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DVSMS: dynamic value stream mapping solution by applying IIoT

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Abstract. The purpose of any business is to delight the customer as a primary stakeholder, thereby enhancing the growth and profitability. Understanding customer needs and building them on end to end value chain not only will result in serving customers on time, but also improve the effectiveness of the processes to retain competitiveness. Value stream mapping remains a popular visualization tool in the hands of the Lean Manager who seeks to produce more with less. However, value stream mapping (VSM) tends to be static and skill dependent. With the advent of Industrial Internet of Things (IIoT), there could be a paradigm shift on how VSM could be leveraged for maximizing results. IIoT makes it possible to convert the VSM as a dynamic one, enhancing with several additional parameters measured simultaneously in real time, making the relationship between cause and effect more visible. Literally, with the addition of IIoT, we could digitally re-live the moments from the past to identify the connections between the cause and effect more specifically with better accuracy. In this paper, we attempt to clarify how IIoT could enhance the VSM as a strategic differentiator for making better decisions. In a sensor-based efficiency monitoring system, the VSM becomes dynamic; thereby all the parameters including the bottleneck operations could be continuously monitored and acted upon to attain the future state eliminating the dependency on the expertise of the people.

Keywords. VSM; dynamic VSM; IIoT; smart manufacturing; industry 4.0.

1. Introduction

During the past decades, several manufacturing companies improved their productivity using continuous improvement methods and lean tools. Even though many methods introduced, the success rate of the realized benefits could diminish in due course. It becomes very difficult and expensive to identify and eliminate inefficiencies and wastage. Hence new methodologies need to be introduced in the production environment from time to time. Smart manufacturing is a technology-enabled manufacturing setup that uses IIoT to monitor and improve the production process.

The leanness of the manufacturing environments can be estimated through the parameters like throughput rate, on-time delivery (OTD), overall cost, lead time, inventory, setup times, manpower utilized, etc. Time is a key denominator in all. A time-based stream is considered as an essential critical factor of lean.

The real-time actionable information will help the manufacturers to improve the process in the assembly line. Traditional VSM does not reflect the dynamic changes in the data due to its static nature. The inclusion of the Internet of Things (IoT) will help the manufacturers to provide real-time information. The results after implementing the IoT will support to identify the improvement areas. The inclusion of IoT ensures an authentic value stream mapping (VSM) in the manufacturing line. The sensor-based approach will provide a nonstop real-time monitoring methodology. This will help to identify the current state and one could plan the necessary strategy to reach the future state. In this paper, a sensor-based efficiency monitoring system (SBEMS) [1] is introduced on the shop floor to provide the real-time data of various processes involved in the production. It helps the people to repeat the VSM professionally and quickly.

IoT can provide real-time data analysis and VSM is part of lean production [2]. The integration of both will be an excellent foundation for improvements. Ultimately, the IoT and Machine to Machine (M2M) communication will help the manufacturers to accomplish the state of lean which is very difficult to achieve before and impossible to consider using conventional lean initiatives and manual processes. This paper proposes a dynamic value stream mapping solution (DVSMS). The dynamic nature is achieved with the help of analyzing the real-time data created with the inclusion of IoT.

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Section 2 contains various researches related to this paper. The reason for conducting this research work and related problems are listed in section 3. The proposed DVSMS model is explained in section 4. The DVSMS case study and setup are explained in section 5. The benefits and results achieved using the DVSMS model and the associated methodology are discussed in section 6. The conclusion and future work are discussed in the last section.

2. Related activities

The conventional VSM well documented by Mike Rother and John Shook in “Learning to see” clearly defines it as a “go-to shop floor” technique to understand the where value is created, the flow of materials and information with a set of parameters measured process-wise like cycle time, changeover time, availability, inventory and rejections. Also, all the lean tools employed in the journey towards ideal state and their impact on the value stream could be completely recorded for deeper understanding and making horizontal deployment elsewhere more feasible.

VSM was originally introduced as a method within the Toyota Production System (TPS). This is an easy and efficient way to get a comprehensive overview of a condition of the value streams in an organization. A value stream [3] contains all the operations and its processes to convert the raw material into final goods or services, including the non-value added activities. VSM is a proven lean manufacturing tool used to plan the production process involving lean initiatives through systematic data capture and analysis. A VSM based lean manufacturing implementation for a pump manufacturing company is discussed in [4]. Novel models for flexible manufacturing systems and agent-based information architecture for shop floor control are discussed in [5, 6].

A VSM study conducted in an assembly process for tractor parts is discussed in [7]. By applying the VSM tool, the lead time of the assembly process reduced thus the throughput increased. A glide manufacturing case study is discussed in [8]. By applying VSM, the lead time was reduced by 60.88%, the processing time by 4% and the manpower reduction by 25%. Always the goal of lean is to reduce waste and improve value in the manufacturing process. The effectiveness of lean principles can be improved by introducing advanced technologies like the IoTs. It provides consistent real-time monitoring and helps the decision-makers for accurate and quick decision making [9]. RFID- Enabled dynamic value stream mapping proposed in [10]. It provides real-time data with the help of RFID connected for value stream mapping. The simulation model of the dynamic value stream presented in [11] used to investigate a more complex system than the conventional VSM. The usage of value stream mapping in a manufacturing shop-floor is discussed in [12] and in the warehouse is discussed in [13]. The comparison between the value stream and dynamic value stream mapping is deliberated in [14] and the authors concluded that the dynamic value stream mapping in superior to static value stream mapping in many parameters especially in case of complex material and information flow.

When IoT intersects with the lean techniques, it is possible to take the lean implementation to the next level. The data gathered from connected things can be analyzed by factories to enhance the manufacturing process and reduce the wastage. From various related works, it is very clear that the state of lean is possible with the help of IoT real-time data. This paper proposes a DVSMS. This system takes advantage of both VSM and SBEMS [7]. In this experiment, the VSM is carried out with the help of real-time data captured using SBEMS model [7].

The next section gives a brief introduction to the traditional value stream mapping and its limitations.

3. Conventional VSM and limitations

Value stream mapping is one of the most popular lean visualization tools. This tool is used to illustrate, communicate, analyze and improve the processes required to deliver a service or a product. It reveals the flow of both material and information from the origin to delivery through various processes. VSM uses different types of symbols to depict the work activities and information flows. This is useful in identifying and eliminating waste. From the customer’s standpoint, it determines the value and non-value added items associated with each process. Decision-makers can visualize the current and future state of the process and where waste is occurring. They can locate the problems related to process delays, unnecessary downtime and inventory related issues.

3.1 *Limitations of the conventional VSM*

Even though the traditional VSM has several benefits, it is not capable of reflecting the dynamic situation and the result depends on the expertise of the people who are mapping the value stream. Following are some of the limitations of the traditional VSM

- VSM is a paper-based manual procedure with a limited number of observations; hence the accuracy level is limited. Making the VSM is tedious and time-consuming, where an expert should conduct several walks in the shop-floor and need to spend more time on analysis; the time required to map the value stream will increase significantly for high mix and low volume manufacturing setup.

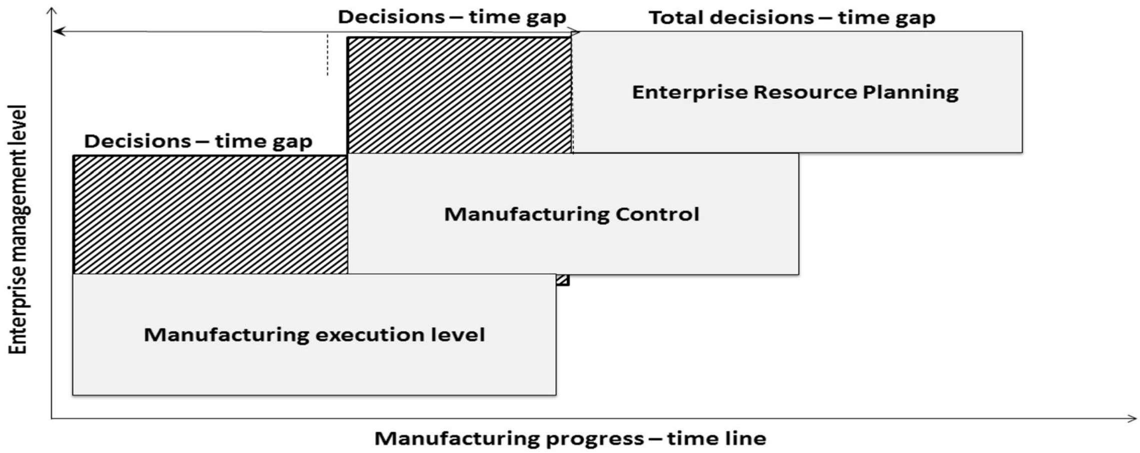


Figure 1. Identified time gaps between the data stream and manual events through administration levels in a manufacturing enterprise.

- Because of the static nature of VSM, it cannot precisely see, map and model the dynamic behavior over time. Alternatively collecting the average values of the aggregated data to create the VSM hoodwinks the actual situation and misdirects the decision-makers. Also, the unconsidered information in the manufacturing environment may contain useful clues for wastage and probable improvements.
- VSM cannot provide the variations for product flows, controls, process moments and time-based causal effects.
- VSM fails to provide the continuous visibility of lean related transformation and sustenance after implementation.
- VSM is a snapshot. Hence, it cannot track the time variances accurately during batch processing.

To overcome the above shortcomings, a DVSMS is proposed in this paper. This method will provide the power of flexibility to monitor the dynamically changing states. The next section will describe the model of the proposed system.

4. Proposed DVSMS model

The proposed DVSMS model provides a higher degree of flexibility. One of the key problems facing lean enterprises in the present dynamic manufacturing environment is to derive quick decisions against sudden changes. Other than being lean, enterprises need to react quickly and need to be more agile. The proposed DVSMS is more suitable to understand the relationship between cause and effect and facilitates lean tools deployed in the dynamic environment.

An experiment has been conducted in a real-time manufacturing environment. The product is taken in the testing environment contains 12 processes. The organization requires a methodology for manufacturing the product with better efficiency, lower cost, increased reliability and a dynamic plan to handle the change in demand.

Figure 1 shows the decision time lag in every process between execution and control. Enterprise resource planning is used in the organization, which provides the visibility of efficiency and analytics across every aspect of the business. The aim of the proposed system is to reduce the decision time gap by providing real-time information and analytics, thereby alerting essential management resources for timely decisions

The block diagram of the proposed DVSMS model is represented in figure 2. Mike Rother and Rick Harris suggest the following five steps for implementing the future state VSM in their book Creating continuous-flow.

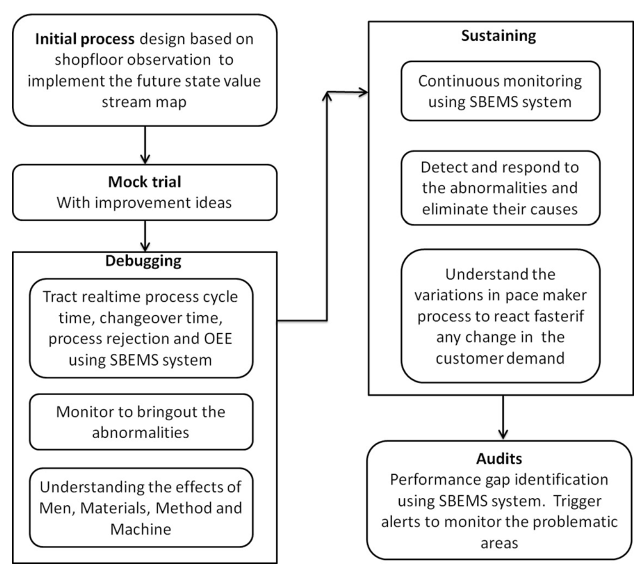


Figure 2. Block diagram of the proposed DVSMS model.

- Initial process design
- Mock Up
- Debugging
- Sustaining
- Audits

The above-said methodology is adopted for implementing the future state VSM.

System/Flow and Process kaizen are the two types of kaizen defined in most of the lean training and resources. A system/flow kaizen handles the complete value stream being assessed for improvement prospects and will generally include the actions for a different level of management. Process kaizen will focus only on single process improvement. Implementation of process kaizen consists of a cross-functional team to improve the individual process.

4.1 *Initial process design*

A core team of people was created to define the value stream and implement the future state value stream map. The team collected information about the selected processes based on their observations on the shop floor. They have developed the initial process design based on theoretical ideas.

4.2 *Mockup*

In this stage, the initial process design created by the core team was explained to the actual production team. A mock trial was done and the improvement ideas suggested by the actual production team were taken. These improvements ideas were incorporated into the initial process design.

4.3 *Debugging*

Debugging is the time when the new process is implemented and it starts operating. In this phase, the actual process implemented needs to be improved to the point where it can function as desired during the initial process design. Hence it is necessary to have real-time production data and a quick response system to monitor and bring out abnormalities. An SBEMS is implemented in the production line to get real-time information. The production setup selected for this implementation consists of 12 processes. These processes were being operated in 18 shifts per week.

Future state implementation was done a loop by loop to avoid large scale production disruption. Four process parameters namely process cycle time, changeover time, availability and process rejection were tracked on the real time for these 12 processes using SBEMS system. The introduction of SBEMS system has enabled the team to understand the variations in the process parameters at different times of the day. It has also helped the team to pinpoint the effect of change in 4Ms (men, materials, methods, and machines). Process Kaizens were initiated to eliminate these variations. The smart manufacturing system reduces the time lag between data collection and analysis. It also helps to understand the results of any improvement actions immediately.

SBEMS system has enabled the team to provide immediate feedback to the operators against the standard specified in the operator balance chart. It has also helped them to understand the actual time taken against the takt time, actual production performance in terms of cycle time achieved, actual rejections, setup time taken and highlighted the delays in the changeover.

4.4 *Sustaining*

Once the process is implemented it needs to be monitored and managed to arrest the deviation over the passage of time in the system. Since both production and support functions are linked to the takt time, a reliable support system is necessary which enables rapidly detecting and responding to the production abnormalities and eliminating their causes. Implementation of smart manufacturing system enables monitoring of the quantity of material delivered, stock replenishment time and quantity in the supermarket, availability of excess parts or shortage of parts and Work in progress (WIP) inventory at each cell.

To achieve and maintain continuous flow, the pacemaker process needs to run with as little fluctuation as possible. Two factors contributing to this variation are a change in customer demand and internal variations in the pacemaker process like machine problems, quality defects, etc., To run the pacemaker process smoothly, require a rapid response to issues or adding more finished goods inventory downstream. Smart manufacturing helps us to understand the variations in the pacemaker process and to react faster in case of a change in customer demand.

4.5 *Audits*

An excellent way to sustain improvements is to establish a routine audit system. Implementation of SBEMS system helps to identify the performance gaps online and enables the monitoring of problematic areas more closely by initiating suitable alerts.

To sum up, the implementation of smart manufacturing has infused dynamism in the value stream map, which is otherwise static. It helps to understand the performance of the whole value stream in a systematic manner and enables us to identify and rectify the abnormalities quickly. It also provides a great insight into the behavior of the system over time and the presence of assignable causes which creates distraction. It also acts as an early warning system.

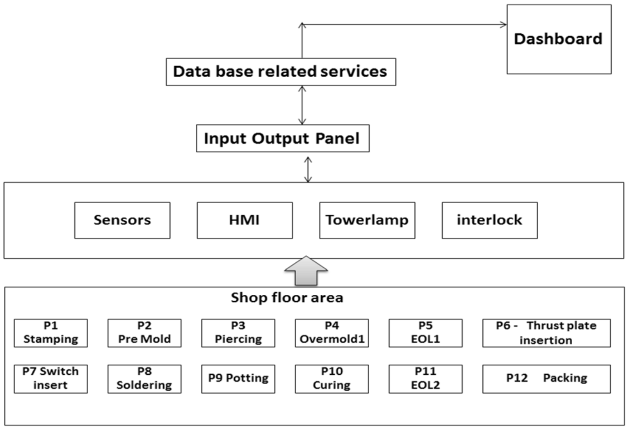


Figure 3. SBEMS model.

The experimental setup and real-time case study of the proposed DVSMS model are explained in the next section.

production shop-floor by connecting different types of sensors to machines associated with the production processes. The SBEMS system will provide real-time visibility of the processes in a production line.

The overall architecture of the industrial IoT setup established using the SBEMS model [7] is represented in figure 3. The process flow for manufacturing and assembling the product is shown in the 'Shop floor area' of figure 3. In the machines, different types of sensors connected to gather various machine-related parameters. The sensors convert the physical parameters (triggers) to the electrical signals. In this experiment, Infrared sensor (IR), Proximity and Reed sensors are selected for getting the signals from the machines and feed them to the Input/Output (I/O) panel with the available network. The I/O panel converts the electrical signals into digital form. Further, the data has been transferred to the data bridge application for further analytics and actuation. Human Machine Interface (HMI) indicated in figure 3 is a user interface device.

This setup is used for getting real-time data for VSM.

The algorithm for the DVSMS model is given below

DVSMS algorithm

Input: Current state value stream mapping

Output: Future state value stream mapping

Step 1: Develop an initial process design with theoretical ideas

Step 2: Identify the improvement ideas and incorporate them into the initial process design.

Step 3: Improvise the implemented new process

    Call monitor_data()

Step 4: Monitor and manage the implemented process

    Call monitor_data()

Step 5: Sustain improvements

    Call monitor_data()

5. Experimental set-up and case study

This experiment has been conducted in a real-time manufacturing environment. Twelve machines represented in the shop floor area are used to manufacture and assemble an automotive product. The processes involved are Stamping (P1), Pre moulding (P2), Piercing (P3), Over moulding (machine1-P4), Over moulding (machine2-P4), End of line testing (EOL1-P5), Thrust plate insertion (P6), Switch insertion (P7), Soldering (P8), Potting (P9), Curing (P10), End of line testing (EOL 2-P11) and Packing (P12).

The industry is moving towards more connected production lines to make informed decisions. SBEMS is an integrated solution to monitor the efficiency in the

The monitor_data() procedure is used to display the real-time contents of the shop-floor details. The screenshot of the monitor_data is given in figure 4.

Figure 4 depicts the SBEMS output screen. It shows the status of various sensors attached to different machines on the shop floor. This screen is used for monitoring the continuous flow of sensor data.

The real-time data is retrieved from various sensors connected with machines. The get_data() procedure will fetch the data from the sensor signals and convert them into a usable format to the monitor_data() procedure. The algorithm for the get_data method is given below.

Input: Sensor signals from various machines

Output: Real-time data

Tf – the time frame for collecting data from machines

Cnt – count, DT – Data table

DP – Data packet // Single line code of the machines connected in the shopfloor

DPc – Converted Data packet D- Data. MCU: Microcontroller unit

Pd – Parallel data format, Sd – Serial data format, Ed – Ethernet compatible format

```
Procedure get_data()
Begin
    Begin
        ∀Tf  generate DP        //  Data packet transferred in the given time frame
        µ controller   Pd→Sd      // Parallel to Serial data conversion
        UART converts Sd→ Ed // Serial to Ethernet compatible format conversion
DPc = Fetch the data using IP address
        For each DPc
        Begin
          Analyze the data pulse pattern of DPc in defined frequencies
          D = Machine status by analyzing all sensor values
          If  D = valid data
DT.insertdata  (Machine code,count,time)            End if
End
  End
      End
```

Figure 4 is the screenshot of the SBEMS [7]. This screen is used for getting real-time data. The current state value stream map is given in figure 5. The sequence of manufacturing processes has been depicted through the value stream mapping diagram in figure 5. Each process has a box below which contains production-related parameters like cycle time in sec., changeover time, availability and rejection for every process in a manufacturing cycle. Visualization of different parameters and other findings gives actual information and triggers for abnormalities in each process. The icons used for creating the value stream mapping are explained in Appendix A of [15].

The results of the current state value stream mapping are tabulated below in table 1. The SBEMS model [7] is used for mapping the current state VSM validating the data collected.

With the inclusion of IoT technology, the following benefits have been achieved while deriving the future state VSM in the DVSMS compared to the conventional VSM.

- The improved accuracy level of process parameters.
- Real-time data.
- No variation for product flows, process conditions and time-based usual effects.
- To monitor the sustainability after implementation.

With the help of DVSMS model, the real-time data gathered and the following kaizen activities carried out to achieve the future state.

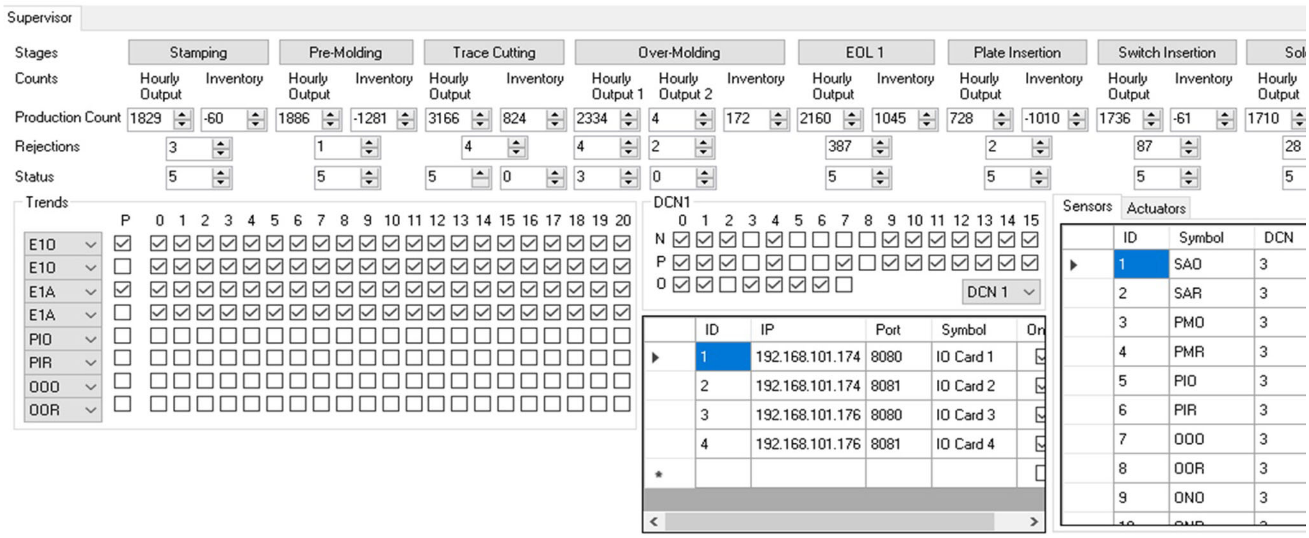


Figure 4. SBEMS output screen.

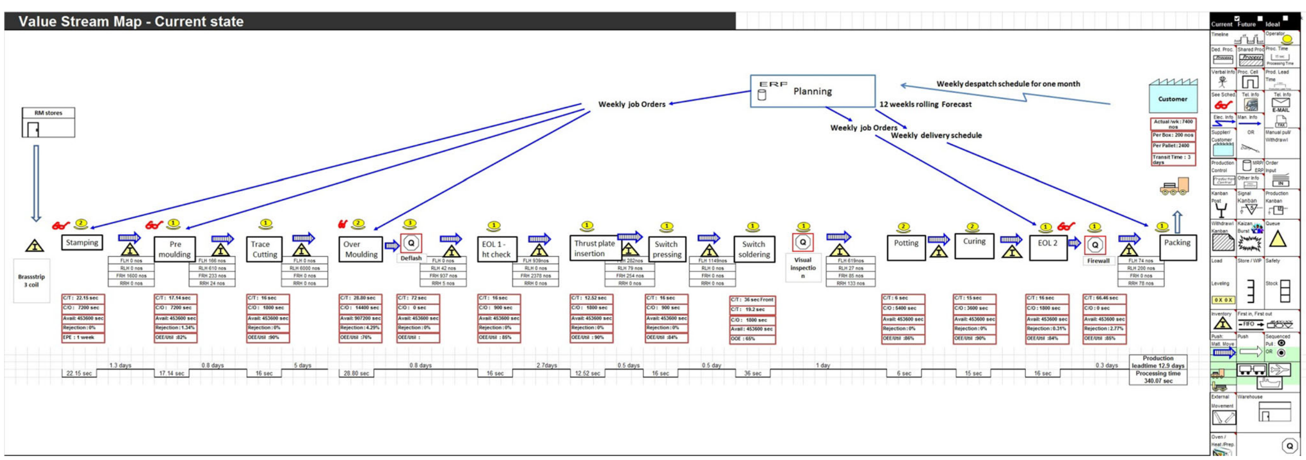


Figure 5. Value stream mapping—current state.

Table 1. Value stream mapping—current state.

	P1	P2	P3	P4	De-flashing	P5	P6	P7	P8	Visual inspection	P9	P10	P11	Firewall
Cycle time in seconds	22.15	17.14	16	28.8	72	16	12.52	16	36	19.2	6	15	16	66.46
Changeover time in seconds	7100	7200	1800	14400	0	900	1800	900	1800		5400	3600	1800	0
Availability in seconds	453600	453600	453600	9907200	453600	453600	453600	453600	453600		453600	453600	453600	453600
Rejection %	0	1.34	0	4.29	0	0	0	0			0	0	0.31	2.77
Every Part Every Internal (EPEx)	1 week													
Utilization in %		82	90	76	0	85	90	84	65		86	90	84	85

5.1 *Kaizen activities implemented in pacemaker loop*

The Kaizen activities carried over in the pacemaker loop is given in table 2, table 3 and table 4.

Process capability study on the parameters checked based on the past results and two parameters were consistently meeting the specification 100%. Hence 100% checking of these two parameters was eliminated in the EOL testing. This has effectively reduced the EOL testing cycle time by 2 s.

These two parameters are being checked on a sample basis for each lot to ensure conformity.

5.2 *Kaizen activities implemented in EOL1, Disc pressing, switch pressing and soldering loop*

Table 5 represents the Kaizen activities carried over in the soldering process. Switch pressing and soldering related Kaizen activities are given in table 6.

This has resulted in the elimination of one part loading operation, one fixture movement and one part unloading operations which have resulted in the cycle time reduction of 19 s.

The Kaizen activities related to EOL and thrust plate insertion are given in table 7.

The process was modified in such a way that fixture carry a part first moves to a height checking position, the head moves down and checks. If it ok in moves further down to the thrust plate insertion position and comes out after thrust plate insertion.

5.3 *Molding process loop*

The overmolding related Kaizen activity is given in table 8.

DVSMS model is an excellent tool and will provide various useful insights about the manufacturing process. Guided by the SBEMS results, the future state of VSM is implemented. The dynamic results of the SBEMS help the management to find value-added and nonvalue-added activities. It also acts as a strategic decision-making tool for redesigning the process and continuous improvement. The future state value stream map is shown in figure 6.

Table 9 represents the improved state accomplished by implementing the future state value stream map. The non-value added activities such as de-flashing, visual inspection and firewall have been eliminated. Few processes have been combined, such as P6&P7 as one pair and P10&P11 as another pair.

6. Benefits and performance

In this section, the performance of the proposed DVSMS model is compared with the conventional VSM. The major limitations of the traditional VSM are its accuracy level, sustenance after implementation, no real-time data, higher

Table 2. Kaizen activity 1 (KAP1): Elimination of firewall inspection.

Before	After
Number of inspection checkpoints: 20	1. Sixteen inspection checkpoints were eliminated by the introduction of Poke yoke—6 poke yoke for control and 10 poke yoke for warning/alert 2. In 4 inspection points inspection process was automated using cameras and shutdown control was initiated on detection

Table 3. Kaizen activity 2a (KAP 2a): cycle time reduction of 4 s in pacemaker loop.

Before	After
1. The number of parts per fixture is two 2. Two types of fixtures are used for Left hand (LH) and Right hand (RH) variant 3. Orientation required of loading of the fixtures into the conveyor	1. Number of parts per fixture is 4 2. A single fixture is used for both the variants 3. Orientation not required for loading the fixtures into the conveyor 4. Cycle time reduced by 4 s

Table 4. Kaizen activity 2b (KAP 2b): cycle time reduction of 2 s in EOL (End of Line) testing.

Before	After
1. The number of parameters checked in EOL: 6	1. The number of parameters removed: 2 and the Number of parameters checked: 4

Table 5. Kaizen activity 1 (KAE1): elimination of inspection after soldering.

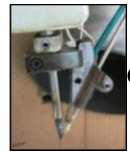
Before	After	
1. 100% inspection of soldered parts	1. 100% inspection eliminated by (a) optimizing the process parameters (b) improving the fixture design 2. By changing the solder wire diameter and procuring from the reliable branded manufacturer	 Customized feeder setup

Table 6. Kaizen activity 2 (KAE2): cycle time reduction of 19 seconds in switch pressing and soldering.

Before	After
1. Switch pressing and switch soldering were done in two different stations 2. The fixture used in the Soldering station can hold two components. The machine can solder only one part at a time and the soldering machine arm will move from the first part to the second part after soldering the first part	(1) Switch pressing was integrated with switch soldering in a single station (2) The process was modified in such a way that switch pressing is done in one position, then fixture moves to the second position for soldering and moves out after soldering

Table 7. Kaizen activity 3 (KAE3): integrating height checking (EOL 1) and thrust plate insertion processes

Before	After
1. Height checking and thrust plate insertion was done in two different stations	(1) Thrust plate insertion was integrated with the height checking station

Table 8. Kaizen activity 1 (KAM1): elimination of de-flash in over-molding.

Before	After
1. Flash was observed in the over-molded part and extra people were engaged in removing the flash	1. Trials were conducted to arrive at the right clamping fore, right packing pressure, barrel temperature, and nozzle temperature. After performing 20 sets of experiments these parameters were optimized for every machine and part combination 2. The process of mold maintenance based on the last shot sample inspection was formalized and implemented. Once the Last Shot has been inspected, a determination is made as to what defects will be corrected. This information is then incorporated into the instructions on the repair sheet

analysis time, expertise requirement, restricted number of observations and its manual nature. The performance of the DVSMs model is measured below.

6.1 *Iteration time*

Figure 7 indicates the walkthrough time required for different iterations for data collection. Kaizen is a fact-based approach and needs repeating the PDCA cycle until the desired results envisaged in the future state map is achieved. Iteration is the number of times the PDCA cycle is repeated. It indicates that data collection time in VSM is directly proportionate to the number of iterations. It consumes more time when the number of iterations increases. But DVSMS data collection is an IoT based and does not require any additional time for data collection even when the number of iteration increases.

Also, the accuracy level will be improved by conducting more studies. The accuracy level indicates the absence of assignable causes of variation in the process. In SBEMS, the data collection was automated and the number of datasets is much more than the data collected by the manual

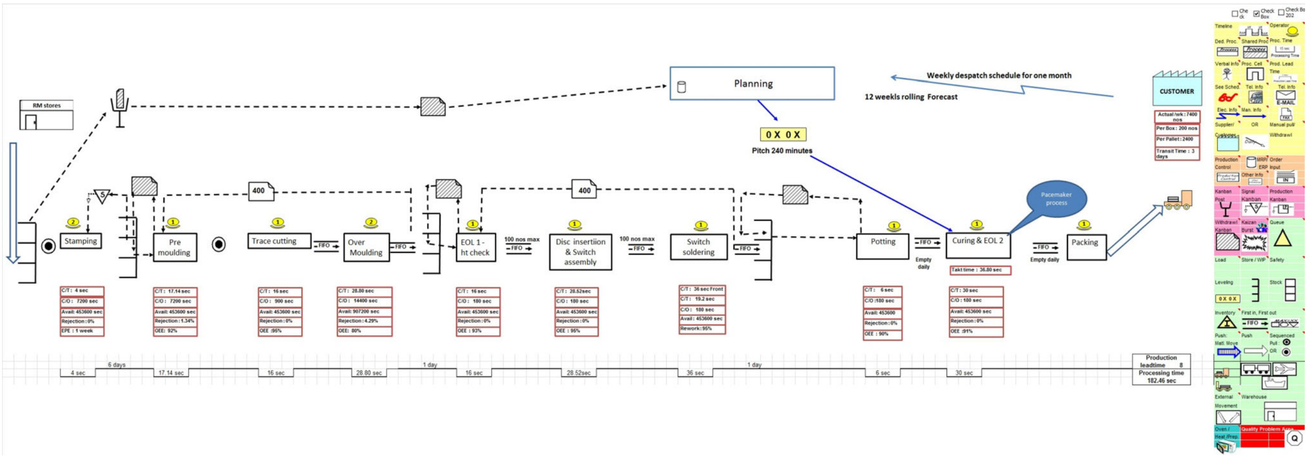


Figure 6. Value stream mapping—future state.

Table 9. Value stream mapping—future state.

	P1	P2	P3	P4	P5	P6 and P7 combined	P8	P9	P10 and P11 combined
Cycle time in seconds	4	17.14	16	28.8	16	28.52	36	6	36.8
Changeover time in seconds	7200	7200	900	144400	180	180	19.2	180	180
Availability in seconds	453600	453600	453600	907200	453600	453600	453600	453600	453600
Rejection %	0	1.34	0	4.29	0	0			
Every Part Every Internalx(EPEx)	1 week								
Utilization in %		92	95	80	93			90	91

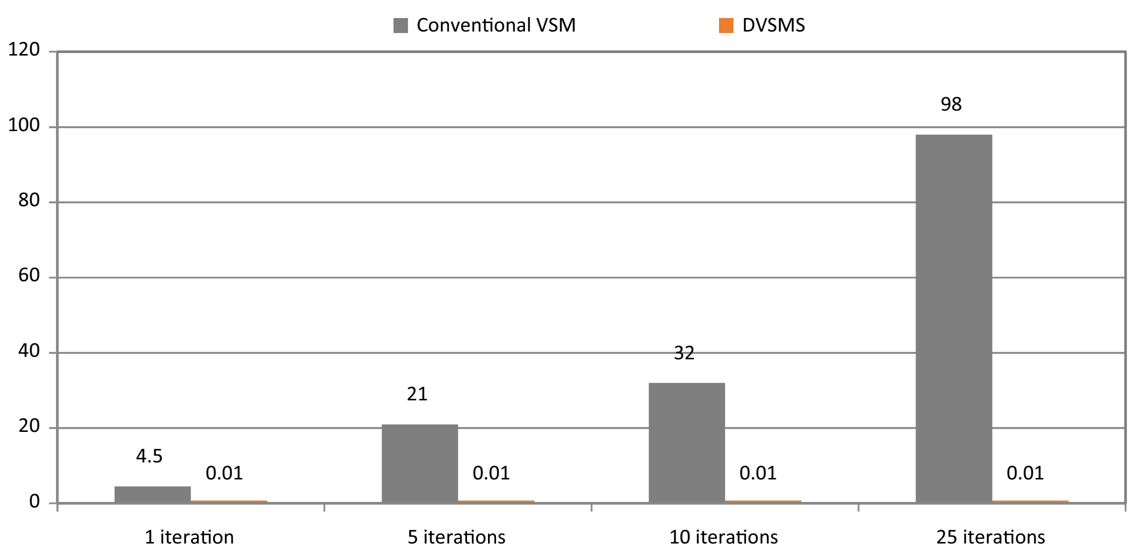


Figure 7. Iteration time (h) for VSM and DVSMS.

observation. It is very difficult, and a tedious job in conventional model DVSMS will have a higher accuracy level because of its dynamic nature and capacity to handle a large volume of data. SBEMS helps in capturing more data without manual intervention which improves the accuracy of the information.

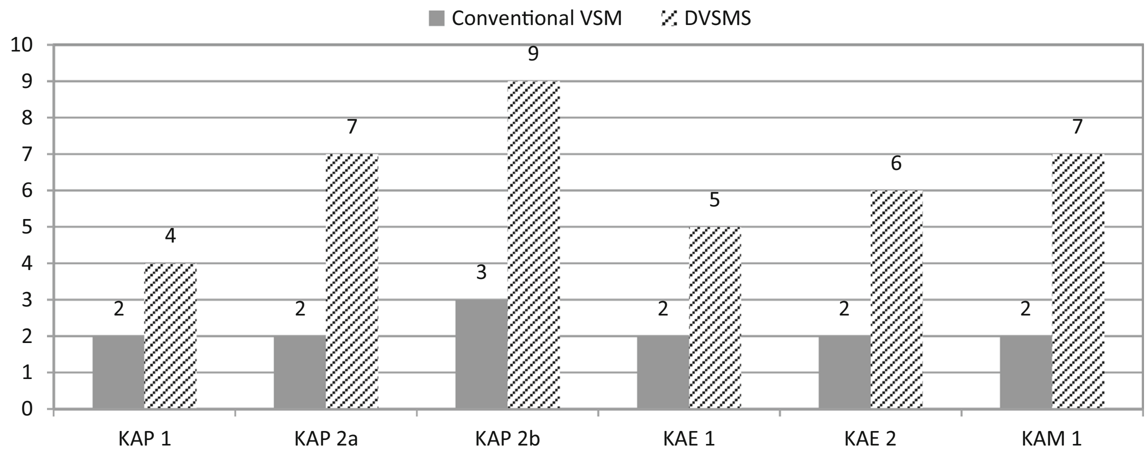


Figure 8. Number of PDCA cycles conducted.

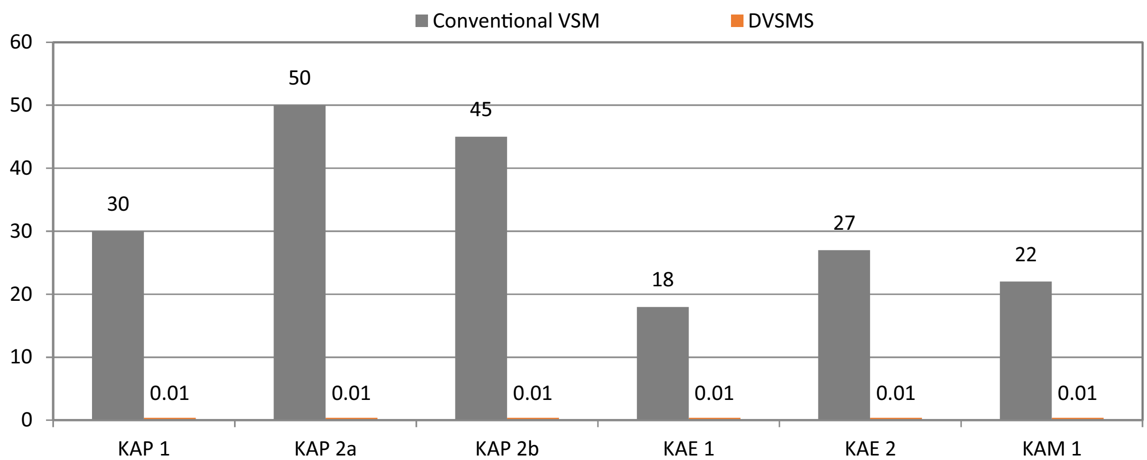


Figure 9. Response time VSM/DVSMS (for PDCA).

6.2 *Response time analysis*

Response time is the time taken between to introduce a change in the process and to see its effect on the result. In this experiment, different kaizen activities were applied in the pacemaker loop, EOL, Disk Pressing, Switch pressing and soldering loop and molding process loop. Four kaizen activities are done in the pacemaker loop, 3 activities in the second loop and 1 in the molding process loop. After applying the kaizen activity in various processes, the data study conducted after every kaizen.

KAP1, KAP2a, and KAP2b are variable names used for indicating different kaizen activities conducted in the pacemaker loop. Kaizen activities related to EOL are represented as KAE1, KAE2, and KAE3. Molding related kaizen activities are represented as KAM1. The number of PDCA cycles conducted in VSM/DVSMS is listed in figure 8. DVSMS provides the advantage to perform a number of PDCA due to its slower response time. Hence the accuracy level is increased.

Figure 9 indicates the time required to perform the PDCA cycle. In DVSMS, it indicates that the response time is not increased when the number of cycles increases.

This system helps the organization to carry out the number of process corrections in a short time. Table 10 shows the benefits of DVSMS model over the conventional VSM model.

In an automated DVSMS model, since the alert is automatic, it is possible to avoid idle time due to manual intervention. In the case study, the estimated machine idle time due to manual intervention is around 5% of availability which is successfully eliminated by having appropriate alerts. Likewise, MTTR also improved in DVSMS. The following are the indirect benefits of implementing the DVSMS model in the manufacturing shop-floor.

Table 10. Comparison of VSM and DVSMS model.

Serial number	Parameters	VSM	DVSMS
1	Project implementation time in days	64	52
2	Time taken to check the results after every PDCA (Plan, Do, Check, Act) cycle in hours	4	1
3	Number of times PDCA cycle is repeated	2	4
4	Man hours spent on training	28	18
5	The actual time taken against the takt time (customer demand)	At the end of every shift	At the end of every operation
6	Job card progress update	At the end of every shift	At the end of every hour
7	Time spent on daily project progress review in hours	2	0.5
8	Machine idle time	>5%	0
9	Mean time to repair (MTTR) in hours	1.5	0.5
10	Overall plant efficiency	90%	96%
11	The number of indirect employees reduced	1	2

- The morale of the team was very high as they were able to see the results of their kaizen activity very quickly.
- People working in the line learned the new process very quickly and able to maintain the pace of production.
- This has created a strong sense of achievement in direct operators.
- The availability of real-time data was very much useful in reviews and initiating appropriate action on time.
- The implementation of kaizen was much easier to manage.
- Measurement methods were standardized across the organization.
- Other than this, the benefits can be measured in terms of accuracy,
- Lean principles applied to eliminate the waste

7. Conclusion

Lean manufacturing is an improvement technique. It focuses on the real requirement of the customer by avoiding wastage being built in the manufacturing system. In lean, VSM is a tool of importance for accomplishing continuous improvement in the system. The conventional VSM is a paper-based manual procedure with a restricted number of observations. This paper proposed a smart real-time monitoring IT solution for the next generation manufacturing set-up with intelligent aspects concerning lean targets. This experiment has been conducted in a production shop-floor with the integration of IoT and VSM.

DVSMS model helps to monitor values in realtime with the help of SBEMS model. DVSMS facilitates to carry out the number of observations. Hence the accuracy level is improved. It helps to see the results of the kaizen very quickly.

This paper opens a new horizon for future research work. This research work can be extended to develop further lean modules like Toyota Production System (TPS), SMED based on real-time data. This work can be connected with the simulation software. Thus, it provides the ability to explore on likely consequences in advance to avoid serious consequences as well as to validate the critical choices for critical conditions in advance.

When there is no proper standardization, security risk increases and the system becomes more vulnerable to cyber-attacks. Appropriate algorithms and cryptographic logic should be applied to avoid data-related issues. The proposed solution demands expertise for the implementation and maintenance of the smart system. Also, people have to be taken into confidence for effecting the necessary cultural change on the shop floor.

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