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Design and Development of Industry 4.0 Smart Lean Kaizen Manufacturing: A Case Study on Extrusion Line of Vacuum Hose

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Lean manufacturing, lean kaizen, Industry 4.0, autonomation, smart manufacturing

Abstract

This paper investigates a manufacturing company's extrusion process in demonstrating the value-added benefits of Lean Kaizen Approaches through autonomation and adoption of Industry 4.0 technologies. This study proposes using Lean Kaizen Approaches, SolidWorks, Arduino and IR4.0 sensors in designing, developing and adopting a four-phase framework for Lean Kaizen continuous improvement from sampling and manual weighing to an automated real time weighing and segregation system of good and out of specification vacuum hose product. The findings showed that with full financial and non-financial support from top management and the whole organization's willingness to transform the company to Smart Manufacturing, the automated unmanned weighing and separation system have been able to achieve the company's intended target in using no manpower to weigh the hose and has a real time monitoring system of all vacuum hoses extruded. This study has contributed to the improvement of extrusion line operations using an unmanned operator for the weighing system as well as collecting data on vacuum hose weight and length in real time. By incorporating Lean Kaizen Approaches and Industry 4.0 technologies, the company enhanced operational efficiency through automated weighing and separation system, manpower reduction and provide greater customer satisfaction as it is guaranteed that all vacuum hose weight and length meet the required specifications. Further research is needed to explore the applicability of the proposed approaches in different manufacturing and Industry 4.0 contexts to investigate additional factors influencing the successful implementation of Smart Manufacturing.

1. Introduction

Kaizen which is a continuous improvement process is a fundamental component of lean manufacturing methods that focuses on waste elimination, productivity improvement and continual improvement in organizational activities [1]. Smart manufacturing, on the other hand, encompasses a range of technologies and solutions that, when implemented in a manufacturing ecosystem, optimizes the entire manufacturing process and increases overall profitability. Smart manufacturing incorporates tools such as artificial intelligence, block chain, industrial internet of things, automation, condition monitoring, and cybersecurity [2]. The concept of smart manufacturing aligns with the Industry 4.0 trend towards automation and data exchange in technology and processes [3].

The case study is a company established in 1999 and produces appliances such as plastic hose parts for vacuum cleaners, manufacturing of plastic and metal air-conditioning components as well as supplying automotive upholstery fabric materials and synthetic leather. The objective of this case study is to reduce the dependency on the manpower in weighing the vacuum hose as well as to collect data on the weight and length of the extruded vacuum hose. The company is moving towards achieving their mission which is to sustain profitable growth through lean and smart operations by focusing on customers' quality, cost, and delivery requirements as well as on employees' safety and morale [4].

Due to the impact of the pandemic, the case study company is currently facing manpower deficiency and is depending on the external workforce from Indonesia, Nepal and Bangladesh for operators working in the extrusion line. Thus, the company crucially requires interventions in Lean Kaizen to transform the company into a Lean Smart Manufacturing Factory. The change towards productive and value added practices in the company is much more needed, especially in their efforts to grow and expand the business.

This study is significant in providing optimization of processes and manpower through the usage of Lean Kaizen Approaches in establishing a Smart Manufacturing Company. This is a pilot case study for the company and will be the evidence of the impact of Lean and Industry 4.0 approaches that can help to improve the productivity and performance of the company in terms of manpower reduction as well as real time monitoring and management of data. In addition, this study is an industrial oriented applied research work that shows the symbiosis of collaborations of university and industry in sustaining business excellence as well as developing the nation.

2.1 Lean Manufacturing and Toyota Production System

As manufacturing industries face increased pressure to meet the dynamic nature of customer demand in today's competitive world, lean manufacturing is a key tool to greatly reduce this strain. Toyota Motor Corporation, a Japanese automaker, is where the idea of lean manufacturing (LM) first emerged [5]. Taiichi Ohno, Toyota's chief engineer, created the Toyota Production System (TPS) in 1988 as a business strategy aimed at making the most of the limited resources available in Japan to ensure the company's growth and survival [6]. The LM is concentrated on the elimination of any type of waste, aiming to provide the precise quantity of products required by clients in perfect time and with excellent quality. This is in contrast to the U.S. manufacturing model, which is operated with many different machines and had a large amount of intermediate products [7].

Value stream mapping, 5S, Kaizen, line balancing, just-in-time, poka-yoke, autonomation (jidoka), kanban, total preventive maintenance, and single-minute exchange of die are some of the lean methodologies that are reportedly being implemented in industries to enhance efficiency, reduce overall cycle time, reduce lead time, non-value-added time, set-up time and number of operators required [8], [9]. Companies recognize lean practices as a valuable methodology for improving efficiency in manufacturing processes. The fundamental principle underlying the success of lean manufacturing is the identification and elimination of manufacturing waste from the system such as underutilized manpower, waiting and motion in boosting operational performance by improving production planning and reducing waste by eliminating non-value added activities [10]. In the current industrial environment, Industry 4.0 is evolving rapidly. Industries have used several cutting-edge technologies, including smart manufacturing, artificial intelligence, the internet of things, and cyber-physical systems. Real-time data from manufacturing processes can be obtained using these techniques, allowing for faster and more precise outcomes. To address the production problems encountered in operations management, lean has been revolutionized, and the integration of lean with smart manufacturing has emerged [11]. Implementing lean principles and smart manufacturing together enables the management system to create an industry 4.0 intelligent decision-making system [12].

2.2 Industry 4.0

Production model disruption has historically been linked to industrial revolutions [13]. It started with the development of steam engines, continued with the use of electricity and culminated with the Digital Revolution, which brought about the use of computer technologies in production settings. The speed of technology advancement is altering how society functions and interacts with the environment [14]. The Fourth Industrial

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Revolution attempts to increase value chain efficiency and accelerate innovation in manufacturing processes [15]. By placing a strong emphasis on process flow automation, Industry 4.0 promotes product and service customization and flexibility, which ultimately improves profitability towards smart, lean, green and sustainable manufacturing [16]-[19]. When it comes to developing a smart and open manufacturing platform for the data application of an industrial network, Industry 4.0 could be considered a new production stand [20]. Smart factories will be able to monitor real-time data, track product status and positions, and maintain instructions for controlling production processes by converting common machines into self-conscious and self-learning equipment to improve their overall performance and management [21]. Low code algorithm and platform are being used in the implementation of Industry 4.0 environment in automation and digitalization [22], [23] for quality control [24], and inventory management system [25].

2.3 Kaizen Practices

The main objective of Kaizen is to improve effectiveness of operations [26]. Numerous studies conducted in different countries have demonstrated that Kaizen has gradually gained worldwide acceptance and can easily and effectively combine various waste elimination tools and techniques [27]. Van Scyoc studied numerous quality improvement methods and tools, including Kaizen and poke-yoke, in order to boost fieldwork team's efficiency and the leadership's commitment to process safety. He examined the strategies used to increase product quality while maintaining process safety [28]. In this study, autonomation or *Jidoka* in Japanese is about automation with human intelligence [29]. *Jidoka* is used to provide an automated weighing and separation of extruded vacuum hose. In this study, *Jidoka* is a lean manufacturing concept used in which machines detect abnormal conditions of the extruded vacuum hose automatically and separate the abnormal weight of the extruded hose.

2.4 Implementation Barriers of Lean Manufacturing and Kaizen

Lean implementation challenges might differ from one country to another, depending on the country's geography and organizational work cultures [29]. Ineffective organizational practices, a disorganized structure, and a lack of communication cause numerous losses and wastes, which ultimately renders the organization ineffective [30]. Since waste elimination and zero defects are primary goals of LM, lean operation can be achieved by increasing lean awareness, identifying lean drivers, removing lean barriers, developing a better organizational culture through effective leadership, preparing cross-functional teams, implementing suggestion schemes, rewarding and appreciating employees, adopting innovations, and implementing an efficient information system based on a thorough understanding of lean principles [31]. A framework was developed by Carmignani and Francesco to highlight important issues that can prevent lean from being adopted in the luxury apparel industry. Application of the proper tools and procedures, top management, and employee relationships are all necessary for lean implementation [22]. Following the installation of LM, the organization's various systems and processes are examined to identify areas for ongoing improvement [25]. There is still no systematic process for implementing lean in the industrial world of today. Furthermore, as opposed to the organization's logical reasoning, the optimal lean strategy selection is dependent on rational thinking [32].

3. Methodology

The research methodology for this study involved four phases of Lean Kaizen Continuous Improvement Approaches which are Phase 1: Data Collection, Phase 2: Current Works Standardization Analysis, Phase 3: Future Kaizen Works Standardization and Phase 4 to improve work and standardization analysis.

3.1 Phase 1: Data Collection

Phase 1 is the data collection phase. Phase 1 starts with *Genba, Genchi and Genbutsu* which are the key principles of the Toyota Production System. The Lean Principles and Toyota Production System encourages the workers to go and see the real place or to go and observe (*Genba*) while *Genchi* and *Genbutsu* is to see, hear, touch and feel the problem area or the work place to obtain accurate and real time data and information as well as identifying the 8 types of waste available at the research case study area. The 8 types of wastes that have been analysed are transportation, inventory, motion, over-processing, overproduction, defects and underutilized skills and talents. From this, the next step was understanding the current condition and work sequence for operators through the documents and records review such as Standard Operation Procedure, Standard Inspection Procedure, Machine Operation Procedure, six months customer orders records (plan and actual quantity), the current Standard In-Process Stock and Standard Packaging before recording the cycle time for the extrusion line.

3.2 Phase 2: Current Works Standardization Analysis

Phase 2 is about defining the process time measurement study by using current Material and Information Flowchart (MIFC) or Value Stream Mapping (VSM) in defining the machine and process as well as man and machine synchronization. In this case, we decided on VSM to examine, create, and oversee the information and material flow needed to deliver a product to a client.

3.3 Phase 3: Design and Develop Smart Extrusion Weighing System

In Phase 3, Solidwork software is used to design the smart extrusion weighing system that will automatically weigh each extruded vacuum hose and separate between the in and out specification vacuum hose.

3.4 Phase 4: Validation of Improve Work and Standardization Analysis

In this phase, monitoring of the operations of the Smart Extrusion Weighing System has been conducted in ensuring smooth, lean and sustainable operations. Input and feedback from the users are collected for continuous improvement especially in monitoring the quality of the extruded vacuum hose and the cycle time reduction from the unmanned and automated weighing and segregating system.

4. Results and Discussion

The results obtained below are based on the 4 phases mentioned in the methodology. Data was collected, analyzed and used to solve the problems that occurred. All of the data and solution finally drove this study to the final phase which is the completion of the Smart Assembly Line System.

4.1 Phase 1: Data Collection

The end of extrusion line in Fig. 1 shows that there is no automation system involved whereby a plain bent aluminium plate has been used to drop the hose produced from the conveyor to the temporary storage box.

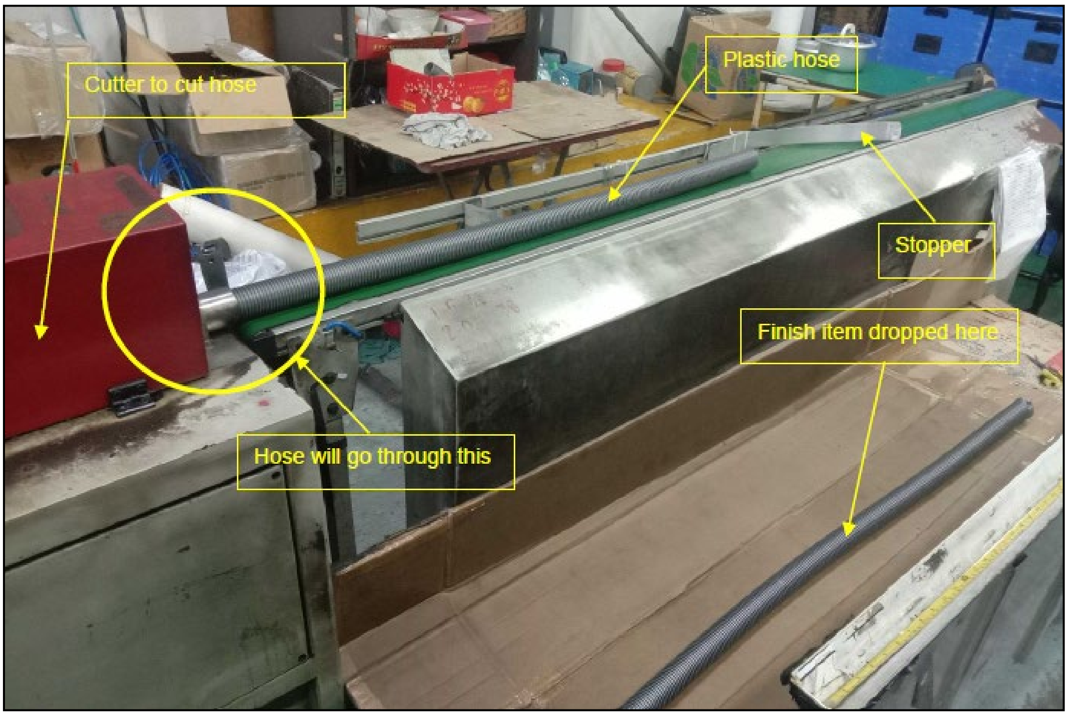

Fig. 1 *The previous extrusion line system with no automated weighing and separation system*

4.1.1 Understanding the Specification Dimension of the Vacuum Hoses

There are 5 variations of the vacuum hose length; 1.3, 1.4, 1.5, 1.6, 1.8; all units in meter while the average weight of the vacuum hose from 3 samples are as indicated in Table 1. The operators of the machine will take one or two hose samples from 50 vacuum hoses extruded to be checked manually using a measuring tape (for the length) and weighing scale (for the weight).

Table 1 *The dimension of the vacuum hoses (length and weight)*

Length (m)	Weight Sample (kg)			Average Weight (kg)
	No.1	No.2	No.3	
1.3	0.233	0.222	0.222	0.222
1.4	0.236	0.236	0.236	0.236
1.5	0.251	0.251	0.251	0.251
1.6	0.268	0.268	0.268	0.268
1.8	0.300	0.301	0.300	0.300

4.1.2 Understanding the Extrusion Process and the Cycle Time

The vacuum hose extrusion processes start with mixing the substances, moulding into extruded shape, pressing the hose into the desired shape and cutting the hose according to the specified length as illustrated in Fig. 2. The time taken for the extrusion process is in average as illustrated in Table 2.

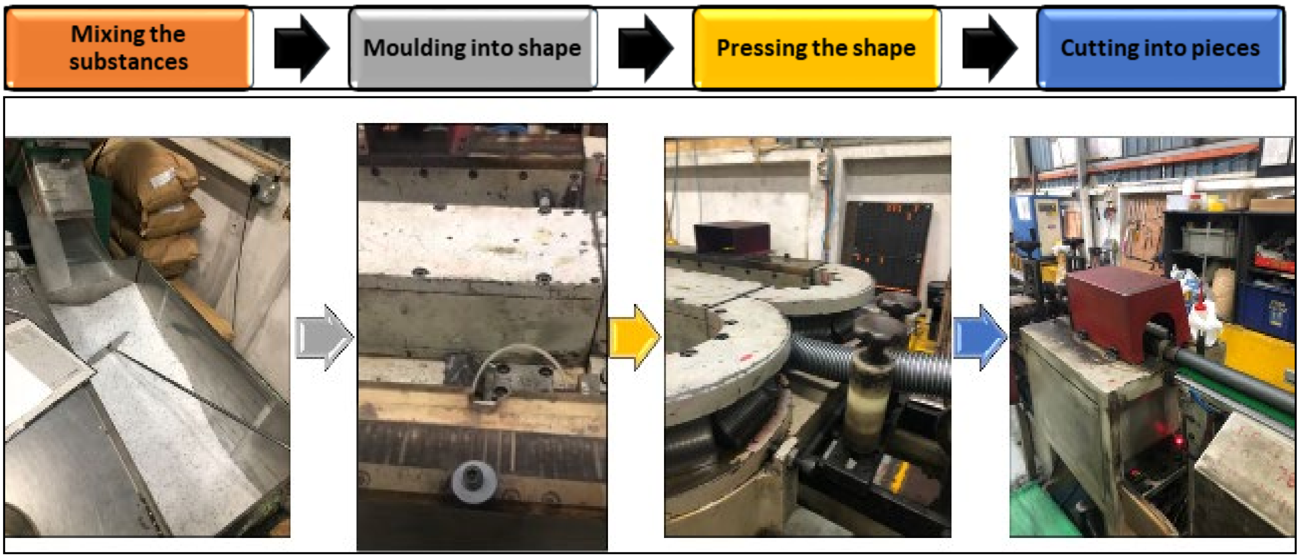

Fig. 2 *The extrusion process (start with this at phase 1)*

Table 2 *The time taken for extrusion process*

Date	Day	Morning (s)	Afternoon (s)	Evening (s)	Average (s)	Total Average (s)
20/02/23	Monday	95	90	95	93	
21/02/23	Tuesday	93	93	90	92	
22/02/23	Wednesday	92	93	92	92	
23/02/23	Thursday	88	92	93	91	92
24/02/23	Friday	95	92	88	92	
25/02/23	Saturday	95	93	-	94	

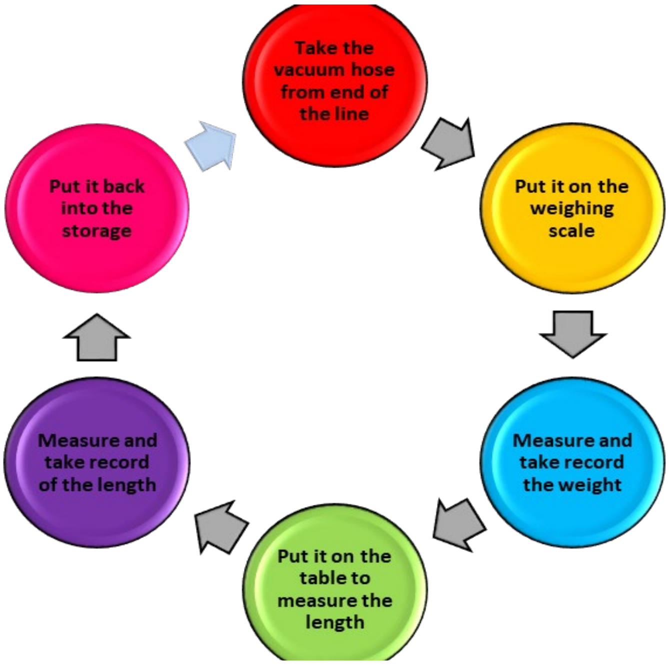

Fig. 3 *The quality control process*

The quality control process of weighing and measuring the length of the vacuum hose is illustrated in Fig. 3. The time taken for manually weighing and measuring the length of the extruded vacuum hose from 3 samples for each day is as tabulated in Table 3.

Table 3 *The time taken for quality control*

Day	Sample 1 (s)	Sample 2 (s)	Sample 3 (s)	Average (s)	Total Average (s)
1	35	33	38	35	
2	38	38	37	37	
3	37	37	35	36	36
4	35	38	37	36	
5	35	37	38	36	

4.2 Phase 2: Current Works Standardization Analysis

Fig. 4 illustrates the Value Stream Mapping (VSM) of the current extruded vacuum hose. The order starts when a call is received from a client to the production controller who manages the orders from the client. Then, production controller will first check the ready stock in inventory and contact the supplier to get all the material needed to fulfil the requirement of the clients' orders before mixing process, extrusion process, quality control and assembly process. The orders will be delivered to the clients each month as required by the customers. This VSM is crucial to analyse where Kaizen implementation should be applied. As shown in the figure, there are 3 points that should be improved for the mean time which is the production control, quality control and assembly process. However, this study only focuses on the quality control process that requires improvement.

4.3 Phase 3: Design and Develop Smart Extrusion Weighing System

For Phase 3, the Smart Extrusion Line system had been designed using Solidwork. This design has been approved by the client based on the design itself, material used and the safety protocols. Fig. 5 to Fig. 7 describe the early design of this Smart Extrusion Line System from the sketch, draft and finally translated into Solidwork format. This shows how the idea of the design has been developed from raw idea and hand sketch into the formal and Computer Aided Design (CAD).

4.4 Phase 4: Validation of Improve Work and Standardization Analysis

Phase 4 is to determine whether the problems faced by this company and factory is solved or not. It started by waste identification which is time, cost and movement followed by implementation of new method of Smart

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Extrusion Line. After the work is done, there will be follow-up steps to monitor the progress of the machine to ensure the machine is completely working in good condition.

To validate the improved work and standardization analysis, Fig. 8 to Fig. 11 illustrate the flowchart of the system and machine working process. The weight and length measuring in Fig. 9 and Fig. 10 validate the improvisation in work from staffs or operators work to machine work. This would minimize the workload by the operator or cut off the need of a human operator at the end of the extrusion line for quality control. Fig. 11 shows the flow of buzzer to buzz when desired number of hoses needed to be produced is achieved by counting them using an automatic counter.

4.5 Final Phase: Completion of Smart Extrusion Line System

With the input obtained from Phase 1 and Phase 2, the new smart weighing and separating extrusion system has been designed by using Solidwork software, fabricated and installed with sensors and IoT as well as monitored in real time as illustrated in Table 4.

Fig. 12 shows the complete design of the Smart Extrusion Line System. Aluminium profile and stainless steel sheets were used as the base, foundation and stand of this machine. For the IoT parts, Arduino Uno R3 takes the role as the brain and the controller of the circuit. Wheel encoder and load cell are crucial parts where both of them are entrusted to take, calculate and record both length and weight of the hose produced. Movement sensors are also used to detect the presence of the hose coming out from the cutter through the conveyor and linear actuator is the one which moves the wing of reject items.

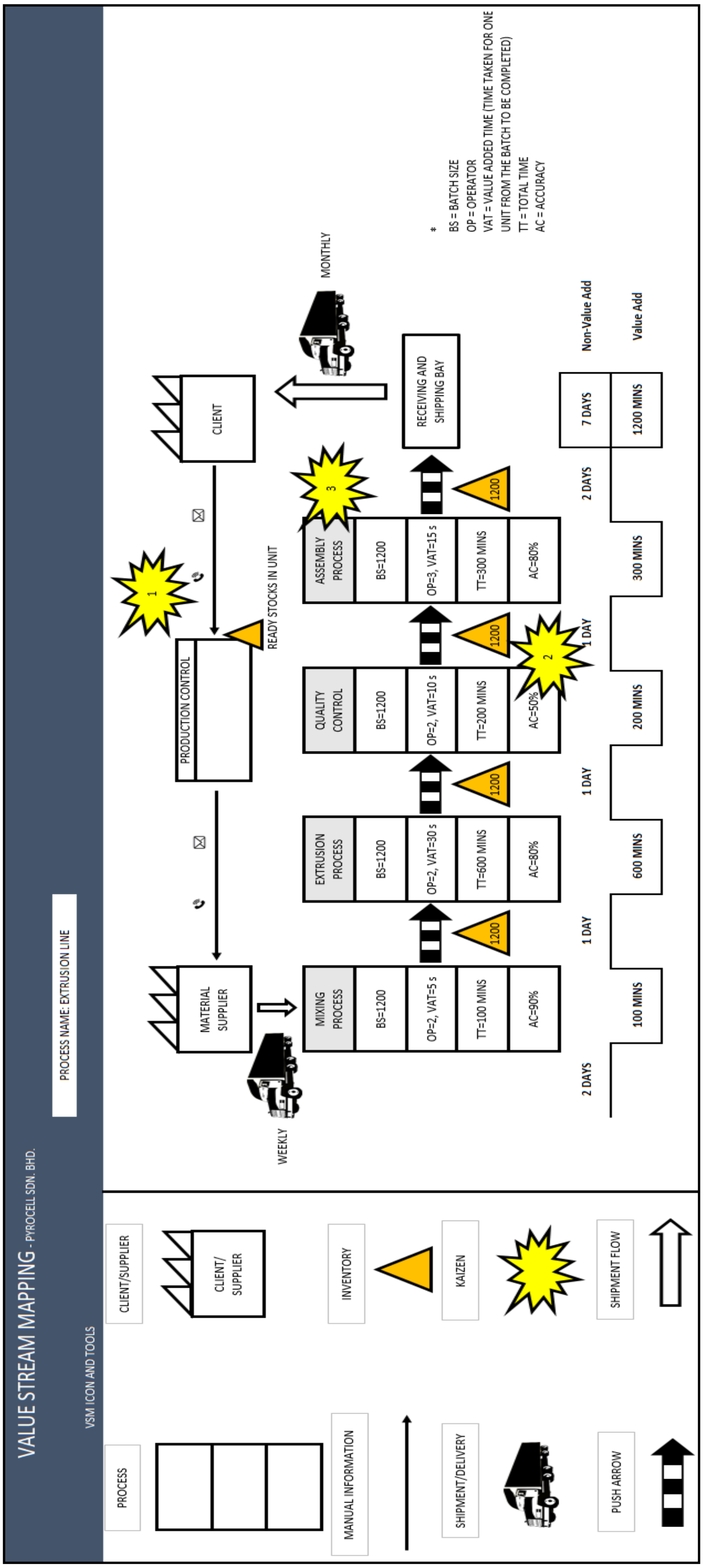

Fig. 4 *Current value stream mapping*

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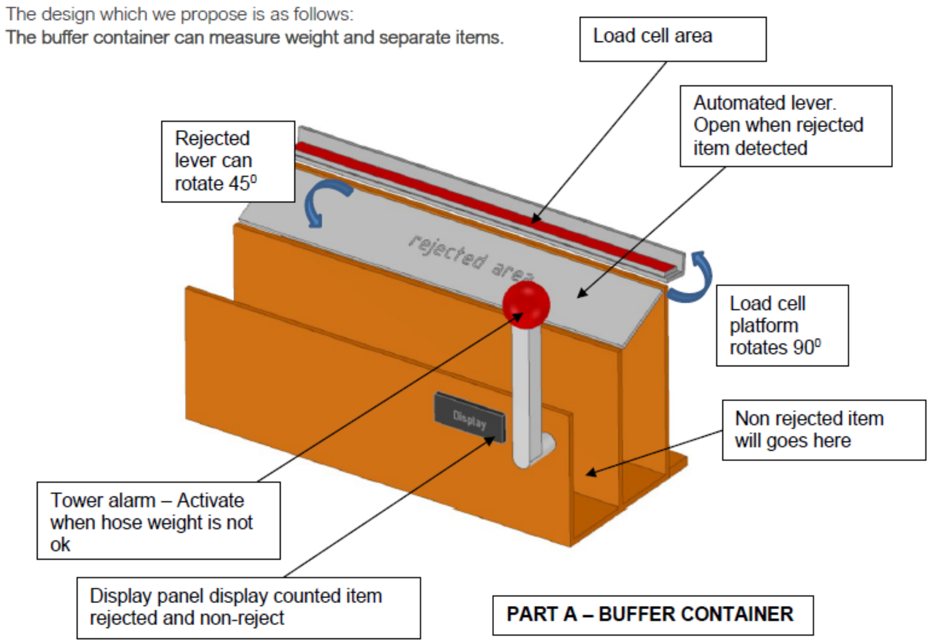

Fig. 5 *The proposed design - early design by sketch*

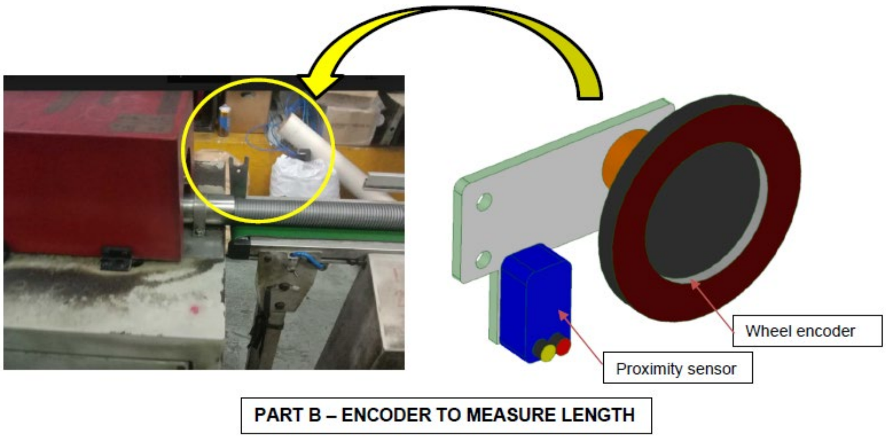

Fig. 6 *Wheel encoder and proximity sensor designed by sketch*

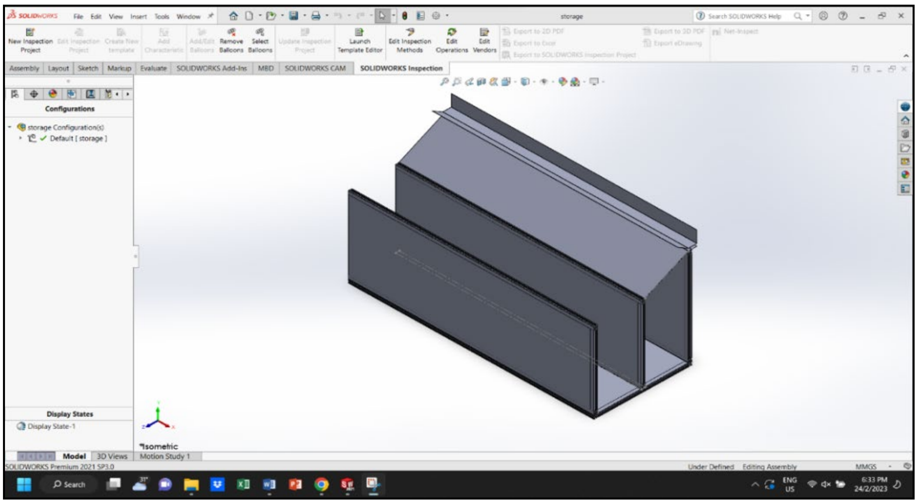

Fig. 7 *The early stage proposed design of Smart Extrusion Line translated into Solidwork format*

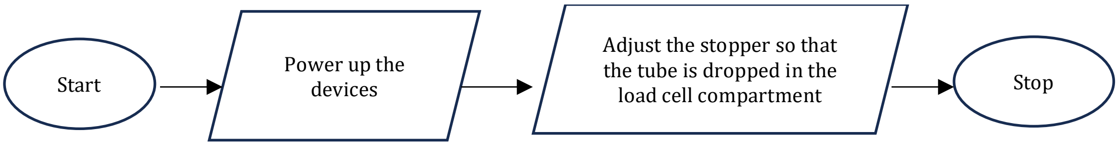

Fig. 8 *Flowchart (machine setup)*

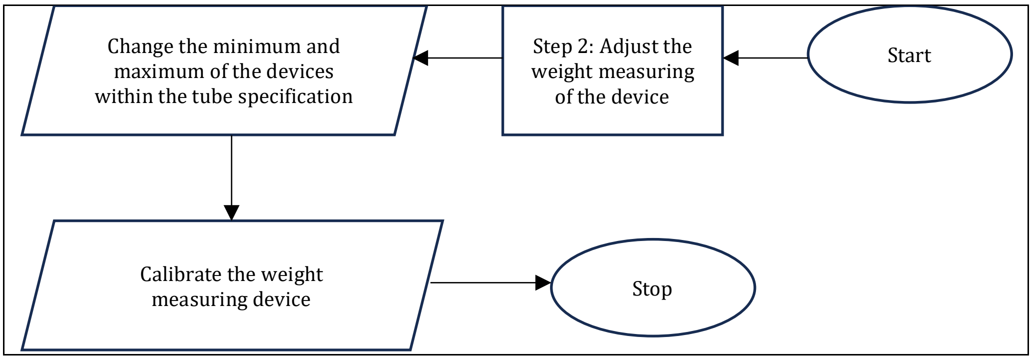

Fig. 9 *Flowchart (weight measuring)*

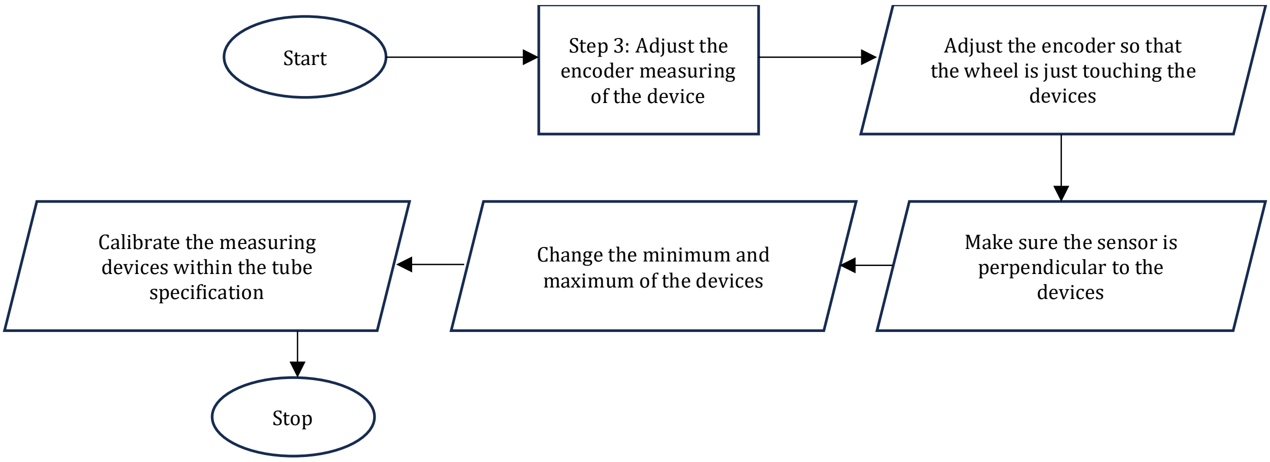

Fig. 10 *Flowchart (wheel encoder measuring)*

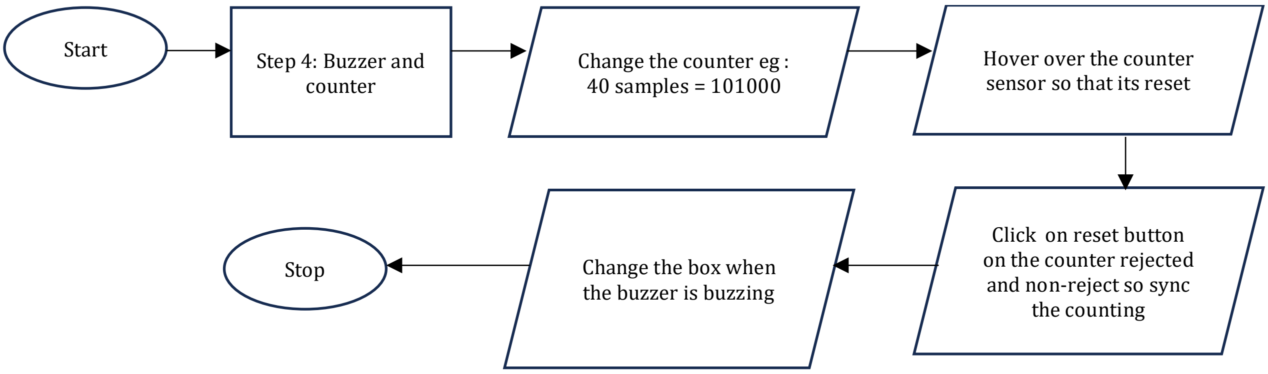

Fig. 11 *Flowchart (buzzer and counter)*

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Table 4 *Components and parts*

Name	Load cell	Wheel encoder	Sensor	Arduino mega	Linear actuator	Aluminium Profile
Components/ Parts						

Fig. 12 *Smart extrusion line system*

Fig. 13 *The machine installed at the end of the extrusion line in the factory*

After the Smart Extrusion Line machine has been installed as shown in Fig. 13, the data of time taken had been retaken and compared with the data before the use of the machine. Table 5 and Table 6 show the manual weighing of extruded vacuum hose (before Kaizen) and the time taken by Smart Extrusion Line System (after Kaizen). A huge difference is shown in the result where more than 80% of the time spent on the previous system used is cut off by the usage of the new machine. Fig. 14 and Fig. 15 show the illustrated differences on the cut off time when Smart Extrusion Line System was implemented and the end of the extrusion line of the vacuum hoses.

Table 7 shows that there are a lot of impacts of this study that could benefit the factory and company in terms of reductions, quality control delivery and morale.

Table 5 *Manual weighing of extruded vacuum hose (before Kaizen)*

Hose	Day 1 (s)	Day 2 (s)	Day 3 (s)
1	25	29	22
2	23	26	23
3	27	25	25
4	28	24	25
5	22	26	23
6	25	26	25
7	24	27	22
8	25	24	25
9	25	26	28
10	23	25	25
Total Time	247	258	243
Average Time	24.7	25.8	24.3

Table 6 *Time taken by automated weighing and separation system (After Kaizen)*

Hose	Day 1 (s)	Day 2 (s)	Day 3 (s)
1	5	4	6
2	5	5	5
3	5	4	5
4	4	5	4
5	6	5	4
6	4	4	4
7	6	4	6
8	5	5	5
9	4	5	4
10	5	5	5
Total Time	49	46	48
Average Time	4.9	4.6	4.8

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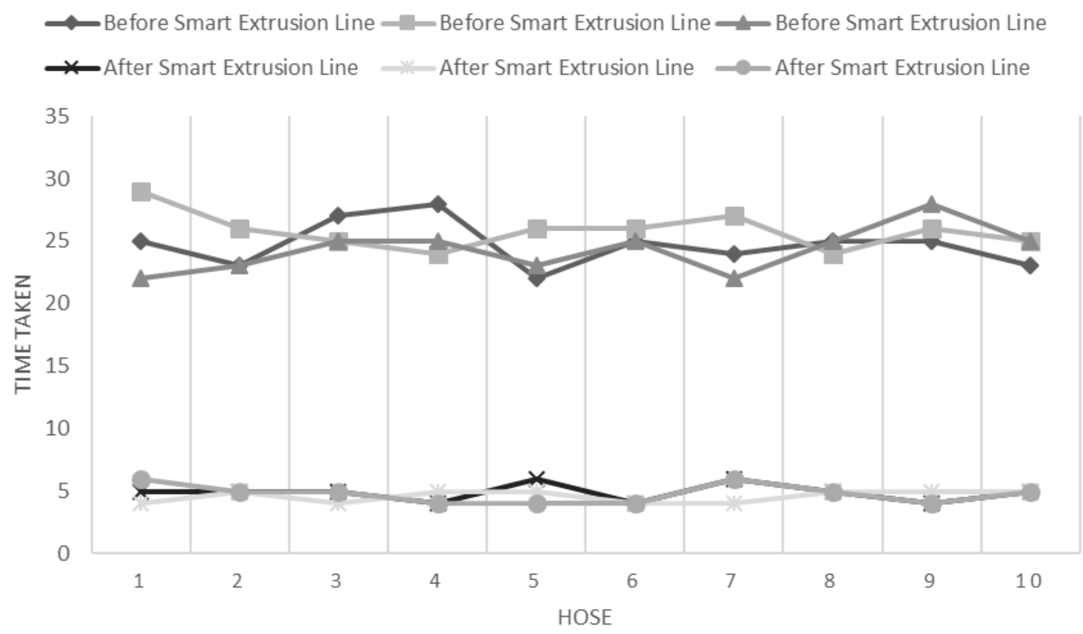

Fig. 14 *Time taken vs hose graph*

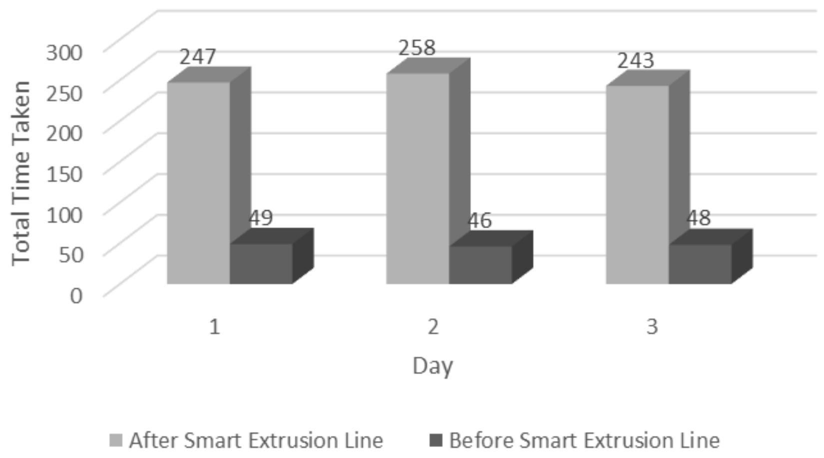

Fig. 15 *Total time taken vs day graph*

Table 7 *Impacts of this study*

Type of Impact	Benefits
Cycle time reduction	80% cycle time reduction.
Manpower reduction	From 2 operators to zero operator
Quality control and assurance	Increase customer satisfaction by providing 100% assurance of meeting the specifications
Cost reduction	Manpower cost, paperless quality record, reduce reject cost
Delivery	On-time delivery and earlier delivery of higher quality
Morale	Manpower can be relocated to other value-added jobs that can bring more profit to the company

5. Conclusion

This is an industrial oriented applied research study that requires strong collaboration between industry and university. This study comprises Lean Kaizen Approach, design and IR4.0 technologies such as IoT and real time monitoring dashboard, sensors and automation involves integrated mechanical and Lean Industry 4.0 knowledge in producing highly skilled talent that can cater the future need of Industry 4.0 smart engineers and managers. The outcome of this research can be used for other manufacturing systems that hold the same type of waste studied and the same issues. It is hoped that this study will be a starting point of more smart manufacturing industrial and university research collaborations that will bring benefits to the nation and the global sustainable development goals achievement. The outcome of this study in terms of reduction in cycle time, manpower and cost as well as increase in customer satisfaction and consistent on-time delivery in Lean Manufacturing [33] are other benefits that are gained as the results of automation of weighing and separation system such as that of the Smart Extrusion Line.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Noor Azlina Mohd.Salleh, Afiq Durrani Azli;* ***data collection:*** *Afiq Durrani Azli, Joshua Goh, Goh Wai Kah, Mah Lai Ching;* ***analysis and interpretation of results****: Noor Azlina Mohd.Salleh, Afiq Durrani Azli, Falah Abu;* ***draft manuscript preparation:*** *Noor Azlina Mohd.Salleh, Afiq Durrani Azli, Mohd. Hazri Mohd.Rusli. All authors reviewed the results and approved the final version of the manuscript.*

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