Industry 4.0 Enhanced Lean Manufacturing

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Abstract—**The current global manufacturing landscape is fast changing with growing worldwide demand for better, more innovative, value added and satisfying products. Therefore, industrial and manufacturing system must rise to meet these challenges and fulfil the appetite of consumers worldwide for the products efficiently. Manufacturing industries value creation must be geared towards higher efficiency and productivity. Industry 4.0 sets about bringing manufacturing capabilities to the next level, the fourth stage of the industrial revolution. This paper reviews the literature available on the Industry 4.0 (Industrie 4.0) initiative and sets out to identify the highly cited papers examples. Later, a review of the impact of Industry 4.0 technologies on Lean Manufacturing effectiveness, in particular, the elimination of different wastes was also presented. It is clearly established from this review and assessment exercise that there are much potential for Industry 4.0 environment to further improve the effectiveness of Lean Manufacturing initiatives to drive efficiency and productivity better.**

Keywords-Industry 4.0; Cyber Physical Systems (CPS); 7 wastes; lean manufacturing

I. INTRODUCTION

In the current competitive landscape with globalization and new technologies development, there is pressure for manufacturing organizations to continuously change and further improve [1, 2]. Since the first industrial revolution, there have been continuous attempts to improve the capabilities and efficiencies of manufacturing as a whole, fulfilling the demand for better and more value added products. More recently, the governments of Germany, USA, EU, UK, China, South Korea and India [3] which are well established manufacturing power house of the world in their own niche have unveiled ambitious plans to transform the manufacturing sector. Notably, Germany have shared the concept of Industry 4.0 in 2013 and since then many researchers have shared further views on the role and potential of the Industry 4.0 manifesto. This paper will review through the literatures that have been written about Industry 4.0 to review through some key views and examples from different researchers. The information compiled will be further used in comparison with the principles of Lean Manufacturing 7 wastes which has been widely accepted as a way to improve manufacturing productivity and efficiency.

Thus, we will better understand on the potential for Lean principles in Industry 4.0.

II. BACKGROUND

A. Industry 4.0 (Industrie 4.0)

The world have already seen and widely benefited from the progress that is brought about by the first three industrial revolution. The fourth industrial revolution is termed Industry 4.0 and promises further improvements to the manufacturing environment. The industry 4.0 manifesto was published by the German National Academy of Science and Engineering in 2013 (see [4] for details). The idea behind it was first mentioned by Kagermann et al. [5] in 2011 and since then there have further research and development of the idea by multiple stakeholders and researchers. As with Lean Manufacturing, Industry 4.0 also is made up of not only advance technological tools but also includes the aspects of a management vision. As outlined in its founding report, the vision of Industry 4.0 is for the implementation of a smart factory with the appropriate adjustment to the management strategies, business model and new processes [4].

The core technology advancement in Industry 4.0 is the advent of Smart Factories that will have Cyber Physical Systems (CPS) at its core. CPS enables the fusion of the real world with that of the virtual cloud environment which is considered to be an important component of Industry 4.0 [4, 6]. CPS is defined to be the "*integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa*." [7].

Although the origin of Industry 4.0 can be traced back to Germany, there are increasing interest from researchers and industries from advanced manufacturing nations including the United States and others to develop the concept and related technologies further (see [3, 8, 9]).

B. Lean Manufacturing and the 7 Wastes

Lean manufacturing is highly acknowledged to have evolved from the Toyota Production System (TPS). The TPS was developed by Taichi Ohno who was an engineer in Toyota Motor Japan at the end of the Second World War as a means to improve the competitiveness of the automotive company production capabilities. The TPS brings about a set

of methods and tools together with a clear set of management philosophy to address the seven forms of waste or "muda" that may affect a manufacturing facility [10, 11]. Anything in production that does not add value to the product is considered to be a form of waste, therefore waste can be in the form of overproduction, waiting for processing, additional or non-conformance work, inventory, motion, and corrective actions. The house of TPS is shown in Figure 1 below and it is evident that the waste reduction which is key enabler of continuous improvement in manufacturing thus contributing to better efficiency and productivity (see [12] for further details of TPS).

Ohno [12], Shingo and Dillon [13] and Liker [10] have categorized waste into seven categories. By reviewing the similarities and accounting for some differences in their definition, a summary definition of each of the type of waste is presented in Table I.

Some studies have shown on the possible complimentary role for Lean Manufacturing in delivering the vision outline in Industry 4.0 [14-16]. There have been numerous studies that have indicated the positive impact of lean on manufacturing processes (see [17-19]. This study seeks to review through some of the potential impact of Industry 4.0 technologies on the seven different categories of wastes as shown in Table I.
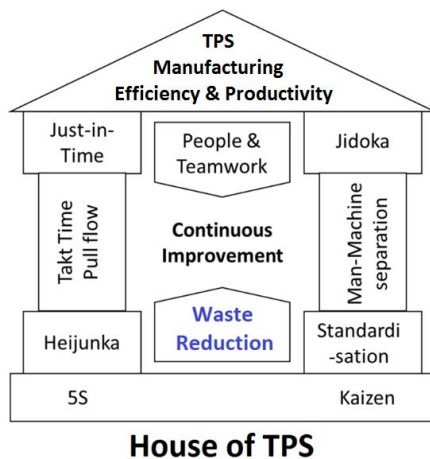

Figure 1.   House of TPS. (adapted from [20])

TABLE I.   SEVEN TYPES OF WASTE IN LEAN MANUFACTURING
(SUMMARIZED FROM [10, 12, 13])

Waste	Summarized definition
Over-production	Producing too much / when not needed / without actual orders
Waiting	Waste of time or delays, idling or unable to process due to unforeseen reasons
Transportation	Waste of movement of materials or product unessential to the production process
Over-processing	Unnecessary steps taken to produce the product, produce anything that is not valued / required by customer
Inventory	Waste due to excess Work in Progress (WIP) / stocks / materials finish or unfinished
Unnecessary motion	Waste due to movements that do not add value to the product
Defects	Waste from making products that is defective, unacceptable quality or require corrective rework actions to be accepted by customer

III.   RESEARCH APPROACH

A.   Literature Review on Industry 4.0

This research follows a systematic literature review which a defined by Jesson [21] "*a review with a clearly stated purpose, a question a define search approach, stating inclusion and exclusion criteria, producing a qualitative appraisal of articles*". This ensure that this review results are transparent and reproducible by other. The key steps are as follow:

- Mapping the field through a scoping review
- Comprehensive search
- Quality assessment
- Data extraction
- Synthesis
- Write-up

There is a need for this research as there is a lack of a proper review into the impact of Industry 4.0 technologies on role of lean manufacturing and its associated tools. Lean Manufacturing has been well established and much researched on by academics as well as industry practitioners whereas Industry 4.0 was just recently conceived. In particular, the seven types of wastes was selected to be focus from the broad measures that make up lean manufacturing philosophy. The research on literature about Industry 4.0 was then executed using the Scopus database. The keywords combination of "Industry 4.0" or "Industrie 4.0" was used in the search and the search was limit to papers that had the keywords appearing in the title and/or keyword section. Only journal and conference papers written in English were considered in this study. Although many researchers would prefer the use of only peer reviewed journal papers, the conference proceedings have been included in this study as Industry 4.0 is a very new area and some of the highly cited papers exist as conference proceedings.
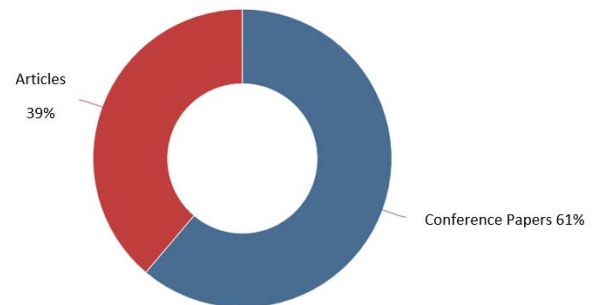

Figure 2.   Breakdown of document type.

From the search, a total of 925 documents were located. Figure 2 illustrate the breakdown of document types and it is clear that there are much more publications in the conference proceedings form than that of articles. From only just two publications in 2012, the number of documents published per year have increasing year on year as shown in Figure 3. The list of 925 documents was later sorted in terms of times cited in Scopus. The highest ten were selected and the abstract was read in order to confirm the relevance of the papers to the aims of this study. The paper must be about Industry 4.0 and

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include one or more examples or scenarios. All these papers will then be read in detail and the examples or scenarios were noted in detail. From the shortlisted ten papers, only eight were identified to have fulfilled the requirement of being about Industry 4.0 and include one or more examples or scenarios. The details of the shortlisted papers are shown in Table II. The data extracted and noted will then be synthesized and organized to provide better insights when used for the assessment using the seven waste of Lean Manufacturing.
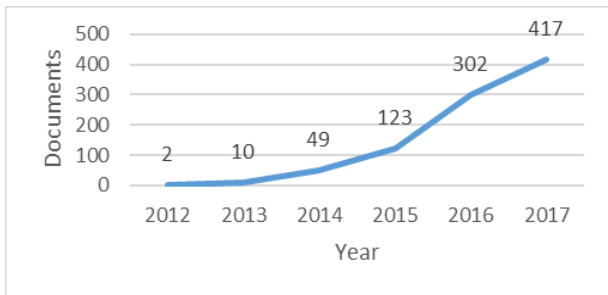

Figure 3.   Distribution of publication per year over the period studied.

TABLE II.   THE TOP CITED PAPERS OF THIS STUDY ON SCOPUS

Document title	Authors	Year	Source	Type	Cited by	CA	CB
A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems	Lee et al. (a)	2015	Manufacturing Letters	Article	289	Yes	Yes
Service innovation and smart analytics for Industry 4.0 and big data environment	Lee et al. (b)	2014	Procedia CIRP	Conference	132	Yes	Yes
Industry 4.0	Lasi et al. (c)	2014	Business and Information Systems Engineering	Article	95	Yes	Yes
Design principles for industrie 4.0 scenarios	Hermann et al. (d)	2016	Proceedings of the Annual Hawaii International Conference on System Sciences	Conference	70	Yes	No
Implementing Smart Factory of Industrie 4.0: An Outlook	Wang et al. (e)	2016	International Journal of Distributed Sensor Networks	Article	60	Yes	Yes
Human-machine-interaction in the industry 4.0 era	Gorecky et al. (f)	2014	Proceedings - 2014 12th IEEE International Conference on Industrial Informatics, INDIN 2014	Conference	57	Yes	Yes
Visual Computing as a Key Enabling Technology for Industrie 4.0 and Industrial Internet	Posada et al. (g)	2015	IEEE Computer Graphics and Applications	Article	50	Yes	Yes
Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm	Shrouf et al. (h)	2014	IEEE International Conference on Industrial Engineering and Engineering Management	Conference	48	Yes	Yes
Cyber physical systems in the context of Industry 4.0	Jazdi (i)	2014	Proceedings of 2014 IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2014	Conference	47	Yes	Yes
Smart manufacturing: Past research, present findings, and future directions	Kang et al. (j)	2016	International Journal of Precision Engineering and Manufacturing - Green Technology	Article	39	Yes	No

CA: Is the paper is highly related to Industry 4.0?

CB: Does the paper contains one or more examples or scenarios of the use of Industry 4.0?

(a)= [7], (b)=[22], (c)=[23], (d)=[24], (e)=[25], (f)=[26], (g)=[27], (h)=[28], (i)=[29], (j)=[8],

B.   Evaluation Method

A group of 12 Lean Manufacturing researchers were invited to attend a workshop in November 2017 to do the assessment activity. They were each brief on the exercise and presented with the summary details of above identified papers and the further details of the examples or case of Industry 4.0. There was also a round of discussion on the definition of the seven types of waste.

The evaluation method used was adapted from the method use by Wagner et al [30]. The code "+" means that there is a low positive impact of this Industry 4.0 technology on the particular waste reduction. "++" means that there is a high positive impact of this Industry 4.0 technology on the particular waste reduction. "+++" stands for the highest possible impact of this Industry 4.0 technology on the particular waste reduction. However, in this study, "NA" is included to indicate that Industry 4.0 technology is not related to the particular waste reduction. A group consensus approach was taken to finalize each of the ratings given and the summary of the overall results from the assessment exercise is presented in Table III.

TABLE III.   EVALUATION MATRIX OF INDUSTRY 4.0 EXAMPLES USING LEAN MANUFACTURING 7 WASTES

Document title	Example /Case / Scenario	Over-production	Waiting	Transportation	Over-processing	Inventory	Unnecessary motion	Defects
A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems	5 Level CPS architecture for factories	+	++	NA	NA	NA	NA	+++
Service innovation and smart analytics for Industry 4.0 and big data environment	Smart remote machinery maintenance systems with Komats	NA	++	NA	NA	NA	NA	+++
Industry 4.0	Example for interdependencies of a supply chain in the context of the future project "Industry 4.0"	+++	++	+	NA	+++	++	+
Implementing Smart Factory of Industrie 4.0: An Outlook	Flexible conveying system of the smart factory	+++	++	++	+	+++	NA	NA
Human-machine-interaction in the industry 4.0 era	AR, VR Adaptive Learning in helping workers in manual assembly	++	++	+	NA	NA	+	+++
Visual Computing as a Key Enabling Technology for Industrie 4.0 and Industrial Internet	Machs,	NA	+	++	+	NA	+	+
	Cognito	NA	+	++	+	NA	+	+
	SLOPE	+	+	++	++	+	+++	NA
Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm	Energy management in Smart Factories	NA	NA	NA	+	NA	NA	++
Cyber physical systems in the context of Industry 4.0	Industry 4.0 application for an industrial coffee machine	+	++	NA	+	++	++	+++

IV. RESULTS AND DISCUSSION

From the assessment, it is clear that different parts of the Industry 4.0 technology have a positive impact on different types of waste in Lean Manufacturing. There are different levels of impact and it is clear that some of the examples reviewed may not have a direct impact on reducing all the seven categories of wastes.

Although the eight examples from the highly cited papers on Industry 4.0 used in this study is not an exhaustive list of examples, the variation of the application is quite diverse. There are examples, which has a focus on mass manufacturing, manufacturing support services, energy management and outdoor-based production. An improvement on the supporting manufacturing services could also have a profound impact on the core production performance. Therefore, a "smarter" production planning, maintenance system, energy management system and workers working environment have direct relations to that of improved manufacturing efficiencies [31-33].

- Minimizing and eliminating overproduction

Lean manufacturing seeks to minimize and eliminate overproduction in the factory. Thus, there must be fewer occurrences of producing too much, when there is no direct order for the product or when the products are not needed by the consumers. In an Industry 4.0 manufacturing facility, better order management and information can be communicated to the factory floor and equipment directly[23]. Orders can be immediately directed, decisions could be made more instantaneous and effectively. Industry 4.0 factories are envisioned to be able to have production equipment that collects real time information [25] and act autonomously based on information from the rest of the production facility, supply chain and customer input [34].

- Minimizing and eliminating waiting time

The CPS provides a better opportunity to have precise control of the activities on and off the manufacturing shop floor. Better or "smarter" decisions can be made on site (on the process or machine level) in order to address the many different types of waste that hinder efficiency. The ability to get immediate feedback from related stakeholders on the vertical and horizontal level [25] could be key in efforts to minimize production waiting time. Better control of individual production equipment will help eliminate waiting time for production. In the Industry 4.0 factories, there will be fewer occurrences of equipment idling or unable to process due to unforeseen reasons. With better autonomous maintenance capability including the use of smart sensors and components to allow better predictive and smarter maintenance [22, 35]. Unplanned delays and interruption to the production process will be kept to a minimal[36]. Better training and use of Augmented Reality /Virtual Reality (AR/VR) adaptive technology [26] will be beneficial in improving workers capabilities and minimizing idling in production process together with better data analytics [22].

- Minimize transportation

The movement of materials or products unessential to the production process is another key area of waste in production. Minimizing or eliminating unnecessary transportation in the production process is possible with the infrastructures brought about by Industry 4.0. Transport of materials by itself does not add value to the product, however, transportation is still in many cases a prerequisite in the overall manufacturing flow. Industry 4.0 will enable the better control of the need for transportation including the ability to determine the best route and scheduling on the shop floor for the work in progress (WIP) materials [25, 27].

- Minimizing and eliminating over-processing

Over-processing occurs when more work is done than required which may also include the use of a more complex process or components than necessary for production. Industry 4.0 connectivity will enable the better relay of information and instruction on the shop floor as to enable the accurate diagnostic, visualization and instruction for processing is provided in every step of the production flow [27]. Accurate detection and diagnostics of production processes could potentially translate into huge direct and indirect manufacturing cost savings such as energy consumption [28].

- Minimizing Inventory

The build up of inventory either in WIP form, stocks, finished or unfinished state would also be much better in the era of Industry 4.0. The better connectivity between real time information from the customer, supply chain and also individual processing equipment in the factory floor allows for a better control of production materials [23, 25, 27]. Traditional lean approaches such as KANBAN and just in time (JIT) (see [37, 38]) can be further optimized in the smart factory environment of the future. Fast and accurate information flow in Industry 4.0 supports the production of JIT materials [30] enabling just in time production to be achieved in much more different manufacturing environment and industries.

- Preventing unnecessary motion

The unnecessary human or machine movements contribute to the waste of resources on the production floor. The use of smart sensors and CPS coupled with machine learning will enable the proper identification and control of such occurrences. Thus, unnecessary motion during the operations and servicing of equipment could be minimize further [27, 29]. This could be achieved not only in the operational stage of production but also in the design stage of future smart factories [27, 39]. Mapping of the production process value streams would become easier and much more accurate with the real time feedback from the host of sensors and controllers in all of the key manufacturing equipment in the factory floor.

- Preventing defects

Waste on the production floor occurs when products are produced which has unacceptable quality, defective or require corrective rework actions to be accepted by the customers. Much efforts and resources may be wasted due to defects but Industry 4.0 allows for the prevention and elimination of defects. Better equipment sensors and network integration allow a better monitoring of the production process [7] potentially allowing production process anomalies to be detected well in advance. Accurate machines information on the condition and performance improves not

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only production delivery capabilities but also ensures consistent quality of product [7, 29, 40]. Smarter maintenance capability would ensure better processing equipment performance [22] and fewer defects during production. Industry 4.0 could also be used in the development of factory workers and personnel to achieve their full potential and assist them in improving production quality [26].

Lean manufacturing in an Industry 4.0 factory environment will have a profound impact on waste reduction. Thus, it is expected that there will be much improved manufacturing productivity in the smart factories of the future. In this current research, an effort has been made to look into the positive contributions of Industry 4.0 examples on to the different type of waste targeted in Lean Manufacturing. The issues of overproduction, waiting, transportation, over processing, inventory, unnecessary motion and defects could clearly be better identified and controlled in an Industry 4.0 manufacturing scenario.

V. CONCLUSIONS

As globalization intensifies competition among manufacturers, there is an immense pressure for organizations to achieve higher level of manufacturing performance. Lean Manufacturing has been a beneficial approach in improving productivity and this study has shown that the upcoming Industry 4.0 technologies have the potential to further increase that. Prior to this, there has not been a proper comparison on the impact of Industry 4.0 on Lean Manufacturing 7 types of waste. This paper had identify and review some of the key Industry 4.0 papers technology examples and these examples were used in an assessment exercise on the different categories of waste. There are still much research and development efforts on the concept and underlying technologies behind Industry 4.0. Therefore a conclusive statement about the impact of Industry 4.0 on the Lean Manufacturing measures may not be easily drawn. However, this initial study have presented some key indications that Industry 4.0 will enhance the efforts of Lean Manufacturing initiatives and thus enable a more efficient and productive manufacturing sector in the future.

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