Wu, P. and Wang, X. (2016). "A Critical Review of the Factors Affecting the Success of Using Lean to Achieve Green Benefits." In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA,sect.10 pp. 33–42. Available at: <www.iglc.net>.

A CRITICAL REVIEW OF THE FACTORS AFFECTING THE SUCCESS OF USING LEAN TO ACHIEVE GREEN BENEFITS

Peng Wu[1], Xiangyu Wang[2],

ABSTRACT

Due to the rising recognition of sustainable development, various industrial sectors, including the building and construction sector, are facing increasing pressures to improve their environmental performance. The lean concept has proven to be effective in reducing waste streams and increase productivity. Many studies have therefore been conducted to link waste reduction and environmental performance improvement. A comprehensive literature review is conducted to investigate the development of integrating lean to achieve green benefits. The comprehensive literature review covers all journal articles in Scopus that have "green" and "lean" in their titles. It appears that majority of the studies within the area of lean and green focus on the conceptual framework. Very limited studies focus on the implementation of lean and green to address specific problems and provide measurable benefits. It should be noted that whether or not measurable benefits can be achieved affects the degree of implementation of lean and green at the industry level. As such, it is proposed that future studies on lean and green should be conducted and measurable benefits should be clearly articulated.

KEYWORDS

Lean, green, conceptual development, measurable benefits.

INTRODUCTION

The concept of sustainable development was firstly defined in the Brundtland Report as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" (WCED, 1987, p.43). The report highlited the importance of meeting human's economic and social needs with the consideration of the natural environment. Since its inception, sustainable development has gradually been recognized as another fundamental pillar for construction projects, along with time, cost and quality. While construction and building activities are essential to satisfy the demands from increasing populations and developing economics, these activities harness

[1] Senior Lecturer, Department of Construction Management, Curtin University, Perth, Australia. + 61 8 9266 4723, peng.wu@curtin.edu.au

[2] Professor and Co-Director of Australasian Joint Research Centre for BIM, School of Built Environment, Curtin University, Australia; International Scholar, Department of Housing and Interior Design, Kyung Hee University, Korea. Xiangyu.wang@curtin.edu.au

nature, consume energy and resources and pose significant stress on the environment (Wu et al., 2016). Worrell et al. (2001) found that the cement sector accounts for almost 5% of global man-made carbon emissions. Transportation of raw materials is also energy intensive for countries which rely heavily on import of materials. As such, the construction industry is reported to have a significant impact on the environment. For example, Bribián et al. (2011) found that building represents 24% of global extraction. Yohanis and Norton (2002) found that the initial embodied energy from building materials in a single-storey office can account up to 67% of its operating energy over a 25 year cycle. Rodríguez et al. (2015) found that the European Union produces approximately 530 million tonnes of construction and demolition waste per year, which is 25% to 30% of the total solid waste generated.

Originating from the Toyota Production System, the core of the lean production philosophy is the observation that there are two aspects in all production systems: conversions and flows (Koskela, 1992). Conversion activities refer to those which actually add value to the product or process. Flow activities refer to non-value adding activities, which consume time, costs and resources but do not add value to the product or process. The concept was found to be effective in improving environmental performance. For example, the lean concept has proven to be effective in increasing environmental benefits by eliminating waste, preventing pollution and maximizing the owners' value (Huovila and Koskela, 1998). EPA (2003) found that lean produced an operational and cultural environment that was highly conducive to waste minimization and pollution prevention, and that lean provided an excellent platform for environmental management tools such as life cycle assessment and design for environment. However, there are a few studies which found that the use of lean does not necessarily bring about green benefits. For example, Helper et al. (1997) found that there was no appreciable relationship between lean and green in the manufacturing industry.

In order to facilitate future research on the relationship between lean and environment, this paper presents the preliminary findings from a comprehensive literature review on previous studies around lean and green. However, different from previous studies on examining the relationship between lean and green, this paper has a special focus on the articles discussing why lean cannot always bring green benefits. In addition, this paper aims to find out whether measurable benefits can be achieved by integrating lean and green, as such benefits are the core KPI which most practitioners will examine. Considering this, the main research questions of the paper are:

1. Can lean be used to achieve green benefits?
2. Are there measurable benefits when integrating lean and green?
3. What are the factors that may affect the success of using lean to achieve green benefits?

RESEARCH METHOD

In order to address the research question effectively, a comprehensive literature review should be conducted. The comprehensive literature review covers all articles focusing on green and lean in the Scopus database. "Lean" and "Green" were used as the two

keywords. Only journal articles (including magazines) were selected from the database. A total of 97 documents were identified.

A few key factors of these articles were recorded after the review. These factors include publication year, industry sectors, research method, lean technologies applied and green benefits recorded. This paper only presents some preliminary findings from the analysis focusing on the three research questions proposed earlier.

LEAN AND GREEN

CAN LEAN BE USED TO ACHIEVE GREEN?

Majority of the studies have reported that lean can be used to achieve green benefits. The integration of lean and green seems to be around their focus on waste reduction (Garza-Reyes, 2015). It seems that waste reduction is the key term when it comes to the integration of lean and green. For example, Mollenkopf et al. (2010) argued that the green-lean system searchers for opportunities to reduce the production of undesired products. By reducing the environmental impacts along with the undesired products, the environmental impact from their conception, supply chain to operations will be reduced. The discussion of the reasons leading to the integration of lean and green can be divided into several categories, including conceptual investigation (which discusses the theoretical development of lean and green), theoretical integration (which discusses the feasibility and benefits by integrating lean and green, and possibly other techniques), practical investigation (which investigates the potential of using lean and green to address specific industry problems) and empirical implementation (which investigates the implementation and quantifies the results of the implementation).

In the category of conceptual investigation, Duarte and Curz-Machado (2015) used the balanced score card to investigate the lean and green supply chain linkages and found that employee training and education (one essential lean element) can help achieve waste reduction, including scrap, waste water, solid waste, hazardous waste and energy waste, thus supporting the theoretical linkage of lean and green. Dües et al. (2013) investigated the theoretical background of lean and green and identified possible areas where the use of lean can achieve green benefits. For example, both lean and green have common attributes, including waste reduction, waste reduction technique, people and organisation, lead time reduction, supply chain relationship, service level and tools/practices. As such when the implementation of lean is centred on these common attributes, a favourable result can be expected. However, extreme care should be executed. There is a large difference when defining waste in lean and green. The waste concept in lean includes the production of goods not yet ordered, waiting time, rectification of mistakes, and excess processing, movement, transport and stock (Disney et al., 1997). These waste types are not necessarily environment-related waste.

In the category of theoretical integration and practical investigation, the integration of lean and green is discussed within specific industry sectors due to varied industry characteristics. For example, Dües et al. (2013), Wiengarten et al. (2013) and Duarte and Cruz-Machado (2015) discussed the integration of lean and green in supply chain management. It is found that environmental investment does not significantly improve

operational supply chain performance. However, based on the complementarity theory, it is found that the impact of lean practices on operational supply chain management can be significantly improved with investment in environmental practices, indicating that there is a synergy between lean and green in operational supply chain management. Similarly, Galeazzo et al. (2014) and Sobral et al. (2013) found that the integration of lean and green can help achieve better environmental performance in manufacturing. However, the significance of the achievement is dependent on a few factors, such as the time of the implementation. There are a few isolated studies which discusses the use of lean and green in other sectors, such as automobile (see Kurdve et al., 2014) and product development (see Johansson and Sundin, 2014). However, majority of the studies are focused on supply chain improvement (e.g. see Cabral et al., 2012; Kainuma and Tawara, 2006; and Duarte and Cruz-Machado, 2014). These studies supported the argument that lean and green can be usefully integrated to achieve environmental benefits.

ARE THERE MEASURABLE BENEFITS?

There are a few studies which demonstrated that lean can be used to achieve green using measurable and quantified benefits. Only articles that quantified the environmental performance improvement using experiments, simulation or other similar research methods are discussed in this section. Studies using survey and questionnaires to quantify the benefits of lean and green are excluded.

King and Lenox (2001) quantified the contribution of lean to emissions reduction from 17,499 manufacturing facilities from 1991-1996 and found that lean production is complementary to environmental performance. Besseris (2011) applied the lean concept in maritime operations and collected a series of data on vessel speed, exhaust gas temperature and fuel consumption. The results show that desirable results on all three key factors have been achieved.

From 2014, the number of publications discussing measurable benefits of lean and green has been increasing. Pampanelli et al. (2014) proposed a lean concept model for managing environmental impacts of manufacturing cells and found that in terms of reducing environmental impact and increasing productivity, the lean and green model reduces the use of resources, on average, by 30%-50% for the cells examined. Marimin et al. (2014) used value chain analysis to map and analyse green productivity of a natural rubber supply chain and propose strategies to increase green productivity level. It is found that seven sources of green waste, including energy (1.830KWh), water consumption (900 m^3), supporting material (131.84kg), garbage (147.33kg), transportation (2769.17km), emissions (3094.30kg) and biodiversity (2715.45 ha) can potentially be reduced. Domingo and Aguado (2015) used the Overall Environmental Equipment Effectiveness (OEEE) to evaluate the measurable benefits by applying lean and green in the manufacturing system and found that significant environmental improvement was found in activities such as receiving and cutting. However, no environmental improvement was found in activities such as bending, control, labelling and shipping. Ng et al. (2015) used the Carbon-Value Efficiency indicator to demonstrate the applicability of lean and green. The results showed that Carbon-Value Efficiency could be improved by 36.3%, given that an improvement in production lead time of 64.7%

was also recorded. When measured by carbon footprint, the overall improvement was found to be 29.9%.

Many studies discussed the feasibility and necessity of integrating lean and green but failed to provide measurable benefits. The integration of lean and green has been focused heavily from the theoretical side. For example, Calvalho et al. (2011) argued that both lean and green practices have their own attributes. Some lean attributes (e.g. production lead time reduction and transportation lead time reduction) are positively related to relevant green attributes (energy consumption and carbon emissions). However, not all lean attributes are positively related to green attributes. This appears to be the reason leading to more and more articles discussing the measurable benefits of lean and green. Only upon successful implementation can relevant factors affecting the success of lean and green be identified.

UNSUCCESSFUL STORIES

There are also a few studies which found that the use of lean does not necessarily bring green benefits. These studies are briefly explained in the following section.

Rothenberg et al. (2001) found that there is a complex relationship between lean and environmental performance. This complex relationship is dependent on the environmental performance being examined. For example, when volatile organic compound (VOC) emissions are examined, manufacturing facilities need to rely more on advanced pollution abatement equipment to reduce the emissions. Lean provides little or no benefits in terms of VOC emissions reduction. Similarly, lean provides little or no benefits in reducing energy and water use quantitatively, although qualitative analysis (i.e. interview results) provides a convincing evidence of complementarities.

Mason et al. (2008) examined the supply chain of orange juice and found that modification of the orange juice or its packaging to allow ambient storage can provide greater environmental benefit than reconfiguration of any upstream supply chain step. This indirectly shows that the lean concept can help achieve environmental benefits, but at very minimal level.

De Sousa Jabbour et al. (2013) collected the manufacturing data from 75 companies and found that lean manufacturing is positively associated with environmental management. However, the explanation power of lean in green is weak/moderate.

Chiarini (2014) investigated the use of five lean tools, including value stream mapping, 5S, cellular manufacturing, single minute exchange of die and total productive maintenance in manufacturing firms and found that the success of lean and green is dependent on the technology and the intended environmental improvement areas. For example, it is found that value stream mapping does not necessarily bring about environmental benefits. However, it can be used to identify environmental impact of production processes. Cellular manufacturing can directly lead to a decrease in electricity consumption and TPM can reduce oil leakage. One interesting finding is that the use of single minute exchange of die (SMED) brings no significant environmental improvement to the manufacturing process.

At the theoretical level, Johansson and Sundin (2014) argued that lean and green have significant differences in their goals and focuses, including value construct, process

structure, performance metrics and tools/techniques used. These significant differences do not support that green is lean, indicating that the use of lean does not automatically lead to greener products or the use of green does not automatically lead to efficiency improvement in product development process. It can only be concluded that both lean and green share similarities that a synergistic relationship can be expected.

FACTORS THAT MAY AFFECT THE SUCCESS OF LEAN AND GREEN

From the preliminary results of the review, it is useful to identify a few factors which may affect the success of lean and green. These factors include:

- Industry. Lean and green has been implemented in different industries. For example, Verrier et al. (2015) applied the lean and green concept to the housing industry and proposed an implementation structure to help identify and eliminate waste in the production process. According to Verrier et al. (2015), there was a strong link between lean and green in the housing industry. On the other hand, the implementation of lean and green in other industries may not have such strong link. For example, Garza-Reyes (2015) found that due to the limitations and challenges of lean and green at the individual level, the integration of lean and green would not usually achieve its full potential in the manufacturing industry. Further analysis is needed to quantify the correlation between the success of lean and green and the industry that the implementation is applied to.
- Lean technology. It should be noted that different studies focused on different lean technologies which may lead to different results. For example, Greinacher et al. (2015) discussed the use of buffering and its impact on delivering green results. It is suggested that a concept called "cost-time-profiles" (CTPs) should be used to analyse the impact of buffering on carbon emissions of the manufacturing process. On the other hand, Govindan et al. (2015) investigated a few lean technologies in supply chain and found that the most effective lean technologies are just-in-time, flexible transportation and environmentally friendly packaging. It appears that different lean technologies can have different levels of impact on the success of lean and green.
- Environmental factors. As discussed earlier in this study, lean may have different impacts on different environmental factors. Rothenberg et al. (2001) found that lean has little or no impact on VOC emissions, energy and water consumption. Chiarini (2014) found that TPM can reduce direct oil leakage.
- Processes. The implementation of lean and green was at different processes in previous studies. While some studies focus on conceptual consideration (see Verrier et al., 2015), other studies focus on a variety of processes. For example, David and Found (2015) discussed the external influences that may affect the success of lean and green. Reyes-Garza (2015) discussed the implementation of lean and green at a strategic level. Verrier et al. (2015) investigated the change management procedure that is brought about by the implementation of lean and

green. The management of these processes may also affect the success of lean and green.

It should be noted that these factors are not exhaustive, but rather illustrative of the importance of a few variables which may affect the success of lean and green. To identify a complete list of variables, further investigations will be conducted.

CONCLUSIONS

This paper provides some preliminary findings from a comprehensive literature review of lean and green. It appears that lean and green are considered as two separate frameworks which both include the consideration of waste. However, the definition of waste is not the same in lean and green. While the elimination of some lean waste sources can bring environmental benefits, the elimination of other lean waste sources does not necessarily bring about improvement in environmental performance. However, one interesting finding is that all examined studies focus on the use of lean to achieve green benefits. The investigation of the relationship between lean and green is one-way at the time of the study. It is recommended that future studies should be conducted to see whether the use of green development can achieve efficient and lean benefits.

Another finding from the literature review is that there are very limited number of studies which investigate the measurable benefits of lean and green. Only five studies are identified from a list of 97 journal articles. It appears that majority of the studies is focused on investigating the synergistic relationship between lean and green from the theoretical perspective. As noted previously, the integration and lean and green aims to bring measurable benefits to industry. As such, future studies should focus on quantifying the two-way relationship between lean and green, which appears to be a large research gap.

In addition, the unsuccessful stories of lean and green prove that the success of lean and green is dependent on a few factors, including the lean technology used, the industry and the process that the concept is implemented in, as well as the environmental performance measured. It cannot be concluded that the use of lean can achieve green benefits and the use of green development can lead to efficient and lean production. From the theoretical development, the relationship between the lean attributes and the green attributes have been mapped. However, the mapping should be evaluated against the aforementioned factors so as to understand the impact of technology-, process-, industry- and environmental-related factors on the success of lean and green.

This study has several limitations. The findings are based on a preliminary examination of evidence and a quantitative examination of these studies has yet been provided. From this study, it can be found that the lean implementation in various industries can lead to different results. How will the characteristics of different industries affect the implementation requires further investigation. In addition, the sample is obtained by searching lean and green in Scopus, which may overlook some of the valuable contributions from the IGLC society. The papers published by the IGLC society will be included in the future to provide a more complete list of lean and green studies.

REFERENCES

Besseris, G.J. (2011). Applying the DOE toolkit on a lean-and-green six sigma maritime-operation improvement project. *International Journal of Lean Six Sigma*, 2(3), 270-284.

Bribián, I.Z., Capilla, A.V. and Usón, A.A. (2011). "Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential". *Building and Environment*, 46, 1133-1140.

Cabral, I., Grilo, A. and Curz-Machado, V. (2012). "A decision making model for lean, agile, resilient and green supply chain management". International Journal of Production Research, 50(7), 4830-4845.

Carvalho, H., Duarte, S. and Machado, V.C. (2011). Lean, agile, resilient and green: divergencies and synergies. *Journal of Lean Six Sigma*, 2(2), 151-179.

David, S.M.C. and Found, P. (2015). An implementation model for lean and green. In: Understanding the lean enterprise: strategies, methodologies, and principles for a more responsive organization, Springer International Publishing.

Disney, S.M., Naim, M.M. and Towill, D.R. (1997). "Dynamic simulation modeling for lean logistics", *International Journal of Physical Distribution & Logistics Management*, Vol. 27, Nos 3/4, pp. 174-96.

Duarte, S. and Cruz-Machado, V. (2015). Investigating lean and green supply chain linkages through a balanced scorecard framework. *International Journal of Management Science and Engineering Management*, 10(1), 20-29.

Dües, C.M., Tan, K.H. and 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.

EPA. (2003). Lean Manufacturing and Environment. [Online] Available at: http://www.epa.gov/lean/performance/index.htm [Accessed 14 Nov 2010].

Galeazzo, A., Furlan, A. and 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.A. (2015). "Green lean and the need for six sigma". *International Journal of Lean Six Sigma*, 6(3), 226-248.

Govindan, K., Azevedi, S.G., Carvalho, H. and Cruz-Machado, V. (2015). Lean, green and resilient practices influence on supply chain performance: interpretive structural modelling approach. *International Journal of Environmental Science and Technology*, 12(1):15-34.

Helper, S., Clifford, P.G. and Rozwadowski, H. (1997). Can Green Be Lean. A paper submitted to the Academy of Management Annual Meeting. Organizations and the Natural Environment.

Huovila, P. and Koskela, L. (1998). Contribution of the Principles of Lean Construction to Meet the Challenges of Sustainable Development. In Formoso, C.T., ed. Proceedings of IGLC-6. Guaruja, Brazil, 1998.

De Sousa Jabbour, A.B.L., Jabbour, C.J.C., De Souza Freitas, W.R. and Teixeira, A.A. (2013). Lean and green? Empirical evidence from the Brazilian automotive industry. *Gestao e Producao*, 20(3), 653-665.

Johansson, G. and Sundin, E. (2014). "Lean and green product development: two sides of the same coin?". Journal of Cleaner Production, 85, 104-121.

Kaewunruen, S., Remennikov, A.M. and Murray, M.H. (2011). Greener and leaner – unleashing capacity of railroad concrete ties via limit states concept. *Journal of Transportation Engineering*, 137(4), 241-247.

King, A.A. and Lenox, M.J. (2001). "Lean and green? An empirical examination of the relationship between lean production and environmental performance". *Production and Operations Management*, 10(3), 244-256.

Kurdve, M., Zackrisson, M., Wiktorsson, M. and Harlin, U. (2014). "Lean and green integration into production system models – experience from Swedish industry". *Journal of Cleaner Production*, 85, 180-190.

Koskela, L. (1992). Application of the new production philosophy to construction. CIFE technical report#72. Stanford University.

Mason, R., Nieuwenhuis, P. and Simons, D. (2008). "Lean and green supply chain mapping: adapting a lean management tool to the needs of industrial ecology". *Progress in Industrial Ecology – An International Journal*, 5(4), 302-324.

Marimin, M.A., Darmawan, M.P.I.F., Machfud, Puttra and Wiguna, B. (2014). "Value chain analysis for green productivity improvement in the natural rubber supply chain: a case study". *Journal of Cleaner Production*, 2014, 201-211.

Ng, R., Low, J.S.C. and Song, B. (2015). "Integrating and implementing lean and green practices based on proposition of carbon-value efficiency metric". *Journal of Cleaner Production*, 95, 242-255.

Ohno, T. (1988). Toyota Production System: Beyond Large-Scale Production. Tokyo: Diamond, Inc.

Pampanelli, A.B., Found, P. and Bernardes, A.M. (2014). "A lean and green model for a production cell". *Journal of Cleaner Production*, 85, 19-30.

Rodríguez, G., Medina, C., Alegre, F.J., Asensio, E. and Sánchez de Rojas, M.I. (2015). "Assessment of construction and demolition waste plant management in Spain: in pursuit of sustainability and eco-efficiency". *Journal of Cleaner Production*, 90, 16-24.

Sobral, M.C., Jabbour, A.B.L.S. and Jabbour, C.J.C. (2013). "Green benefits from adopting lean manufacturing: a case study from the automotive sector". *Environmental Quality Management*, 22(3), 65-72.

Verrier, B., Rose, B. and Cailaud, E. (2015). Lean and green strategy: The lean and green house and maturity deployment model. *Journal of Cleaner Production*, 116, 150-156.

WCED. (1987). Our Common Future. Brudtland report. Oxford: Oxford University Press.

Wiengarten, F., Fynes, B. and Onofrei, G. (2013). Exploring synergetic effects between investments in environmental and quality/lean practices in supply chains. *Supply Chain Management: An International Journal*, 18(2), 148-160.

Womack, J.P. and Jones, D.T. (1996). Lean Thinking. New York: Simon and Schuster.

Worrell, E., Price, L. K., Martin, N., Hendriks, C., and Meida, L. O. (2001). "Carbon dioxide emissions from the global cement industry". *Annual Review of Energy and Environment*, 26, 303-329.

Wu, P., Mao, C., Wang, J., Song, Y. and Wang, X. (2016). "A decade review of the credits obtained by LEED v2.2 certified green building projects." *Building and Environment*, 102, 167-178.