Abstract

Today, Industry 4.0 concerns a rapid advancement in manufacturing technologies which help industries increase their productivity. To adopt Industry 4.0 concept is still visionary by certain lean manufacturers when the communication technologies interfaces are not fully equipped at the production system. Most of the facilities towards digitalization are also expensive and require many specialists in different fields to manage the technologies. Therefore, most data analytics (DA) engineering is cannot be employed broadly for process enhancement by Industry 4.0 environment. However, starting with Internet of Things (IOT) concepts, Andon system with simulation was enhanced to support decision making in lean manufacturing. The aims of this research paper is to develop a decision support system (DSS) framework which intersects between Andon and simulation through IOT concept. A better decision-making information flow are demonstrated in detail. To illustrate the applicability of the DSS, it has been implemented in lean manufacturing for automotive part assembly. The results indicate that the DSS can easily be adopted in digital factories to support in planned and operational activities.

Keywords: Industry 4.0, Lean manufacturing, Decision support system, Internet of things, Andon

1. Introduction

Visual management system is one of the approaches to communicating information by utilizing signal, diagrams or chart instead of texts. It is to act as a solution of wastage reducing in Industry 4.0 since its goal is to make the situation effortlessly understand with shortest observation time as possible (Mayr et al., 2018). Andon can be defined as a ‘Sign’ or ‘Signal’ that provides visual management aid when highlighting an issue, as it occurs, which helps to introduce countermeasures immediately so as to avoid re-occurrence (Kemmer et al., 2006). As a communication tool, the Japanese employ the Andon systems for communicating to all production employees on the production floor regarding the status of a production line or a process. Andon systems are available in various forms, ranging from traffic light systems or simple status lights to complete display boards placed in visible locations within the production plant. The ability to reduce waste of various resources like time taken to understand the data, process time taken make Andon is a tool in lean manufacturing. Therefore, Andon is selected as an appropriate tool for communication medium since it has a special trait for a management system to suit Industry 4.0.

Information such as data analytics (DA) of engineering processes in modern business allows manufacturing sectors to achieve real competitive advantage in market place. In Lean manufacturing (LM), there are various type of data come from lean manufacturing tools such as Overall Equipment Effectiveness (OEE), single minute Exchange of Dies (SMED), Kaizen, 5S, Value Stream Mapping (VSM), Jidoka, Kanban, Poka Yoke, Line Balancing and as well as Andon (Wagner
et al., 2017 and Mohamad et al. 2016). DA in lean manufacturing tools such as the numbers of machines used, operators, operations time, the volume of materials and etc., will affect the success rate of a lean manufacturing implementation. One of the most challenging aspects in LM is to decide based on data analytics. If problems happen, they cannot be applying as an alternatives strategy to solve the problem.

However, DA in LM such as data process engineering is not employed broadly for process enhancement (Wang, 2016). Few of these data are employed just for tracking. Apart from that, the management group is not able to analyze accurately the impact of process variables on lean to establish communication and decision making (Mohamad et al., 2017). Production facing problems without establishing a proper communication interconnection vertically where data is analyzing in real time is not ready. From the issue, shows that it has some ‘smart’ solutions which could be recognized as innovative solutions when Industry 4.0 elements are integrated. Therefore, this research is to utilize real data information to support dynamic and management tasks. And from the established Andon system, the aim of this research is developing a decision support system (DSS) framework which intersects between Andon and simulation through IOT concept for better decision making.

2. Research Background

The aims of Industry 4.0 are to provide digital manufacturing where the human, product, systems are connected to increase the productivity (Zhou, 2015). The core idea of Industry 4.0 in this research is to use emerging information technologies to implement IOT concept, so that business process and engineering process are deeply integrated making production operation is efficient (Mohamad et al., 2018). On the other hand, internet networking such as IOT which capable connected between human and system to achieve real time output can be applied for optimization for high quality, cost reduction, flexibility and reduce lead time (Wang et al., 2016). Through this direction, simulations will be developed become useful tool to support decision making within lean manufacturing operations to assess the benefits and risks of strategies for process improvement.

The adoption of information and communications technology into the manufacturing industry started in the 1970s. It was shared in 2011 by German government in “High-Tech Strategy 2010 Action Plan”. Similar strategies have also been proposed in other industrial countries but there is no one formally respected definition for it. However, production evolution about the communication systems was shared by Wywicka (2014) as Table 1 where Internet of Things (IOT) is a new approach of the communication method in Industry 4.0.

| Communication System | Past         | Present                  | Future                  |
|----------------------|--------------|--------------------------|-------------------------|
| Communication System | Analog       | Internet and Intranet    | Internet of Things (IOT) |
| Concept Solution     | Neo-Taylorism| Lean Production Automation and Computerization | Smart Factory Virtualization and Integration |

Communication takes an important place for data infrastructure such as the internet in Industry 4.0. And one of the significant advances in the development of computer science, information and communication technologies which representing IoT concept (Mrugalska, 2017). In the IoT paradigm, many of the objects that surround us, in which information and communications system are invisibly embedded in the environment around us (Gubbi et al., 2013). IoT was first introduced by Kevin Ashton in the year 1998 (Bandyopadhyay and Sen, 2011). It is a system of interrelated between internet-oriented, things of oriented (sensors) and semantic oriented (knowledge) (Gubbi, 2013). The IoT is referring to vertical networking where various objects are embedded with electronic sensors, actuators, or other digital devices so that they can be networked and connected for the purpose of collecting and exchanging data (Mohamad et al., 2018). Therefore, in general, IoT is able to offer advanced connectivity of physical objects, systems, and services, enabling object-to-object communication and data sharing (Zhong, 2017). To implement IoT concepts, sensors or actuators are required to connect with the cyber world (Lee and Seshia, 2016). In this research, cloud computing is a...
search engine platform where they provide various Internet services. Virtualization technology provides cloud computing with flexible extensions, dynamic allocation, resource sharing, and other features. The cloud computing model provides services to the user including software, hardware, platforms, and other IT infrastructure resources as required. The user simply uses resources depending on application needs, relying on on-demand access to computers and storage systems. In manufacturing, the cloud is used as a platform where various production resources and capabilities can be intelligently sensed and connected into the cloud. Then IoT technologies such as sensors or actuators can be used to automatically manage and control these resources so that they can be digitalized for sharing.

One of the main goals to set-up a company is to obtain a generous profit. Therefore, to achieve a good profit is by increasing productivity. To manage high productivity, the computing simulation is become more widely to use in the lean production process. Through the simulation, decision-makers are allowing to study the optimal condition for the coming production line in the virtual world before making the change of production line. Simulation models entails oversimplified assumptions and rough approximations to overcome the complexity of manufacturing systems which widen the gap from reality (Wang and Wang, 2016). This has become a new challenge since modern information and communication technologies are a rather complex set of hardware, software and organizational solutions processed with the data (Koscielniak and Puto, 2015).

3. Development of Methodology of Decision Support System

In the development stage, firstly, IoT ecosystem involves web-enabled smart devices that use sensors, embedded processors and communication hardware to collect, act and send the data acquired. Through the Andon system, production will be notified via IoT. Then secondly the DA will be utilized in simulation for better decision making based on real data output. Fig. 1 shows how is proposed DSS framework is designed for lean manufacturing in term of communication and decision making. The system divided into three portions, which are collecting data, storing data and, simulation and decision making.

3.1 Collecting Data

The smart production system is fully automated where sensors are used to collect process data by employing the Programmable Logic Controller (PLC) systems. Data is installing into the database at the machines before transmitting to the server through intranet. Through MySQL command, these data are compiled and coding to align the simulation requirement inputs. This is the main basis of the networking system towards Industry 4.0. With the help of the concept, all physical devices can be connected to the Internet. A proposed framework is to provide a more meaningful and effective framework on how LMT data (Andon) can be simulated for decision making.

3.2 Storing Data

By using a database, through internet network the data is keeping on physical servers maintained and controlled by a cloud computing provider. Post collection of the set of data, analyses are carried out via visual studio software and cloud computing is employed to store into the database as a computing services server. An example in Fig. 2 demonstrates how the display board of Andon Signal notifies real-time information of the production process. Different colours are assigned for setting readings and status lights. Colour coding is considered to be a crucial characteristic for Andon signals as different colors could signify different meanings as well as prompt actions by process operators, management and supervisors.
Fig. 1 DSS proposed framework for Lean Manufacturing

Fig. 2 Andon signal display board.
With the Andon signal display board, the signal notifies others when a problem occurs within the production or quality-control streams. Usually, activation of the Andon is done via a pull-chord or button, which automatically stops the production so as to allow the team to gather, execute Plan-Do-Check-Action (PDCA) and perform root cause analysis, and rapidly apply a solution. The warning lights are placed in an easily visible, overhead signboard, which also helps to detect the area or specific workstation with the issue. Should the abnormal or undesired conditions extend more than the predefined time, the information via email and mobile phone is sent to the manager or department head. Figure 3 presents how the Microsoft Flow software can be employed to automate processes like approval process and email triggering via mobile notification to provide immediate support when there is an occurrence, in order to prevent line stop.

3.3 Simulation and Decision Making

In an SQL server, a compilation of the data from Andon is done. The Microsoft BI software is employed to analyze data pertaining to the actual unit produced, operator headcount, hourly production rate and production loss time. The data is then presented in a graph or compiled in a report, which can be utilized by the management group as sources for decision making during a department meeting. Based on the system an analysis report triggered through the Andon display panel.

Simulation is used to assist in the decision to implement lean manufacturing principles at an existing assembly operation. Models are developed for the existing assembly system. In addition to the manufacturing processes, the related elements such as warehousing, inventory management, transportation, and production quality control systems are included in the model to enable the quantification of lean manufacturing's impact on the total system. Simulation experiments measure each system's resource requirements and performance, thereby quantifying benefits to be derived from applying the shop-floor principles of lean manufacturing (Detty and Yingling, 2000). To demonstrate the DSS, discrete event simulation (DES) will be applied as a tool to assist organizations with the decision to implement lean manufacturing by quantifying the benefit based on the specific situation (Salama and Eltawil, 2018). DES is one of the most common techniques for solving production problems (Negahban et al., 2014). Before decision making has made, the DES model is used to estimate the system response for the optimal settings of decision variables obtained from the optimization module. Decision-making results will be analyzed based on the management of business rules. Business rules specify how to operate the action in certain circumstances. Therefore, it is important to align operational and

![Fig. 3 Notification system via IOT](image_url)
strategic decision makers with business rules. And the organizations should have culture of decision-making based on evidence for continuous improvement. Lack of awareness about organization business rules such as the complexity of the problem, lack of accurate information and financial limits will give impact to the output results.

4. Implementation Examples

4.1 Problem Statement

The production Line T7AX manufacture rear left wheelhouse comp (LH), right rear wheelhouse comp (RH) and cross member (C/MR) as shown in Fig. 4. All the parts will assemble in supporting frame of ABX car model. The research project started at wheelhouse comp and cross member for T7AX production line. The automatic spot welding machine is utilizing in this production line to fabricate the wheelhouse comp and cross member. The child parts of each product are assembly through three automatic spot weld robots and undergo inspection process before disposing to the customer. There is total of twelve stations and eight operators in this production line to manufacture three types of finished products. Based on current layout design, the production line process flow is unequal workload among operators and waiting time operators is too high and not fully utilized. To eliminate the wastes, line balancing technique and simulation model approach was developed to improve productivity performance.

![Fig. 4 Pictorial diagram of rear wheelhouse comp (left side), rear wheelhouse comp (right side) and cross member manufacturing process.]

4.2 Data measurements

From Andon system, data was compiled and illustrated in the graph defined as a monthly report. Reported that in January 2019 as shown in Fig. 5, production target was not achieved caused by bottleneck issue which contributed 53.19 % among the problems. Since the part quality problems are higher, it is not covered in this research scope. The countermeasure was taken through PDCA method and time study was performed to collect the significance data such as standard time and utilization.

In order to obtain the standard time to evaluate the line balancing the time study is conducted for all workstations. The standard time for every station is shown in Table 1. Before obtaining the standard time as in Eq. (1), the normal time stated in Eq. (2), needs to be calculated and the allowance factor will be given based on the observation of operator performance.

\[
\text{Normal time (NT)} = \text{Average Time} \times \text{Rating Factor} \quad (1)
\]

\[
\text{Standard Time (ST)} = \text{Normal Time} \times (1+ \text{Allowance Factor}) \quad (2)
\]
Fig. 5 Analysis report from ASS

Table 2 Standard Time for Each Workstation.

| Process: Spot Welding | Product: Right Side Wheel House Comp, Left side Wheel House Comp, Cross Member |
|-----------------------|--------------------------------------------------------------------------------|
| Station               | Average Time (s) | Range | Performance Rating (%) | Rating Factor | Normal Time (s) | Standard Time (s) |
| 100RH                 | 261.4            | 20    | 100                     | 1.0           | 261.4           | 300.6             |
| 150RH                 | 216.2            | 19    | 100                     | 1.0           | 216.2           | 248.6             |
| 200RH                 | 232.7            | 11    | 90                      | 1.1           | 256.0           | 294.4             |
| 300RH                 | 263.1            | 13    | 110                     | 0.9           | 236.8           | 272.3             |
| QG1                   | 133.0            | 16    | 110                     | 0.9           | 119.7           | 137.7             |
| Total                 | 1090.1           |       |                         |               |                 | 1253.6            |
| 100LH                 | 238.2            | 18    | 100                     | 1.0           | 238.2           | 273.9             |
| 200LH                 | 247.6            | 25    | 90                      | 1.1           | 272.4           | 313.2             |
| 300LH                 | 263.3            | 8     | 110                     | 0.9           | 237.0           | 272.6             |
| QG2                   | 79.0             | 21    | 100                     | 1.0           | 79.0            | 90.9              |
| Total                 | 826.6            |       |                         |               |                 | 950.6             |
| 100                   | 285.2            | 10    | 100                     | 1.0           | 285.2           | 328.0             |
| Manual Welding        | 53.8             | 20    | 90                      | 1.1           | 59.2            | 68.1              |
| QG3                   | 83.3             | 22    | 100                     | 1.0           | 83.3            | 95.8              |
| Total                 | 427.7            |       |                         |               |                 | 491.9             |

Takt time is the rate where the production process requires to be accomplished in order to achieve the target. The purpose of using this data is to improve the current process and decision making (Provost and Fawcett, 2013; McAfee et al., 2012). The takt time is calculated by total time available over unit required. Fig. 6 shows the line balancing of the existing production line.
4.3 Waiting Time for each operator

Based on the time study conducted, the time of the machine for welding is longer than the work content of the operator. Therefore, the operators have long idle time to wait for the welding process and inspection process. Data total idle time for the operator in the inspection is shown in Table 2.

| Operator | Workstation | Idle Time (second) | Total idle Time for each operator (second) |
|----------|-------------|--------------------|------------------------------------------|
| 6        | QG1         | 336 – 133 = 203   | 203                                      |
| 7        | QG2         | 324 – 78.9 = 245.1| 245.1                                    |
| 8        | QG3         | 291 – 83.3 = 207.7 | 207.7                                    |
| Total    |             |                    | 1960.6                                   |

4.4 Simulation Model Assumption

Model assumption is the important step before simulation modeling started. There are several assumptions included into the simulation process. The simulation focuses only for the inspection process in production line T7AX and the simulation run for one shift only. The simulation model is demonstrating the production line T7AX in January 2019 while the allowance factor given for the inspection station is assumed to be 15%.

4.5 Verification of Model

Verification is a process to ensure that the model implementation accurately presents the associated data and behaves closely to the actual system. As a consequence, simulation model needs to be verified in order to prove that the model is reliable and capable to perform testing with the given input parameter values. When the entities enter the system by correct sequences, it demonstrates that the entities have pursued the order that has been set. The first step of verification is to identify the number of workstation for inspection station. In the production line T7AX, there are a total of 9 workstations following 3 quality gates for each product which are QG1, QG2, and QG3. All 12 workstations are defined and set in the Arena simulation modeling according to the sequence of the actual assembly process. Fig. 7 shows the
arena simulation model logic model for existing production line. The simulation is a test run for 10.5 hours which working hour for one shift in the production line T7AX. The comparison between the actual output and simulation output is 98.67 to 100%.

4.6 Validation of the model

Validation of this simulation model has completed by associate the outcome between simulation modeling and the existing production line. The results of the actual output in production line and simulation outcome had been compared to validate the accuracy of the Arena simulation model. Based on the result, the accuracy of the model is in the acceptable range which is 96.77 % and above. Regarding minimum accuracy criteria, ISO 15197:2013 stipulates that at least 95% of measurement results (Freckmann, 2015). Therefore, the current production output and simulation model output hence the model is acceptable.

5. Results and Discussion

Based on the simulation results, the usage resources are tabulated. In the graph, it is clearly shown that some of the operator’s utilization are higher and some are merely utilized. Fig. 8 show the analysis of the utilization of operator 1, 2 and 3 to reveals their workload is lower. Among them, the highest utilized resource is operator 1 with only 46.8 % while the lowest utilized resource is operator 2 with 23% and operator 3 with 27.5%.

![Scheduled Utilization](image-url)
A brainstorming session among technical staff had done to carry out the best solution. A simulation model is created to predict the outcome after the implementation of corrective action. The new simulation model is similar to the existing production simulation model, but the number of workstations and operators had been changed. The inspection station is modified into one station instead of three stations for all finished products. All three finished products will flow into one inspection station to finish their inspection process by one operator. The precedence diagram technique was applied during the troubleshooting to demonstrating the new process flow as in Table 3. And a line balancing technique was used to improve the existing line based on precedence limitation as shown in Fig. 9.

| Station | Process Sequences |
|---------|-------------------|
| 100RH   | -                 |
| 150RH   | A                 |
| 200RH   | -                 |
| 300RH   | B, C              |
| 100LH   | -                 |
| 200LH   | -                 |
| 300LH   | E, F              |
| 100     | -                 |
| Manual Welding | H       |
| QG3     | D, G, I           |

Table 4 Precedence diagram for the new layout of production T7AX

On the other hand, a new simulation shown in Fig. 10 was created based on a precedence diagram to shows the process sequences for redesigned layout of the workstation. Based on the data collected, there is a total of 12 workstations where operators at QG1, QG2 and QG3 have lesser workload compared to other operators. For this reason, the combination of three inspection process into one station was suggested as a solution in order to reach optimum production line planning.

![Line Balancing Improvement](image_url)

Fig. 9 Line balancing after proposed solution

![Simulation logic model proposed solution](image_url)

Fig. 10 Simulation logic model proposed solution.
Based on the results of simulation model for existing production line, the output of the finished products is 387 units in total per shift with the labour productivity is 3.07. The same way, the simulation result from the new simulation model for the redesigned number of workstations show that the total outputs are 351 units per shift where the labour productivity is 4.17 with two operators while for one operator is 8.36. In addition, the salary for operator is RM4 per hour based on information given by the manufacturer. Table 4 shows the productivity before and after line balancing improvement. Based on the Table 4, the management is enabled to make better decision making to aim optimum capacity.

| Table 5 Productivity matrix |
|-----------------------------|
| **Productivity Matrix**     |
| **Resources**               | **Scenario 1** | **Scenario 2** | **Scenario 3** |
| Inspector 1                 | ✓              | X              | X              |
| Inspector 2                 | ✓              | ✓              | X              |
| Inspector 3                 | ✓              | ✓              | ✓              |
| Productivity (unit/RM)      | 3.07           | 4.17           | 8.36           |
| Percentage difference       | -              | 35.8% (up)     | 172.3% (up)    |

Based on the simulation model of line balancing conducted at T7AX, three scenarios have been suggested to verify the capability of DSS in dealing with tactical and operational planning decisions. However, scenario 3 was selected by the management as a best solution and where the productivity increased to 172.31%. Compare to the scenario 2 the productivity just up to 35.8% while scenario 1 consumed maximum 3 operators.

IOT is key technology for data perception and collection from Andon system. It can be incorporating into simulation model for decision making of process improvement. Through the simulation results, the managements are enabled to predict the output based on the given scenarios. Accurate and fast decision is obtained in this case study where the data is collected from actual lean production line.

6. Conclusion

Concluding, this paper shows an approach which enables companies to fully understand the changes and potential of DSS, in order to develop long term strategies to fit new business challenges. Interconnection of sensor devices providing the ability to share information across platform through Andon system, developing a common operating picture for enabling innovative applications. The proposed framework of DSS enables manufacturers to get benefits in communication based on real time data output. The adaptability and usability in real production give good impact to manufacturers implementing Industry 4.0 environment. From the proposed framework, enable policy makers to convert DA become meaningful through simulation for fast decision making. The proposed approach was adopted to solve line balancing issue through embedded system between Andon and simulation was succeed. Some recommendations were suggested in future, the study shows that Andon system is no longer stand alone to support LM compared to previous. On the other hand, through this approach, LMT tools such as Overall Equipment Effectiveness (OEE), single minute Exchange of Dies (SMED), Kaizen, 5S, Value Stream Mapping (VSM), Jidoka, Kanban, Line Balancing can be applied for continuous improvement once Andon system is available to capture cycle time of the processes. Besides that, costing system is also can be calculated into the simulation model once the real data is acquired. It is to ensure that the design of the system meets numerous demands. Apart from that, system standardisation for the DSS is needed to allow documentation as a standard procedure for a network between the connected elements.

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