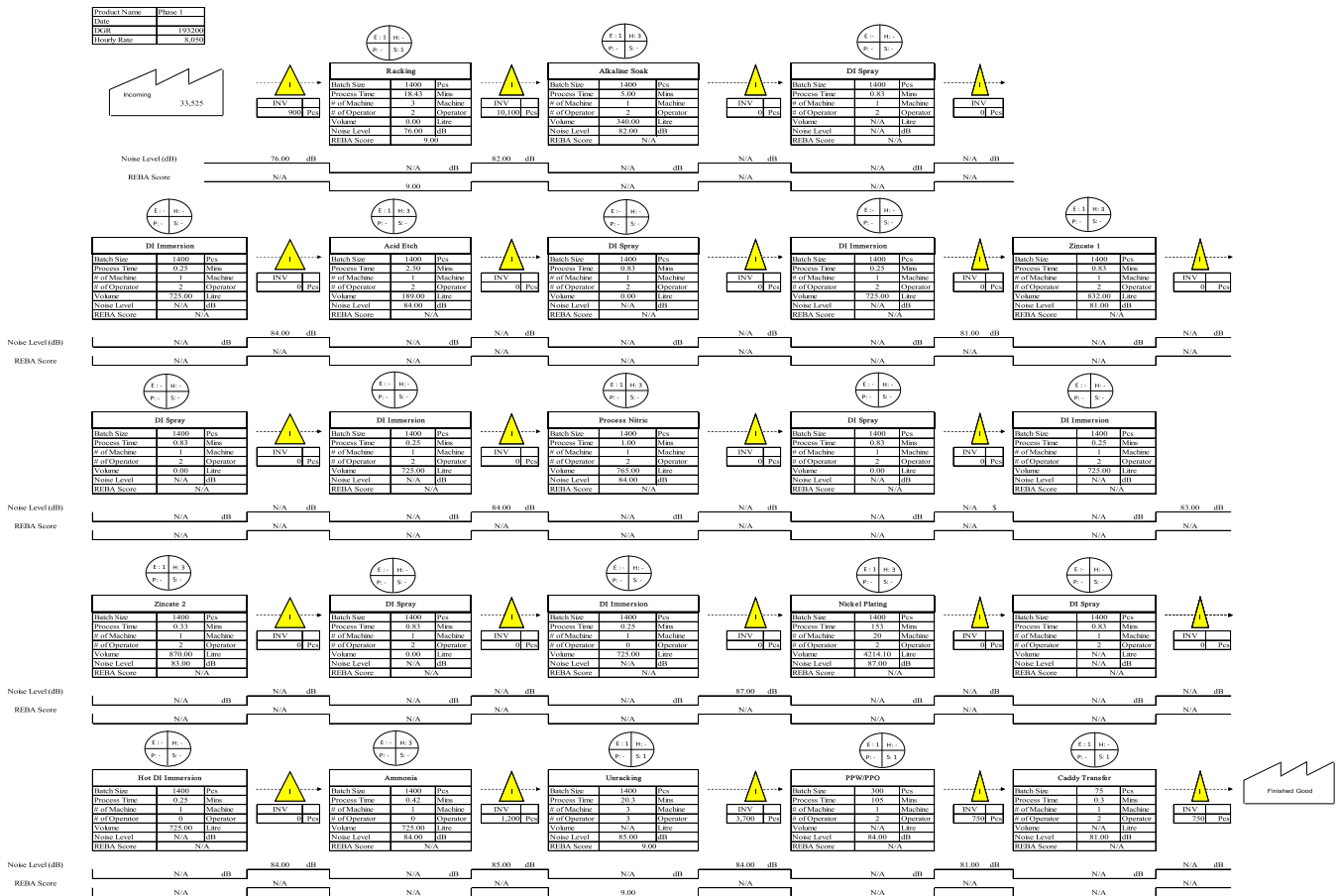
FIGURE 5. The current-state Socio-VSM for the EN-Plating process.

V. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

The manufacturing of socially- and environmentally-sustainable products require manufacturing techniques that are far removed from the sole traditional aim of minimizing cost and improving efficiency; emphasis should instead be made on the environmental and societal implications of operations involved in the manufacturing of such products. The transition to sustainable manufacturing can start by taking cues from existing techniques from which innovative methods can be developed. One of the most prominent lean manufacturing techniques is VSM which is capable of identifying waste and – with continuous improvement – eliminating it. Despite efforts to extend VSM into green/environmental VSM, there has yet been any substantial inquiry on its extension for societal sustainability analysis in manufacturing.

This paper hence presents a methodology for developing a Social VSM (Socio-VSM) consisting of evaluation metrics for measuring the performance of a manufacturing line in terms of societal sustainability. This study is therefore contributed to filling the gap of limited studies on the extended application of VSM through:

- The provision of substantial examples of the application of VSM as well as validation of its efficacy in addressing

serious societal issues due to unsustainable manufacturing operations;
- The proposal of a rational and clearly-sequenced approach that would enable companies to implement Socio-VSM in a systematic manner;
- The incorporation of important metrics in the Socio-VSM complete with their respective visual symbols to ensure visual clarity and to maintain their utility;
- The validation of its application and its establishment as a guiding reference for operations managers; and
- The move to motivate researchers and practitioners to carry out additional studies on Socio-VSM, so as to further narrow the gap of this under-researched field.

This research as a preliminary study has been undertaken to develop the application of the highly used VSM tool to address the social challenges in the manufacturing systems, with a distinct identity, i.e. Socio-VSM. It is hoped that this proposed methodology would be the driving and facilitating factor for industrialists to achieve more socially-sustainable operations. However, the proposed methodological approach is subject to the limitations that suggest directions to further research. Although it is endeavored to encompass the critical societal metrics by thoroughly reviewing the
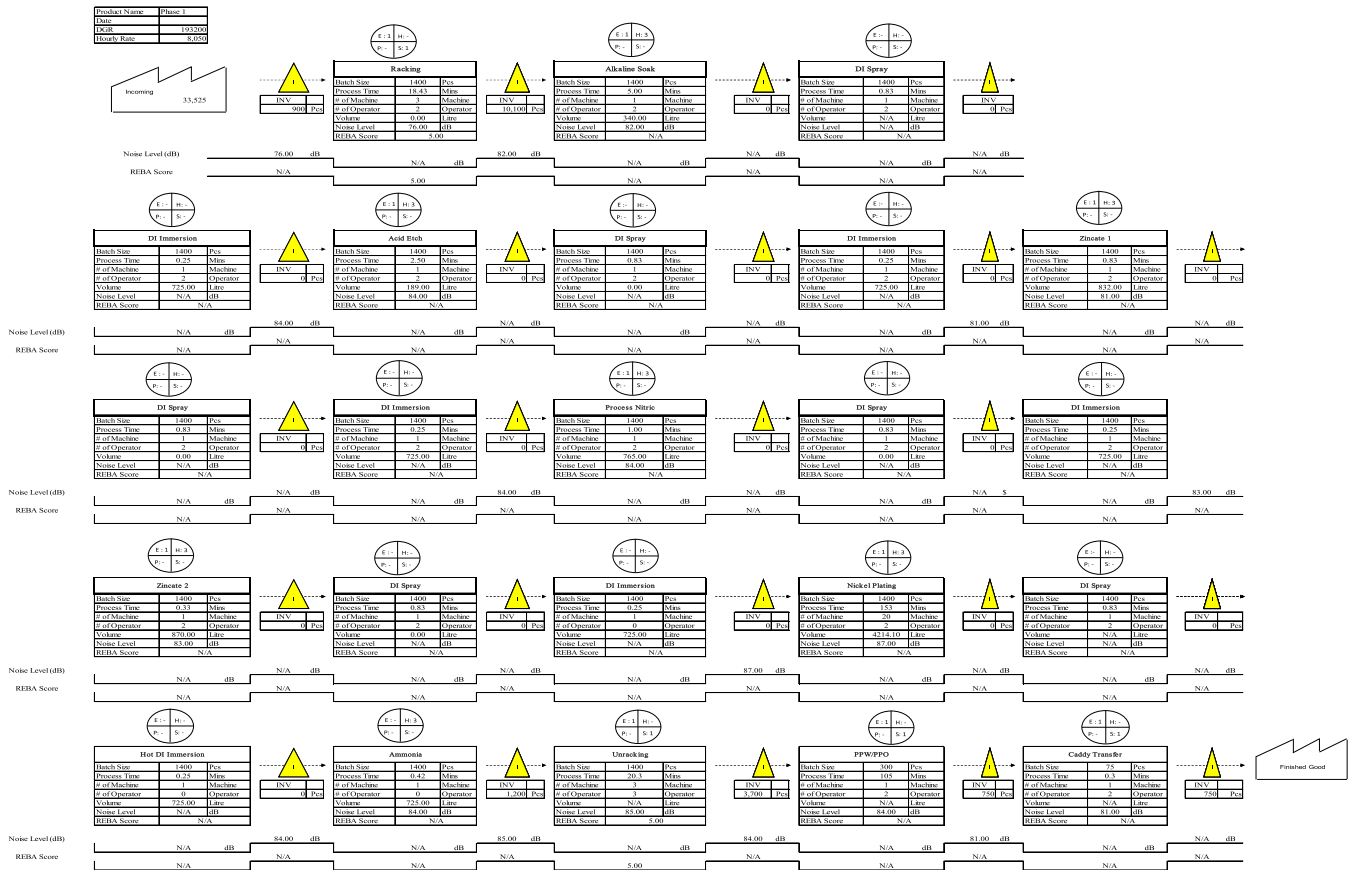
FIGURE 6. The future-state Socio-VSM for the EN-Plating process.

state-of-the-art literature on the extended VSM studies, there may be other critical metrics which should be taken into consideration. It must be noted here that the chosen societal metrics are not specific to certain sectors as the development of the methodology is aimed to be generically applicable industry-wide. Certain sectors may require their own customized metrics. From a societal standpoint, Socio-VSM is a prerequisite in sustainability assessment where it facilitates in the identification of areas for further examination via detailed ergonomic analyses. Further development in this area requires the in-depth inquiries about the benefits, challenges and success factors of Socio-VSM studies, similarly as presented in the literature to Conventional VSM studies. It should hereby be developed in a cumulative manner to complement and support the body of knowledge on the extended application of VSM from the unsustainable status quo to a more sustainable-based state.

APPENDIX A
See Fig. 5.

APPENDIX B
See Fig. 6.

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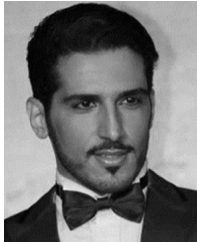
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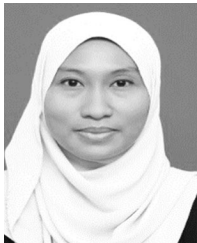
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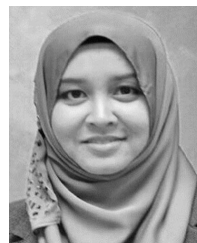
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