Productivity assessment studies in Solenoid valve manufacturing Company – A Case Study

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Abstract

Lean organizations have dual advantages of increased flexibility and increased response time. Due this reason, many industries the world over have been transitioning themselves to become lean. An effort has been made in this article to present how by using the value stream mapping (VSM) tool different forms of waste can be identified, methodically, in a solenoid valve manufacturing company and also how it has helped in improving the productivity of the organization. In this article, the current value stream map (CS map) is drawn for the manufacturing line. The current value stream map shows the different forms of wastes in the production line. The value stream map also shows the production lead time. The CS map is then evaluated and the future value stream is then proposed.

Keywords

Value stream mapping, Solenoid valve manufacturing Plant, Productivity improvement, Lean system, Lean Production System

1. Introduction

Manufacturing organizations using conventional means like mass production cannot meet the present-day customer expectations concerning product variety. The present-day customer expects a high-quality product in a short time. Also, the expectations vary from customer to customer. To be competitive, modern-day manufacturing demand reduced batch size, increased variety of products, and very low response time. These demands can be met only if the organization is lean. Hence, many companies are trying to become lean. Many researchers in the recent past have studied, application of lean concepts and tools in many domains. But, as for the authors' knowledge goes, not many have studied the application of lean tools in a solenoid valve manufacturing company. In this context, the present research work, where an effort has been made to apply value stream mapping for identifying the different forms of waste and thereby improving the performance of the organization, assumes special significance.

2. Literature review

Lean philosophy has the advantage of focusing on value creation by eliminating waste has resulted in many companies transforming to lean (Peters 2010). Traditional manufacturing companies were practicing Push, where the raw materials were pushed into the system by looking into the marketing forecast. That is, the products are made even when there are no orders. This has resulted in excess inventories- raw material, in-process and finished product. Excess inventory has resulted in investment tied-up and also resulted in inventory carrying costs. To overcome these drawbacks, companies have started implementing lean. Whereas, companies practicing lean concepts and tools, will start manufacturing products only if there is an order by a customer. Thus, in lean companies' raw materials are pulled into the system. The pull system is designed to minimize the different types of inventory present in the system.

Toyota, the pioneers in implementing lean concepts and tools became very successful (Womack 1990). This has motivated many companies to transform to lean. Womack et al. (2010) first used the term 'Lean'. Slowly, many companies other than manufacturing were also started practicing lean concepts to reduce waste and improve productivity (Staats et al. 2011, Sawhney et al. 2005, Esain et al. 2008, Stone 2012, Paez et al. 2005). Waste exists in many forms and many places in an organization (Nicholas, 1998). Waste is defined as any activity for which a customer is not going to make payment (Russell and Taylor 2006). Russell and Taylor (2006) have defined non-value

(NVA) added, essential but non-value (ENVA) added, and value-added (VA) activities. NVA for which the customer is not making any payment. Examples of Non-value added but essential activities include set-up time and change-over-time. Similarly, the transportation of raw material from one machine to another machine in a manufacturing line is an example of essential non-value-added activity. By performing essential but non-value-added activity do not receive any customer payment. Hence, the objective must be to reduce them as soon as possible. Processing time on a machine is an example of value-added activity. One of the purposes of using a VSM is to identify the bottleneck in a manufacturing line. As the efficiency of a line is determined by the slowest machine in the line. The first step in waste reduction starts with identifying and classifying the activities into one of these three categories. For identifying, non-value-adding activities the lean framework provides tools (viz. 5S, SMED, Single piece flow, Poka-yoke, Kaizen, etc.) (Kaynak 2003, Womack et al. 1990, Rother and Shook 1999, Mohanty et al. 2007). The purpose behind using lean philosophy is to eliminate waste and help in value creation for the customer. Lean production also has the merits of craft and mass production (Kaynak 2003). Lean philosophy strongly believes in the involvement of people. That is, for achieving maximum benefit, active people's participation is a must. Many researchers have started using VSM for eliminating different types of waste (Emily Lee et al. 2014, Dorota and Powel 2019, Barot et al. 2020, Grewal and Singh 2006, Hines and Rich 1997). Grewal et al. (2006) have applied the value stream mapping tool in an automotive company, for identifying and then reducing all forms of waste. Singh et al. (2020) have also developed schemes and metrics for measuring the leanness of a manufacturing company.

Researchers have also applied VSM as a redesigned tool within manufacturing industries (Womack and Jones 2010, Serrano et al. 2008). Zheng et al. (2008) have reported having achieved the cycle time reduction by applying lean tools. Researchers (Chitturi et al. 2007) have also explored things like the location of supermarkets in the value stream map, calculating takt time, challenges in handling several product varieties. Researchers (Sahoo et al. 2008, Wong et al. 2012) have applied VSM in the forging industry for waste reduction. They constructed and evaluated the CS map and then constructed an FS map. Vinod et al. (2011) have reported having done the leanness assessment by using a conceptual model using a fuzzy-based approach. They have classified leanness into (a) management responsibility (b) production management (c) workforce leanness (d) technology leanness (e) manufacturing strategy leanness. Leanness helps an organization in becoming more responsive to customer orders. Wong et al. (2012) have been reported to have designed and developed a scheme for measuring leanness. Vinod et al. (2011) have designed a new scheme for assessing the leanness of a manufacturing company.

Almomani et al. (2014) have designed a leanness assessment model that evaluates the manufacturing company in different dimensions- staff issues, inventory, suppliers, maintenance, safety, safety, manufacturing, and customer. They had used a questionnaire-based method for assessing the relative score of each dimension. Wen Li et al. (2017) have proposed a scheme, using an energy value stream mapping tool for addressing complex energy, material, and time dimensions, while manufacturing a product. They have claimed to have demonstrated the usefulness of their scheme, in an Australian recycling company. They had used Sankey diagrams for identifying bottlenecks and inefficiencies in the manufacturing company. Philip Roh et al. (2019) have worked on improving the efficiency of the Information stream of a manufacturing value stream, in a manufacturing company. They have proposed five metrics for assessing the quality of the information stream. They have claimed to have tested the efficiency of the scheme on the shop floor of a product manufacturing company. They have identified wastes associated with administration and have proposed schemes for their elimination.

Many researchers in the recent past have studied, application of lean concepts and tools in many domains. But, as for as the authors' knowledge goes, not many have studied the application of lean tools in a solenoid valve manufacturing company. In this context, the present research work, where an effort has been made to apply value stream mapping for identifying the different forms of waste, comprehensively, and thereby improving the performance of the organization, assumes special significance.

3. Methodology

For the current research work, a solenoid valve manufacturing company has been selected as a case study. The company manufactures different types of solenoid valves, depending upon the customer requirements. Suppliers of the company provide coil molding. Solenoid valves are used for the automatic control of fluids in pipelines. The solenoid valve has different components- valve body, an inlet port, etc. To meet increased demands from customers, the company may outsource manufacturing certain components to the contractors. The specification of a typical solenoid valve: Pressure range: Up to 400 bar; Orifice: 0.5 mm to 90 mm; Mounting: All positions; Operating temperature: 00C to 900 C; Body: Anodized aluminum.

Different technologies are used for manufacturing solenoid valves-Direct-acting (DA) valve, Indirect acting valve, Forced lift valves. The company has an average demand for producing about 5000 solenoid valves every day. The company has gained experience by executing projects for many years. The objective of the current research work is to improve productivity in the manufacturing line of the company, by eliminating all forms of waste. The current research work consists of: construction of CS map, construction of FV Stream, Results and Discussions and Conclusion.

4. Current Value Stream Map

Figure 1 depicts the CS map for the solenoid valve production line. While constructing the value stream map for the manufacturing line, the required data was collected from the downstream side to the upstream side.

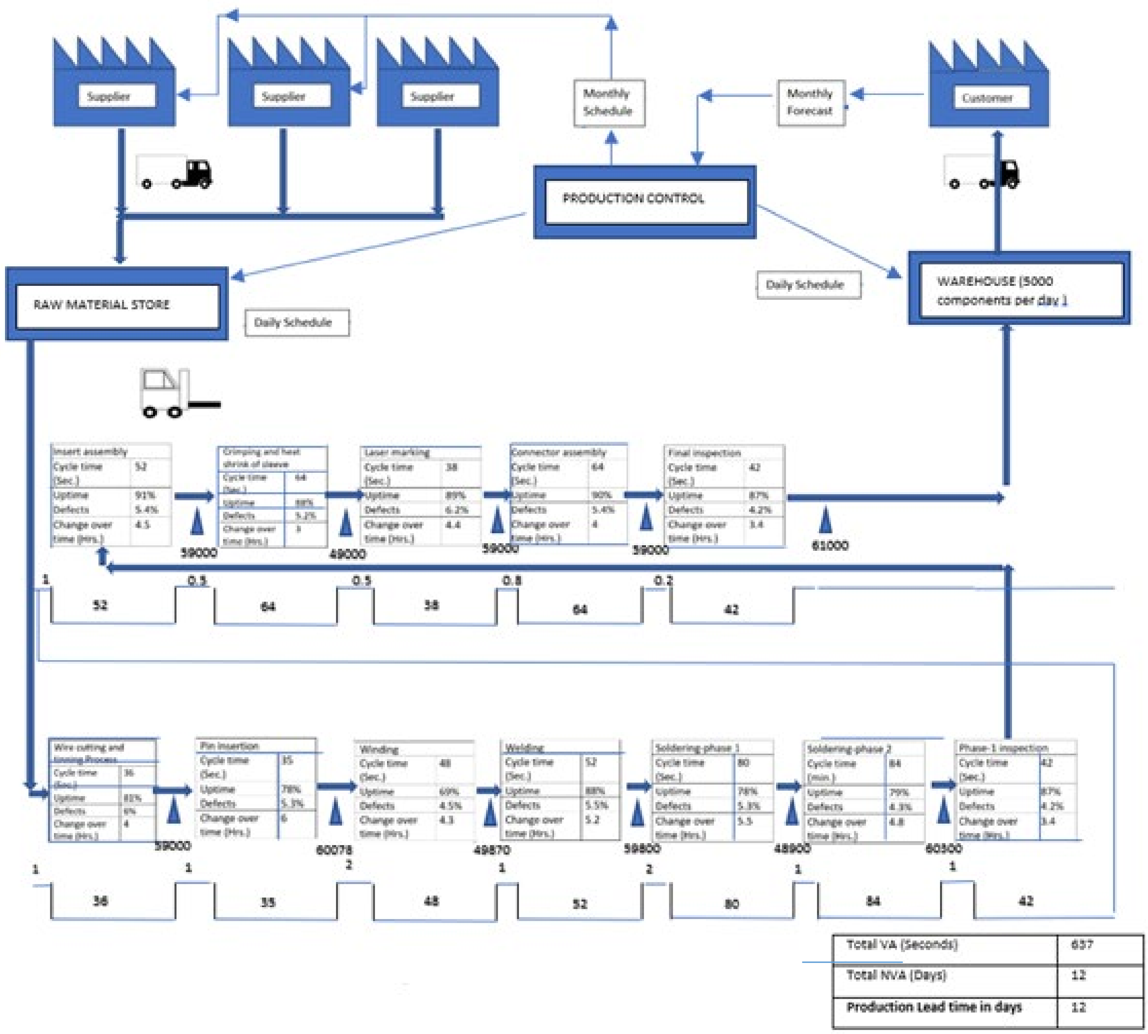

Figure 1 Current State Value Stream Map

The data collected for the research work can be broadly classified into two categories.

Material Flow assessment: To assess the productivity of the material flow in the manufacturing line data collected, at different work stations, include- set-up time, cycle time, change-over-time, defect-related data, percentage of the time machine is available for work, available time of the machine per day (e.g. single shift, two shifts, or three shifts), work-in-process storage between different work stations, the study of the movement of operators, cleanliness of work station, the safety of operators, the arrangement of tools, jigs and fixtures, and scrap disposal mechanisms.

Information flow assessment: type and nature of information exchange happening between operators, nature of communications between operator and supervisors or managers, study the quality of communication on a sample basis, Any waste/ or unnecessary communication, the result of communication.

$$Takt\ time\ = \frac{\text{(Available time)(in minutes/day)}}{Customer\ demand/day} \quad (1)$$

Available time / shift/ day = 7.5 Hours= 450 minutes; Total available time (3 Shifts / day) = 22.5 Hours= 1350 minutes; Takt time = 1350/1200 = 1.125 minutes= 67.5 seconds.

5. Future state map

Figure 2 depicts the FS map for the solenoid valve manufacturing process. In the FS map, the raw material is procured from the different suppliers on weekly basis by Milk run type of delivery mechanism. In this case, a truck will collect the required raw materials from the different suppliers in the required quantities.

6. Results and Discussions

Figure 3 shows the comparison of manufacturing processes concerning TAKT time (67.5 seconds). The black solid line represents TAKT time. The graph clearly shows that the cycle time for many processes is lower when compared to TAKT time. But in the case of Soldering processes (S1 and S2), cycle time is more than takt time (Table 1). These are the bottleneck processes. That is, these two processes cannot meet customer demand. Hence, these two processes are considered for exploring the possibility of cycle time reduction. For exploring a possibility for cycle time reduction, steps are: Machine with the highest set-up time is identified, for analysis; All sub-activities of the element set-up time/ or change over time, are identified; All sub-activities are either classified as internal / or external set-up time; All internal set-up times are analyzed for the possibility of converting them into external set-up times.

After careful analysis, it is found that soldering processes had a very high setup time. About 70% of the cycle time is consumed by the set-up time. Hence, the introduction of two fixtures is proposed. So that when the soldering process is on using one fixture, set-up for the next component is made in parallel using the second fixture. By using this arrangement, the cycle time for soldering processes could be brought down from 80 seconds to 24 seconds for the soldering process (S1). Similarly, by the same arrangement, the cycle time could be brought from 84 seconds to 27 seconds for the soldering process (S2). Table 1 shows the states of the CS map and FS maps.

From figure 2, it is evident that the VAT is minimized from 637 seconds to 260 seconds. Also, the non-value-added time in the manufacturing line is reduced from 12 days (Current state) to 4 days (Future state). This indeed is a significant reduction.

While collecting data, it is noticed that, at each workstation, there is no standardization of the work process followed. This is reflected in the variation of process quality. The average defect rate is very high (around 5%). The machine up-time is very low. The average machine up-time is about 80%. It is also noticed that there is no proper maintenance carried out.

The wire cutting process is done for cutting the wire to proper lengths. Wire cutting is done manually. This is taking more time. Measurement or Inspection of wire lengths is also done manually. The cycle time is very high (36 seconds). Set-up time is also very high (The change-over-time in the current state map is 4 hours. To solve this a new fixture is planned so that the change over time can be reduced to one hour. During the cutting process, there is a lot of scrap generation. One of the reasons, for the scrap, is that the cutting process is manual and it is prone to mistakes. Even the inspection after cutting is done manually. After analyzing the current scenario, it is suggested to use a CNC wire (WC) cutting machine. By using a CNCWC machine, cycle time could be reduced. In wire cutting stations, the work in the process used to consume a lot of space. This is a huge waste. With the introduction of supermarkets and Kanban-based systems, wire cutting used to happen. The work in process is creating a lot of clutter and caused a lot of inconvenience for the movement of operators. There is also a possible risk for the operator as they are handling hot molten solder during tinning. Also, solder fumes are causing an unhealthy work environment.

This has made operators less productive. This is reflected in the quality of the product produced. This also is one of the reasons for producing scrap, during the process

Tinning is the process used after wire cutting, for giving a thin coating of tin, for the wire. The coating is normally applied for preventing oxidation or rusting of the wire. During the process, the wire of a specified length is passed through hot molten solder, to form a coating on the wire. Because of the low machine up-time of 91%, the work in process is held very high (59000). This is also to safeguard against possible machine breakdown.
The pin insertion process has a maximum changeover time of 6 hours. Hence this process is considered for the study, for exploring a possibility, for change overtime reduction. During the study, an effort is made so that all the sub-activities were first listed. The sub-activities are then classified as internal or external. An effort is made to see whether the internal activities can be made external. In case, an activity cannot be made external then it is analyzed further to see whether the activity is required or not. If not required, the activity is removed. By following this process, the change over time is brought down from 6 hours to 1.2 hours. This indeed is a very significant reduction.

In the winding work station, it is observed that the cycle time is high (Table 1). It is mainly due to the set-up time. Setup time is more than 50% of the cycle time. After careful observation, it is found that during winding there were a lot of rejects happening. The quality of winding done the first time is not good. There is a lot of rework. Again, rework is also a type of waste, as the customer is not going to make payment for rework-related activities. It is also found that there is a lot of misunderstanding between the operators and the supervisors, and this has resulted in increased defect rates. Most of the time the instruction is given is mainly oral and only sometimes there were written instructions. This is the main reason for the communication gap. After careful analysis future state map is constructed where the messages were purely electronic. Also, it is observed that the scrap disposal system in the winding workstation is not properly designed and this is causing a lot of inconvenience for the operators. This is also causing a lot of clutter in the workstation. Most of the space is used by the scrap storage and there is less space available for the operator movements. The work environment is not safe for the operators. During the movement of operators, there were chances that the operator getting injured because they coming in contact with the sharp wires. It is also observed that the material handling equipment used for the disposal of the scrap is not proper. While constructing a future state map. It is also suggested to use a different material handling equipment, for disposing of scrap.

The welding workstation also shows a lot of clutter. The storage of incoming materials and the storage of work in the process were not handled properly. This has created a lot of clutter in and around the welding workstation. This resulted in inconvenience for the operators. It is observed, during welding, the operators were not given personal protective devices. This practice, especially not good, from the viewpoint of operator safety and well-being. It is suggested to use personal protective devices during welding so that the workstation will become safe and conducive for working. In the current scenario, the welding fumes generated during welding are not properly taken out of the workstation environment. This improper ventilation has created health hazards for operators. Therefore, it is suggested to use proper ventilation for making the welding workstation safer and also improve the productivity of operators.

In soldering workstations (both S1 and S2), the cycle time is very high (S1: 80 seconds and S2: 84 seconds respectively). After thorough analysis, it became apparent, that more than 65% of cycle time is due to the set-up time (Table 1). Set-up time is then considered for further analysis. Much of the setup time is due to the loading and unloading of the workpiece. Only a small amount of time is spent on performing soldering. Hence it is suggested to use two fixtures so that when soldering operation is being done for the first component using one fixture, parallelly, the second component would be set up using the second fixture. This arrangement would reduce the cycle time to 24 seconds and 27 seconds for the soldering process (S1) and soldering process (S2) respectively. It is also observed that both soldering workstations S1 and S2 did not have proper ventilation. This has caused a lot of inconvenience to the operators. This is reflected in the quality of soldering. It is suggested for the soldering workstations to implement a proper ventilation system so that the workplace becomes better concerning the health and safety of operators.

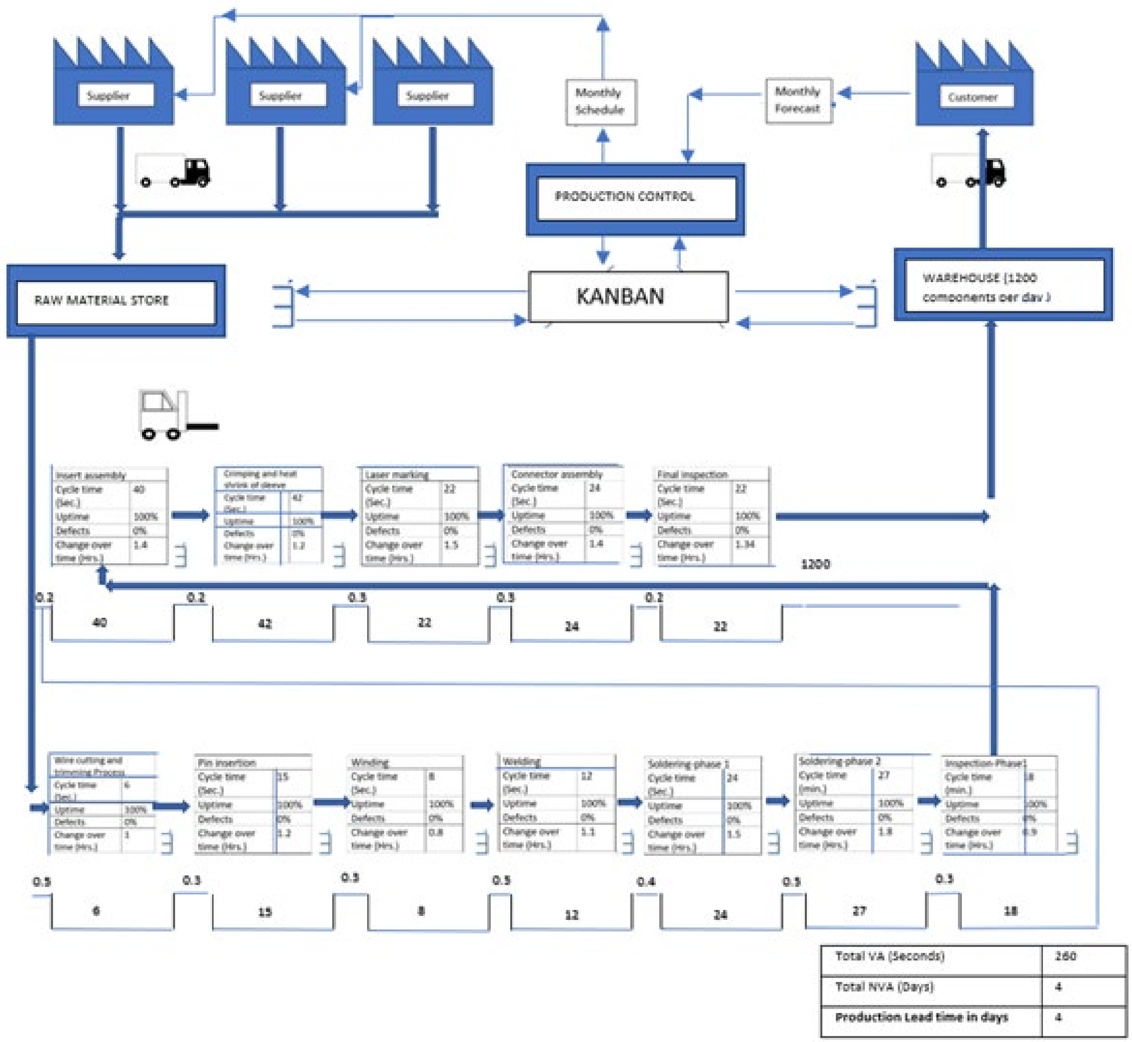

Figure 2 Future State Value Stream Map

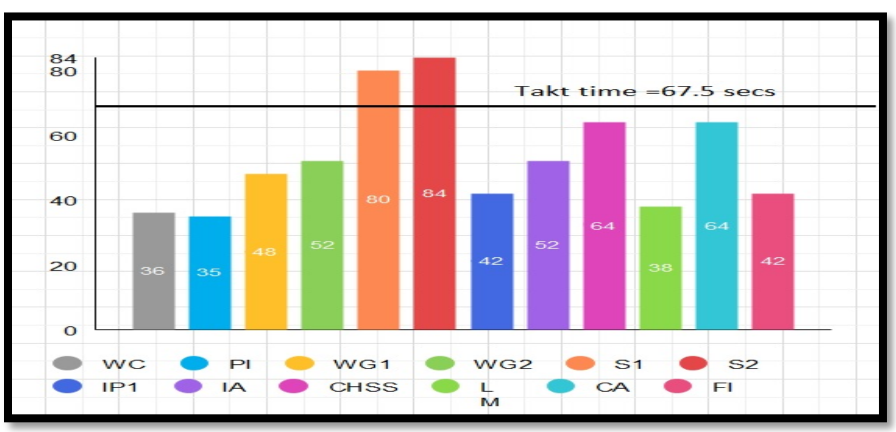

Figure 3 TAKT time comparison with manufacturing processes

Note: In Figure 3, PI: Pin insertion, WG1: Welding, S2: Soldering process-phase 2, CA: Connector assembly, FI: Final Inspection, WC: wire cutting and tinning, S1: Soldering Process-phase1, WG2: Winding, LM: Laser marking, IA: Phase 1 inspection, IP1: Insert assembly, CHSS: Crimping and heat shrinking of the sleeve.

Table 1 State details for the current state and future state

	ST		CT		COT		DR		MUT	
Item	CS1	FS1	CS1	FS1	CS1	FS1	CS1-%	FS1-%	CS1-%	FS1-%
WC1	26.0	2.0	36.0	6.0	4.00	1.00	6.00	-	91.0	F
PI2	23.0	3.0	35.0	15.0	6.00	1.20	5.30	-	89.0	F
WG13	33.0	3.0	48.0	8.0	4.30	0.80	4.50	-	89.0	F
WG24	30.0	3.0	52.0	12.0	5.20	1.10	5.50	-	88.0	F
S15	56.0	4.0	80.0	24.0	5.50	1.50	5.30	-	78.0	F
S26	60.0	4.0	84.0	27.0	4.80	1.80	4.30	-	79.0	F
IP17	32.0	6.0	42 .0	18.0	3.40	0.90	4.20	-	87.0	F
IA8	20.0	6.0	52.0	40.0	4.50	1.40	5.40	-	91.0	F
CHSS9	32.0	7.0	64.0	42.0	3.00	1.20	5.20	-	88.0	F
LM10	20.0	7.0	38.0	22.0	4.40	1.50	6.20	-	89.0	F
CA11	26.0	6.0	64.0	24.0	4.00	1.40	5.40	-	90.0	F
FI12	21.0	7.0	42.0	22.0	3.40	1.34	4.20	-	87.0	F

Table 1-Index: WC1: wire-cutting-tinning; PI2: Pin-insertion; WG13: -Winding; WG24: -Welding-process; S15: -Soldering-Process-phase1; S62: Soldering-process-phase 2; IP17: Phase 1-inspection; IA8: Insert-assembly; CHSS9: Crimping- heat-shrinking of the sleeve; LM10: Laser- marking; CA11: Connector- assembly; FI12: Final-Inspection; CS1: Current- state; FS1: Future- State; Set-up- time: ST; Cycle- time: CT; Change-over- time: COT; Defect- rate: DR; Machine- uptime: MUT; F: 100% available.

In the inspection station it is observed, not all the inspection tools were available at the time of inspection. This has resulted in wastage of time by inspectors in searching for and locating the inspection tools. Thus, this has resulted in an increased inspection cycle time of 42 seconds (Table 1). This scenario also resulted in increased defects (4.2%) (Table 1). This is also because inspectors were not focused at work. Because of the non-availability of the right tools at the right time. It is suggested to keep the tools handy and keeping each tool in its place. After this, the inspection cycle time is brought down to 18 seconds. It is suggested to use a vision-based inspection system in the future. This would further reduce the inspection cycle time. However, this would result in a one-time investment from management. However, it is informed to the management that the investment could be recovered in about one year.

Insert assembly workstation had a high cycle time. After a thorough analysis, it is found that the required components for assembly were not to be available in time. This has resulted in waiting time during the assembly of components. Also, the change over time is 4.5 hours (Table 1). This aspect is considered for further analysis. After careful observation and analysis, it is found, by using two fixtures this can be reduced. In this method, when the assembly is happening using one fixture, another fixture would be used for setting up/or preparing the next set of components for assembly. By using this method, change over time could be reduced to 1.4 hours (Table 1). This is a significant contribution. This is certainly a good contribution towards making the manufacturing line flexible for meeting customer orders.

Heat shrinking of the sleeve (HSS), is a process used for shrinking a plastic tube, when heated, to a pre-decided shrink ratio. In this case, the size of the sleeve is selected in such a way that it is larger than the size of the wire and its components. Heat shrinking will make the components being held together securely so that the components will not come out after assembly. It is observed that there were many rejects. It is as high as 5.2% (Table 1). Also, many reworks were happening during the process. This has resulted in having a huge work in process inventory (Figure 1). This again is a type of waste. With the introduction of the Kanban and supermarket scheme, there is no need of having any work-in-process requirements. Because the HSS process would happen only when there is a demand from the subsequent (laser marking) section. This is a pull system). Also, the scrap disposal system is not proper and this is causing inconvenience for the movement of operators. To overcome this problem, it is suggested to use the proper storage and disposal mechanism for the scrap. With this scheme, when the scrap reaches a certain level, immediately it is sent to disposal, using a proper material handling system (Trolley).

Laser-marking workstations also had a lot of reworks happening (Table 1). After careful analysis, it is found that the operators were not experienced. There is no standard procedure followed during the process. This is reflected in the variation in-process quality of the manufactured product. Also, many of the products made for the first time were not meeting the specification. As the result, many reworks were happening. The rework is a type of waste. It is suggested to send the operators for training as per a pre-defined schedule so that the defect rate could be brought down. Again, because of a lot of rework, they were keeping huge work in process inventory. With the introduction of the pull system, this problem is solved.

The connector assembly work station had a high cycle time (Table 1). This is mainly because of the very high setup time. This problem is solved by introducing two fixtures, so that, while assembly of one set of components is in progress, the second set of components were set up for assembly using the second fixture. By this arrangement, the cycle time is reduced from 64 seconds to 24 seconds (Table 1). It is also observed that there were delays sometimes. That is, all components will not arrive for assembly at right time. By implementing Kanban and supermarket system this problem is solved.

The final Inspection station inspects whether all the products that are being produced are meeting specifications are not. It is observed that during the inspection, of the product, the required tools were not available in the place. Thus, the inspectors were spending time locating the particular inspection tool. It is suggested to keep every tool in its place. By following this simple practice, it is found that cycle time is reduced from 42 seconds to 22 seconds (Table 1). This again is a significant contribution.

7. Conclusions

Current research work considers a solenoid valve manufacturing company as a case study. An attempt is made in this work to construct a VSM for the CS of the production line of the company. Value stream map is constructed after collecting all relevant data such as cycle time, machine uptime, changeover time, defect rates, information flow between operators and supervisors, work in process, raw- material- inventory, and finished- goods- inventory. After constructing the current state map, different types of waste were identified in the manufacturing line. After evaluating the current state map an attempt is made to propose a future state map for the same manufacturing line. It is seen that the productivity of the line is enhanced. Also, the line became very flexible. Improvements after lean implementation are: Wire cutting and tinning process: 16% reduction in cycle time; Pin insertion process: 42% reduction in cycle time Winding process: 16% reduction in cycle time; Welding process: 23% reduction in cycle time; Soldering Process: 30% reduction in cycle time; Insert assembly: 76% reduction in cycle time; Crimping and heat shrinking of sleeve process: 65% reduction in cycle time; Laser marking process: 57% reduction in cycle time.

Also, Table 1 shows the reduction in changeover time achieved for different processes of the manufacturing line. The average change over time reduction achieved for the entire manufacturing line is 28%. With the introduction of Kanban and the supermarket scheme, the WIP, raw material, and finished goods inventory were reduced. Also, from figure 2, it is evident that the VAT is reduced from 637 seconds to 260 seconds. Also, the non-value-added time in the manufacturing line is reduced from 12 days (Current state) to 4 days (Future state). This indeed is a significant reduction. Productivity improvement is a journey and not a destination.

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References

Almomani, M.A., Abdelhadi, A., Mumani, A., Momani, A., and Aladeemy, M., A proposed integrated model of lean assessment and analytical hierarchy process for a dynamic road map of lean implementation, *International Journal of Advanced Manufacturing Technology*, vol.72, pp.161–172, 2014.

Barot, R.S. Keyur Raval, and Berawala, HS, Amar Patel, Implementation of lean practices in water heater manufacturing industry, *Materials Today: Proceedings*, ISSN 2214-7853,2020.

Chitturi, R.M., Glew, D.J. and Paulls, A. Value stream mapping in a job shop, *IET International Conference on Agile Manufacturing, Durham University, Durham, 9-11 July*, pp. 142-7, 2007.

Dorota Stadnicka, and Paweł Litwin, Value stream mapping and system dynamics integration for manufacturing line modeling and analysis, *International Journal of Production Economics*, vol.208, pp. 400-411, 2019.

Emily Lee, Richard Grooms, Soumya Mamidala and Paul Nagy, Six Easy Steps on How to Create a Lean Sigma Value Stream Map for a Multidisciplinary Clinical Operation, *Journal of the American College of Radiology*, vol. 11, issue 12, part A, pp. 1144-1149, 2014.

Esain, A., Williams, S. and Massey, L. Combining planned and emergent change in a healthcare lean transformation, *Public Money and Management*, vol. 28, no. 1, pp. 21-26, 2008.

Grewal, C.S. and Sareen, K.K. Development of a model for lean implementation: a case study of the automobile industry, *Industrial Engineering Journal*, vol. 5, pp. 24-7, 2006.

Grewal, C.S. and Singh, B. Application of value stream mapping in a traditional Indian environment: a case study, *International Conference on Advances in Mechanical Engineering, Fatehgarh Sahib, December 1-3*, pp. 127-133(M-III).,2006.

Hines, P. and Rich, N. The seven value stream mapping tools, *International Journal of Operations & Production Management*, vol. 17, pp. 46-64, 1997.

Kaynak, H., The relationship between total quality management practices and their effects on firm performance. *Journal of Operations Management*, vol. 21(4), pp. 405–435., 2003.

Mohanty, R., Yadav, O., and Jain, R., Implementation of lean manufacturing principles in the auto industry. Vilakshan–*XIMB Journal of Management*, vol.1, no.1, pp.1–32., 2007.

Nicholas, J., Competitive Manufacturing Management: Continuous Improvement, Lean Production, Customer-Focused Quality, *Irwin/McGraw-Hill*, New York, NY, 1998.

Paez, O., Salem, S., Solomon, J. and Genaidy, A., Moving from lean manufacturing to lean construction: toward a common Socio technological framework, *Human Factors and Ergonomics in Manufacturing*, vol. 15, no. 2, pp. 233-245, 2005.

Peters, A., Your Journey to Lean: Continuous Improvement Supported by Tools, *Forrester Research*, available at www.forrester.com, 2010.

Philip Roh, Andreas Kunz, and Konrad Wegener, Information stream mapping: Mapping, analyzing, and improving the efficiency of information streams in manufacturing value streams, *CIRP Journal of Manufacturing Science and Technology*, vol. 25, pp. 1-13, 2019.

Rother, M. and Shook, J., Learning to See: Value Stream Mapping to Create Value and Eliminate Muda, *Lean Enterprise Institute, Cambridge*, MA.,1999.

Russell, R.S. and Taylor, B.W. *Operations Management*, 2nd ed., Prentice-Hall, Upper Saddle River, NJ.,2006.

Sahoo, A.K., Singh, N.K., Shankar, R. and Tiwari, M.K., Lean philosophy: implementation in a forging company, *International Journal of Advanced Manufacturing Technology*, vol. 36 no. 5/6, pp. 451-62., 2008.

Sawhney, R. and Chason, S. Human behavior-based exploratory model for successful implementation of lean enterprise in the industry, *Improvement Quarterly*, Vol. 18 No. 2, pp. 76-96,2005.

Serrano, I., Ochoa, C., and de Castro, R., Evaluation of value stream mapping in manufacturing system redesign, *International Journal of Production Research*, vol. 46, no. 16, pp. 4409-30., 2008

Singh, B., Garg, S.K. and Sharma, S.K. Development of leanness index to measure leanness: a case of an Indian auto component industry", *Journal of Measuring Business Excellence*, vol. 14, no. 2, pp. 46-53, 2020.

Staats, B.R., Brunner, D.J. and Upton, D.M. Lean principles, learning, and knowledge work: evidence from a software services provider, *Journal of Operations Management*, vol. 29, no. 5, pp. 376-390, 2011.

Stone, K.B., Lean transformation: organizational performance factors that influence firms Leanness, *Journal of Enterprise Transformation*, vol. 2, no. 4, pp. 229-249, 2012.

Vinodh S., Balaji S.R., Fuzzy logic-based leanness assessment and its decision support system, *International Journal of Production Research*, vol.49(13), pp. 4027–4041, 2011.

Wen Li., Sebastian Thiede, Sami Kara, and Christoph Herrmann, A Generic Sankey Tool for Evaluating Energy Value Stream in Manufacturing Systems, *Procedia CIRP*, vol. 61, pp. 475-480, 2017.

Womack, J. P., and Jones, D. T., Lean Thinking: Banish Waste and Create Wealth in Your Corporation, ISBN-10: 0743249275, 2003.

Womack, J. P., Jones, D. T., and Roos, D., The machine that changed the world. New York: Simon and Schuster, ISBN-10:1847370551, 2007.

Wong W.P., Ignatius J., and Soh K.L., What is the leanness level of your organization in lean transformation implementation? An integrated lean index using the ANP approach. *Production Planning & Control*: *The Management of Operations*, pp.1–15, 2012.

Zheng, L., Xiao, J., Hou, F., Feng, W. and Li, N., Cycle time reduction in assembly and test manufacturing factories: a KPI driven methodology, *IEEE International Conference on Industrial Engineering and Engineering Management, Singapore*, pp. 1234-8, 2008.

Biography

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