CLEANER PRODUCTION IMPLEMENTATION USING EXTENDED VALUE STREAM MAPPING FOR ENHANCING THE SUSTAINABILITY OF LEAN MANUFACTURING

A., Ishak*, E., Mohamad , L., Sukarma , AB R. , Mahmood, M.A., A Rahman , S.H. Yahya , M.S., Salleh and M.A., Sulaiman

Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

Email:*nuar@doe.gov.my

ABSTRACT: This paper investigated the measures by Cleaner Production (CP) embedded in the modified VSM technique, i.e., Cleaner Production VSM (CPVSM) to be an effective visualisation technique for Lean and promoted the sustainability at 2 local Small and Medium Enterprises (SME's) for demonstrating the level to which the CPVSM process can be applied. Our findings showed that the implementation of the CP technique was improved through this CPVSM approach and thus promoted the Lean Manufacturing (LM) sustainability.

KEYWORDS: *Carbon footprint, cleaner production, lean manufacturing, value stream mapping*

1.0 INTRODUCTION

Currently, as expressed in the Kyoto Protocol, we need to create an environmentally sustainable society which would help in fulfilling our present needs without affecting the future generation [1]. The environmental effects like climate changes and the carbon emissions are some major environmental problems that have to be taken care on a priority [2]. SMEs form the backbone of a country's economic growth [3]. They are seen to play a very important role globally [4] and can be launched in any of the urban or rural localities for conducting any business [5]. However, they cannot easily comply with the environmental legislations as compared to the larger industries [6-8]. A better awareness for carrying out sustainable practices amongst the businesses is very important for broadening their attention from an economic well being to encompass the societal and environmental aspects [9-12].

CP is a technique used for minimizing waste and environmental pollution [13-14] while LM makes the manufacturing process more efficient while decreasing the waste elimination in every production stage [15-18].

Furthermore, CP also improves the environmental production process by further adopting a more precautionary manner and seeks to decrease the environmental waste and its generation [19]. The VSM technique was originated from Toyota Production System, and is an essential process used in LM for waste identification [20-21]. In this method, all actions, i.e., Value-Added (VA) or Non-Value Added (NVA), are mapped, which are necessary for passing the products through the major flow processes, or the production flow through which a raw product passes before going to the customer or even passes the designing flow from its basic concept to the final presentation [22].

The traditional VSM process does not consider the societal or the environmental metrics that are essential for determining the production line sustainability. When the VSM is capable to visually determine the environmental and the societal performance, it is seen to increase its usefulness as a LM tool [23] and improves the CP implementation. This study has presented a complete framework for developing the case study, which implemented the CP using VSM. The main objective of our study was to develop the Current State Map (CSM) and determine the different wastes (environmental, economic and societal metrics) which were identified using the CSM. Our results could be used as a basic input for generating the Future State Maps (FSM) for an improved technique.

2.0 RESEARCH BACKGROUND

The LM and the green manufacturing processes have presented fuzzy evidence regarding their association with the sustainable manufacturing and production [24-25], which is an approach that ensures a manageable and viable future industrial development [26]. Furthermore, the Lean practitioners and the Environmentalists currently practice “in-silo” [27] activities. It is seen that great benefit can be obtained for the business if all the activities are grouped together.

The environmental wastes are not easily visualized and along with lean wastes, it is known as the Seven Deadly Wastes [28]. Learning to reduce the environmental waste helps in improving business and also improves the Lean results, thus providing many environmental benefits [29-33]. In Malaysia, the Guidelines laid by the Malaysian Dept. of Environment, 2014 is limited to CP activity and focused on the general evidence for the CO_2 quantification which are difficult to be implemented in the mainstream processes and present a difficulty while performing the Kaizen activities [34-35]. One other toolkit was also developed which discussed the energy consumption with the help of the

VSM process [28]. USEPA suggests that the industries must observe and assess the energy consumption while carrying out in-house energy audits [28].

Furthermore, the USEPA also encourages the energy efficiency using visual controls like energy dashboards for determining if the industries have fulfilled the energy goal. Many studies have been carried out which describe the sustainability measurement which is carried out in several ways for improving the VSM in combination with the environmental and societal metrics. Learning to reduce the environmental waste helps in improving business and also improves the Lean results, thus, providing many environmental benefits [29-33]. In Malaysia, over the past few years, many CP implementations or known as the Green Industry audits, are applied as per the Guidelines [34]. However, these Guidelines need a general evidence for the CO_2 emission activities [35] which are difficult to be implemented in the mainstream processes and present a difficulty while performing the Kaizen activities.

3.0 LITERATURE REVIEW

For enhancing the efficacy of the lean implementation and addressing the issue regarding the environmental wastes, the USEPA creates a massive lean and environmental toolkit. The environmental waste can be described as unnecessary usage of the resources or substances that are released into the environment which could affect human or animal health [27]. One other toolkit is also developed which discusses the energy consumption with the help of the VSM process [28].

USEPA suggests that the industries must observe and assess the energy consumption while carrying out in-house energy audits [28]. Furthermore, the USEPA also encourages the energy efficiency using visual controls like energy dashboards to determine if the industries have fulfilled the energy goal. Similar to the earlier USEPA toolkit [27], the above method does not mention the way to visualize and track several metrics simultaneously using one VSM. After visualizing and tracking the environmental metrics like the water or material usage, in addition to the general VSM metrics, the industries can identify and decrease the environmental wastes. Many studies have been carried out which describe the sustainability measurement which is carried out in several ways for improving the VSM in combination with the environmental and societal metrics [36-44]. The EE-VSM technique proposes a lean sustainable process for a real-time dashboard, coupled with constant improvement of the chosen sustainability metrics [43]. However, water or energy consumption, material usage, and CO_2 are emitted during the procedure which exclude the energy which is consumed while transporting during specialty storage and does not also consider the societal and environmental metrics for validating the case study.

Table 1: Summary of the extended VSM technique which measures the sustainable performance

Tool	E1	E2	S	Source
Sustainable VSM (SVSM)	√	√	X	Simon & Mason, [37].
EPA Lean and Environmental Toolkit	√	√	X	US EPA, [27].
EPA Lean and Energy Toolkit	√	√	X	US EPA, [28].
Environmental VSM (EVSM)	√	√	X	Torres & Gati, [40].
Sustainable Value Chain Map (SVCM)	√	√	X	Fearne & Norton, [39].
Sustainable Manufacturing Mapping (SMM)	√	√	X	Paju et al., [42].
Energy & Environment VSM (EE-VSM)	√	√	X	Kuriger & Chen, [41].
Lean Sustainable Production Assessment Tool	√	√	X	Kuriger et al., [43].
Green VSM	√	√	X	Dadashzadeh & Wharton [46].
Sustainable VSM (Sus-VSM)	√	√	√	Faulkner et al., [44], Brown et al., [45].

**Notes: E1-Economic, E2- Environment & S – Social.*

A study [40] described an EVSM technique which analyzes water consumption. However, they do not provide any explanation for the differences noted between the 2 sustainability pillars. The sustainability using VSM has been measured in many ways by various authors, i.e., SVCM [36,38,39]; SVSM [37]; and the SMM [42]. However, all these techniques have described some major limitations. The recently-developed Sus-VSM toolkits [44,45] are to be very accessible and they have added an EPA stamp for identifying the processes using EHS (Environmental, Health, and Safety).

Table 1 summarizes the results published earlier which have extended the VSM technology and developed a sustainable application of VSM, and also described their coverage along with the limitations seen, with regards to incorporating the sustainable measurement. The Table presents a '√'sign, which indicates a specific aspect described in the cited article, while 'X' indicates the article that has not mentioned that specific aspect.

4.0 METHODOLOGY

Similar to the traditional VSM approach used for the identification of the Kaizen activities [47], the CPVSM process must also incorporates the various sustainability metrics for observing the sustainability performance and identifying the opportunities to improve them. In order to analyze the sustainability process using the VSM approach in our study, the frameworks used was similar to those proposed earlier by respective authors [44,45]. Additionally, the CPVSM model could be applied in addition to [27] and its toolkits [28] then re-engineered based on the Malaysian Green Industry Audit Guidelines [34], which acts as the standard for formulating the CO_2 equivalent emission, i.e., $kgCO_2e$ quantification.

Table 2: Summary of the comparison criteria investigated in the traditional VSM and CPVSM approaches

Criteria	Previous Extended VSM [36-46]	CPVSM	Metric Type
Cycle time	+	+	E1
Change over time	+	+	E1
Uptime	+	+	E1
Number of operators	+	+	E1
Raw water consumption	x	+	E2
Electricity consumption	x	+	E2
Fuel consumption	x	+	E2
Waste water generation	x	+	E2
Solid waste generation	x	+	E2
Noise level	x	+	S
Job hazard	x	+	S

Note; '+'sign indicated that a specific item was included, whereas 'x' sign indicated that it was not present.

Data collection for this study was performed through observation, documentation audit, estimation and field measurement to collect the potential sustainable wastes in the respective plants.

Table 2 presents the comparison of the criteria applied in the previous VSM and CPVSM approaches. Two case studies were also conducted at the E-Waste Recovery and Chromate Plating Plants, and the main process has been described in Figures 2 and 3. In these figures, the author discussed the differences in the implementation while carrying out the CPCSM survey and then determining the sustainable wastes (i.e., Economic, Environmental, and Societal).

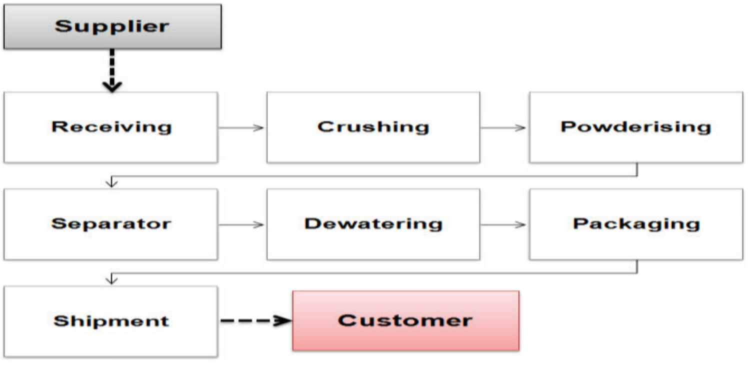


Figure 2: ABC recycling process

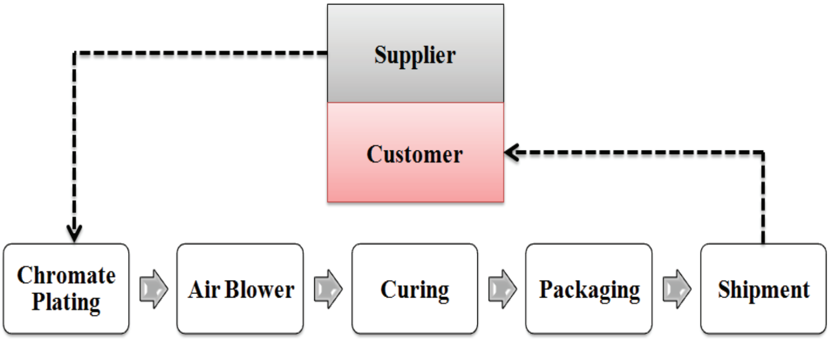


Figure 3: DEF Chromate plating process

The case study has outlined further details of the particular data collection technique in our case study based on the direct observation and estimation, which helped us collect data about cycle times, number of operators, inventories, and all the CPVSM-related metrics. Furthermore, an assessment has been carried out through observing the production process and identifying the relative activities and problems.

As shown in Figure 4, there are 5 steps for obtaining the flow of information in our process, machine specifications, production capacities, water usage, electricity usage and the fuel information in addition to the solid and waste generation, noise levels and job hazards, which is shown in Figure 5. Furthermore, the waste data like the solid waste, waste waters and toxic waste were also taken into consideration and improved using the economic waste data with the help of all CSM steps. However, if under certain circumstances, the observation data were difficult to collect, the observable parameters could be assumed or estimated and the necessary data could be calculated using Equation (1) as follows:

$$\sum CO_2e(KgCO_2) = CEF \text{ x unit of entity} \quad (1)$$

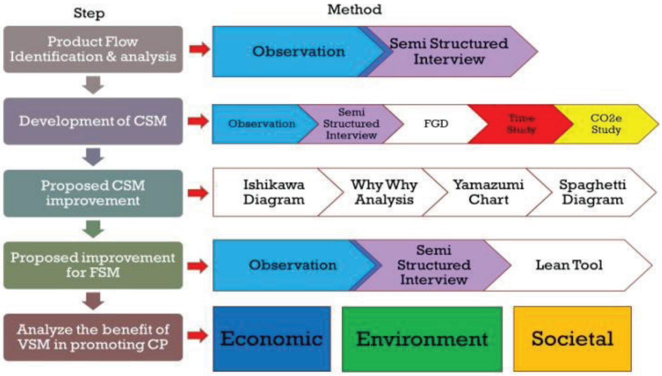


Figure 4: Research methodology framework

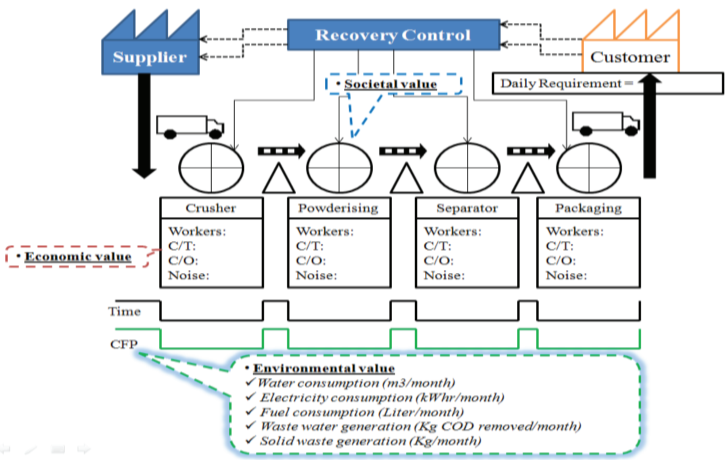


Figure 5: CPVSM conceptual platform

5.0 RESULTS AND DISCUSSION

This study describes a methodology for developing a sustainable CPVSM approach that includes several metrics for evaluating the economic performance along with the environmental and societal performances for any manufacturing line. Different metrics have been selected for assessing the production process, machine specifications, production capacity, water and electricity usage, fuel-related data along with waste information for solid and water wastes, noise levels, and job hazards for the employees.

Figures 6 and 7 describe the major characteristics for the economic values of the cycle times in both the studied plants, which consisted of the Non Value-Added (NVA) time and the Value-Added (VA) time improvements. The study noted that there was a 50% improvement in the NVA for the crushing process used in the ABC Recycling Plant whereas an overall 37.27 % improvement was noted for the DEF Plating Plant, from 11 to 6.9 days of the waiting time using the Kaizen activities.

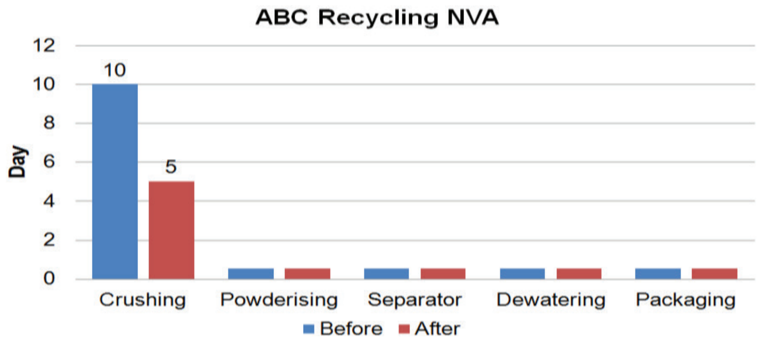


Figure 6: NVA for ABC recycling plant

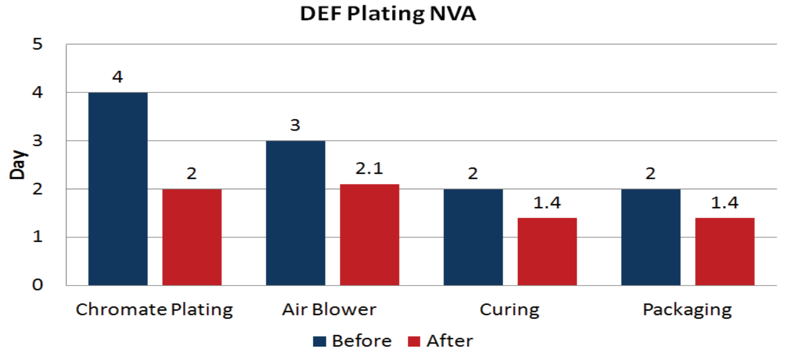


Figure 7: NVA for DEF plating plant

From the data in Table 3 & 4, a very clear trend for the VA is decreased by enhancing the process used in the workstations. One of the major improvements in the dewatering procedure was seen after reducing 50% of the cycle time, in the ABC Recycling Plant. Furthermore, standardizing the plating process, surprisingly, was able to decrease the VA in the Chrome Plating Plant from 4041 to 3232 minutes for every batch. Thus, from our study, it must be noted that all environmental metrics could be estimated by applying the CPVSM approach. This was an unexpected result which suggested that the economic metric improvement was concurrently beneficial as it decreased the CO_2 equivalent emission after using the Kaizen activities.

Table 3: Value-Added Time improvement seen at ABC recycling plant by applying the CPVSM approach

Process	Before (min)	After (min)	Δ
Crushing	92	64	+30.43%
Powderising	29	29	-
Separator	120	66	+45.00%
Dewatering	10800	5400	+50.00%
Packaging	26	26	-

Table 4: Value-Added Time improvement seen at DEF plating plant by applying the CPVSM approach

Process	Before (min)	After (min)	Δ
Chromate Plating	4041	3232	+20.00%
Air Blower	37	28	+24.32%
Curing	55	44	+20.00%
Packaging	41	41	-

Figures 8 and 9 have illustrated the estimation and decrease in CO_2 equivalent emission for all the workstations. Our results concluded that: the improvement in the electricity consumption could be difficult after applying the minimal monetary Kaizen programs in ABC Recycling but it could be achieved by high cost investment i.e., machine & process modification and proper PM procedure; however, the study also showed the improvement of water and solid waste generation using some inexpensive Kaizen activities such as 5S and FIFO in DEF Plating was possible.

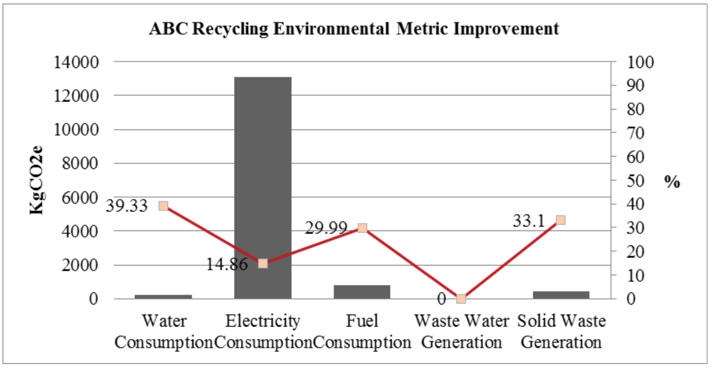


Figure 8: Environmental improvement in ABC recycling plant

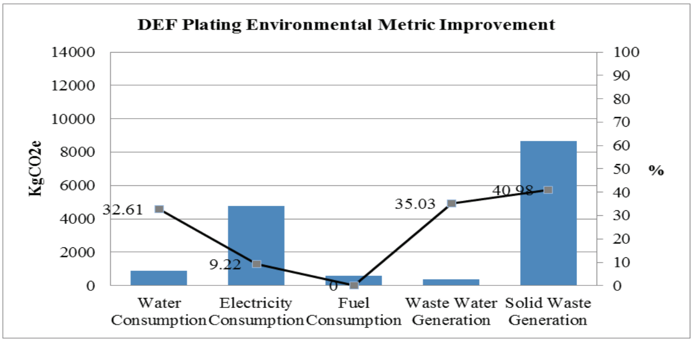
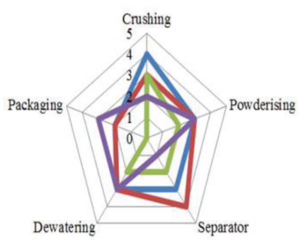
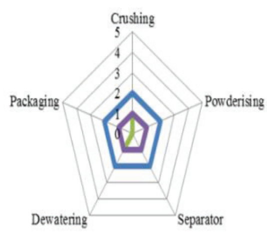
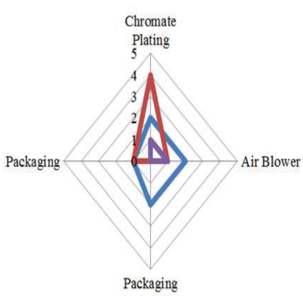
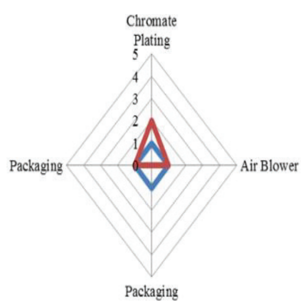


Figure 9: Environmental improvement in DEF plating plant

Table 5 also shows that societal metrics for the two plants studied, along with the 4 major components of the job hazard have improved after using the CPVSM approach.

Table 5: Improvement of the Job hazards in the two companies

Before	After
	
	

6.0 CONCLUSION

In conclusion, the results have shown that the proposed CPVSM approach for sustainability measurement is a good technique to be used in the manufacturing sector. This technique helps in the easy visualization of the economic and the environmental wastes along with improving the Kaizen activities. The study also verifies that the implementation of the CPVSM approach could enhance the societal benefits and needs a minimal cost and effort for its performance. Future works can determine the application of the CPVSM approach, especially in assisting the local SME's in the maintenance of the business.

ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Education, Malaysia for the financial support of this study via Grant (PJP/2014/FKP/(9C)/S013262).

REFERENCES

[1] L.C. Angell, and H.S. Lewis, *Environmental and Operations Management Face the Future Decision Line*. Pennsylvania: 1999.

[2] F. Tilley, "Small Business Environmental Ethics: How Deep do They Go?" Business Ethics: A European Review, Vol. 9, No. 1, pp. 31 – 41. 2000.

[3] R. Thurik, and S. Wennekers, *"Entrepreneurship, Small Business and Economic Growth"*. J. Small Buss. Enter. Dev., Vol. 11, No.1, pp. 140-149. 2004.

[4] K. Veskaisri, P. Chan, and D. Pollard, *"Relationship between strategic planning and SME success: empirical evidence from Thailand"* in the Conference of the International DSI/Asia and Pacific DSI. 2007.

[5] M. Khalique, J. A. N. Shaari, A. H. Md. Isa, , and A. Ageel, *"The challenges faced by the small and medium enterprises (SMEs) in Malaysia: in intellectual capital perspective"*. Int. J. of Current Research, Vol. 3, No.6, pp. 398-401. 2011.

[6] Greenpeace International, Greenpeace Guide to the Kyoto Protocol. Amsterdam: 1998.

[7] G. Keijzers, *"The Transition to the Sustainable Enterprise"* J. Clean. Prod., Vol. 10, pp. 349-359. 2002.

[8] H. Walker, and L. Preuss, *"Fostering Sustainability through Sourcing from Small Businesses: Public Sector Perspectives"*. J. Clean. Prod., Vol. 16, No. 5, pp. 1600 – 1609. 2008.

[9] B. Ageron, A. Gunasekaran, and A. Spalanzani, *"Sustainable Supply Management: An Empirical Study"*. Int. J. Prod. Econ., Vol. 140, No. 1, pp. 168 – 182. 2012.

[10] J. Elkington, Partnership from Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Environmental Quality Management, Vol. 8(1), pp. 37 – 51. 1998.

[11] N. R. Khalili, *"Practical sustainability: From grounded theory to emerging strategies"*. Int. J. of Strategic Decision Sciences, Vol. 3, No.3, pp. 61-63. 2011.

[12] United Nations "General Assembly". Available: http://www.who.int/hiv/universalaccess2010/ worldsummit.pdf.

[13] J. Frijns, and B. V. Vliet, Small-Scale Industry and Cleaner Production Strategies. World Development, Vol. 27, No. 6, pp. 967–983. 1999.

[14] H. Bradbury, *"Sustaining Inner and Outer Worlds: A Whole-Systems Approach to Developing Sustainable Business Practices in Management"*. J. Mngmt. Edu., Vol. 27(2), pp. 172-187. 2003.

[15] J. Womack, D. Jones, and D. Roos, *"The machine that changed the world: The story of lean production"* Harper Perennial, New York: 1991.

[16] G. Hilson, *"Pollution prevention and cleaner production in the mining industry: an analysis of current issues"*. J. Clean. Prod., vol. 8, no. 2, pp. 119–126. 2000.

[17] J. Womack, and D. Jones, Lean Thinking. Simon & Schuster. New York: 1996.

[18] E. Mohamad, and M.A. Sulaiman, *Simulation-based approach to Lean Manufacturing*. Penerbit Universiti, Universiti Teknikal Malaysia Melaka: 2016.

[19] S. Bushell, J. Mobley, and B. Shelest, *"Discovering lean thinking at progressive health care"*. The Journal for Quality and Participation, Vol. 25, No. 2, pp. 20–25. 2002.

[20] M. Braglia, G. Carmignani, and F. Zammori *"A new value stream mapping approach for complex production systems"* Intl. J. Prod. Research, Vol. 44, Issue 18-19, pp. 3929-3952. 2006.

[21] E. Mohamad, M. A. Ibrahim, A. S. Shibghatullah, M. A. Rahman, A. Sulaiman, M. A. Rahman, A. A. A. Abdullah, and M. R. Salleh, *"A Simulation-Based Approach For Lean Manufacturing Tools Implementation: A Review"*, J. Eng. and Appl. Sc., Vol.11, No.5, pp. 3400-3405. (2016b).

[22] M. Rother, J. Shook, *"Learning To See: Value Stream Mapping To Add And Eliminate Muda"*. The Lean Enterprise Institute, Massachusetts:1999.

[23] F. Abdulmalek, and J. Rajgopal, *"Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study"*, Intl. J. Prod. Econ.,v Vol. 107, No. 1, pp. 223–236. 2007.

[24] D. Dornfeld, C. Yuan, N. Diaz, T. Zhang, and V. Athulan, *"Introduction to Green Manufacturing"*. Green Manufacturing: Fundamentals and Applications, pp. 1 – 23. New York: 2013.

[25] M. Helu, and D. Dornfeld, "Principles of Green Manufacturing: Fundamentals and Applications, pp. 24–35. 2013.

[26] Census Bureau, U.S. & World Population Clock, United States Census Bureau. USA. 2014.

[27] EPA, *"The Lean and Energy Toolkit: Achieving Process Excellence Using Less Energy"* United States Environmental Protection Agency. USA: 2007.

[28] EPA, *"The Lean and Environment Toolkit"* United States Environmental Protection Agency. USA: 2007.

[29] J. Maxwell, F. Briscoe, B. Schenk, and S. Rothenberg, Case study: Honda of America Manufacturing, Inc.: Can lean production practices increase environmental performance? Environmental Quality Management, Vol. 8 No.1, pp. 53–61. 1998.

[30] T. Larson, and R. Greenwood, "Perfect complements: Synergies between lean production and eco-sustainability initiatives". Environmental Quality Management, Vol. 13, No. 4, pp. 27–36.2004.

[31] G. G. Bergmiller, *"Lean manufacturers transcendence to green manufacturing: Correlating the diffusion of lean and green manufacturing systems"*. Dissertation Abstracts International. 68(1), supplement B, 294. 2006.

[32] S. Novkov, & I. Dakov, *"Assessment of the lean production effect on the sustainable industrial enterprise development"*. Bussines Theory and Practise, Vol. 8, No.4, pp. 183 – 188. 2007.

[33] C. M. Dües, K. H. Tan, and M. Lim, *"Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain"*. J. Clean. Prod., Vol. 40, pp. 93–100. 2013.

[34] Guidelines for Green Industry Auditor, Department of Environment Malaysia, Putrajaya, Malaysia:2014.

[35] R. Rahim, and A.A. Abdul Raman, *"Cleaner Production implementation in a fruit juice production plant"*, J.Clean. Prod., Vol. 101, pp. 215 – 221.2014.

[36] J. Guinee, *"Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards"*. Dordrecht, Netherlands:2002.

[37] D. Simons, and R. Mason, *"Environmental And Transport Supply Chain Evaluation With Sustainable Value Stream Mapping"* in Proceedings of the 7th Logistics Research Network Conference. Birmingham, UK:2002.

[38] A. Norton, *"Sustainable Value Stream Mapping as a Technique for Analysing and Reducing Waste in the UK Chilled Food Sector"* PhD Thesis, University of London, Imperial College, Centre for Environmental Policy. 2007.

[39] A. Fearne, K. Waldron, and A. Norton, "Sustainable Value Stream Mapping in the Food Industry".Handbook of Waste Management and Co-Product Recovery in Food Processing, Woodhead Publishing, Cambridge:2009.

[40] A. Torres, and A. Gati, *"Environmental Value Stream Mapping (EVSM) as Sustainability Management Tool"* in the Proceeding of Portland International Center for Management of Engineering and Technology Conference 2009, August 2-6, Portland, Oregon, pp. 1689-1698.2009.

[41] G. Kuriger, and F.F. Chen, *"Lean and Green: A Current State View,"* in Proceedings of the 2010 Industrial Engineering Research Conference, June 5-9, 2010, Cancun, Mexico. 2010.

[42] M. Paju, J. Heilala, M. Hentual, A. Heikkila, B. Johansson, S. Leong, and S. Lyons, *"Frameworkand Indicators for a Sustainable Manufacturing Mapping Methodology"* in Proceeding of the 2010 Winter Simulations Conference, December 5-8, Baltimore, Maryland, pp. 3411-3422. 2010.

[43] G. Kuriger, Y. Huang, and F. Chen, *"A Lean Sustainable Production Assessment Tool"* in Proceedings of the 44th CIRP Conference on Manufacturing Systems, May 31 - June 3, 2011, Madison, Wisconsin.

[44] W. Faulkner, W. Templeton, D. Gullett, and F. Badurdeen, *"Visualizing Sustainability Performance of Manufacturing Systems Using Sustainable Value Stream Mapping (Sus-VSM)"* In Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management Istanbul, Turkey, July 3-6, 2012. 2012.

[45] A. Brown, J. Amundson, and F. Badurdeen, *"Sustainable value stream mapping (Sus-VSM) in different manufacturing system configurations: application case studies"*. J. Clean. Prod., Vol. 85, pp.164-179. 2014.

[46] M. Dadashzadeh, and T.J. Wharton, *"A value stream approach for greening the IT department"*. Intl. J. Mgmt. Inf. Syst. Second Quarter, Vol. 16 No. 2, pp. 125-136. 2012.

[47] E. Mohamad, S.N.F. Ab Rasid, T. Ito, M.A.M. Ali, M.A. Sulaiman, M.A. Azam, and A. Saptari, *"An Initiative To Implement Lean Manufacturing Using Value Stream Mapping In Textile Manufacturing Company"*, 24th Design Engineering Systems Division JSME Conference [No.14-27] Japan Society of Mechanical Engineers, 17-19th September, Tokushima , Japan, pp. 2309. 2014.