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ORIGINAL ARTICLE

Immersive virtual reality to vindicate the application of value stream mapping in an US-based SME

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Abstract Value stream mapping (VSM) assists in identifying opportunities for improvement by revealing the inefficiencies in the current state. However, several difficulties appear while evaluating such "as-is" state for leaner future state. Trial and error method is often employed for continuous improvement to accomplish the desired level of future state. This causes numerous iterations and improper usage of resources which makes lean application costly and inefficient. In order to tackle this, an immersive virtual reality (IVR) approach to visualize and interact with the image of real models in a computer graphics environment is presented in this article. This allows conducting a quick experimentation in a virtual world to reach optimal future state without exhausting resources or incurring additional cost. In order to reinforce applicability and usefulness of the proposed framework, a case study of an US-based SME is also discussed. This paper first illustrates the implementation procedure of VSM in the manufacturing processes to develop current and future states. Data is collected for a year to analyse the current state and then IVR is used to validate results for future state. A reduction of more than 40 % in lead-time, 41 % in floor space and 47 % in manpower is achieved after a period of 3 months of implementing the recommendations.

Keywords Value stream mapping · Immersive virtual reality · Plant layout · Takt-time

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1 Introduction

In the past decade, lean emerged as a comprehensive philosophy to redesign and manage the manufacturing processes [1, 2]. Lean encompasses a set of strong manufacturing practices, tools and methods such as just-in-time, 5S, value stream mapping (VSM), etc. [3]. Among them, systematic application of VSM has produced significant and promising results in various sectors [4–6]. VSM provides a visual platform not only to capture the information/material flow such as input/output of "door to door" steps but also pertaining matrices such as involved resource, inventory level, cycle time, utilized time, etc. [7–9]. Therefore, VSM has replaced conventional recording approaches that often document only the product/material flow. VSM assists in identifying and reducing seven deadly wastes embedded in a process in forms of transportation, inventory, movement, waiting, over-production, over-processing and defects (TIMWOOD). Waste is defined as any process step/activity that does not add value in the final product delivered to the end consumers.

An overview of VSM implementation phases and their objectives in a single but definable process is shown in Fig. 1. The initial analysis (scan and plan) is conducted to identify the main pain points and to select a bunch of potential processes for improvement. Selected processes are prioritized based on the user-specific metrics to define the manageable scope. Next, current state VSM is developed for the targeted process with the prospect of reaching an efficient version in future to become lean. In order to achieve this, the engineers determine the value that each activity in current state adds to the final product. They then remove all the non-value added activities to determine the future state. An action plan is formalized to implement the required changes in actual process and realize the potential benefits. Some experimentations using Plan Do Check Act (PDCA) cycle are also performed

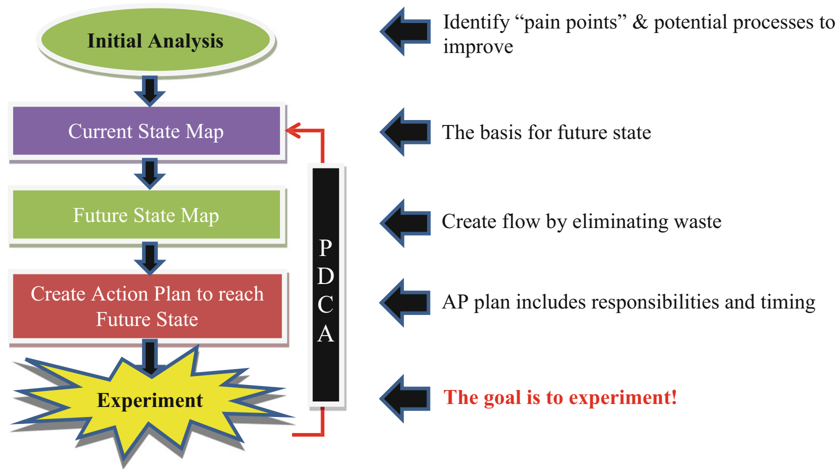

Fig. 1 VSM implementation phases and their respective objectives

to explore optimal settings for future state and improve results. Several difficulties arise when evaluating such "as-is" state for optimal future state. Fargher [10] stated that lean is merely a collection of methods and tools focussed onto to generate savings. Unfortunately, implementation endeavours often have undesirable outcomes. It is due to the fact that random elements of processes under stochastic conditions often make parameters estimation cumbersome [11]. These parameters for future state are ensured by trial-and-error approach for various unforeseen problems which results in wasted efforts at augmented costs [6]. Iterations or unsuccessful attempts are considerable obstacles because organizations cannot reap the benefits as quickly as they wish [12].

With a wide range of applications, production paradigm is shifting toward integration of human and technology practices [13]. A simulation is a versatile tool for cost-effective analysis while considering all parameters and constraints in the normal working conditions [14–16]. It provides answers to those questions which could not be addressed using static view revealed by VSM. With an extension of three-dimensional (3-D) modelling, simulation has gained importance as a tool that can validate the proposed action plan by visualizing results beforehand, thereby reducing the number of iterations [17, 18]. Simulation that specifically uses virtual reality (VR) replicates real processes structure in an immersive 3-D environment [19]. Replication of existing and modified system in an interactive environment allows users to imagine and anticipate the real world even before the start of actual production [20, 21]. Hence, it provides an opportunity to quantify the accrued benefits of VSM even before the actual implementation. Immersive virtual reality (IVR) creates a simulated environment in computer graphics with an intention to deal with virtual models, instead of with the objects and their operations in the real world. IVR allows the user to take a feel in an immersive environment by interacting with virtual objects.

In this article, a case study of a XYZ company is presented in order to strengthen the view that lean is an excellent tool and a viable method. The research contribution of this paper is twofold. The first purpose is to implement VSM in an US-based SME with a view to improve the plant layout to reduce takt-time, floor space occupancy and manpower. Next contribution is to analyse the proposed recommendations in an immersive environment and validate them. This enables management and workforce to understand the importance of implementing VSM in a manufacturing environment.

Rest of the paper is organized as follows: the next section reviews the literature of VSM and IVR in the context of research objective. The highlights of VR are provided in Section 3. Section 4 justifies the integration of IVR with VSM and presents it as a solution methodology. Section 5 provides the background information of underlying industry and targeted processes. Current state VSM, identified problems and data collection are detailed in Section 6. Obtained results and their discussion are provided in Section 7. Section 8 summarizes the entire paper and discusses where future work can be concentrated.

2 Literature review

Womack and Jones [8] emphasized that "lean" mainly depends on one critical starting point called "value" which can be defined only by the customer. Once wastes are avoided, both timeline and cost of a product are decreased. However, challenge lies in highlighting wastes and inefficiencies embedded in a manufacturing process. VSM is a powerful and effective tool specialized in exposing them [22–26]. A VSM map is a collection of all actions [value-adding and non-value-adding] that are required to bring a product into existence [27]. Numerous papers have been published on direct or integrated application of VSM in various domains including health care, food industry, finance, manufacturing, software development, engineering and service industries [7, 8, 28–31]. Cookson et al. [29] used VSM in health care to improve the quality of an emergency department care. Brunt [30] developed the current state VSM map within the whole supply chain of steel components and constructed an action plan to reach future state in order to illustrate the lean benefits. Arbulu et al. [31] followed the workflows from design to fabrication phase of pipe supports to develop VSM and identify improvement areas. Melvin and Baglee [32] applied VSM in a dairy industry to identify weaknesses and proposed solution to resolve them. Singh et al. [33] applied it in accounting department to find money drain points in their balance sheets and to cut down operational cost. Differences between theoretical concepts of VSM and real-world applications are enlisted by Serrano et al. [22] based on numerous case studies on manufacturing domain. Seth and Gupta [4] and Kumar et al. [34] exploited VSM to achieve productivity improvement for a two wheelers industry in the Indian market. A significant reduction in set-up time and inventory level in a forging industry after identifying and eliminating wastes are reported by Sahoo et al. [35]. Further, Domingo et al. [36] proposed an improved VSM to eliminate some limitations of old VSM and validated that based on resolving practical issues in a job shop. Grewal and Sareen [37] developed a model for lean improvement to utilize VSM as an improvement evaluator and presented a case study of an automobile industry. Cottonseed oil industry experimented with a traditional VSM by including open-ended questions during observations and interviews [38]. Queuing model has been proposed to identify a systematic method to structure the hierarchical cycle time key performance indicators framework and used VSM to minimize factory variability [39]. These researches primarily witnessed the improvements in lead-time, waiting time, cycle time, inventory, etc.

In all aforesaid studies, manual approaches are used to reach future state and demonstrate benefits of VSM. In this case, the accuracy level is pretty limited because unforeseen problems often surfaced in the real-world application can alter actual benefits from projected values. A static model developed using a pen and pencil in VSM cannot reveal how parameters will vary for different scenarios [40]. Detty and Yingling [15] reported that without quantifiable evidence and sufficient justification, persuading senior management to adopt lean is hard (VSM). Management support is generally received as a credit to their “belief” in VSM or reported results from others who have implemented [16]. Absence of such “belief” causes difficulties in getting commitment and resources from management. In this scenario, a complementary tool that can quantify the gains during upfront planning and assessment is required. Moreover, companies are investing millions of dollars in employee training to sustain such improvements so training has become an integral part of lean transformation process [12]. Physical simulations contribute greatly in educating employees and management regarding the difference between a chaotic traditional production setting and a systematic lean system. Physical simulations have proven records in increasing employee efficiency and in sustaining lean improvements to support the growth of an organization without management having to desert lean efforts and aimlessly seek for a new buzz word [41–45]. A simulation is capable of handling uncertainty in creating dynamic views for different future state options and can be customized for specific needs. It empowers management to compare the expected performance in comparison to that of an existing system [15]. Nevertheless, VSM without any validation approach is frequently discussed, and simulation is given a little importance and moderately discussed. The lack of viability on performance improvement of a system reveals a gap in the literature.

A few researchers used simulation to illustrate before and after performance improvement scenarios and potential benefits [13, 15, 46, 47]. The production system of a bag company was simulated in arena [48] while the impact of lean principles was built to enhance the flow of construction material [13]. The current system’s functioning in warehouse-receiving process at a large food distribution centre was quantified using a discrete event simulation model through a detailed VSM exercise [15]. These simulations discussed in literature are limited to evaluating or validating real-time data without any immersive interaction of user [43]. A simulation falls short in its ability to train employees, especially in the manufacturing sector, wherein VSM is in demand [44, 48]. From early research to latest feedback, IVR has been spanning globally to multiple technologies, tools and situations, and yet the amount of research into understanding factory layouts, work flow and product life cycle remains limited. The journey of lean from dynamic 3-D simulations has not yet reached the immersive interface between human and computer. If realized, application of IVR in VSM in a manufacturing setting serves two most important purposes. The first is to validate the implementation plan by walking the flow and acquiring much more predictable data/results without disturbing the actual process or layout. The second is to train employees on the successful new flow/layout/process in an interactive and cost-effective manner, without having to resort to physical simulations.

3 Virtual reality

VR is defined as an alternative world that is similar to the original world, but generated through computer graphic images [49, 50]. The simulation is generated with the aid of a data suit, primarily consisting of stereophonic head-mounted video goggles, fiber-optic gloves, proximity sensors or occupancy sensors. All equipment makes the computer respond to the instincts of a human present in the immersive world and present the output accordingly [51, 52]. There are two types of IVR systems: (1) desktop—the virtual environments are displayed on a screen and (2) immersive system—a user is immersed in an environment created by projectors and screens [52]. A simulation needs to fulfil four conditions to become an immersive environment: (1) a computer that generates the image of objects; (2) head-mounting devices or 3-D vision goggles with a wide view so that objects are detected by peripheral vision; (3) motion detectors that interpret the user's natural behaviours, such as looking and pointing as commands to the computer; and (4) negligible delays in the rate at which the virtual environment is updated in response to participants' movements and actions [21]. Figure 2 illustrates an example of IVR, wherein a user has entered the immersive world with a haptic device and a head mount, allowing him to manipulate and view objects in a 3-D environment [53].

IVR has a profound usefulness in many fields such as motion pictures, video games, construction, health care, military training, etc. Lee et al. [20] developed a virtual manufacturing technique and applied to many aspects of an enterprise, including production activities, materials processing and coordination control. It allowed evaluating feasibility of a product design and a manufacturing process plan prior to actual production. Richard et al. [54] developed tools that assist in assembling mechanical parts manually in a virtual environment. The user plans the assembly process and verifies assembled parts, thus enabling potential cost saving. IVR also resulted in better performance of the pilots and helped in increasing their overall skills [55]. A pilot sits in a dome and the virtual images are projected onto the inside surfaces. The simulated environment has a provision for the pilot to view realistic readings, while his movements and actions produce a sensation similar to that of actually flying an aircraft. McDougall et al. [56] utilized IVR to train a group of medical students for laparoscopic suturing skills. Even though the students with actual training performed better than the students trained in IVR, but it was useful in familiarizing them with laparoscopy more effectively. Companies like Ford and Boeing have used virtual techniques to train their employees in assembly operations and to perform assessment of a new design, representing sizable savings in time and money [49, 57].

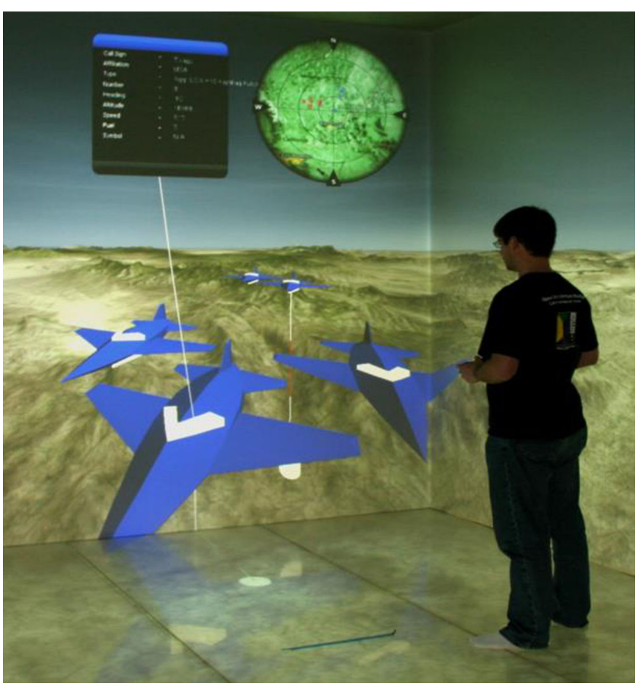

Fig. 2 An example of an immersive environment

Even with increasing technical complexity, IVR tool allows developing a seamless integration of cross-functional departments throughout the product lifecycle including Concepts, Design, Engineering and Manufacturing. An assembly sequence can be defined, assessed and shared with other departments, whose input is valuable in developing an optimised final design. Other departments have concurrent access to evolving IVR data allowing teams to construct technical illustrations in parallel with the design evolution process [58, 59]. Therefore, IVR enhances the ability to plan and make decisions quickly and efficiently. Part fit clearances can also be verified in advance to truly optimize the build process before any physical parts are available. It can carry out detailed assessment and identify any potential concerns and resolve them upfront. These potential problems and other complexities can be accurately assessed to integrate production functions much earlier than previous projects to reduce risks. It communicates and optimizes designs of assembly process to provide assurance that the build sequence is feasible. Therefore, IVR assists in saving considerable time and valuable resources, and improves cross-functional working and overall communication across the enterprise.

As much as the benefits of IVR, the drawbacks also need to be discussed. Haptic devices that provide feedback or allow an articulated presence within IVR can sometime become clumsy and cause problems during usage. Hardware including head-mounted display often breaks the sense of immersion owning to the adjustments required to the device. Occasionally, wires and headphones obstruct the natural movement and create interruptions in IVR [60–62]. An immersive experience requires some type of display that sometimes may fool the human senses. IVR system is costly and a little complex to use, owing to the fact that few people have the technical knowledge to use/maintain them. Additionally, interchangeability with different hardware is missing in most IVR systems that augment the total cost. There are concerns about the social impact and psychological effects of prolonged usage of IVR. Extreme interactions occurring in a virtual world than in the real world have the potential to create social isolation. Users who extensively indulge in IVR for entertainment could run the risk of failing to recognize the true consequences for actions in real world. Irrespective of these limitations, it is a substantive concept liking tools and people allowing everyone to empathize and improve continuously. The next section details the integration of lean with IVR as a solution methodology.

4 Solution methodology: integration of lean and IVR

The proposed solution methodology demands to rearrange the working cells in a plant layout at an US-based SME in order to reduce takt-time, factory space consumption and manpower. The reduction is achieved with the help of VSM and is reinforced by integrating it with IVR. Four high level steps of solution methodology are to (1) observe and collect information flow from customer order to finished goods, (2) develop the current state map of activities, (3) develop future state to rearrange shop floor cells in order to achieve a single piece flow, and (4) develop an immersive environment for optimal future plant layout and calculate metrics to show the benefits. First, material flow and key time metrics from customer order to finished goods are collected. This is accomplished by Gemba walk with the subject matter experts along the actual process. The information is represented pictorially in the form of predefined symbols or icons using a paper and a pencil. These symbols are arranged in the order of existing processes being carried out in the plant. The resulting map captures the "as-is" state and is called as current state VSM. It enabled business to see current processes in actual conditions (as opposed to what they think they are) and analyse them to identify weakness and wastes. Once identified, they are removed and another "to-be" map is created, which provides a design for the future set of operations, called as future state map. Future state map paved the way to a complete standardization of manufacturing processes. The final step requires implementing the recommendations of future state that omit wastes and weaknesses from the current state. Here, IVR is exploited to validate the proposed future state by walking through the flow in an immersive environment which is supported by the excellent graphics. The complete process of manufacturing a ring that involves x operations across y stations was simulated in IVR. A walkthrough the entire factory layout provided by IVR helped the user in understanding the details of the process taking place at the job shop. IVR acted as a tool to display machines, the type of work conducted at each machine and product movement from one machine to another. Machines that are utilized in the future state plant layout; space constraints such as walls, doors and windows; operations that are carried out in the job shop (these are simulated in order to assign the exact time consumed at each process); overview of all processes and those that a given product experiences and space consumed by workers were also simulated in IVR. The new factory layout was tested using IVR which aided in tweaking the changes in it. Here, user had the ability to understand, regulate and control different operations carried out at XYZ Company. A detailed assessment of the build process was carried out and potential concerns were upfront identified and resolved. These changes were made in the simulation itself even before the recommendations were implemented. SMEs from other departments also made contributions to the design process and influenced design based on their experience and specialist knowledge. Therefore, power of IVR visualization allowed any design or process changes to be validated and optimized accordingly. Production was improved with the implementation of proposed method by reducing the concerned metrics (see Section 6). The next section introduces the processes and identified problems at the XYZ Company.

5 XYZ Company and its processes

The unit considered in this study is a leading ornaments manufacturing company. It specializes in three types of gold: white gold, yellow gold and platinum gold. Due to globalization, the company is witnessing a sharp jump in orders by various retailers from all over the world. The retailer can choose a customized design from the existing moulds. The company wants to achieve on time delivery of best in quality products at the cheapest cost. Processes required to create a typical ornament are initiated when an order is received. The sales department prints two job tickets. These tickets have a bar code that has complete information of order, specifications for the rings and their delivery routing. One ticket is sent to the fabrication department, and other ticket is sent to the wax department.

(a) Fabrication department: Once a ticket is received, fabrication department selects the gold type and other metals according to the ring(s) to be manufactured. These metals are melted and mixed to form a precious gold alloy. Then, Material Control Department separates impurities from the mixed gold alloy and required quantities are sent to the casting department.
(b) Wax department: The wax department examines the job description received from the sales department and prepares "Christmas tree" with wax or plastic rings as branches. These wax and plastic parts are stored in department store, which has a huge inventory. Depending on the order, these parts are pulled from inventory and added to branches of the tree, forming a combination of different rings on each tree. The wax department also prints (1) a shortage ticket, in order to notify the affected worker to replace the pulled part from inventory, and (2) a daily ticket that travels with the ring and offers its description and routing. When number of rings is fixed on a tree, final assembler prints another paper that indicates the complete set of rings therein placed. All orders generally are accepted until 5:00 PM for big trees and

until 6:00 PM for small trees, as the casting department takes 12 and 8 h, respectively, to cast the gold tree. Each tree is then sent to casting department.

(c) Casting department: The casting department takes each order as it fills in and loads the trees in a container, with a material made of sand and gypsum that solidifies when it is wet. All containers are loaded in furnace to solidify. Furnace causes wax or plastic part to evaporate and form a mould for the gold ornaments. These moulds are taken out of furnace next morning and are filled with liquid gold alloy. Once all the moulds are filled with gold alloy, they are cooled down and gold "Christmas tree" is taken out of the mould.

(d) Tumbling: After casting, a gold tree is then sent for tumbling which is a technique for smoothing and polishing the rough surface on relatively small parts. The tree is placed in a container filled with metal pieces. The tumbler vibrates and makes the metal pieces flow in and out around the tree. This causes the metal pieces to be in friction with the entire tree and to remove the extra material stuck to a tree. Tumbling also burnishes, deburres, cleans, removes rust, polishes, brightens, hardens the surface and prepares the rings for further finishing.

(e) Clipping: The rings are detached from a tree in the department with the help of a clipping machine. All rings from each tree are placed together with the list of all rings on the tree. The extra material left from the machine is sent back to fabrication department so that the gold can be reused.

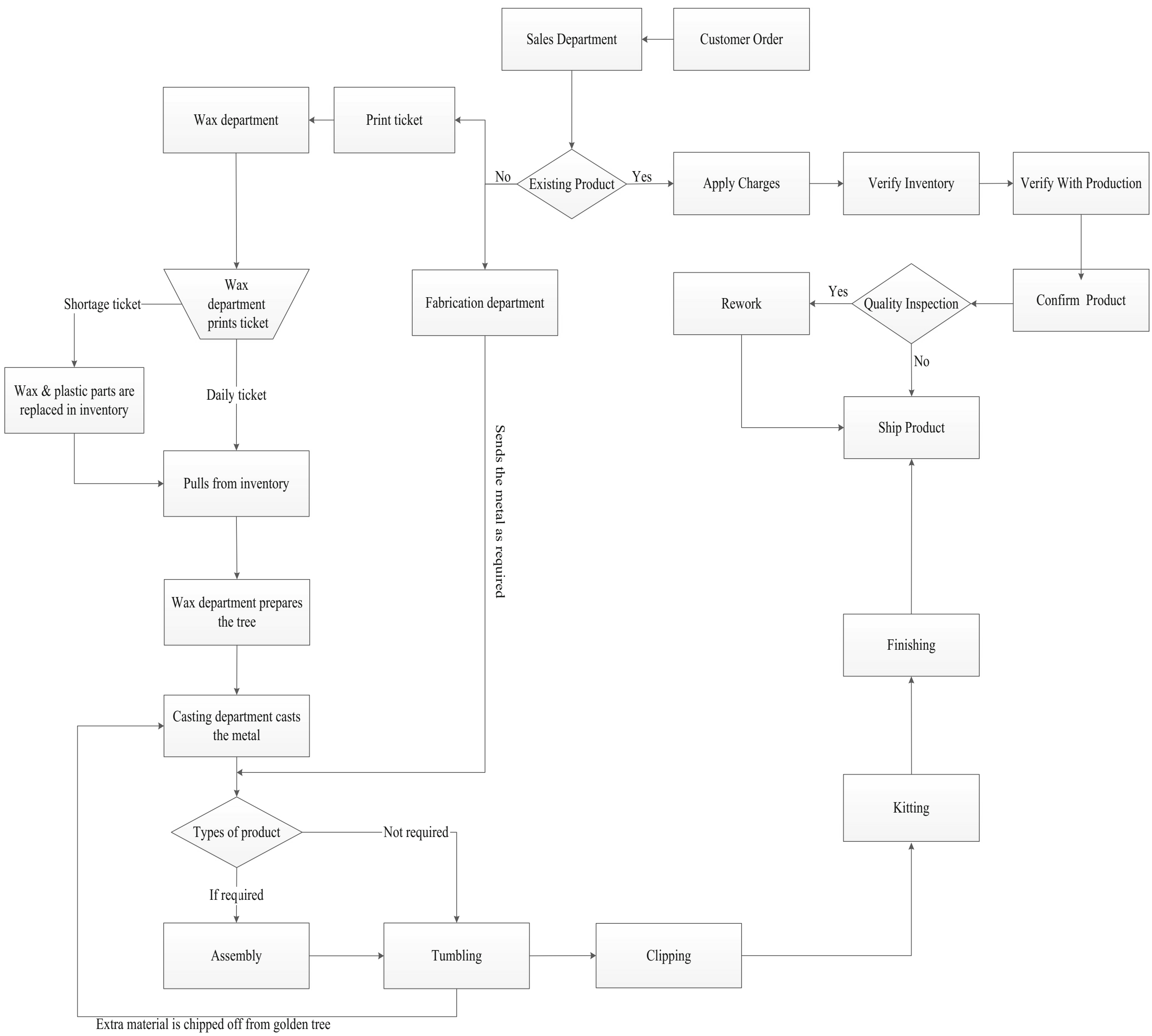

Fig. 3 Inventory flowchart of process steps

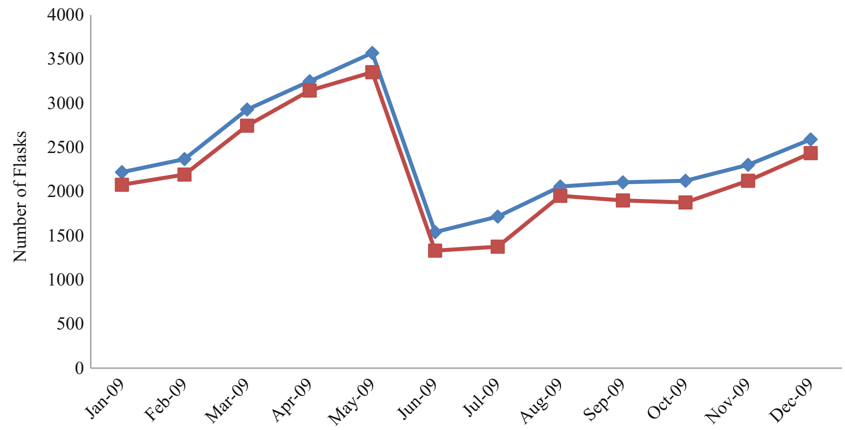

Fig. 4 Comparison of demand and production flasks

(f) Kitting department: The kitting department receives the collection of all rings from each tree after clipping. The clipping department segregates each ring and prints the job description to be conducted on the ring. The ticket consists of a bar code in first part, which gives information of ring type, description, material, quantity and due date of the ring, second part has list of routings. Each route labels the job description to be carried out on the ring, so as to achieve better finishing, and third part shows the bill of materials. The ring and the ticket are matched. Then, ring is placed in an envelope with the ticket and is sent to the finishing department.

(g) Finishing department: The finishing department has various subdivisions. Each subdivision was placed in a random manner all over the company. The finishing department consists of many finishing machines that lap, buff, sand blast, laser cut, assembles, polish, clean, wax and round a ring. These processes help to remove rough surfaces on a ring and also enhance its aesthetic beauty. The ring is then sent immediately to the shipping department with rework if any is needed after a quality inspection. This is the last step performed by the company. Almost every ring goes through the same process with few exceptions when outsourced (not in scope). The entire process of product movement is depicted in form of a flowchart in Fig. 3. The flowchart was derived after a critical examination of all the processes. All process/machine occupies a total of 512 ft^2. The next section discusses the current situation and data collection.

6 Current state VSM

XYZ Company's main objective is to deliver adequate quality products on time in order to enhance customer satisfaction. The company is expecting to achieve all aforesaid benefits by implementing VSM. For this, the researchers scrutinized the entire plant with a view to acquire in-depth knowledge of manufacturing processes, their flows, available machines for the job and activities being carried out on the shop floor. The required information was collected while directly being involved in the processes, starting from customer orders to product delivery. In order to develop the current state VSM, the processes are followed systematically and data has been recorded. Moreover, data should be as recent as possible to ensure the accuracy of information. For this reason, data from January 2013 to December 2013 is collected and studied. The

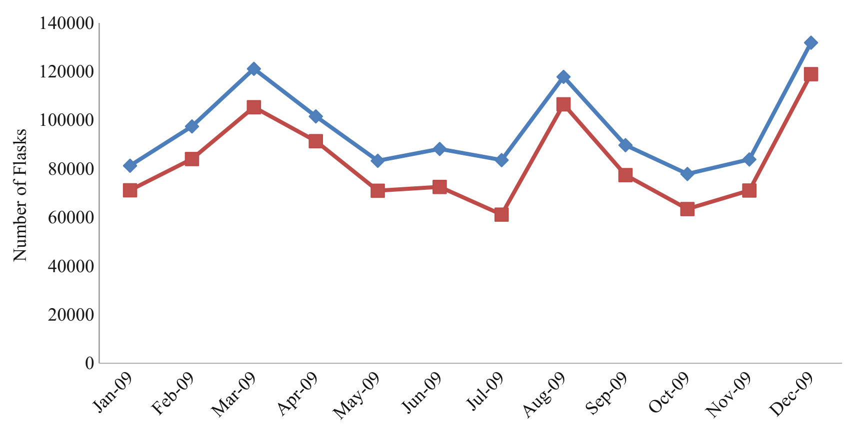

Fig. 5 Comparison of demand and production pieces/rings

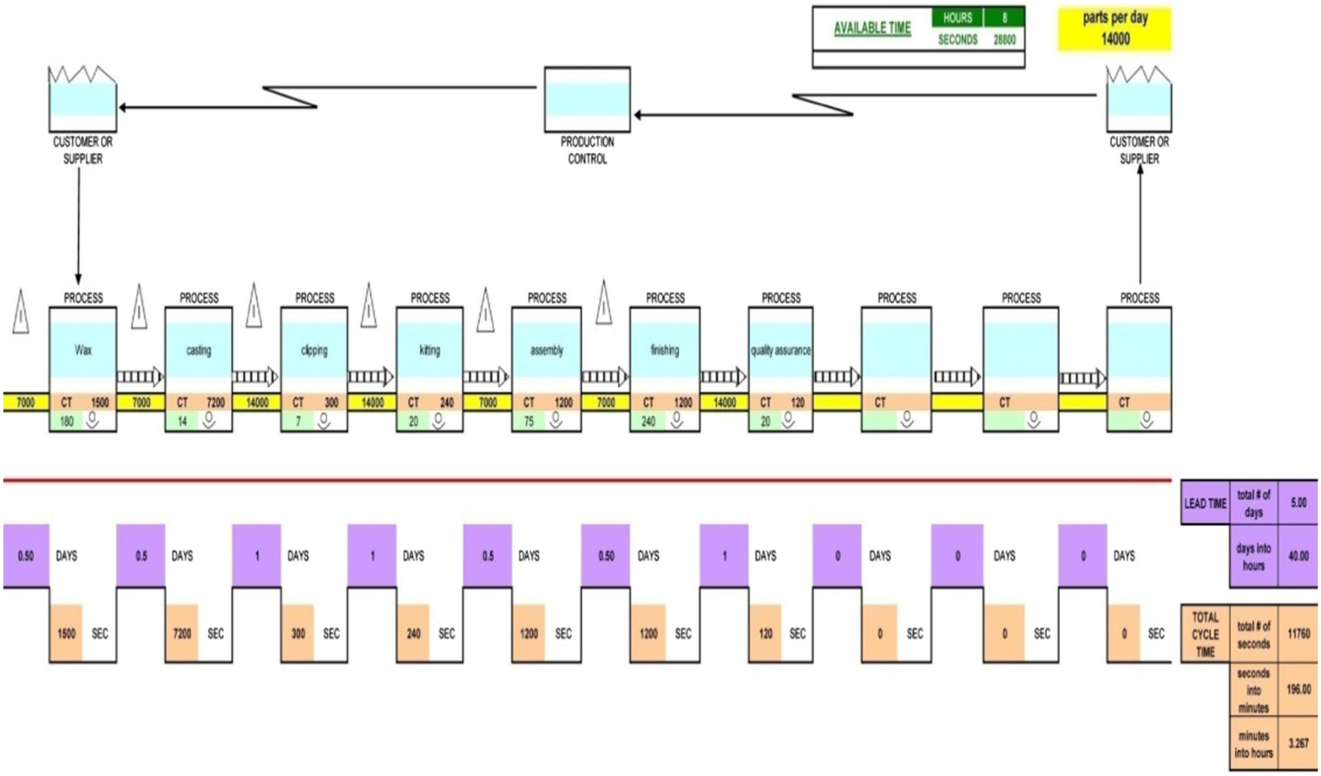

Fig. 6 Current state map

collected data is summarized in Figs. 4 and 5. These figures indicate that production is not able to satisfy the demand. After closely following the processes for a year, it was possible to identify some of the problems that were causing the entire system to run under its capacity. The developed current state VSM has the number of processes, the time taken to finish them and the number of people working on each process as shown in Fig. 6. The map has been sketched after taking all readings precisely. After closely following the processes, numerous problems were identified but the top three listed here are in the scope of the paper.

6.1 Identified problems

(1) The entire process is a batch and queue type. Three hundred rings are manufactured at once in one particular process during one working day (8 h). Once processes on 300 rings are finished, the batch is transferred to the

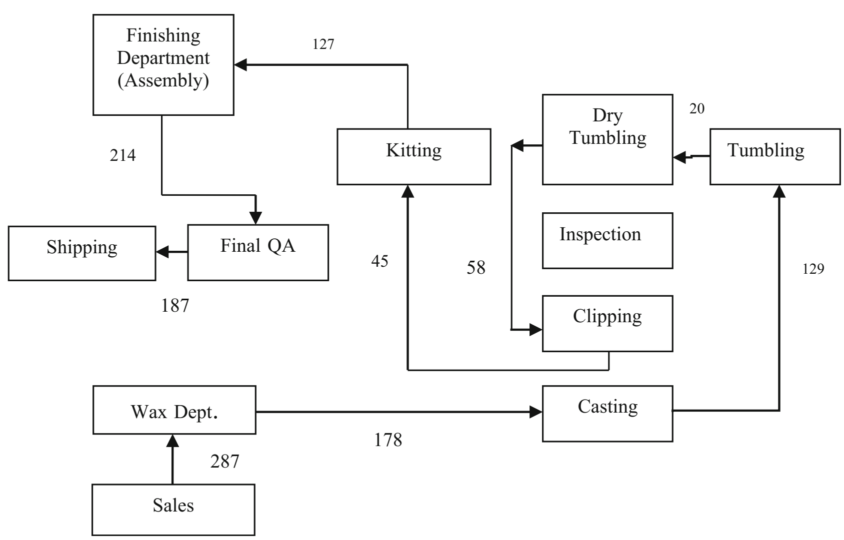

Fig. 7 Footsteps between departments

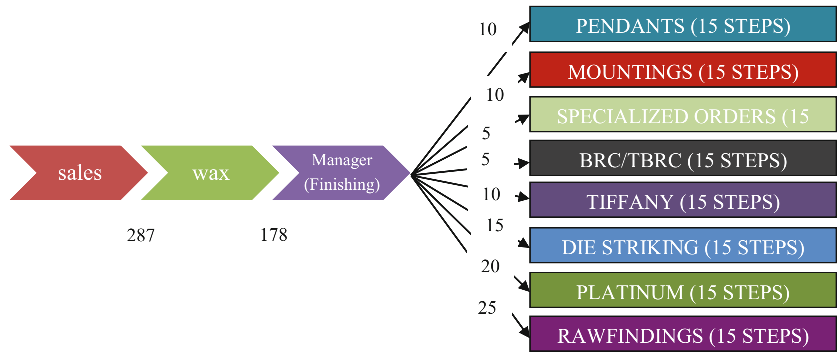

Fig. 8 Changed plant layout with number of steps in optimal future state

next department. As such, it is quite difficult to identify whether any particular ring in the lot is damaged and needs rework. It consumes a lot of time to identify and rework a defective ring. Identification and response time on defects impact the overall process efficiency.

(2) The kitting, finishing, tumbling, final quality assurance, assembly and waxing departments are functioning as separate entities. There is no interconnection between them. The distance between the departments is also a crucial drawback (movement waste) and leads to augmented lead-time and increased floor space occupancy.

(3) Company employees were hired to work on one particular process for the entire day. Hence, the skills and efficiency of each worker are not adequately utilized.

It was evident that the best option is to eliminate non-value-adding activities occurring when job transfers from one department to other, reduce distance between the different departments and efficiently utilize an employee's skills.

Current state VSM identified only 11 activities, out of 39 in total, that add value in the final product. Hence, it is important to eliminate the rest 28 steps which add no value from customer's point of view. In order to apply any changes to shop floor operations, manual entries of all orders, number of footsteps, workforce, total time taken for production in each department and waiting time data are recorded. It is noted from VSM that cycle time taken for producing 14,000 rings was 5 days with a total of only 3.627 h production time (value added). The rest of the time was spent in travelling and

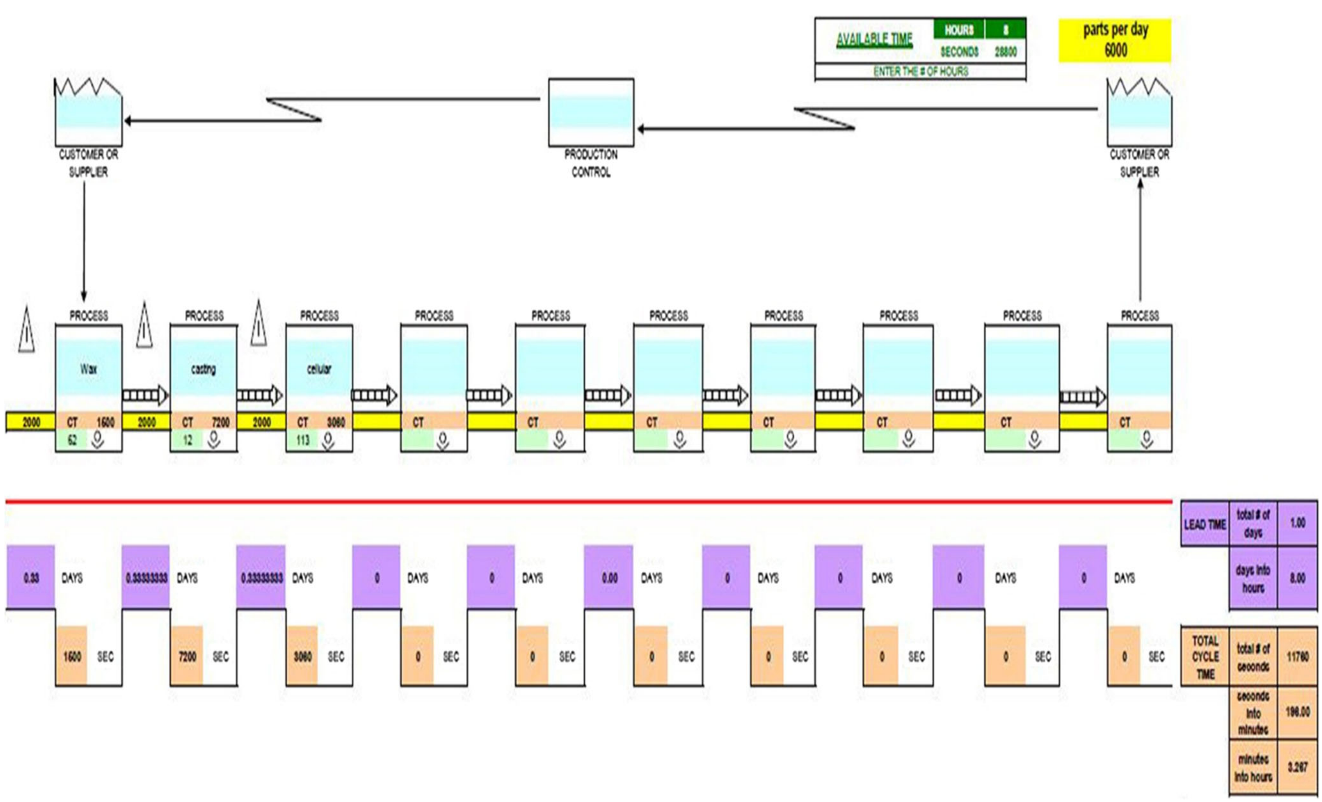

Fig. 9 Future state map

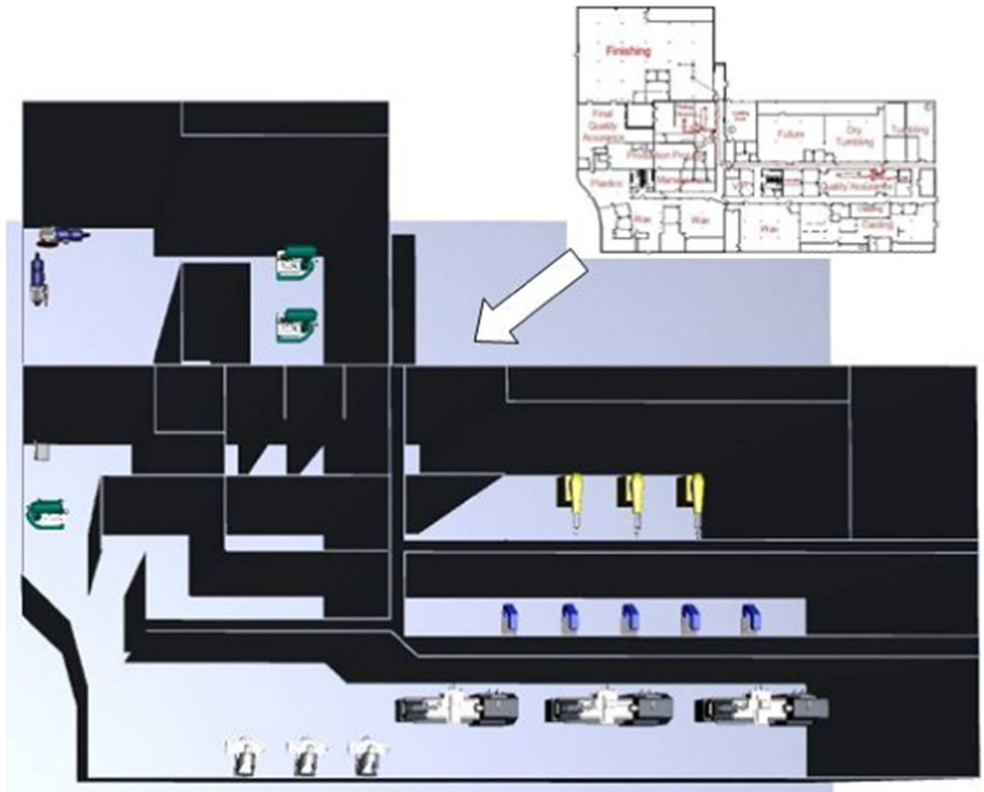

Fig. 10 Top view of 3-D immersive factory layout with machines before implementing lean

waiting. For example, step count for the present plant layout is calculated as 1,245 steps as shown in Fig. 7. The symbol $\underbrace{O}$ represents the man power in the particular job. The takt-time for current state is calculated as 10.3 s (Fig. 8).

$$\text{Takt-time} = \frac{5(\text{days}) \times 8(\text{working hours}) \times 60(\text{minutes}) \times 60(\text{seconds})}{14,000} = 10.3 \ \text{seconds}$$

7 Results and discussion

Once current state VSM is developed, brainstorming session is conducted to come up with recommendations to reach the future state. All value-adding processes, as well as non-value-adding processes, have been identified and eliminated. Future state map as shown in Fig. 9 demonstrates the output of the proposed changes based on the gaps identified in the snapshot

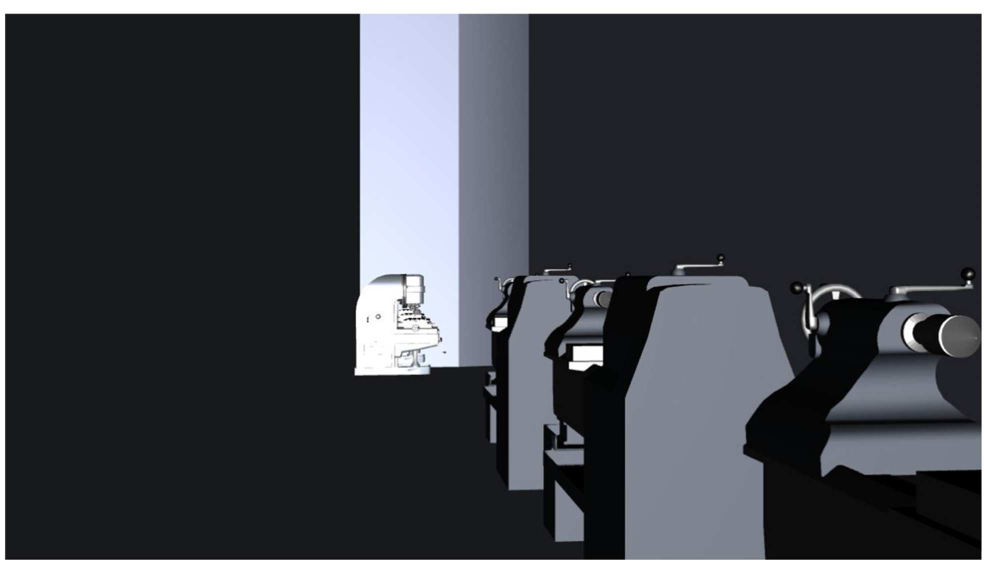

Fig. 11 3-D Walkthrough of the factory layout

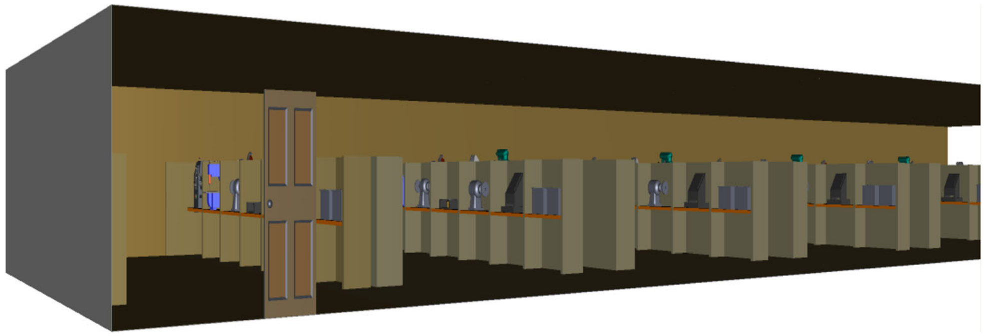

Fig. 12 Front view of the future state map (212 ft^2)

of the as-is situation. For example, updating, waiting time, loading the cart, waiting for the cart, etc. all are removed from manufacturing processes. This is simply possible by co-locating and integrating all departments for seamless product flow.

7.1 Integration of departments

Integration of department is most viable and sought solution to achieve a reduction in takt-time. The tumbling, kitting, clipping, finishing (assembly), quality assurance and shipping were integrated and placed in a common work place. The assembled department houses many processes and machines such as assembly, lapping, burring, rounding-out, laser cutting and many other finishing processes like polishing, sand blasting and cleaning. It also consists of quality inspection and shipping operations. This has been divided into eight different groups that are named according to the job description and used material, i.e. gold or platinum. Figure 8 depicts the eight different processes after integration. The manager placed in the centre receives the daily order. The manager then distributes work orders to each group. Each group on average has eight workers who received training on all machines and processes available in the shop floor. The training helped the company to utilize worker skills efficiently. Figure 8 represents the changed plant layout with steps (505 steps). The average time taken for all stations has been recorded as 1, 080 s. By integrating these departments, footsteps and floor space consumption got reduced and a single-piece flow was achieved. Initiated single-piece flow and efficient utilization of each worker's skills resulted in a better and consistent product quality. The amount of scrap and rework for each product was also decreased. Finally, the overall plant capacity was increased, thereby satisfying even more customers.

7.2 Validating the future plant layout using IVR

Advent of IVR helped in creating a 3-D environment of the future plant layout. Figure 10 is a 3-D representation of the factory layout for optimal future state. The factory layout has been drawn to scale using software called EON REALITY PROFESSIONAL (Version 6.1) in an IVR laboratory. Cost incurred and time taken in the transformation are reduced with the aid of simulation. Figures 11 and 12 show future plant layout in the immersive world. IVR is a human-computer interface that helped in visualizing complicated 3-D models, in understanding their spatial relationships and in simulating situations where testing the methods and monitoring employee training are required. IVR simulation was developed to inspect the feasibility and make required changes before implementing the future state in real settings. The walkthrough within the IVR helped in calculating floor space occupancy and developing the optimal future state.

7.3 Comparison of metrics for current state and future state

As indicated in future state map, all aforesaid departments have been integrated, and a similar study (as mentioned in the methodology) was conducted for a period of 3 months, i.e., from January 2014 to March 2014. All vital information was recorded after achieving the single-piece flow. After

Table 1 Comparison of values for current and future state

Metric	Current state value	Future state value	Margin	% Improvement
Number of steps	1,245	505	740	40.56 %
Floor space occupancy	512 ft^2	212 ft^2	300	41.43 %
Production per week	14,000	30,000	16,000	46.67 %
Manpower	356	187	169	47.4 %
Takt-time	10.2857 s	4.8 s	5.4857	53.37 %

implementing the recommendations in future state, actual results achieved are shown in Table 1.

7.3.1 Reduction of floor space occupancy and number of steps

With the integration of all departments, the distance between each machining operation was decreased. It is recorded that 40.56 % of floor space occupancy or 300 ft were reduced. With single-piece flow, if rework is required for any ring, it was attended immediately by sending it back to the previous station. This reduced the time consumed for rework, and it also resulted in reduction of scrap. In addition, by placing different machines in each group, the scope of different operations conducted on a single ring was increased within the reduced floor space.

7.3.2 Production per week

With the formation of groups, the production has changed from 14,000/week to 30,000 rings per week. Hence, production satisfies the demand for rings. Demand and supply data was recorded for 3 months to track and compare the performance shown in Figs. 13 and 14. It should be noted that production exceeded demand with a marginal allowance.

7.3.3 Manpower

Manpower dropped due to reduction of non-value-adding activities. By considering the pendants group, the process map has been derived. Because of the decrease in processes, manpower dropped from a total of 356 to 187 people (see Table 2). Even though, the rings production capacity increased to 6,000 per day, takt time on each ring was dropped from 10.29 to 4.8 s in the future state.

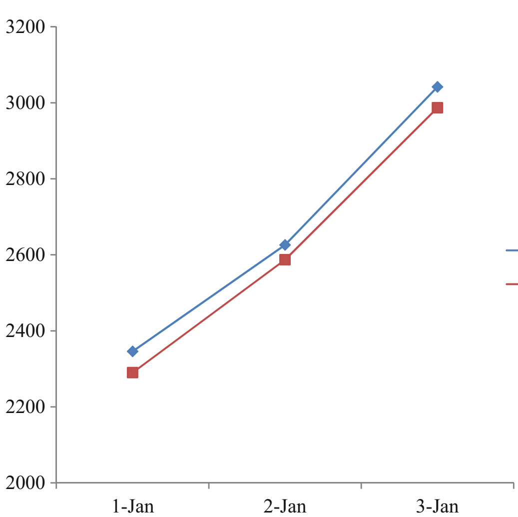

Fig. 13 Comparison of production and demand for flasks

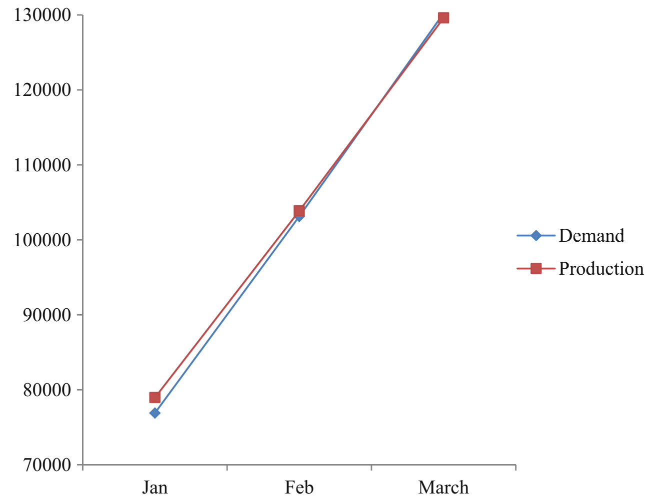

Fig. 14 Comparison of production and demand for pieces

$$\text{Takt-time} = \frac{1(\text{days}) \times 8(\text{working hours}) \times 60(\text{minutes}) \times 60(\text{seconds})}{6,000}$$

$$= 4.8\text{seconds}$$

Future state map demonstrates the output of the proposed changes based on the gaps identified in the snapshot of the as-is state. It transform the culture from “firefighting” to a “problem solving” one increasing the flow of communication across the organization (enforce the discipline). It also shifts the attitude of employees towards surfacing problems and treating them as opportunities for improvement. Quick access to relevant, complete, correct amount of available knowledge without waiting escalates the dispositions resulting to improved efficiency of individuals. Finally, the industry is able to witness some intangible benefits including an enhancement in respect for culture, identity and relations among the employees. Even though there are evident benefits of VSM, the end user should be careful while working. VSM can be misleading for the decision maker if the current state is not captured preciously at any given time to understand the situation. Additionally, VSM provides the situation to explore the areas which need immediate attention for improvements. It basically does not provide any direct solution of the issues. Irrespective of both these limitations, VSM is a substantive

Table 2 Number of people reduced in each department

Department name	Workforce reduction
Waxing department	118
Casting department	2
Cellular (clipping, kitting, assembly, finishing, quality assurance departments)	249

concept liking tools and people allowing everyone to empathize and improve continuously regarding understanding of lean and their organization.

7.3.4 Managerial relevance

First relevance is to change the mindset of employees by reorienting their thinking around the lean philosophy. Once the employees start to live the lean culture, the industry will start to realize more benefits (long-term advantage). Second contribution is to provide a step by step approach in form of a systematic framework to implement lean tool (VSM). This systematic framework can be further modified, customized or tweaked to implement tools to other efforts in same or different research domain. The third relevance is to improve the competitive position through wastes reduction in a manufacturing environment to make the existing process leaner. The waste reductionist approach assists in reducing the lead-time and achieving cost targets with competitive advantage (short-term benefit).

8 Conclusions and future work

The objective of an US-based SME company is to reduce the takt-time, floor space occupancy and manpower. For this, current state VSM is developed to identify non-value-adding steps and then a refined future state was outlined. The future state VSM was able to achieve single-piece flow that resulted in better production and in reduction of the floor space occupancy. Additionally, future VSM served as a guide to standardize the new process, which contributed in higher efficiency with less manpower and significant reduction in takt-time. It can be concluded that lean application results in considerable business profits. IVR was used as a powerful tool to check its feasibility of future state during practical implementation. Time taken for each process step in future state was recorded and assigned in IVR to comprehend and provide a better explanation for it. Using IVR, some parameters were also optimized for better future state. Clearly, application of tracking sensors and haptic devices in order to pick and drop the machines to test various possibilities and adding textures/colours to the machines to give the job shop a more realistic look are the topics for future research. Development of haptic devises which are more accurate and sensitive can further be utilized to improve the experience with IVR. Application of wireless hardware can offer uninterrupted movement of the user to ultimately result in improved the user experience.

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