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Development of Multivariate Framework for Lean and Green Process

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The supply and demand on manufacturing industry has always been contributing significantly towards global economic growth. With the criticality of global warming and climate change, the manufacturing industry has suffered from being accused as the main contributor to environmental pollution. The volatility of global economic and competition has also hit the manufacturing industry badly. The urge to shift the manufacturing industry towards lean and green paradigm is inevitable. A sustainable process is favourable to cope with global supply demand. Lean and green process can act as a strategy and solution for developing country to achieve sustainable manufacturing. The development of multivariate framework for lean and green process covers five major areas (e.g. manpower, machine, money, material and environment) that will enhance the industry to be more sustainable through lean and green approach. The multivariate framework aims to establish the relationship between five major areas to identify the potential debottlenecking possibilities. This framework evaluates the lean and green factor to form a balance solution to the operation. Lean and green framework is expected to act as an effective tool in assisting the industry to strive for greater sustainability.

1. Introduction

Exponentially growth of global supply demand and climate change have been a critical issue to global society. With the advancement of technology and connectivity, globalization has opened up global market opportunities for more manufacturing industry. Globalization has helped the manufacturing players to grow rapidly as well as pose great challenge. Political influence, economic stability, technology innovation, regulatory restructuring and environmental pressure have constantly altering the competitive landscape (Issa and Chang, 2010). Many industry players are struggling to stay competitive in the global market due to uncontrollable factor and competition. Besides that, the cost of energy and resources are constantly increasing due to rising demand but limited supply (Paul et al., 2014). Lam et al. (2017) discovered that the world energy consumption will grow by 48 % until 2040. Energy and resources are two major contributor that not only affects the economy performance but also the competitiveness of the manufacturing industry. In fact, many large manufacturers (e.g. Toyota) have already ventured into lean approach to manufacturing industry stay competitive (Jasti and Kodali, 2014).

Apart from global economic challenge, global warming and climate change has also pose a great challenge to every country in contributing to environmental remediation. Global warming has triggered social concern and people are giving more attention to the environment. The manufacturing industry started to look into green manufacturing (GM) considering environmental impact in the early 1990s (Sezen and Cankaya, 2013).

The combination of lean and green (L&G) approach has been an interesting area for many researchers to explore. The relationship between L&G waste can be incorporated as one to enhance operation performance in waste reduction (Verrier et al., 2016). There is a lack of implementation method to L&G approach that can be easily implemented in the industry. The lack of industry expertise has also delayed the implementation of L&G in the industry.

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1.1 Lean Processing

Lean processing or known as lean manufacturing (LM) has developed alongside with the industry revolution. LM is known as a systematic approach on existing operation to improve productivity through value creation. Toyota production system (TPS) is well recognised as one of the pioneers in LM (Maynard, 2013). The evolution of goods processing from traditional method to lean has unlock the potential and benefit for the industry to operate at more competitive and higher efficiency. LM approach work by five key principles starting with defining value, identifying value stream, create smooth value flow, implement pull based production and strive for excellence (Mourtzis et al., 2016). Apart from the principles, LM focuses in improving productivity through eliminating seven wastes from the operation. The seven wastes are categorised as over-production, waiting, transport, over-process, inventory, motion and defect (Liker, 2004).

Since the development of LM, many lean tools have been created to assist industry to achieve lean. Misapplication of lean tools might cause additional resources waste (Pavnaskar et al., 2003). There are many lean tools such as value stream mapping, bottlenecking analysis, gemba analysis and key performance index (KPI) that can be used for value improvement. By developing more tools, it will create confusion in lean tools selection for implementation. The effectiveness in implementing LM is still very highly depending on industry lean expert.

1.2 Green Processing

Green processing or known as green manufacturing (GM) helps to achieve greater economy without compromising the environment (Mittal and Sangwan, 2014). GM approach is essential to achieve healthy environmental performance. Helu and Dornfield (2012) proposed a simplified framework that covers five principles of GM. The five principles consist of i) a comprehensive system approach must be used to evaluate and improve manufacturing processes from a green perspective, ii) the system should be wholly viewed across both the vertical and horizontal directions, iii) harmful input and output of the system to the environment and humans should be reduced or removed, iv) net resources use should be lowered and v) temporal effect on the system should be considered. According to Ma et al. (2012), the lifecycle analysis (LCA) of the product is relatively important at the initial design stage. LCA helps in identifying the potential environmental impact throughout the entire life cycle of the product from raw material to disposal. This input can be feed into Design of Environment (DfE) where green element will be included into process design.

From the industry point of view, the challenges faced in implementing GM approach is highly depending on current operation configuration. Other than LCA and DfE, energy consumption behavior has the direct impact towards GM. Energy efficient technology such as co-generation, biogas and photovoltaic can improve and enhance green factor of a processing plant (Paul et al., 2014). The green technology has achieved certain technology maturity but still occupied comparatively low market occupancy (Wolfgang and Rainer, 2014).

1.3 Lean and Green Processing

The development of L&G approach in the industry and academic has started since the pass decade (Varrier et al., 2016). The synergy between L&G approach enables the industry to achieve higher production efficiency without compromising the environment. According to Dües et al. (2013), LM and GM approaches indicate similarities where both have strong commitment on efficiency drive practice and minimum waste.

It is found that factory that operate with lean principles have better ability to reduce environment pollutant (Sawhney et al., 2007). Production premises that inhibit continuous improvement in their production have positive effect towards higher efficiency and environmental performance (Galeazzo et al., 2014). LM indicate positive effect on environmental impact but LM does not specially address environmental waste as the main subject.

Jabbour et al. (2013) concluded that the implementation of environmental program (ISO14001) can have positive impact on various areas on organization performance. GM approach has a positive influence on process operation to create the synergy between environmental management and operation performance. Both L&G complement each other to enhance the effectiveness and efficiency of operation compare to individual approach.

One of the challenges in L&G application is the lack of development of measurement method and model (Garza-Reyes, 2015). There is also a limited approach that integrate L&G that merge their fundamental principles together (Pampanelli et al., 2014). A systematic L&G framework should be developed to ease the organization to have a better understanding on application and benefit of L&G.

2. Lean and Green Model Development Framework

The development of lean and green (L&G) framework consist of five major areas such as Manpower, Machine, Material, Money and Environment. Figure 1 shows the proposed L&G framework which exhibit the relationship between five major areas with L&G.

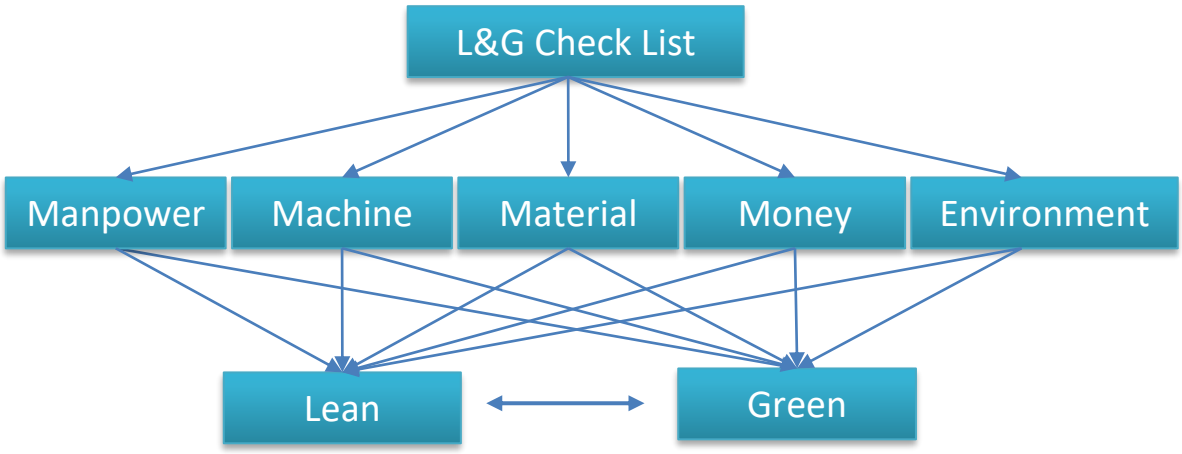

Figure 1: Lean and Green Framework

The framework starts with L&G check list which act as a summary of data collection from the five major areas. Checklist will be used as a tool to obtain industry input that will be incorporated into the L&G framework for further analysis and modelling. The design of L&G checklist is based on input from the industry as well as from the academic. Each major area focuses on its individual contribution in the industry context. Contribution from the major areas will indicate the weightage of L&G approach in the industry.

2.1 Manpower

The role of Manpower also known as human resource plays an important role in a manufacturing processing. Tom (2018) performed a study on the important of human resource on manufacturing industry. With the advancement on technology, the change of demand in manufacturing workforce has switched. Industry revolution 4.0 has shift the industry focus towards technology and automation. This leads to shortage of highly-skilled workforce with competent capability to cope with paradigm shift in the industry. The industry realized retaining and improving employee capability is very crucial in ensuring competitiveness in the global context. Lilian (2016) discovered the major human error in manufacturing related to competency and health condition of the employee. Referring to Table 1, data will be collected based on several factors to evaluate the performance of manpower. The data obtained is expected to provide an overview on the area of improvement to improve the efficiency and effectiveness of workforce.

Table 1: Manpower evaluation factor

Factors	Description
Age Group	To observe the age group distribution of employee
Competency	To evaluate competency of employee (e.g. in-house training or mentorship)
Attendance	To observe the commitment of employee
Working hours	To observe effect of working hours on employee performance
Employee Performance	To gauge the achievable target of employee
Employee Satisfactory	To obtain feedback on employee's concern related to working environment

2.2 Machine

In a manufacturing process, machine works together to complete the entire process of goods production. The main function of machine is to ensure production of goods are produced at the designed rate. The development and advancement of new technology will contribute to improve the production efficiency and reliability. The improvement in machine can enhance the L&G factor in operation. In short, the data is expected to show better understanding on the relationship of the equipment which will enhance L&G approach further.

Table 2: Machine evaluation factor

Factors	Description
Critical equipment	High criticality: Critical or core equipment that will cause production to cease if equipment failure Low criticality: Failure of equipment will not cause production to cease.
Maintenance schedule	Time required for scheduled / unscheduled maintenance (unexpected downtime)
Operation behaviour	To observe the total production schedule, operation parameter and production efficiency based on machine configuration
Environmental performance	To monitor carbon footprint emission based on equipment.

2.3 Material

In the material context, the input and output of material (e.g. inlet product, output product and by product) are the major focuses for material. Quality of input material is significant to reduce amount of defect product. Material will have direct contribution to L&G factor in preserving the environment without comprising production efficiency.

Table 3: Material evaluation factor

Factors	Description
Material handling	Inspect the quality of input and output material to ensure quality specifications are met. Determine the amount of by-product and waste generated from the production.
Material storage	Evaluate storage condition for raw material or product (e.g. condition of storage tank, requirement of inert gas, requirement of storage temperature and etc).

2.4 Money

Economic feasibility of project implementation on existing process technology is highly depending on the cost factor. A study has been carried out to show correlation between cost saving, efficiency and sustainability (Jason, 2016). Money factor is a direct indication to the performance of manufacturing company. It can be used as a performance index in the L&G framework for further improvement. Operation cost optimization is highly dependent on the evaluation factor as shown in Table 4.

Table 4: Money evaluation factor

Factors	Description
Material cost	Input of total material cost consumed for the production of product.
Utility cost	Evaluation of utility cost consists of electricity, thermal energy, cooling capacity, compressed air and etc. Proper utility management is suggested to be able to reduce utility cost
Labour cost	The number of competent employee to manage and handle specific task according to shift or production schedule.
Logistic cost	Transportation and handling of input resources and product from the product. This includes farm tank, warehouse and etc.
Waste cost	Evaluate total energy and production loss during production. Waste of energy and resources can be associate directly with cost.

2.5 Environment

With the increased concern in global warming and climate change, many countries have tighten their environmental enforcement. The implementation of environmental program (ISO14001) shows positive impact on various area on organization performance (Jabbour et al., 2013). Environmental emission will be monitored and improved through operation as well as technology improvement. As one of the main pillar in sustainability, environment aspect is taken into consideration in L&G framework. The environment contribution in industry will be reflected in the L&G framework. The standard of environmental emission can be obtained and compare with the standard from Department of Environment.

Table 5: Environment evaluation factor

Factors	Description
Air emission	To capture and monitor air emission within the production boundary.
Water emission	To capture and monitor water emission to the environment within production boundary
Noise emission	To monitor noise emission based on critical equipment and total production boundary
Schedule waste	Monitor amount of schedule waste produced.
Production waste	Production waste can be categories as non-value added by-product and defect from the production.
Energy waste	Energy lost such as thermal loss, cooling loss, pressure loss etc.

2.6 Recommendation for Future Work

The development of L&G structure will form the inter-relationship between the five major areas. It is suggested that an analytic model will be further developed to perform analysis on the input data. Principle component analysis (PCA) is considered as one of the analysis method to be incorporated into the model. PCA is able to convert huge amount of correlated variables into smaller set of uncorrelated variables known as principal component (PC) without losing the too much of information (How and Lam, 2017). Other analysis method such as multi-objectives optimization and analytical hierarchy process (AHP) are also considered for further study. Figure 2 shows the future development works that needs to be done for L&G model.

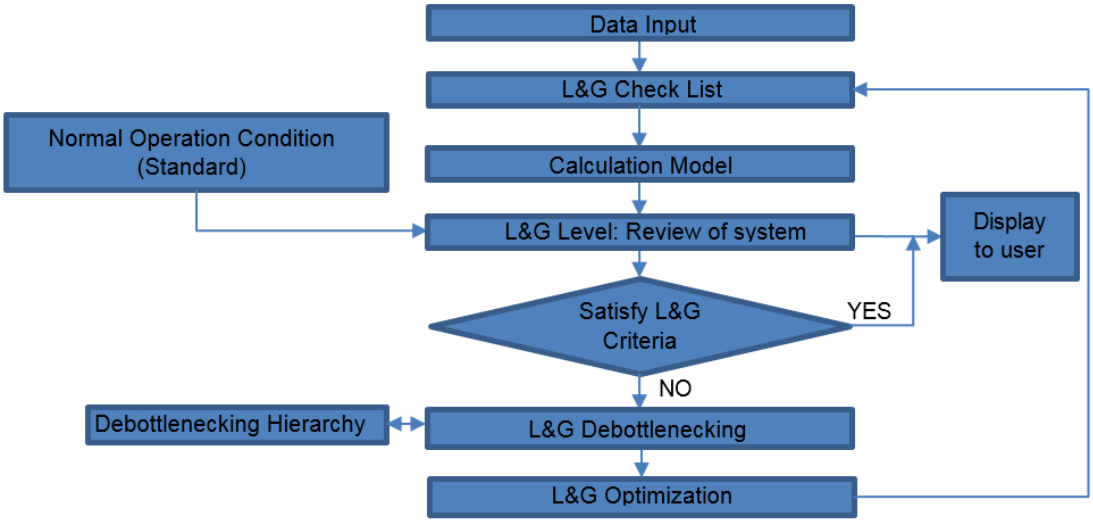

Figure 2: Lean and Green Model Flow

3. Conclusions

The development of lean and green structure covers five major areas in the manufacturing industry. The five major areas consist of manpower, machine, money, material and environment. The development of lean and green structure will be discussed and collaborated between the industry player and academic to obtain a balance input. The contribution from the five major areas will be evaluated based on actual industry data. Data obtained from the industry will be studied for area of improvement and debottlenecking. The expected outcome from the structure is to evaluate the lean and green performance of the industry. A multivariate analytic model will be further developed from the structure to analyse the relationship among the five major areas. The proposed lean and green structure is expected to able to provide a comprehensive analysis based on a mathematical model to identify level of lean and green and potential debottlenecking opportunities.

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References

Dües C., Tan K., Lim M., 2013, Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain, Journal of Cleaner Production, 40, 93-100.

Galeazzo A., Furlan A., Vinelli, A., 2014, Lean and green in action: interdependencies and performance of pollution prevention projects, Journal of Cleaner Production, 85, 191-200.

Garza-Reyes, J., 2015, Lean and green – a systematic review of the state of the art literature, Journal of Cleaner Production, 102, 18-29.

Helu M., Dornfeld D., 2013, Principles of Green Manufacturing, Chapter In: Dornfeld D. (Ed.), Green Manufacturing. Springer, Boston, MA, 107-115.

How B.S., Lam H.L., 2017, Novel Evaluation Approach for Biomass Supply Chain: An Extended Application of PCA, Chemical Engineering Transactions, 61, 1591-1596.

Issa D., Chang A., 2010, Sustainable Business Strategies and PESTEL Framework, GSTF INTERNATIONAL JOURNAL ON COMPUTING, 1(1), 1-8.

Jabbour C., Jabbour A., Govindan K., Teixeira A., Freitas W., 2013, Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing, Journal of Cleaner Production, 47, 129-140.

Jason S., 2016, The Efficiency, Cost Savings and Sustainability Equation <www.sdcexec.com/home/article/12193183/the-efficiency-cost-savings-and-sustainability-equation> accessed 22.03.2018.

Jasti N.V., Kodali R., 2014, Lean production: literature review and trends, International Journal of Production Research, 53(3), 867-885.

Lam H., Chong C., Tan T., Ponniah G., Tin Y., How B., 2017, Debottlenecking of the Integrated Biomass Network with Sustainability Index, Chemical Engineering Transactions, 61, 1615-1620

Liker J., 2004, The Toyota way, New York, NY: McGraw-Hill.

Liliana L., 2016, A new model of Ishikawa diagram for quality assessment, IOP Conference Series: Materials Science and Engineering, 161, 1-6.

Ma J., Yin F., Liu Z., Zhou X., 2012, The Eco-design and Green Manufacturing of a Refrigerator, Procedia Environmental Sciences, 16, 522-529.

Maynard M., 2013, How Eiji Toyoda Created The Modern Version Of Toyota <www.forbes.com/sites/michelinemaynard/2013/09/17/how-eiji-toyoda-created-the-modern-version-of-toyota/#a204fdc2d70e> accessed 09.11.2017

Mittal V., Sangwan K., 2014, Prioritizing Drivers for Green Manufacturing: Environmental, Social and Economic Perspectives, Procedia CIRP, 15, 135-140.

Mourtzis D., Papathanasiou P., Fotia S., 2016, Lean Rules Identification and Classification for Manufacturing Industry, Procedia CIRP, 50, 198-203.

Pampanelli A., Found P., Bernardes A., 2014, A Lean & Green Model for a production cell, Journal of Cleaner Production, 85, 19-30.

Paul I., Bhole G., Chaudhari J., 2014, A Review on Green Manufacturing: It's Important, Methodology and its Application, Procedia Materials Science, 6, 1644-1649.

Pavnaskar S.J., Gershenson J.K., Jambekar A.B., 2003, Classification scheme for lean manufacturing tools, International Journal of Production Research, 41(13), 3075-3090.

Sawhney R., Teparakul P., Bagchi A., Li X., 2007, En-Lean: a framework to align lean and green manufacturing in the metal cutting supply chain, International Journal of Enterprise Network Management, 1(3), 238.

Sezen B., Çankaya S., 2013, Effects of Green Manufacturing and Eco-innovation on Sustainability Performance, Procedia - Social and Behavioral Sciences, 99, 154-163.

Tom D., 2018, Report One: Technology and the Manufacturing Workforce: An Overview, The Future of The Manufacturing Workforce, Manpower, 4-11.

Verrier B., Rose B., Caillaud E., 2016, Lean and Green strategy: the Lean and Green House and maturity deployment model, Journal of Cleaner Production, 116, 150-156.

Wolfgang E., Rainer W., 2014, Emerging Green Technologies for the Manufacturing Sector, Vol 1, United Nation Industrial Development Organization, Vienna, Austria.