JOURNAL OF LEAN SYSTEMS, 2021, Vol. 6, Nº 4, pp. 117-141

Applying Lean and MES toward Smart Manufacturing - Application of a Thai Automotive Company

Chinglung Chang* - toliverchang@gmail.com
*Fu Jen Catholic University - Taiwan, Province of China

Article History:

Submitted: 2021 - 08 - 10 Revised: 2021 - 08 - 10 Accepted: 2021 - 09 - 06

Abstract: Lean, manufacturing execution systems (MES), and Smart manufacturing are of different disciplines. The objective of this study is to explore the integrated application of these three disciplines. This study conducts a field observation and interview of a selected car wheel frame manufacturer in Thailand to generate five applications. The extended technology acceptance model (TAM2) and overall equipment effectiveness (OEE) are applied to verify the effectiveness of the case company. This study's results show that MES facilitates production transparency and increases the firm's ability to focus on value-added activities. Employees can predict potential issues and proactively eliminate them. Improved transparency also enhances employee ownership, enabling employees to independently problem solve and implement improvements before an issue arises.

Keywords: extended Technology Acceptance Model, Lean production, MES, and Smart manufacturing

1. Introduction

The fourth industrial revolution (or Industry 4.0) refers to the current trend of automation within traditional manufacturing technologies, of which Smart manufacturing is an important concept (Tsuchiya et al., 2018). Lean is regarded as a foundational pillar within production. It provides shop floor visibility with visual management tools and Kanban (Sahoo et al., 2008). A manufacturing execution system (MES) provides real-time data collection from the shop floor and plays a key role in bridging planning systems (e.g., enterprise resource planning (ERP)) and manufacturing floor controls (Choi and Kim 2002). MES is regarded as a popular platform within Smart manufacturing due to its transparency and predictive capacity (Nakamura et al., 1996). Smart manufacturing is the application of artificial intelligence technology to manufacturing. Today, most of its application or theory comes from individual disciplines. The objective of this study is to explore the integrated and cross-discipline application of Lean, MES, and Smart manufacturing.

This study conducts field observations and interviews at a selected car wheel frame manufacturer in Thailand to generate five applications. The extended technology acceptance model (TAM2) and overall equipment effectiveness (OEE) measure are applied to verify the effectiveness of the whole application. The significance of this study is that it provides a application of the cross-discipline application of Lean, MES, and Smart manufacturing. Operator behaviour change is also discussed.

2. Related work

2.1 Stages of Industry 4.0 development

Smart manufacturing is a broad category of manufacturing that employs computer-integrated manufacturing, high levels of adaptability and rapid design changes, digital information technology, and more flexible technical workforce training (Davis et al., 2012). Other goals include fast changes in production levels based on demand, optimisation of the supply chain, efficient production, and recyclability (Shipp, 2012). The four stages of Industry 4.0 are visibility, transparency, predictive capability, and adaptability (Schuh et al., 2017).

Sensors enable processes to be captured from beginning to end with a large number of data points. This makes it possible to keep an up-to-date digital model of a factory at all times. This is referred to as the company's digital shadow (Fang et al., 2013). The digital shadow can help show what is happening in the company at any given moment so that management decisions can be based on real data. One problem is that there is usually no single source of truth as data is often held in decentralised silos (McClellan 1997). This further results in captured data in many cases only being visible to a limited number of people who can access and understand the respective domain systems (Islam and Karim, 2011). Wider use of the data is prohibited by system boundaries, despite comprehensive data capturing right across the company being essential for the provision of relevant data about the operation throughout the business (Mullin, 1998). The combination of existing data sources with sensors on the shop floor can deliver significant benefits (Karim et al., 2008). This study applies the four stages as the evolution of Smart manufacturing. Functions of the IT system that are applied in a company are regarded as the scene on which the four stages perform in this study.

2.2 Manufacturing execution systems

MES is an integrated computerised system that bridges the communication gap between an ERP and the shop floor control systems (MESA International, 1994). MES supervises the process control systems, determines the routes that materials follow through the production system, as well as when and where production operations start and end.

MES improves the transparency of the manufacturing data (American National Standards Institute, 2005). Sensor data can be used to calculate production key performance indicators in real time or to monitor the status of the machines and the quality of the manufacturing process (Leea et al., 2012). Equipment and process specific production rules are applied at the process control level through product definition management. The rules are downloaded to the equipment such as to a programmable logic controller in order to change a process. Operational commands and responses interact with production execution. Operational commands are a part of process control, providing information that commands the performance of production steps by personnel or equipment. Operational responses are obtained from these entities by managers who apply them when making the next production execution decision. Equipment and process data that contain information about equipment performance and the production functions are acquired at the process control level.

The real-time traceability and visibility of work-in-progress materials and information plays a critical role in improving shop floor performance with better planning, scheduling, and control decisions (Huang et al., 2008). MES plays a critical role in today's manufacturing environments that require quick responses to customer demands, efficient translations of manufacturing plans into finished goods (Martinez-Olvera, 2009), and manufacturing–marketing integration (Gattiker, 2007).

2.3 Lean principles and tools

Lean production is a manufacturing system with the objective of streamlining the flow of production while continually seeking to reduce the resources (e.g., direct and indirect labour, equipment, materials, space, etc.) required to produce a given set of items; any slack in the system is referred to as waste (e.g., Roos et al., 1990). Lean manufacturing is a management approach to manufacturing that strives to make organisations more competitive in decreasing variability through the elimination of non-value-added steps in the process (Deif, 2012). There are five key principles of Lean thinking (Womack and Jones, 1996). These are: (1) The definition of value from the end customer's perspective in terms of specific product/service capabilities, price, and availability. (2) The elimination of waste, that is, all those activities that do not add value and for which the consumer is unwilling to pay. (3) The organisation of the remaining value creating activities so that material and information continuously flow through the system on a just-in-time basis, avoiding batches, waiting, and down time between activities. (4) The control of all activities by customer 'pull', producing only what the customer wants when it is wanted. (5) The continual improvement of operational processes, striving for perfection. Lean principles emphasise system-level optimisation, where the emphasis is on integration and how the parts work together as a whole, rather than on individual performance and excellence of any one feature or element (Wittrock, 2015).

Lean production has been identified in the literature as a bundle of associated practices, such as just-in-time, continuous improvement, the Kanban system, total productive maintenance (TPM), 5S, total quality management, etc. (Filhoa et al., 2016). Seven types of waste are defined as a foundational tool in Lean. They are transport, inventory, motion, waiting, overproduction, over processing, and defects. Andon is a system that supports collaborative work in a Lean manufacturing organisation. Andon shows the status of operations in an area and signalises the occurrence of abnormalities (Pherson, 2006). When a problem occurs, operators stop work immediately (Subramaniam et al., 2009). The four-step process of abnormality handling (Steege, 1996) in Andon is: (1) Detect the abnormality, (2) stop, (3) fix or correct the immediate condition, and (4) investigate the root cause. Andon system allows employees to stop the line if they encounter any problems or anomalies (Yang et al., 2011).

Kanban is the Japanese word for tag, or signal. It is a simple form of communication that is always at the point where it is needed (Ohno, 1988). Kanban is a method for an order-oriented production control based on physical cards and closed loops between workstations. Cards are used as production orders (Mesut and Elif, 2007). The electronic Kanban (e-Kanban) system is a digitalisation of the conventional Kanban cards (Henrique et al., 2016). Drickhamer (2005) proposes there are five advantages to e-Kanban: (1) It reduces the problem of lost Kanbans (2), it reduces the manual process of Kanban handling and material receiving, (3) it creates clear communication with suppliers, (4) it provides real-time requirement signals, and (5) it quickly reviews supplier performance. With an e-Kanban system, missing or empty bins can be detected and replenishment can be triggered automatically (Ehret and Cooke, 2010). Mistakes in the production control due to lost Kanbans are not possible anymore. Furthermore, Kanban adjustments due to changes in batch sizes, work plans, or cycle times are easily possible (Ehret and Cooke, 2010).

Heijunka is the Japanese term for load or production levelling (Hodge et al., 2011). Levelling refers to both production volume as well as mix (Deif 2012). Heijunka, also known as level production, describes a method for converting customer orders into smaller, recurring batches. Level production can be realised using boards holding Kanban cards to control the production (Pakdila and Leonard, 2017).

Kaizen is also a Japanese term, which means that once the root cause of a problem has been identified, there is a need to find a solution that allows the company to reduce or eliminate waste (Imai, 2012). During a kaizen event, personnel from across disciplines work together in order to find solutions for a particular problem in order to make improvements to the current manufacturing system (Chena et al., 2010). Kaizen activity is the core that supports and sustains Lean improvement initiatives (Rocha-Lona et al., 2013).

The integration or application of the three discipline are discussed. Shahin et al. (2020) provides a comprehensive review on links between Lean tools and Industry 4.0 technologies, and on how simultaneous implementation of these two paradigms affects the operational performance of factories. Tortorella et al. (2020) propose a framework for Lean Automation implementation, in which Industry 4.0 technologies are integrated into Lean practices.

Tortorella et al. (2020) findings also indicate that Industry 4.0 technologies are positively correlated with Lean practices, providing evidence to bear the proposition of a Lean Automation framework that can potentially overcome traditional barriers and challenges of a Lean implementation. Bittencourt et al. (2020) discussed how Lean effect as a trigger for Industry 4.0 from systematic review of 33 papers from 2011 to 2019. In addition, Bittencout et al. (2020) also indicated that management, process, and people were the most cited words, reinforcing the role of these key players in the companies' transformation. People's behaviour change is one of area of the further study.

2.5 Extended technology acceptance model

Davis (1989) developed the technology acceptance model (TAM) based on the theory of rational action. TAM explains that system usage is directly influenced by behaviour intention, and behaviour intention is determined by attitude toward use. It further holds that a user's attitude to science and technology is determined by the technology's perceived usefulness and perceived ease of use. The model also includes external variables that indirectly affect the user's intention and behaviour. TAM has an accuracy of about 40% in predicting a user's use of a system (Legris et al., 2003). Venkatesh and Davis (2000) propose an extended technology acceptance model (TAM2), arguing that social influence and cognitive instrumental processes are the two main variables that affect user perception. Social influence includes the dimensions of subjective norm, voluntariness, and image, while cognitive instrumental processes include the dimensions of job relevance, output quality, and result demonstrability. This study compares its applications that it develops based on observation and interviews with TAM2 to verify whether TAM2 can be applied to explain the applications.

3. Materials and methods

Lean, MES, and Smart manufacturing are cross disciplines. The subject of this study is to explore the integration application of the three disciplines. It is suitable to apply a qualitative methodology to analyse the subject. Case analysis can be carried out with only a few sample points in order to determine results related to questions of how and why (Yin, 2003). Case analysis is applicable when deep research is desired, with the aim of determining practical contexts and logic within the cases. This study adopts case analysis to explore how these cross disciplines are running in the practical world. Selecting one representative case company is required. This method allows researchers to discover new problem sets and shed light on a phenomenon (Strauss and Corbin, 1990).

3.1 Application design

This study explores the integrated application of Lean, MES, and Smart manufacturing. Lean was introduced in the 1990s (Sullivan et al., 2002), MES in the 2000s (Houyou et al., 2012), and Smart manufacturing in the 2010s (Shrouf et al., 2014). The criteria applied to select the case company are that (1) it must have implemented Lean for years as well as must execute annual improvements to its Lean practices, (2) it must have implemented MES for more than one year, (3) staff must be able to flexibly apply IT technology and make improvements based on IT, and (4) it must have policies and action plans to implement Smart manufacturing.

3.2 Case company introduction

This study selects an automobile wheel manufacturing company in Thailand. Toyota Motor is one of the company's customers. By Toyota Motor's request, the case company has implemented Lean for more than 10 years. The case company has won Toyota's Valued Supplier Award many times. This shows that the case company executes a deep application of Lean. It thus meets the first selection criterium. The case company implemented a warehouse management system, an automated guided vehicle (AGV) system, and other information systems in 2016. To better manage manufacturing, the company upgraded its shop floor control system to MES in 2018. Analysing the OEE indicators from 2018 to 2019, there is an overall OEE growth. The second selection criterium is thus satisfied.

Employees are not allowed to use their own mobile phones for work purposes. For better mobility, the company implements tablet PCs as work pads in every workstation. Technicians, supervisors, and managers are also equipped with work pads. Work pads can transfer data to MES through WIFI. Staff can make video calls to each other through the work pads since contact lists are directly downloaded from MES. To avoid confidential information being shared outside the company, all texts, videos, and audit messages are transferred within an intranet. This relates to all communication between work pads and MES. All messages are recorded and stored within a local area network. Meanwhile, the work pads use a service-oriented platform. The work pads only present the applications you subscribe to when you log on. This allows different people to use the same work pad, such as supervisors during different shifts. Since everyone has his or her own account and password, only one person can use a work pad at a time. The technicians' personal phones can be stored in lockers. MES also allows employees to define five emergency numbers that can be directly transferred from the employees' personal phones to the work pads they are logged on to. This allows employees with work pads to be able to fully concentrate on their work despite their personal mobiles being in their locker. This satisfies selection criterium 3.

From 2018, this company has applied intelligent manufacturing to enhance its forging temperature control and installed sensors at critical points to improve its forming quality. This satisfies selection criterium 4. Based on the above, the company is considered ideal for selection as the case company of this study. The case company owns four factories in Bangkok, Thailand, with a total of 2,000 employees. The five main manufacturing processes of the wheel frame business unit are forging, forming, machining, polishing, and painting.

3.3 Data collection and validation

After identifying a case company and receiving permission to conduct the research from the company, this study then conducts observations on the shop floor to observe the use of the application functions of MES. Second, this study arranges semi-structured interviews to obtain opinions and feedback from operators, supervisors, managers, and technicians. Lean-related applications are then identified for the second round of observations and interviews to explore the use the four stages of Smart manufacturing. For validation, the following steps are followed: (1) TAM2 is applied for a quick mapping of perceive usefulness, behavioural intention, and use intention, and (2) indicator OEE is applied to validate the effectiveness of the applications after the implementation of MES.

4. Results and discussion

This study conducts a field observation from July 2019 to Sep 2019. The observation covers our factories. Semi-structured interviews were conducted to 22 operators, 13 supervisors, eight managers, and 11 technicians. Some process has both day shift and night shift. How employee applies MES to continue work is also observed. The following shows the five application of Lean based MES toward Smart manufacturing.

4.1 Application 1: Transparency of seven types of waste

There are seven types of waste that provide a solid perspective to production management (Roos, Womack, and Jones 1991). MES provides a good data collection and management platform with real-time check-in-check-out of information, output, and defect numbers. Four out of the seven types of waste are collected by MES in the case company with real-time data. The following are the definitions and descriptions of the four types of waste that the case company collects.

- *Inventory waste* covers material, WIP, and finished goods. For management purposes, the case company only collects WIP quantities through MES. The supervisor of each station can manage WIP quantities down to each work order. After adding manufacturing costs, production managers can manage WIP amounts for better cash flow. The system also solves the problem if the unit of measurement (UOM) of WIP of each workstation is different. For example, the UOM of forging is kilogram whereas the UOM of painting is piece. It does not make sense to add kilogram and piece together. The WIP formula is thus: *Select if (a) work order status = open; and if (b) work order status = to be delivered but not launched yet. Inventory = (a) +(b).*
- *Overproduction*: Because the workstations of forging, forming, and machining are linked to MES, it is easy to collect real-time statuses directly from the stations. However, polishing and painting are manual operations. Manual calculations can be time wasting and miscalculations may occur. This issue has been improved through electronic meters that are attached to the conveyor belts. MES collects quantity data through electronic meters. Operators place defect items on blankets instead of on the conveyor belt. Operators are freed from counting output numbers and can focus more on operations. The overproduction formula is: *Opd_qty = actual finished quantity – planned quantity, if Opd_qty >0, print Opd_qty.*
- *Waiting*: With real-time comparisons of the difference between output quantity and planned quantity order by order, MES notifies workstations before overproduction occurs. Because of machine limitations in forging, forming, and machining, there are required minimum manufacturing quantities in these three processes to cover minimum manufacturing costs. When a work order is released from a workstation, it initiates a waste-waiting time calculation. Lean production tries to reduce material waiting time as

much as possible. Waste originates from mismatches and transportation between processes. There are two types of mismatches, one is caused by dis-linked scheduling, the other is when abnormal issues occur. Materials must wait until the issue has been solved. In the case company, MES calculates waiting time to highlight material flow production consistency. The waiting formula is: *Select if [work order status] = released and to be delivered to the next process but not launched yet; then calculate time from work order released until now.*

- *Defect*: With sensors in the forging, forming, and machining workstations, these three processes can provide defect statuses to MES. MES displays real-time defect statuses on the e-Kanban. However, for the defects in the polishing and painting processes, the operators must key in defect numbers on the work pad manually. The work pads send data to MES through WIFI. MES notifies supervisors with a yellow light if the defect ratio becomes abnormal. Supervisors can go to the workstation to solve the defect issue before the defect becomes abnormal. The defect formula is: *Quantity of defects.*

The case company uses AGVs to transport material and WIP. The AGVs also have their own algorithms to optimise transportation distance. The case company does not yet include transportation, motion, or over processing in MES. For the purpose of visibility, the case company sets up e-Kanban to present the above charts on every workstation. For the purpose of this study, the following figure is simplified to illustrate how the case company manages the four types of waste through e-Kanban as they are sourced from MES. Figure 1 shows the real-time data on the four types of waste of the five manufacturing processes. Axis is the accumulated quantity from starting of the shift. Production managers can thus quickly know which manufacturing process needs their attention. Figure 2 shows the hourly summary of individual manufacturing processes that supervisors receive.

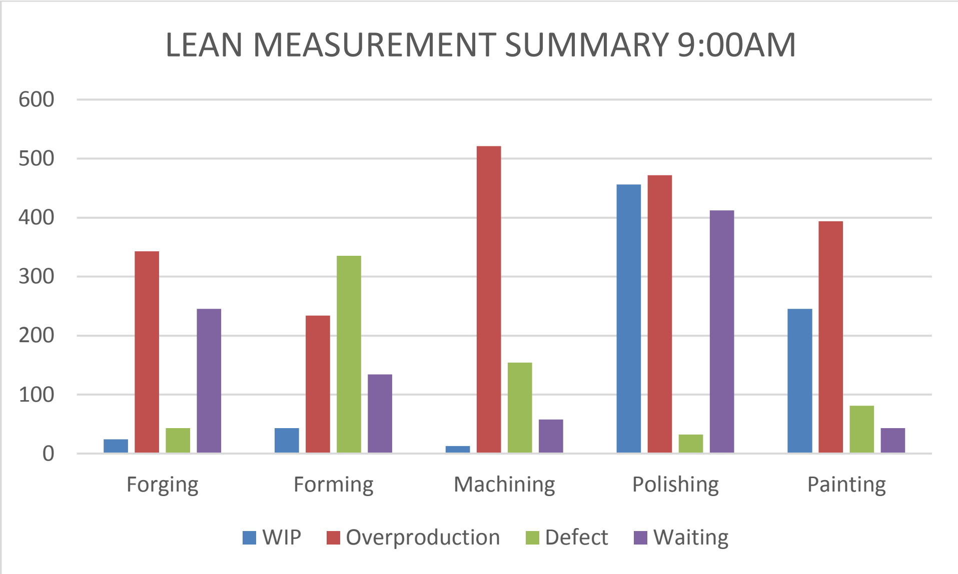

Figure 1 - Real-time data on the four types of waste of each workstation

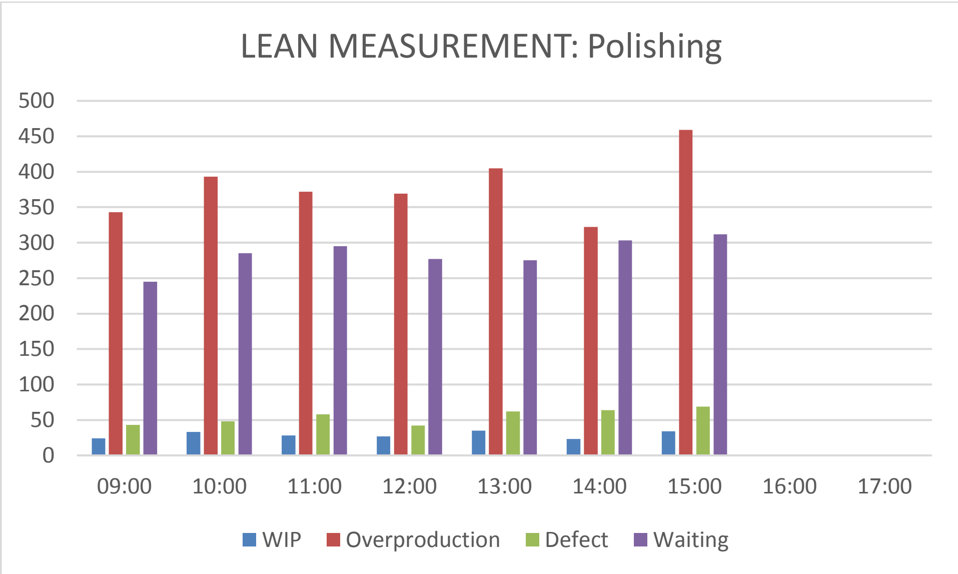

Figure 2 - Hourly summary of individual manufacturing processes

Each process encompasses several workstations. Figure 3 shows the hourly status of overproduction for four polishing workstations. P-1 means polishing workstation 1. MES provides transparency of each issue. Supervisors can address issues before they escalate, while at the same time being free from continuously monitoring operators. This allows them to spend more time on kaizen activities.

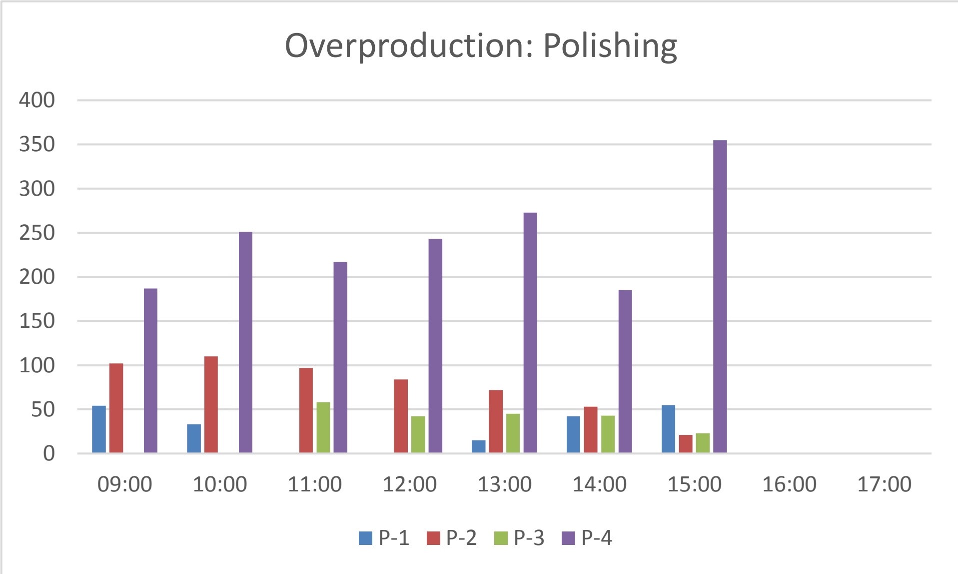

Figure 3 - Hourly summary of individual waste by machine/workstation: Overproduction of polishing.

This improvement lives up to the first Lean principle of identifying value. There is a foundational difference between supervisors and operators in the way they evaluate value of production activities. The case company applies MES to streamline the way people evaluate value of production activities and make it become visible and transparent. The four steps of the logic behind the workstation e-Kanban are (1) identify value, (2) make it visible, (3) define cause and effect, and (4) make it transparent. Transparency is the 2nd stage of intelligence. In this first application, the MES e-Kanban is the link between Lean and intelligence.

4.2 Application 2: Digital andon system

Operators use andon to notify supervisors as an issue occurs (Lu and Yang 2015), such as material defects, machine breakdowns, and quality defects. If the shop floor is open and noisy, it can be hard to find a supervisor or technician when the operator needs support. Based on an analysis of historical andon issues, the case company has defined different types of issues and applies MES to execute its digital andon system.

In order to increase mobility, workstations, technicians, and supervisors are all equipped with work pads in the case company as shown in figure 4. Work pads are the interface by which operations are managed as well as MES. Take polishing as an example. There are three types of buttons on the work pad at each workstation: Quality, machine, and emergency. Sandy, scratching, foggy, and *others* are the four buttons related to quality. Polishing-head, pressure, robot, and *others* are the four buttons related to machine. Emergency is used for any issue related to health and safety and has no subcategory. When operators press a button, the work pad sends a message to MES through WIFI. MES then sends a notification to a predefined person in charge.

Figure 4 - Work pad is applied for daily use

The top three most common quality issues are listed with independent buttons on the operators' work pads. Operators just hit the button and MES calculates and analyses the defect ratio. An alarm message will be sent to a supervisor if certain quality issues are raised and are close to exceeding pre-set standards. This prevents quality issues from exceeding the standards. Like quality, the top three machine issues are listed on the buttons of the work pad. An operator can hit the button if a machine issue occurs. MES sends a message to a maintenance technician's work pad. After receiving the MES notification, the equipment maintenance technician immediately goes to the workstation to solve the machine issue, recording the work on the technician's work pad.

In order to reduce time searching for proper tools and parts, MES also provides recommendations on the technician's work pad. The technician can thus prepare the proper tools and parts before going to the workstation. It improves the right-the-first-time ratio and maintenance efficiency.

Work pads on the shop floor are a powerful tool for the technicians. In the case company, work pads are not only mobile devices by which to send messages, they also provide audio and video functions to improve maintenance efficiency. Voice messages are sent to supervisors and operators for notification if the issue is not urgent. After maintenance, the technician records a voice message as the maintenance report. Audio communication is also provided. The technician can provide timely and online support if he is away.

MES further records the issue frequency for each machine, operator, and technician. The maintenance department can periodically review these records to determine root causes and improve the maintenance plans. The case company also installs sensors at critical machine points. When the sensors detect that the parts are about to wear out or break, MES will notify the operator, supervisor, or technician through the digital andon system. This allows the technicians to perform maintenance on the machines in advance of the machines breaking down.

Supervisors not only receive andon alarms when issues happen or when they are triggered by operators, but they also receive reminders when the quality might fall beyond the bounds of the MES statistical process controls. These reminders help supervisors take necessary action to prevent potential quality issues from occurring. If everything goes well, supervisor work pads are silent. The supervisors can concentrate on kaizen activities that require a clear mind and focus on their discussions with other people. The digital andon system helps management move from reactive processes to prevention. It helps supervisors and technicians have better control of the manufacturing status.

Before the digital andon system was implemented, operators had to find a supervisor when issues occurred. The supervisor would then come to the workstation to fix the issue. The value-added job of an operator is manufacturing, not walking around looking for a supervisor or technician. That is to say, the search was necessary but did not add value. Furthermore, machines were stopped and material was idle. This is waste related to waiting, which is one of the seven types of waste. The digital andon system allows issues to be directly visible to the person in charge. The issue fixing process is transparent on the work pads. This is the application of visibility and transparency of intelligence. The digital andon system enhances the traditional andon system as well as the application of intelligence.

4.3 Application 3: e-Kanban and auto job dispatching

Material delivery Kanban, also known as pull Kanban, provides timely information related to customer requirements. In Toyota, manufacturing processes are treated as a river. Each process is part of the river. Downstream processes are the customers of upstream processes. It is essential to know the requirement of downstream processes before upstream processes start to produce anything. Pull Kanban plays the important role of aligning the output of upstream processes toward the same customer requirements. Therefore, the right items can be delivered to the right processes at the right time. Not only are customer requirements fulfilled, but WIP is also reduced.

Based on the above principle, the case company enhances the pull Kanban with the implementation of e-Kanban. It provides both pull Kanban and auto job-dispatching functions. In the case company, MES collects real-time output quantity and quality data from every machine. MES also holds the production schedule information of every process. The items provided by upstream processes must meet the requirements of downstream processes in terms of time and quantity. Otherwise, the downstream processes must wait until items are finished by upstream processes. To better understand this, Table 1 shows a simplified e-Kanban. *In progress* shows that there are five machines being monitored and that Machine-4 is not running as it is waiting to be changed over at 19:50. Meanwhile, *Next* shows the mould preparation status. The mould for Machine-1 is under preparation for changeover at 14:55. The mould for Machine-2 is ready for changeover at 11:20. Moulds for Machine-4 and -5 are to be issued from the warehouse. No changeover is required for Machine-3 so its mould status is *Same*. Table 1 shows the manufacturing status and changeover schedule of the machining process.

Table 1 - Manufacturing real time status – Machining

							Machining	**Time: 11:07**
In Progress				**Next**				
Machine	Work Order	Progress		Work Order	Qty	Mould	Expected Changeover
M-1	WO937543	338/345	98%	WO938563	736	Preparing	14:55
M-2	WO938593	327/335	98%	WO973833	188	Ready	11:20
M-3	WO966382	98/454	22%	WO938312	324	Same	-
M-4	off	-	-	WO938363	205	To be issued	19:50
M-5	WO933632	124/225	55%	WO933630	382	To be issued	17:30

Mould departments also receive mould preparation schedules from MES as shown in Table 2. This schedule provides production requirements that the mould engineers can follow when preparing the moulds one by one.

Table 2 - Mould preparation schedule

Machine	Work Order	Expected Changeover	Status
M-1	WO938563	14:55	Preparing
M-5	WO933630	17:30	To be issued
M-4	WO938363	19:50	To be issued

Material flow is to production as blood is to the human body. Production stops if there is not a proper supply of material. A person filling the 'water spider' role in Lean production has the responsibility of delivering the right material on time as requested by pull Kanban. MES has the real-time status of every process. MES is the brain that controls the material delivery in the case company. The material delivery schedule is provided by MES to the water spider. As shown in Table 3, real-time output of Machine-1 is 98% complete. Output of Machine-1 is planned to be delivered to workstation Polishing-01 at 10:30. MES sends work orders to the water spider to deliver the output of Machine-1. The water spider then follows the work order to deliver the output of Machine-1 to Polishing-01 before 10:30. The water spider is also equipped with a work pad in order to receive work orders and set the material delivery status to finished. MES can track and control the real-time delivery statuses.

Table 3 - Material delivery schedule

Work Order	From	Qty	Progress	To	Expected
WO937543	M-1	345	98%	P-01	10:30
WO938593	M-2	335	70%	P-03	12:35
WO933632	M-5	225	55%	P-06	14:20
WO966382	M-3	454	22%	P-02	15:05

There are three functions that are improved intangibly through this system. (1) Machining can focus more on manufacturing than managing the placement and delivery of output items. (2) MES manages the material delivery job process of the whole factory. MES allocates resources to maximise the balance of the delivery workload. The water spider just follows up work orders one by one. (3) Downstream processes do not manage their material supply. Everything follows the e-Kanban. Supervisors and operators can have a greater focus on quality. In addition, the case company also implements AGV to improve material traceability and delivery efficiency from polishing to the warehouse. Thus, work orders are sent to either the water spider or to AGV.

MES receives the production schedule from the ERP system and row material information from the warehouse management system (WMS), then MES divides jobs into work orders. MES issues work orders to initiate manufacturing, collect item statuses, and reports the fulfilment of the production schedule to the ERP system. Every job is transformed to become a work order in MES. However, not everything is executed as scheduled. Manufacturing issues such as material shortages, item quality issues, and delivery failures occur. When such issues arise, MES blocks related work orders and automatically dispatches another work order (job) to e-Kanban. Operators and supervisors thus still follow the e-Kanban to continue manufacturing without worrying about the blocked work order. The same logic pertains to the digital andon system: Manufacturing issues are sent to managers' work pads and related persons in charge. When issues are resolved, MES un-blocks the work order, putting it back on schedule, and arranges the proper resources in order to execute it. Auto job-dispatching in MES is treated as the brain of the whole production. People do not see it but work with it closely. Auto job-dispatching improves the efficiency of production material control (PMC), which was originally executed manually. It brings the direct benefit of everyone in the factory focusing on the jobs assigned to them. People are free from manufacturing issues and can spend more time on kaizen.

As information technology becomes widely applied to production, e-Kanban is the next evolution of Kanban. IT systems speed up the adaption of automated processes. Productivity is improved through management decisions and the control of the IT system. e-Kanban not only delivers message correctly, but also fulfils the pull concept of Lean production.

e-Kanban provides timely information. The work-order sequence is properly arranged by MES. WIP items and materials are delivered at the proper time. It achieves the creation of flow, which is the third Lean principle. Auto job-dispatching enhances pull Kanban. It allows items to be made in the right sequence and quantity. e-Kanban and auto job-dispatching are the digital applications of pull, which relate to the fourth Lean principle. MES records issue handling progress from the digital andon system. Auto job-dispatching records provide data for future predictions and optimisation of the production schedules.

4.4 Application 4: Improved maintenance resource management

The case company further applies e-Kanban to track the progress of andon activity and issues, as shown in Table 4. Each andon receives a unique running number in order to identify the individual event. Including the date in the number makes it easier to be remembered and tracked. When an andon is triggered either by a work pad or a sensor installed in a machine, its unique running number is generated and the start time and related machine number is noted in e-Kanban. A technician also receives the event on his or her work pad and presses the confirm bottom to signal the event is being processed. e-Kanban notes the acknowledge time and the name of the technician. This means the technician is on its way to resolve the andon issue. The technician reports on the work pad when the event is finished. e-Kanban notes the time the andon is resolved. An event is only removed from e-Kanban when a 'finished at' time has been noted. Thus, un-finished events are always kept in e-Kanban. Both supervisors and managers review the pending events daily and help ensure events are resolved as soon as possible.

Table 4 - Andon tracking e-Kanban

No.	Andon Start	Machine	Ack. Time	Technician	Finished at
08Aug002	11:23	Polishing-07	11:24	Kasem	11:55 08Aug
08Aug003	13:59	Machining-02	14:02	Pravat	-
08Aug004	14:35	Machining-07	14:38	Pravat	16:27 08Aug

In addition to andon events, the maintenance department also has daily routine jobs. Planned maintenance within e-Kanban, as shown in Table 5, is the tool used to coordinate this. It presents planned maintenance jobs scheduled for the next seven days, detailing which day it will be performed on and by which technician. The technicians know which job they are responsible for in the near future, allowing them to prepare in advance. Unlike traditional maintenance jobs that may have ambiguous names, like *clean roller*, the case company classifies standardised maintenance jobs into activities with individual code numbers. Take activity M-03 as an example. Technician Malee has to follow the procedure defined in the work instructions for M-03. Malee also has to take pictures using the work pad as part of the steps in the procedure as shown in figure 1. The work pad uploads both the time and picture to MES. This is done not only to ensure the technician follows the procedure correctly, but also to review components' aging status after reviewing pictures taken over the past three months. In place of a picture, 30 seconds of video with sound can also be uploaded to MES. Senior technicians can analyse the videos, especially the sound, to uncover potential issues.

Table 5 - Planned maintenance e-Kanban

Running No.	Day	Machine No	Activity	Technician	Finished at
14Aug001	Mon	Machining-05	M-03	Malee	11:02 14Aug
14Aug002	Mon	Froming-02	F-19	Noi	15:50 14Aug
15Aug001	Tue	Machining-07	M-03	Malee	09:47 15Aug
15Aug002	Tue	Painting-05	Pa-23	Pravat	17:18 15Aug
15Aug003	Tue	Polishing-04	Po-82	Kasem	09:55 16Aug

The above two applications of e-Kanban inspire the technicians' sense of job ownership. First, if someone is occupied by other events, others will spontaneously press the button to confirm ownership of the job. Before e-Kanban, supervisors had to assign the technicians to the jobs, leading the technicians to passively take on and resolve them. Through e-Kanban, technicians are intangibly united and support each other more than before. Second, the technicians finish the planned maintenance jobs more efficiently than before. While the technicians cannot predict what andon issue may occur, they can control the maintenance activities planned for the coming days. The technicians spontaneously execute the planned activities that are shown on e-Kanban. Third, the technicians become more aggressive in engaging in preventative maintenance. If certain andon issues keep occurring, technicians from all processes share knowledge and discuss solutions during team meetings in order to determine how to prevent it from reoccurring in the future. The above three intangible changes push technicians toward having positive attitudes and creating a positive atmosphere.

The value-added activity of technicians is maintenance, not paperwork. The technicians record the maintenance statuses in voice messages on the work pads on the spot when they finish their jobs. The voice messages are uploaded to MES as official maintenance records. The technicians can then continue to the next maintenance job or andon activity. Later, the voice messages are transferred into text in MES and department assistants verify and correct errors once per week. Text records are the basic data that are analysed on a quarterly basis in order to determine what updates need to be implemented to the whole maintenance plan.

Technicians would previously walk around to call for help when an issue was beyond his or her capacity. It was necessary but not adding value. The work pads now provide technicians with a video call function that they can use to connect with senior technicians. Senior technicians can thus immediately offer online support. By using the work pads, the risk of leaking company intellectual property is removed compared to if they used their personal mobiles. The above improvements have sped up the issue solving process as well as the protection of intellectual property protection.

The application illustrates the three following Lean principles: (1) Definition of value: It highlights what the technicians' and maintenance department's value-added activities are, (2) Elimination of waste: The technicians clearly know what and how to solve andon issues and perform planned maintenance jobs, and (3) Continuous flow: With the transparent information, andon is solved faster than before.

4.5 Application 5: Upgraded level production to drive kaizen activity

Production levelling, also known as Heijunka in Japanese, is a technique for running plan-do-check-act in cycles. Before MES, the operators at the case company had to write down output and defect numbers on white boards every hour and wait for these to be reviewed by a supervisor, to ensure the quality and output was under control.

Operators needed to manually count the number every hour for this. Now, however, as mentioned in the description of the digital andon system and the auto job-dispatching system, operators no longer need to provide manual output every hour, as this job has been improved by MES. The ownership of output and quality has been shifted to the operators who must maintain the output and quality themselves since e-Kanban shows the running numbers. Before the MES implementation, an operator only sought out a supervisor when an issue occurred. It was top-down management. That is, operators followed the instructions from the supervisors. After MES implementation, both operators and supervisors have better transparency. If a certain indicator is starting to exceed its boundary, the operator will propose what can be done to improve it. The supervisor gives the operator space to test the solution, because there is still room before the indicator exceeds the standard. This changes the kaizen from top-down to bottom-up. This also gives operators the platform to perform themselves.

As mentioned in Application 1, supervisors review the indicators hourly on the work pads. Before MES implementation, supervisors had to gather the operators for a review meeting on the shop floor to know whether certain indicators exceeded their standards the preceding hour. There would be no review meeting if all the indicators were within their boundaries.

The key feature of MES is transparency. For example, if scratch levels are high, a supervisor can drill down to know the root cause such as whether it is due to pressure or tension. This helps the supervisor manage production more easily than before. e-Kanban frees supervisors from hourly reviews and allows them to manage production issues proactively. This leads to a more level production. Supervisors can spend more time on kaizen activities that require independent thinking and support from cross functional teams.

Because there are less material and machine issues, operators can fully concentrate on the manufacturing process, improving both efficiency and quality. In addition, the operators have a greater degree of ownership. Before MES was implemented, supervisors had to give orders that the operators would passively follow. After MES was online, operators have more flexibility regarding the maintenance of the workstations and treat the workstations as their own. The operators also ask more questions than before. This means that the manufacturing ownership is shifting from supervisors to operators. Another positive outcome is that kaizen ideas come from operators now as well. Because e-Kanban helps the operators better control the machines, the operators have room to try new solutions to improve emerging issues before they exceed the set standards. Supervisors provide resources to support the ideas, creating positive interactions between operators and supervisors. This lives up to Lean principle five: Perfection. Operators can also predict issues according to e-Kanban data and their own experience. The data transparency provided by MES offers a good foundation for prediction, which relates to stage 3 of Intelligence.

4.6 TAM2 and OEE verification

This study applies TAM2 to complete a basic comparison in order to verify the above five applications. As shown in the applications, the phenomena of job relevance, output quality, and result demonstrability are easily identified. This study further interviews employees, with similar results. This study thus receives preliminary positive feedback related to the construct of perceived usefulness.

Work pads can provide material delivery and quality defect information. If issues arise, operators can employ the digital andon system using the work pad, which greatly improves the transparency of manufacturing. The work pad also makes communication between employees more fluent. Employees voluntarily use this system more. The user interface of the work pads is like mobile phones. Employees can easily start using them after only a short briefing as their experience gained from using mobile phones can be applied to the work pads. At the same time, employees can maintain communication with family members despite their mobile phones being put in lockers. This shows that behavioural intention is identified, and that the intention is positive. Finally, we ask whether they would support the abandoning of the above five applications and return to the system before MES was implemented. All answers are negative. This shows that the use behaviour of the integrated solution is positive.

OEE is applied for verification as presented in Figure 5. OEE of Q3 2018 drops because MES went live. After an adjustment period, OEE improves in Q4 and becomes stable from Q1 to Q2 of 2019. As mentioned in Case studies 4 and 5, staff are inspired to try various kaizen activities. OEE is not stable in Q2 2019 but subsequently improves. This shows that the integration of Lean, MES, and Smart manufacturing has been effective.

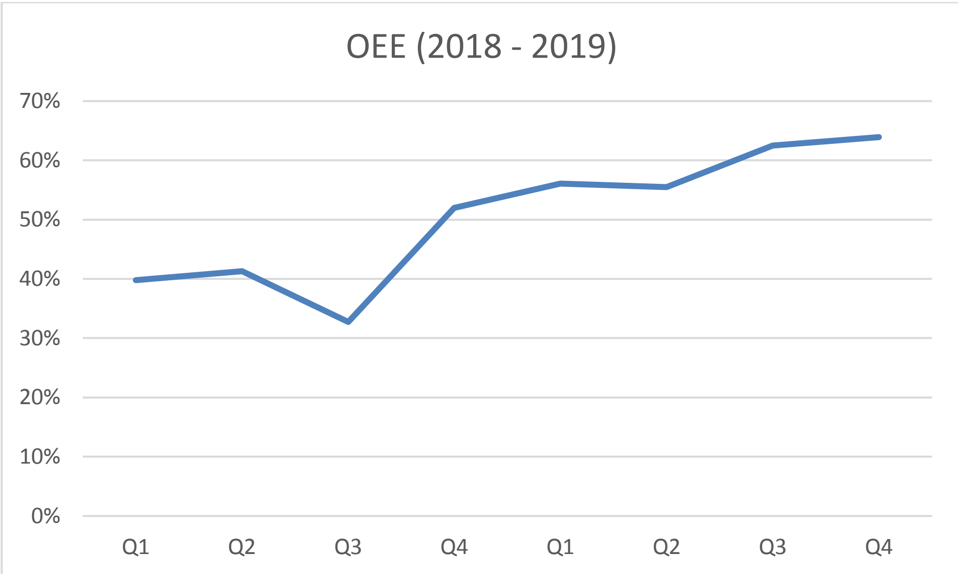

Figure 5 - OEE from 2018 to 2019

4.7 Additional finding of peoples' behaviour change

Most of interviews with technicians are on shop floor when they are maintaining machines. We observed that technicians show stronger teamwork spirit. If maintenance order has been sent to a junior technician, senior technician would spontaneously and personally support. "I know this maintenance order is not easy. Junior technician may encounter challenge when unloading the motor." Said by a senior technician. Junior usually offer support "I know the component would be easier to take off if more than one hand". "Technician teamwork is highly improved after work transparency." Maintenance manager said.

In addition, operators are encouraged to try different kaizen activities. The communication between operator and supervisor are more frequent than before." Before the system, operators execute kaizen activity only when I give commend. Now, operator would come to me to discuss their ideas. I am glad to communicate ideas even if I think most of the ideas are fantasy." "I would share resource to let them try their ideas under no influence of production." One supervisor said." Even if most of the trails are failure, operators are encouraged and inspired. The work atmosphere is positive". The turnover rate has been reduced from 11% last year to 3.7% last quarter. Both technician teamwork and operator's aggressiveness are improved. It is unexpected harvest when implementing Smart manufacturing.

5. Conclusion

This study provides five applications from the case company to illustrate the integration and application of Lean based MES towards Smart manufacturing. Based on Lean principles, MES is used to make the production visible and transparent. Through the advantages of information systems and work pads, production efficiency and quality are effectively improved. Potential production issues can be proactively eliminated. People can focus more on value-added activities.

Additionally, teamwork among technicians and interaction between operators and supervisors are positively improved. How to apply transparency of Smart manufacturing to improve teamwork and interaction is another interesting topic for further research.

REFERENCES

American National Standards Institute. 2005. ANSI/ISA-95 Enterprise-Control System Integration Part 3: Activity Models of Manufacturing Operations Management. International Society of Automation.

Bittencourt, V.L., Alves, A.C., & Leão, C.P. 2020. "Industry 4.0 triggered by Lean Thinking: insights from a systematic literature review". *International Journal of Production Research,* Ahead-of-Print, 1-5.

Choi, B. and B. Kim. 2002. "MES (Manufacturing Execution System) Architecture for FMS Compatible to ERP (Enterprise Planning System)." *International Journal of Computer Integrated Manufacturing* 15 (3): 274–284.

Davis, J., T. Edgar, J. Porter, J. Bernaden, and M. Sarli. 2012. "Smart Manufacturing, Manufacturing Intelligence and Demand-Dynamic Performance." *Computers and Chemical Engineering* 47: 145–156.

Deif, A.M. 2012. "Dynamic Analysis of a Lean Cell under Uncertainty." *International Journal of Production Research* 50 (4): 1127–1139.

Ehret, O., and P. Cooke. 2010. "Conceptualising Aerospace Outsourcing: Airbus UK and the Lean Supply Approach." *International Journal of Technology Management* 50 (3/4): 300–317.

Fang, Ji, G.Q. Huang, and Z. Li. 2013. "Event-Driven Multi-Agent Ubiquitous Manufacturing Execution Platform for Shop Floor Work-In-Progress Management." *International Journal of Production Research* 51 (4): 1168–1185.

Filhoa, M.G., G.M.D. Gangaa, and A. Gunasekaranb. 2016. "Lean Manufacturing in Brazilian Small and Medium Enterprises: Implementation and Effect on Performance." *International Journal of Production Research* 54 (24): 7523–7545.

Gattiker, T. 2007. "Enterprise Resource Planning (ERP) Systems and the Manufacturing–Marketing Interface: An Information Processing Theory View." *International Journal of Production Research* 44 (17): 2895–2917.

Hodge, G.L.,K. Goforth Ross, J. A. Joines, and K. Thoney. 2011. "Adapting Lean Manufacturing Principles to the Textile Industry." *Production Planning and Control* 22 (3): 237–247.

Houyou, A.M., H.-P. Huth, H. Tresk. 2012. "Agile Manufacturing: General Challenges and an Iot@Work perspective." *2012 IEEE 17th Conference on Emerging Technologies & Factory Automation (ETFA):* 1–7.

Huang, G., Y. F. Zhang, and P. Jiang. 2008. "RFID-Based Wireless Manufacturing for Real-Time Management of Job Shop WIP Inventories." *International Journal of Advanced Manufacturing Technology* 23 (4): 469–477.

Imai, M. 2012. Gemba Kaizen: A Common Sense Approach to Continuous Improvement Strateg*y*. 2nd ed. New York: McGrawHill Professional.

Islam, M. and A. Karim. 2011. "Manufacturing Practices and Performance: Comparison Among Small-Medium and Large Industries." *International Journal of Quality and Reliability Management* 28 (1): 43–61.

Karim, M.A., A.J.R. Smith, S.K. Halgamuge, and M.M. Islam. 2008. "A Comparative Study of Manufacturing Practices and Performance Variables." *International Journal of Production Economics* 112 (2): 841–859.

Leea, S. M., S. G. Hongb, P. Katerattanakulc, and N. R. Kimb. 2012. "Successful Implementations of MES in Korean Manufacturing SMEs: An Empirical Study." *International Journal of Production Research* 50 (7): 1942–1954.

Legris, P., J. Ingham, and P. Collerette. 2003. "Why Do People Use Information Technology? A Critical Review of the Technology Acceptance Model." *Information and Management* 40 (3): 191–204.

Lu, J.-C., and T. Yang. 2015. "Implementing Lean Standard Work to Solve a Low Work-In-Process Buffer Problem in a Highly Automated Manufacturing Environment." *International Journal of Production Research* 53 (8): 2285–2305.

Martinez-Olvera, C. 2009. "Reference Model of the Manufacturing Execution Activity in Make-To-Order Environments." *International Journal of Production Research* 47 (6): 1635–1659.

McClellan, M. 1997. *Applying Manufacturing Execution Systems*. Florida: St. Lucie Press.

MESA International. 1994. *MES Functionalities and MRP to MES Data Flow Possibilities.* Pittsburgh: MESA International.

Mesut, Y., and A. Elif. 2007. "Production Smoothing in Just-In-Time Manufacturing Systems: A Review of the Models and Solution Approaches." *International Journal of Production Research* 45 (16): 3579–3597.

Mullin, R. 1998. "Inching Its Way To 'Plug and Play'." *Chemical Week* 160 (20).

Nakamura, T., L. J. B. Vlacic, and Y. Ogiwara. 1996. "Multiattribute-based CIE/CIM Implementation Decision Model." *Computer Integrated Manufacturing Systems* 9 (2): 73–89.

Ohno, T. 1988. Toyota Production System: Beyond Large-Scale Production. New York: Productivity Press.

Pakdila, F., and K. M. Leonard. 2017. "Implementing and Sustaining Lean Processes: The Dilemma of Societal Culture Effects." *International Journal of Production Research* 55 (3): 700–717.

Pherson, T. 2006. "Overall Equipment Effectiveness and Real-Time Visual Management Critical Lean Tools." *Intelligent Manufacturing Solutions June 2006:* 1-18.

Rocha-Lona, L., J. A. Garza-Reyes, and V. Kumar. 2013. Building Quality Management System*s: Selecting the Right Methods and Tools.* Boca Raton, FL: Productivity Press, CRC Press, Taylor & Francis.

Sahoo, A. K., N. K. Singh, R. Shankar, and M. K. Tiwari. 2008. "Lean Philosophy: Implementation in a Forging Industry." *The International Journal of Advanced Manufacturing Technology* 36: 451–462.

Schuh, G., R. Anderl, J. Gausemeier, M. T. Hompel, and W. Wahlster. eds. 2017. Ind*ustrie 4.0 Maturity Index: Managing the Digital Transformation of Companies.* Utz, Herbert.

Shahin, M., Chen, F. F., Bouzary, H., & Krishnaiyer, K. 2020. "Integration of Lean practices and Industry 4.0 technologies: Smart manufacturing for next-generation enterprises". *The International Journal of Advanced Manufacturing Technology*, 107(5–6), 2927–2936.

Shipp, S. S. 2012. "Emerging Global Trends in Advanced Manufacturing." *Emerging Global Trends in Advanced Manufacturing*. Institute for Defense Analysis. Retrieved April 2016.

Shrouf, F., J. Ordieres, and G. Miragliotta. 2014. “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.” *2014 IEEE International Conference on Industrial Engineering and Engineering Management:* 697–701.

Steege, P. 1996. “Overall Equipment Effectiveness in Resist Processing Equipment.” In IEEE/SEMI 1996 Advanced Semiconductor Manufacturing Conference and Workshop. Theme-Innovative Approaches to Growth in the Semiconductor Industry. ASMC 96 Proceedings. IEEE: 76–79.

Strauss, A., and J. M. Corbin. 1990. *Basics of Qualitative Research: Grounded Theory Procedures and Techniques.* Sage Publications, Inc.

Sullivan, W. G., T. N. McDonald, and E. M. Van Aken. 2002. “Equipment Replacement Decisions and Lean Manufacturing.” *Robotics and Computer-Integrated Manufacturing* 18 (3–4): 255–265.

Tortorella, G., Sawhney, R., Jurburg, D., de Paula, I. C., Tlapa, D., & Thurer, M. 2020. “Towards the proposition of a Lean Automation framework”. *Journal of Manufacturing Technology Management* 51(8): 2145-2156.

Womack, J., Jones, D. T., and Roos, D. 1990. “The Machine That Changed the World: The Story of Lean Production”. Rawson Associates.

Yang, T., C.-H. Hsieh, B.-Y. Cheng. 2011. “Lean-Pull Strategy in a Re-Entrant Manufacturing Environment.” *International Journal of Production Research* 49 (6): 1511–1529.

Yin, R. K. 2003. “Application Research: Design and Methods.” Sage Publications, Inc., California, USA.