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Decision-making on the selection of lean tools using fuzzy QFD and FMEA approach in the manufacturing industry

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ABSTRACT

Lean manufacturing is a profound system designed to enhance every manufacturing industry's efficiency by reducing waste through internationally recognized tools and techniques. Manufacturing industries strive to adopt lean concepts to maximize their resources like staff, facilities, materials, and schedules to be economically effective. However, managers face difficulty selecting the appropriate lean tools out of the many available LM tools for successful lean implementation. This study suggests an innovative approach to choose suitable lean tools to maximize these essential resources. Herein the Value Stream Mapping and plant layout are considered for waste identification. Fuzzy QFD and FMEA prioritize the crucial resources concerning the defined wastes and determine the risk associated with each failure mode's sub-element for lean application. It saves time by analyzing only the most critical resources for a successful lean implementation since its focus only on the most important resources. The applicability of the proposed approach is demonstrated through a case study of an Ethiopian shoe manufacturing firm. With the aid of future state plant layout and value stream map, total cycle time is reduced by 56.3%, lead-time is reduced by 69.7%, materials transportation distance and transportation activities are reduced by more than 75%, and workers required are reduced from 202 to 200.

1. Introduction

Companies adopt lean manufacturing (LM) principles and tools for various reasons, including global competition, an uncertain market environment, and rising customers' expectations. The concepts of LM can make it possible to use their resources effectively and increase their competitiveness. According to Deif and ElMaraghy (2014) and Goshime, Kitaw, and Jilcha (2018), LM is characterized by doing more with less. It focuses on reducing/eliminating waste in order to increase productivity and maximize customer values (Belekoukias et al., 2014).

With the origin of the Toyota Production System, several LM techniques and tools were developed and used to achieve lean. Some of them are TPM, JIT, TQM, kaizen, kanban, production smoothing, cellular manufacturing, one-piece flow, Value Stream Mapping (VSM), and standardized work. Most of them are adopted in discrete manufacturers (Kumar & Parameshwaran, 2018). LM techniques and tools where effectively implemented in Automotive (Vamsi Krishna Jasti & Sharma, 2014), chemical (Jilcha & Kitaw, 2015), textile industry (Hodge, Goforth Ross, Joines, & Thoney, 2011), construction (Ko, 2010; Aka, Danladi Isah, Eze, & Timileyin, 2020), and healthcare industries (Barberato, Freitas, Godinho, & Francisco, 2016).

LM implementation is all about the raw materials used (Materials), human resources skill (Man), equipment/machine (Machine), and manufacturing methods/technology (Methods) or 4 M's. These are critical for the successful deployment of LM. These 4 M's may not be a big issue for the developed countries manufacturing organizations. But in developing countries like Ethiopia, the manufacturing organization with undeveloped manufacturing systems has a shortage of these 4 M's. Unlike the raw materials, the machines, the accessories & spare parts are imported, the workforces are unskilled, and the technology level is low. Although there are many available lean tools, lack of standardization in the application, lack of predicting the benefits, insufficient control over the whole value stream & insufficient knowledge, and insufficient view on new methods are barriers to practice lean (Tezel, Koskela, & Aziz, 2018). Since LM is an integrated system the absence of standards is an obstacle in implementing lean practice (Bhamu and Sangwan, 2014). The literature does not address the mechanism to integrate lean tools into low-level technology organizations having undeveloped manufacturing systems with a shortage of these 4 M's. Hence prioritizing the 4 M's and selecting appropriate lean tools out of the many

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available LM tools is necessary for successful lean implementation. Sawhney et al. (2010) revealed that by following failure mode and effect analysis (FMEA), lean system reliability can be improved through the critical resources, like material, equipment, personnel, and schedule.

This study presents a case study in the Ethiopian manufacturing industry using a hybrid model. The case company manufactures different models and sizes of leather shoes. Herein VSM is used to identify wastes. Wherein the fuzzy quality function deployment (FQFD) and fuzzy FMEA prioritize the wastes through critical resources. Henceforth for the prioritized waste categories, lean tools are selected.

2. Literature review

Reviewing related literature on VSM, fuzzy logic, fuzzy QFD, and fuzzy FMEA aims to understand better the tools and techniques (what they are?), their various aspects (for what objectives? why they are used?) and their approaches (how they are used?).

2.1. VSM

A value stream is the collection of activities and related details required to manufacture products, beginning with raw material and finishing with the consumer, via the main flows (Rother & Shook, 2003). In manufacturing industries, anything within the production flow that adds value to customer or product is regarded as value-adding (VA). Any activity that adds no value to the customer or product is regarded as a non-value-adding activity (NVA). These NVA activities are considered as waste, which consumes resources but provides no value to consumers. The seven types of wastes in manufacturing industries, according to Shou, Wang, Wu, and Wang (2020), are defects, overproduction, overprocessing, inventory, unnecessary motion, waiting, and transportation. VSM helps visualize, understand, and document the information and materials flow through the value chain to identify waste quickly (Lacerda et al., 2016). To develop value stream map, there are two stages. The first stage is the current state map, which depicts "as-is" status of the production system's information and material flows. The future state map depicts the firms' future level of performance with enhanced outcomes.

In 1999, VSM was presented for the first time (Rother & Shook, 2003). Since then, there have been subsequent reviews (Dal Forno et al., 2014). The application of VSM was successfully implemented in a complicated manufacturing environment & gains a considerable reduction in cycle time (Seth, Seth, & Dhariwal, 2017). The successful application of VSM in different areas and firms were reported by researchers. To mention some of them: in the automotive industry (Lacerda et al., 2016), in the supply chain of agri-food (De Steur et al., 2016), in textile industry (Behnam et al., 2018)… and so on. Other researchers discovered the extended use of VSM. VSM, with the integration of life cycle assessment in an automotive component manufacturing industry, was studied to ensure its sustainability (Vinodh, Ruben, and Asokan, 2016). Similarly, Faulkner & Badurdeen (2014) uses the extended VSM in identifying lean metrics for performance sustainability of manufacturing firms. VSM is used in this study to recognize wastes and possibilities for lean adoption.

2.2. Fuzzy logic

In actual decision-making, decision-makers face difficulties when dealing with vague information like true/false, very high, high, medium, and yes/no. Such information may be handled by probability theory, but measuring imprecision that mainly comes from human behavior is limited (Filketu, Dvivedi, & Beshah, 2017). Zadeh (1965) designed fuzzy logic to cope with this type of ambiguity correctly. According to Susilawati et al. (2015), the usefulness of fuzzy logic is revealed in a variety of industrial applications. To mention some of them: in service industries (Kumru & Kumru, 2013), in manufacturing industries (Azadegan et al., 2011), in the process industry (Braaksma, Klingenberg, & Veldman 2013), for supplier selection (Chan et al., 2008), and for climate decision support systems (Habib, Akram, & Ashraf, 2017). Similarly, to build the spatial surfaces that describe the application of fertilizer in the spatial domain, Ashraf, Akram, & Sarwar (2014a) used a fuzzy controller. Then Ashraf, Akram, & Sarwar (2014b) used a type-II fuzzy controller in reducing uncertainty to define membership function. Akram, Ashraf, and Sarwar (2014) demonstrated the application of intuitionistic fuzzy digraphs in intelligent systems. They demonstrated a couple of scenarios where they have effectively implemented it. In 2016, Butt & Akram (2016) had used a fuzzy-based CPU scheduling algorithm. The fuzzy number is graphically illustrated, as shown in Fig. 1 (Klir & Yuan, 1995; Susilawati et al., 2015).

The triangular affiliate function is widely used to represent fuzzy numbers and is characterized by triple numbers (a, b, c). Triangular fuzzy number (TFN) membership function can be presented using the following equation:

$$\mu_{\widetilde{A}}(x) = \begin{cases} (x-a)/(b-a), a \leq x \leq b, \\ (d-x)/(d-b), b \leq x \leq d, \\ 0, otherwise. \end{cases}$$

Let

$\widetilde{A} = (a_1, a_2, a_3)$ and $\widetilde{B} = (b_1, b_2, b_3) betwopositivetriangularfuzzynumbers.$ On these fuzzy numbers, simple fuzzy arithmetic operations are:

Addition: $\widetilde{A} + \widetilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$;

Subtraction: $\widetilde{A} - \widetilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3)$;

Multiplication: $\widetilde{A} \times \widetilde{B} = (a_1 b_1, a_2 b_2, a_3 b_3)$;

Division: $\widetilde{A} \div \widetilde{B} = \frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}$ (Wang, Chin, Poon, and Yang, 2009; Dubois and Prade 1980).

2.3. FQFD

QFD is a planning tool that was first introduced in Japan in 1972 and is used to translate client needs into technical specifications (Vinodh & Kumar, 2011; Akkawuttiwanich & Yenradee, 2018). Many sectors commonly use it to enhance decision-making processes, product design, and consumer loyalty by prioritizing the technical descriptors scientifically (Carnevalli & Miguel, 2008). The HOQ translates 'voice of the customer (VOC) (WHATs) to design requirements (HOWs) that define target values and describe how customer requirements will be met by an organization (Liang, Ding, & Wang, 2012). The VOC and technical specifications are related at the center of the HOQ to examine how the technical descriptors will meet the VOC. This relationship matrix examines how each technical requirement affects customer requirements and their degree (Ramírez, Cisternas, & Kraslawski, 2017). A correlation matrix in the HOQ is used to study the technical descriptors against each other based on the VOC. Many research works integrate and use HOQ

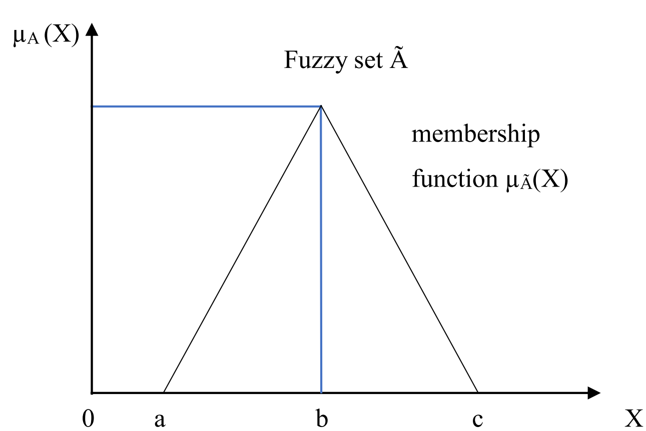

Fig. 1. Triangular membership function.

with fuzzy logic to solve the vagueness of linguistic judgments in the HOQ assessment through a questionnaire.

To get the full benefits of the QFD, several researchers use the combination of QFD with other tools. Haq & Boddu (2017) have applied fuzzy QFD to integrate with the analytical hierarchy process (AHP). Vinodh & Kumar (2011) used fuzzy QFD to prioritize lean enablers. Rodrigues and Ribeiro (2016) have reported using the fuzzy QFD method in an automotive company in choosing the criteria for supplier selection. In translating the linguistic judgments to numerical values, fuzzy logic is used throughout the methodology. This study treats waste as customer requirements, and fuzzy QFD prioritizes the critical resources in the first phase based on the identified wastes.

2.4. Fuzzy FMEA

FMEA is a structured approach used to determine and prioritize the possible modes of failure, frequency of occurrence, and criticality to evaluate them based on the risk priority number (RPN) (De Souza & Carpinetti, 2014; Sawhney et al., 2010). The FMEA is an organized analysis tool that helps practitioners define, identify, and eliminate potential failure modes from the design, process, system, and service (Cicek & Celik, 2013). FMEA method is used in different application areas like mechanical & process industries (Braaksma et al., 2013), automotive (Xu et al., 2017), chemical (Antonio César Ferreira Guimarães & Lapa, 2004), and nuclear industries (Guimarães & Lapa, 2004). Some authors used FMEA with other tools like fuzzy AHP (Abdelgawad & Fayek, 2010). Usually, assessing the risk and prioritizing the failure modes are performed by determining the RPN. The higher the RPN value of a failure mode, the higher the associated risk, which needs great attention. Similarly, the smaller the RPN value, the lesser the risk. RPN calculations are traditionally done using the following formulas:

$$RPN = OxSxD \quad (1)$$

Where O (occurrence) is the likelihood of failure, S (severity) is the magnitude, and D (detection) is the likelihood that failure will not be observed. The risk parameters are evaluated based on a 5, 7, and 10-point scale to determine the failure modes' RPN value (Geramian, Shahin, Minaei, & Antony, 2020). In Eq. (1) O, S, and D are crisp numbers. Hence the value of RPN is also a crisp number. Though this is a usually accepted method to calculate the crisp number, RPN's final value is also a crisp number and has some drawbacks, as criticized by many authors. First, RPN's identical values may be generated from different risk factors, however their hidden risk consequences could be vastly different (Sawhney et al., 2010; Gargama & Kumar, 2011; Liu et al., 2011). Second, it is challenging to precisely give numerical feedback on the risk parameters for the experts. Hence, a slight deviation of one rating may dramatically affect the RPN (Gargama & Kumar, 2011; Mandal & Maiti, 2014). Third, while determining the RPN values, the relative relevance weights of risk factors is not considered (Gargama & Kumar, 2011; Zhang & Chu, 2011). Fourth, the formula for determining RPN is arguable and lacks a scientific basis (Liu, Chen, You, & Li, 2016).

Hence to overcome the drawbacks mentioned above, many authors recommend applying the fuzzy set theory. Mandal and Maiti (2014) suggest to use fuzzy logic integrated with FMEA. In FMEA to evaluate the risk and prioritize the failure modes, Chin et al. (2009), Parameshwaran, Srinivasan, & Punniyamoorthy (2010), and Wang et al. (2009) proposed the use of fuzzy FMEA using fuzzy weighted geometric mean (FWGM) and centroid defuzzification methods. This study uses the FWGM method for FMEA analysis.

This study investigates the combined use of fuzzy QFD, FMEA, plant layout, and VSM methods to apply in determining which lean tools are appropriate. The integrated use of these widely recognized techniques provides a standard for practicing lean implementation.

3. Research methodology

Fig. 2 demonstrates the approach adopted by this research report. The study uses the combination of plant layout, VSM, fuzzy QFD, and FMEA to improve critical resources in a manufacturing organization. In the first phase, wastes are identified using VSM, and with the framework of QFD, fuzzy numbers are integrated. Then the importance weights for the wastes are determined. Then, the HOQ between the identified wastes (WHATs) and the critical resources (HOWs) is developed, followed by identifying the most essential and vital resources. In the second phase, fuzzy FMEA is used to select suitable lean tools for the prioritized lean failure modes of crucial resources.

3.1. Developing the present state VSM and plant layout

Identifying the product family is the initial stage in developing the CSVSM and existing state plant layout. By studying the information and materials flow of each process's activities, the CSVSM is plotted. The VA and NVA actions are identified using the CSVSM. The resources that lead to waste are identified using a time study, observations, and extensive discussions with supervisors and managers.

3.2. Fuzzy QFD

In this study, fuzzy QFD in the HOQ integrates the identified types of wastes and critical resources. The identified wastes (WHATs) are considered as requirements of the customers and the critical resources (HOWs) as technical requirements in the HOQ. Some of the HOQ matrices are not included in this report, such as the preparation (planning) matrix, the technical and target (goal) analysis sections, as they do not apply to this study (Almannai, Greenough, & Kay, 2008).

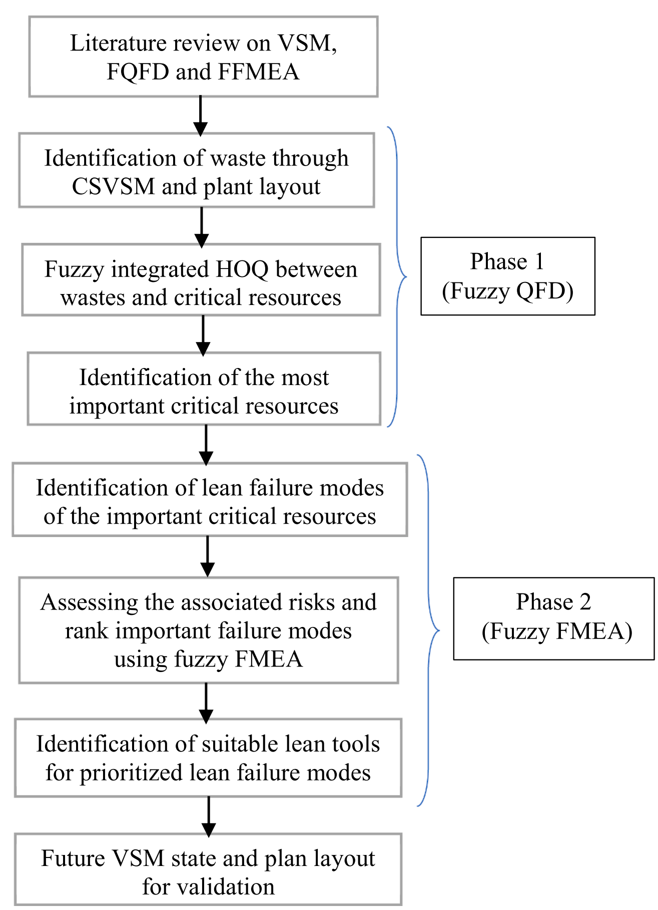

Fig. 2. The framework of the study.

According to Bottani (2009), the fuzzy QFD calculation and the HOQ matrix are defined in the steps below: Step-1: Identifying the importance of customer requirements, i.e., wastes. To properly rank the identified wastes, importance weights should be given (W_i) (i = 1, …, n). Importance weights are obtained from managers, supervisors, and expert's opinions using linguistic terms. Hence fuzzy triangular numbers are used. The importance weights and their associated fuzzy numbers for the identified wastes are shown in Table 1. For the importance weights, a 4-point scale is used to express the study's linguistic values (Bottani & Rizzi, 2006).

Step-2: Calculating the relative importance (RI) of critical resources (HOWs). The relationships are evaluated using managers, supervisors, and expert's opinions. Hence to express the relationships, fuzzy triangular numbers, correlation, and RI are used. In the HOQ, the affiliation matrix (R_{ij}) where (i = 1, …, n; j = 1, …, m) is a matrix whose entry (i, j) shows how j-th critical resource generates i-th waste. Corresponding to the degree of relationships (Ma, Chu, Xue, & Chen 2017), the fuzzy numbers are shown in Table 2. As revealed by Bottani (2009), after evaluating the relationship between wastes and critical resources, the RI of the j-th critical resources (RI_j) is computed using:

$$RI_j = \sum_{i=1}^{n} W_i \otimes R_{ij}, \quad j = 1, \ \dots, \ m \tag{2}$$

The effect of $RI_j onRI_{j'} (j \neq j^{'})$ of the critical resources is expressed in the correlation matrix formed at the roof of HOQ. Letthecorrelationentryisdefinedas$T_{jj'}$. Table 3 displays the degree of the association on the 4-level scale and their corresponding fuzzy numbers.

Step-3: Calculating the final score of critical resources. Having a correlation between the critical resources in the roof of the HOQ matrix, the last score of j-th critical resources is computed using:

$$Score_j = RI_j \oplus \sum_{j \neq j^{'}} T_{jj^{'}} \otimes RI_{j^{'}}, j = 1, \dots, m. \tag{3}$$

Since the measured value (l, m, u) is a fuzzy number, a crisp value is calculated using the following formula:

$$crispvalue = \frac{l + 2m + u}{4} \tag{4}$$

Then the critical resources are prioritized based on the crisp values.

3.3. Fuzzy FMEA

There are many lean techniques and tools to implement lean in the manufacturing industries (Vinodh et al., 2010). But the organizations are facing difficulties in selecting the appropriate lean tools. It is costly, time-consuming, and most firms cannot apply all lean techniques for all the resources (Vinodh, Shivraman, & Viswesh, 2012). A critical issue, especially for low-level technology organizations, is the fear of investing in changes that take time and budget for results. Hence, after prioritizing the essential resources using fuzzy QFD, a profound study will be carried out to determine which sub-elements make the organization fail leanness. These sub-elements in this study are referred to as failure modes. A fuzzy RPN analysis is to be conducted to quantify the associated risks and rank the failure modes. And to complete the calculations with FMEA, data is collected from managers, supervisors, and experts in linguistic terms using a structured questionnaire. Table 4 displays the three factors, linguistic terms (ratings), descriptions, and fuzzy numbers (Ma, Chu, Xue, & Chen, 2017; Bhuvanesh Kumar & Parameshwaran, 2018).

The RI of the risk factors is considered in this study. Table 5 displays fuzzy numbers and linguistic meanings used for the relative weight of O, S, and D (Bottani & Rizzi, 2006). This study uses a fuzzy weighted geometric mean (FWGM) by taking the risk factors' RI weights. It solves the disadvantages of standard FMEA, which calculates the RPN value by multiplying the O, S, and D values.

To calculate the FRPN, aggregating the subjective opinions of the

Table 1
Fuzzy numbers for ranking wastes with their importance weights.

Fuzzy number	Importance weights(Wi)
(0.7; 1; 1)	Very high (VH)
(0.5; 0.7; 1)	High (H)
(0; 0.3; 0.5)	Low (L)
(0; 0; 0.3)	Very low (VL

Table 2
Fuzzy numbers with a corresponding degree of relationships.

Fuzzy number	Degree of relationship
(0.7; 1; 1)	Strong (S)
(0.3; 0.5; 0.7)	Medium (M)
(0; 0; 0.3)	Weak (W)

Table 3
Fuzzy numbers & degree of correlation used in the correlation matrix.

Fuzzy number	Degree of correlation
(0.3; 0.5; 0.7)	Strong positive (SP)
(0; 0.3; 0.5)	Positive (P)
(−0.5; −0.3; 0)	Negative (N)
(−0.7; −0.5; −0.3)	Strong negative (SN)

Table 4
Fuzzy ratings for occurrence (O), severity (S), and detection (D).

Ratings	Fuzzy number	Descriptions		
		Occurrence (O)	Severity (S)	Detection (D)
Very high (VH)	(7, 9, 9)	All workers remember the events and happen very often	Increase cost in the long-term and highly affects the production system	Failure can be detected onlyafter its occurrence
High (H)	(5, 7, 9)	Events are observed by only managers & the people involved	Increased cost in the medium-term and delays the production flow	With a high-level of examination, failure can be identified
Medium (M)	(3, 5, 7)	Managers remember a small number of events	Increased cost in short-term and delays the production flow	Failure can be detected with a medium chance
Low (L)	(1, 3, 5)	Managers recall very few events	A small increase in cost in the short-term but will not impact the production flow	Failure can be detected with small inspection before it occurs
Very Low (VL)	(1, 1, 3)	The occurrences are collected only by managers with difficulty	A minimal increase in cost in the short-term due to the improper use of resources	Failure can be identified directly before its occurrence

Table 5
Fuzzy numbers and linguistic values of the risk factors' relative weight.

Fuzzy numbers	Linguistic value
(0.7, 1, 1)	Very high (VH)
(0.5, 0.7, 1)	High (H)
(0, 0.3, 0.5)	Low (L)
(0, 0, 0.3)	Very low (VL)

FMEA team members is computed using eq. (5) to (10) (Gargama & Chaturvedi, 2011; Parameshwaran et al., 2010).

$$\widetilde{R}_i^O = \sum_{j=1}^{m} h_j \widetilde{R}_{ij}^O = \left(\sum_{j=1}^{m} h_j \widetilde{R}_{ijL}^O, \ \sum_{j=1}^{m} h_j \widetilde{R}_{ijM}^O, \ \sum_{j=1}^{m} h_j \widetilde{R}_{ijU}^O \right), \ i = 1, \ldots, n, \tag{5}$$

$$\widetilde{R}_i^S = \sum_{j=1}^{m} h_j \widetilde{R}_{ij}^S = \left(\sum_{j=1}^{m} h_j \widetilde{R}_{ijL}^S, \sum_{j=1}^{m} h_j \widetilde{R}_{ijM}^S, \sum_{j=1}^{m} h_j \widetilde{R}_{ijU}^S \right), i = 1, \ldots, n, \tag{6}$$

$$\widetilde{R}_i^D = \sum_{j=1}^{m} h_j \widetilde{R}_{ij}^D = \left(\sum_{j=1}^{m} h_j \widetilde{R}_{ijL}^D, \sum_{j=1}^{m} h_j \widetilde{R}_{ijM}^D, \sum_{j=1}^{m} h_j \widetilde{R}_{ijU}^D \right), i = 1, \ldots, n, \tag{7}$$

$$\widetilde{w}^O = \sum_{j=1}^{m} h_j \widetilde{w}_j^O = \left(\sum_{j=1}^{m} h_j \widetilde{w}_{jL}^O, \sum_{j=1}^{m} h_j \widetilde{w}_{jM}^O, \sum_{j=1}^{m} h_j \widetilde{w}_{jU}^O \right), \tag{8}$$

$$\widetilde{w}^S = \sum_{j=1}^{m} h_j \widetilde{w}_j^S = \left(\sum_{j=1}^{m} h_j \widetilde{w}_{jL}^S, \sum_{j=1}^{m} h_j \widetilde{w}_{jM}^S, \sum_{j=1}^{m} h_j \widetilde{w}_{jU}^S \right), \tag{9}$$

$$\widetilde{w}^D = \sum_{j=1}^{m} h_j \widetilde{w}_j^D = \left(\sum_{j=1}^{m} h_j \widetilde{w}_{jL}^D, \sum_{j=1}^{m} h_j \widetilde{w}_{jM}^D, \sum_{j=1}^{m} h_j \widetilde{w}_{jU}^D \right), \tag{10}$$

Where $\widetilde{R}_i^O = \left(\widetilde{R}_{iL}^O, \widetilde{R}_{iM}^O, \widetilde{R}_{iU}^O \right), \widetilde{R}_i^S = \left(\widetilde{R}_{iL}^S, \widetilde{R}_{iM}^S, \widetilde{R}_{iU}^S \right) and \widetilde{R}_i^D = \left(\widetilde{R}_{iL}^D, \widetilde{R}_{iM}^D, \widetilde{R}_{iU}^D \right)$ are aggregated O, S, and D ratings for failure mode FM_i and $\widetilde{w}^O = \left(\widetilde{w}_L^O, \widetilde{w}_M^O, \widetilde{w}_U^O \right), \widetilde{w}^S = \left(\widetilde{w}_L^S, \widetilde{w}_M^S, \widetilde{w}_U^S \right)$, and $\widetilde{w}^D = \left(\widetilde{w}_L^D, \widetilde{w}_M^D, \widetilde{w}_U^D \right)$ are aggregated fuzzy weights for O, S, and D.

Therefore, the FRPN is calculated using Eq. (11) (Wang et al., 2009).

$$FRPN_i = \left(R_i^O\right)^{\frac{\widetilde{w}^O}{\widetilde{w}^O + \widetilde{w}^S + \widetilde{w}^D}} \times \left(R_i^S\right)^{\frac{\widetilde{w}^S}{\widetilde{w}^O + \widetilde{w}^S + \widetilde{w}^D}} \times \left(R_i^D\right)^{\frac{\widetilde{w}^D}{\widetilde{w}^O + \widetilde{w}^S + \widetilde{w}^D}}, i = 1, \cdots, n. \tag{11}$$

Where the i[th] failure mode's fuzzy RPN value is $FRPN_i$.

$R_i^O, R_i^S, and R_i^D; \widetilde{w}^O, \widetilde{w}^S, and \widetilde{w}^D$ are the fuzzy weights of O, S, and D.

It is conceivable to compute the value of FRPN using eq. (5), but the equation with the products and the power of fuzzy numbers is too complicated. Hence, the FRPN of each failure mode can be calculated using alpha-level sets using a linear programming model (LP) (Parameshwaran et al., 2010; Wang et al., 2009).

$$MinZ_1 = u_1 ln\left(\widetilde{R}_i^O\right)_\alpha^L + u_2 ln\left(\widetilde{R}_i^S\right)_\alpha^L + u_3 ln\left(\widetilde{R}_i^D\right)_\alpha^L \tag{12}$$

s.t. $u_1 + u_2 + u_3 = 1$,

$\left(\widetilde{w}^O\right)_\alpha^L.Z \le u_1 \le \left(\widetilde{w}^O\right)_\alpha^U.Z,$

$\left(\widetilde{w}^S\right)_\alpha^L.Z \le u_2 \le \left(\widetilde{w}^S\right)_\alpha^U.Z,$

$\left(\widetilde{w}^D\right)_\alpha^L.Z \le u_3 \le \left(\widetilde{w}^D\right)_\alpha^U.Z,$

$Z \le 0,$

$$MaxZ_2 = u_1 ln\left(\widetilde{R}_i^O\right)_\alpha^U + u_2 ln\left(\widetilde{R}_i^S\right)_\alpha^U + u_3 ln\left(\widetilde{R}_i^D\right)_\alpha^U \tag{13}$$

s.t. $u_1 + u_2 + u_3 = 1$,

$\left(\widetilde{w}^O\right)_\alpha^L.Z \le u_1 \le \left(\widetilde{w}^O\right)_\alpha^U.Z,$

$\left(\widetilde{w}^S\right)_\alpha^L.Z \le u_2 \le \left(\widetilde{w}^S\right)_\alpha^U.Z,$

$\left(\widetilde{w}^D\right)_\alpha^L.Z \le u_3 \le \left(\widetilde{w}^D\right)_\alpha^U.Z,$

$Z \le 0,$

Where $\left[\left(\widetilde{R}_i^O\right)_\alpha^L, \left(\widetilde{R}_i^O\right)_\alpha^U\right], \left[\left(\widetilde{R}_i^S\right)_\alpha^L, \left(\widetilde{R}_i^S\right)_\alpha^U\right]$ and $\left[\left(\widetilde{R}_i^D\right)_\alpha^L, \left(\widetilde{R}_i^D\right)_\alpha^U\right]$ are the α-level sets of O, S, and D ratings and $\left[\left(\widetilde{w}^O\right)_\alpha^L, \left(\widetilde{w}^O\right)_\alpha^U\right], \left[\left(\widetilde{w}^S\right)_\alpha^L, \left(\widetilde{w}^S\right)_\alpha^U\right]$ and $\left[\left(\widetilde{w}^D\right)_\alpha^L, \left(\widetilde{w}^D\right)_\alpha^U\right]$ are the α-level sets of the risk factor weights. Let z*1 and z*2 be the optimal objective function values of models (12) and (13). Then $(FRPN_i)_\alpha^L = exp\left(z_1^*\right) and (FRPN_i)_\alpha^U = exp\left(z_2^*\right)$. By setting different sets of α-level, different $FRPN_i$ values can be generated using:

$$FRPN_i = \bigcup_\alpha \alpha.\left[(FRPN_i)_\alpha^L, (FRPN_i)_\alpha^U\right], 0 \le \alpha \le 1 \tag{14}$$

Since intervals characterize the FRPNs, then the defuzzified centroid of A is computed by the following equation (Wang et al., 2009; Gargama and Chaturvedi, 2011):

$$\widetilde{x}_0\left(\widetilde{A}\right) = \frac{\int_a^d x\mu_{\widetilde{A}}(x)dx}{\int_a^d \mu_{\widetilde{A}}(x)dx}, \tag{15}$$

Where

$\widetilde{x}_0\left(\widetilde{A}\right)$ *is the defuzzified value*. When $\Delta\alpha_i \equiv 1/n, where \Delta\alpha_i = \alpha_{i+1} - \alpha_i, and \alpha_i = 1/n, i = 0, \cdots, n.$ then its defuzzified centroid can be determined using (Wang et al., 2009):

$$\int_a^d \mu_{\widetilde{A}}(x)dx = \frac{1}{2n}\left[\left((x)_{\alpha_0}^U - (x)_{\alpha_0}^L\right) + \left((x)_{\alpha_n}^U - (x)_{\alpha_n}^L\right) + 2\sum_{i=1}^{n-1}\left((x)_{\alpha_i}^U\right) - (x)_{\alpha_i}^L\right], \tag{16}$$

$$\int_a^d x\mu_{\widetilde{A}}(x)dx = \frac{1}{6n}\left[\left((x)_{\alpha_0}^{2U} - (x)_{\alpha_0}^{2L}\right) + \left((x)_{\alpha_n}^{2U} - (x)_{\alpha_n}^{2L}\right) + 2\sum_{i=1}^{n-1}\left((x)_{\alpha_i}^{2U}\right) - (x)_{\alpha_i}^{2L}\right] + \frac{1}{6n}\sum_{i=0}^{n-1}\left((x)_{\alpha_i}^U\right) \bullet (x)_{\alpha_{i+1}}^U - (x)_{\alpha_i}^L \bullet (x)_{\alpha_{i+1}}^L \tag{17}$$

Using the preceding formulae, the unit interval [0, 1] is divided evenly by the sets of alpha levels to calculate the defuzzified centroid value. The failure modes are prioritized and ranked by sorting their defuzzified centroid values. The higher the centroid value, the higher the risk, the higher the priority, and the lower the centroid value, the lower the risk, the lower the priority. Prioritizing the failure modes based on the calculated centroid values provides a list of failure modes' ranks. Based on their level, detailed analysis, the study of the literature, and discussion with industry managers and experts, appropriate tools/ projects for lean implementation are selected.

3.4. Future state value stream mapping (FSVSM) and plant layout

Analyzing the CSVSM and plant layout in detail provides to observe the potential improvement areas and proposed improvement scenarios. By applying the proposed improvement options and modifications, the proposed FSVSM is developed. Implementation of lean takes time to see the results of all the proposed improvement scenarios. Hence all the proposed improvements can not see precisely. But validation is made by comparing the performance metrics of the CSVSM and FSVSM.

4. Case study

This study was conducted in an Ethiopian leather footwear manufacturing company. For the sack of company privacy hereafter, the case company is referred to as ABC. ABC manufactures different types, models, and sizes of leather shoe products. It was established in 1939. In the early 1980s, the company began exporting shoes in limited quantities. ABC gets its leather from local tanneries and other inputs from outside, and it makes its own or imports the sole.

4.1. Current state VSM and plant layout development

The first step in developing the CSVM and plant layout is identifying the product family. As revealed by Ariafar & Ismail (2009), plant layout significantly impacts the performance of manufacturing processes. The existing VSM is developed through plant layout by visiting the organization frequently. Visiting the industry frequently allowed for a thorough examination of each activity's operations. The machines are set up in the correct order. However, WIP is scattered & stored throughout the work locations and before & after each workstation for long time, taking up needless space. The developed current plant layout, shows the flow of products between each workstations (see Fig. 3).

Arrows indicate the movement of materials, WIP, and finished products. The system begins with receiving raw materials from the main store and flows through the cutting, stitching, lasting, and packing sections. In each area, there is an in-process inspection and temporary storing space. Finally, products are stored in inventory in the store until they get dispatched out. Parts within the plant flows in batches of size. The batch size depends on the number of orders. After examining the existing production process closely, the CSVSM is developed, as shown in Fig. 4, by plotting the selected product family's information and material flows. The CSVSM is used to determine the wastes that should be minimized or eliminated. The resources that lead to waste are discovered through time study and observations (Gemba walk) as well as extensive discussion with supervisors and managers.

The cycle time, available time, up-time, and change over time for different processes involved to produce SAWA model shoes are quantified. The CSVSM and layout are evaluated and discussed with managers, supervisors, and experts to summarize the defined wastes. The organization has significant waste and NVA operations, including defects, waiting, labor productivity, unnecessary movement, transportation, inventory, and long lead time.

4.2. Fuzzy QFD

The HOQ is formed between WHATs (wastes) and HOWs (critical resources) to prioritize essential resources. In this study, the wastes are considered as the customer requirements and critical resources as technical requirements in the HOQ. The relationship between the WHATs and the HOWs is assessed through questionnaires from managers, supervisors, and experts, including linguistic values. Therefore, TFNs presented in Tables 1–3 are used to express the importance weights, correlation, and relationship evaluation. Then after developing the relationship & correlation matrix, the computation of RI using Eq. (2), score using Eq. (3), and ranking using Eq. (4) are done as described in the methodology section. Fig. 5 shows the defined HOQ with the ranking of essential resources.

The results of the HOQ show people score the highest value, followed by schedule, equipment, and materials. Since the aim is to implement lean practices and a continuous improvement process, more emphasis will be given to the elements that generate higher waste. As a result, the top two resources (people and schedules) are initially focused on implementing lean methods and eventually identifying their components. These elements are referred to as failure modes in this study

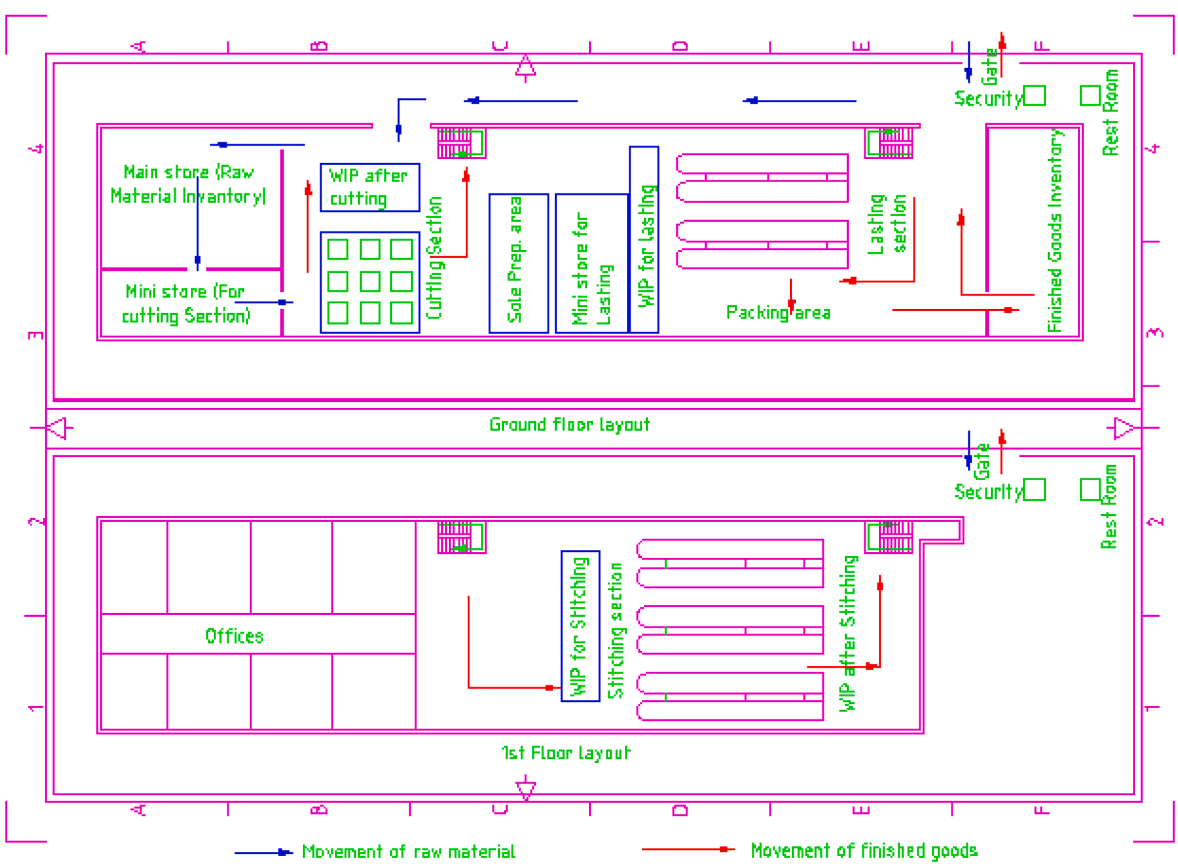

Fig. 3. The current plant layout.

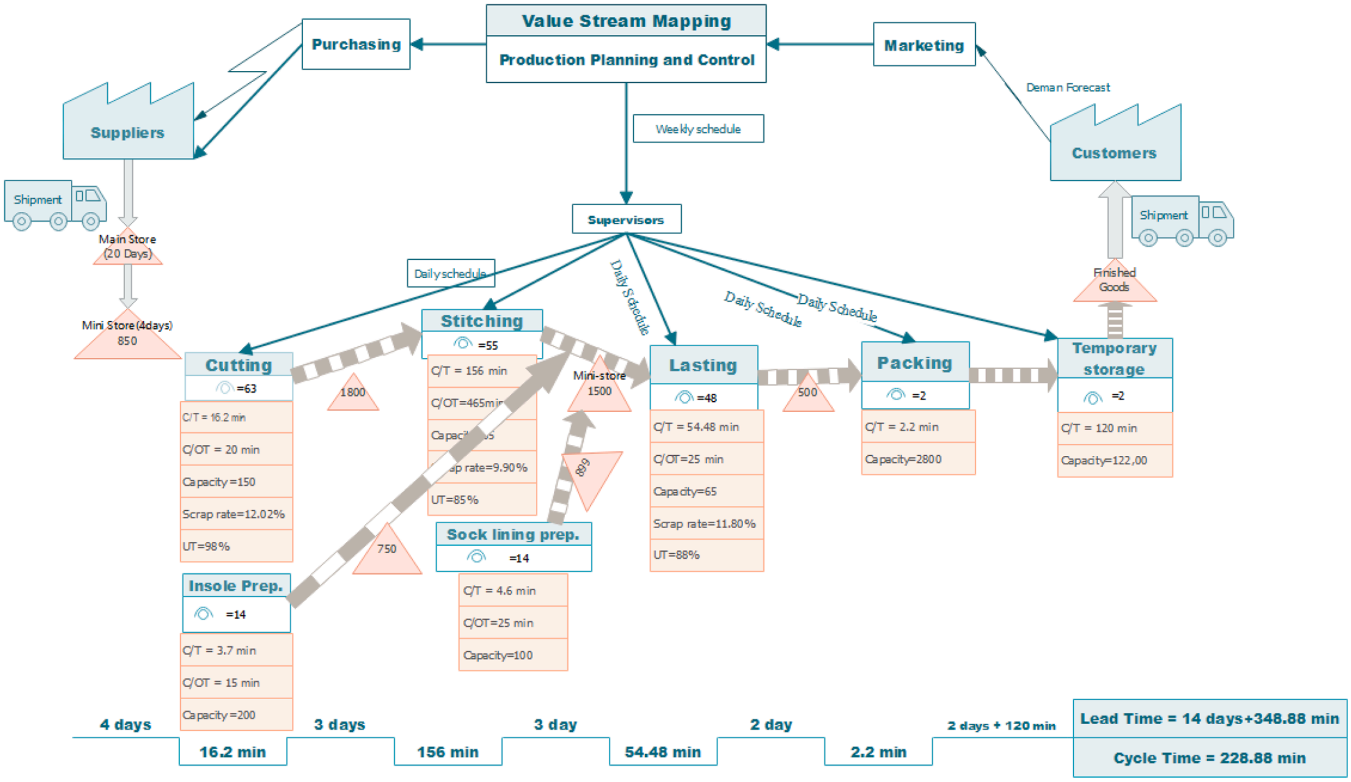

Fig. 4. CSVSM.

Wastes	Weight (W_i)	Critical Resources: People	Equipment	Materials	Schedule
Defects	H	S	M	W	S
Labor productivity	VH	S	M	M	M
Excessive movement	VH	S	S	M	
Waiting	H	S		M	S
Raw material	H			S	
Inventory	L	M		S	W
Transportation	L	S		S	M
Lead time	H	M	S	W	S
RI j		(4.98; 4.2; 5.55)	(1.06; 2.25; 3.4)	(0.92; 2.65; 4.7)	(1.26; 2.75; 4.5)
Score j		(5.676; 7.495; 13.43)	(2.932; 6.52; 12.785)	(0.92; 5.644; 11.425)	(3.072; 6.77; 13.115)
Crisp Values		8.524	7.18925	5.90825	7.43175
Rank		1	3	4	2

Fig. 5. The HOQ.

Table 6
Alpha-level set and fuzzy RPN values.

α	Failure Modes FM1	FM2	FM3	FM4	FM5	FM6
0	[5.3686, 8.6535]	[3.7957, 7.6517]	[3.8204, 7.8622]	[4.8802, 8.2768]	[2.6385, 6.7859]	[6.3327, 9.0000]
0.1	[5.5710, 8.5313]	[3.9987, 7.4703]	[4.0445, 7.6805]	[5.0861, 8.1436]	[2.8485, 6.5790]	[6.5329, 8.9333]
0.2	[5.7732, 8.4081]	[4.2013, 7.2884]	[4.2656, 7.4975]	[5.2915, 8.0101]	[3.0574, 6.3718]	[6.7331, 8.8667]
0.3	[5.9752, 8.2841]	[4.4036, 7.1060]	[4.4845, 7.3130]	[5.4965, 7.8760]	[3.2652, 6.1644]	[6.9332, 8.8001]
0.4	[6.1771, 8.1590]	[4.6058, 6.9233]	[4.7014, 7.1271]	[5.7011, 7.7415]	[3.4723, 5.9566]	[7.1334, 8.7334]
0.5	[6.3789, 8.0330]	[4.8077, 6.7400]	[4.9166, 6.9396]	[5.9055, 7.6065]	[3.6786, 5.7486]	[7.3335, 8.6668]
0.6	[6.5806, 7.9059]	[5.0095, 6.5562]	[5.1304, 6.7505]	[6.1095, 7.4709]	[3.8844, 5.5402]	[7.5337, 8.6003]
0.7	[6.7822, 7.7778]	[5.2112, 6.3719]	[5.3430, 6.5595]	[6.3133, 7.3349]	[4.0896, 5.3315]	[7.7338, 8.5337]
0.8	[6.9837, 7.6485]	[5.4127, 6.1870]	[5.5545, 6.3667]	[6.5169, 7.1983]	[4.2944, 5.1223]	[7.9339, 8.4672]
0.9	[7.1851, 7.5171]	[5.6141, 6.0016]	[5.7651, 6.1719]	[6.7202, 7.0611]	[4.4988, 4.9128]	[8.1341, 8.4007]
1	[7.3864, 7.3864]	[5.8154, 5.8154]	[5.9749, 5.9749]	[6.9233, 6.9233]	[4.7028, 4.7028]	[8.3342, 8.3342]
Centroid	7.1412	5.7572	5.8994	6.6969	4.7132	7.8889
Priority ranking	5	10	9	7	12	1

α	FM7	FM8	FM9	FM10	FM11	FM12
0	[5.4571, 8.6535]	[5.0208, 8.6535]	[4.3749, 8.0886]	[5.9269, 9.0000]	[3.1539, 7.2304]	[5.7924, 9.0000]
0.1	[5.6592, 8.5346]	[5.2215, 8.4912]	[4.5831, 7.9269]	[6.1284, 8.8934]	[3.3695, 7.0375]	[5.9936, 8.8800]
0.2	[5.8611, 8.4159]	[5.4222, 8.3288]	[4.7906, 7.7646]	[6.3299, 8.7868]	[3.5834, 6.8437]	[6.1948, 8.7600]
0.3	[6.0629, 8.2973]	[5.6229, 8.1663]	[4.9974, 7.6014]	[6.5312, 8.8604]	[3.7959, 6.6490]	[6.3958, 8.6401]
0.4	[6.2646, 8.1790]	[5.8235, 8.0037]	[5.2037, 7.4374]	[6.7325, 8.5740]	[4.0071, 6.4534]	[6.5968, 8.5202]
0.5	[6.4662, 8.0608]	[6.0240, 7.8411]	[5.4094, 7.2725]	[6.9337, 8.4678]	[4.2173, 6.2568]	[6.7978, 8.4003]
0.6	[6.6677, 7.9427]	[6.2246, 7.6783]	[5.6148, 7.1067]	[7.1348, 8.3617]	[4.4266, 6.0592]	[6.9986, 8.2804]
0.7	[6.8691, 7.8249]	[6.4251, 7.5155]	[5.8197, 6.9399]	[7.3359, 8.2557]	[4.6351, 5.8604]	[7.1995, 8.1607]
0.8	[7.0704, 7.7073]	[6.6255, 7.3526]	[6.0243, 6.7719]	[7.5369, 8.1499]	[4.8429, 5.6605]	[7.4002, 8.0409]
0.9	[7.2716, 7.5899]	[6.8260, 7.1895]	[6.2285, 6.6028]	[7.7378, 8.0442]	[5.0501, 5.4593]	[7.6010, 7.9213]
1	[7.4728, 7.4728]	[7.0264, 7.0264]	[6.4325, 6.4325]	[7.9387, 7.9387]	[5.2568, 5.2568]	[7.8017, 7.8017]
Centroid	7.1940	6.9008	6.3249	7.6346	5.2222	7.5314
Priority ranking	4	6	8	2	11	3

because of their potential implications and risks.

4.3. Fuzzy FMEA

An in-depth understanding of the critical resources and their sub-elements results in finding six modes of failure from people and six modes of failure from the schedule. These are inspection, purchasing of raw materials, manufacturing quantity & delivery format, material cutting, tool searching, manufacturing process, worker's involvement, and layout.

The three team members are of varying significance based on their respective domain knowledge, skills, and experience. The relative weights are allocated to the three team members as 50%, 30%, and 20% to reflect their opinion in FMEA analysis. Then the twelve failure modes are aggregated using eq. (5 to 10)

The equations given in the methodology were used for calculating the fuzzy RPN. By setting different alpha levels, various fuzzy RPN levels can be determined. In this study, to get eleven fuzzy RPN values, the alpha values are set from 0 to 1, and the calculated values in intervals are shown in Table 6. Therefore, the crisp values are obtained using the centroid defuzzification technique. The failure modes are then ranked based on their centroid values (see the last row of Table 6).

The present case study shows the failure modes and their potential effects, root cause, and recommended lean projects in Table 7. Hence the study uses fuzzy FMEA method to prioritize the twelve failure modes.

After prioritizing the failure modes, they are presented as follows: Manufacturing process, workers' involvement (movement), raw materials purchasing, material cutting, manufacturing quantity & delivery format, tool searching, layout, inspection, and material loading. To overcome the wastes suitable lean projects are chosen related to these modes of failure. Lean projects are selected for execution based on decision-makers interests regarding the top few failure modes.

4.4. Future state VSM and plant layout

The fuzzy FMEA analysis result shows that high WIP in the manufacturing process, workers' movement (involvement) due to work environment, raw materials purchasing, material cutting, and inefficient manufacturing process are the failure modes positioned in the top priority lists. The selected lean projects are: facility planning & layout modification, pull system & FIFO (First-in, first-out), and line-balancing for these failure modes.

The results of the VSM show that stitching and lasting are the main processes that take a higher time, and most of the manufacturing activities are performed. After stitching, the next operation is lasting. But the cycle time of stitching is higher than lasting, which creates high WIP. This indicates a problem of flow production in the manufacturing process, which needs line balancing. Since there is doubt about the quality of raw materials, it is becoming a norm to produce 15% more than the ordered quantity to compensate for products' defects due to raw materials problems, which indirectly increases the WIP. Due to the lack of standards in purchasing and delivery schedules, inventory levels are kept very high. Consequent to the lack of line balancing among the workstations, the workers have an unbalanced workload. Hence after an in-depth investigation of all the activities within the manufacturing processes through Genba walk and time study, line balancing of the manufacturing processes is made. After making the proposed modifications, the FSVSM is presented and shown in Fig. 6. The order fulfillment process of the company is very long and complicated. Every step needs a check and balance of the order quantities and qualities, which leads to a long lead time. It also creates order delays, customer dissatisfaction, and complaints. A pull system is suggested to be integrated into the company to reduce such problems and helps the company to reduce manufacturing costs and overproduction. FIFO procedure is followed to minimize WIP inventory stacking & products for a long time and deliver a better product. And practically, line balancing between

Table 7
FMEA table.

Critical resources	Manufacturing environment						
	Type of wastes	Lean failure modes	Potential effects	Root cause	Centroid	Rank	Proposed lean projects
People	1. Defects	Material cutting	Inappropriate size of components	Unskilled operator/fatigue	7.1412	5	Training the operator and provide break time
	2. waiting	Material loading	Time-consuming	Unskilled operator	5.7572	10	Training the operator
	3. over-processing	Inspection	Uncertain waiting	Unskilled operator	5.8994	9	Training the operator
	4. Waiting	Tool searching	Time-consuming	Unexperienced operator	6.6969	7	Layout modification and workplace organization
	5. Defects	Manufacturing process	Defective products	Unskilled operator/fatigue	4.7132	12	Training the operator and provide break time
	6. Inventory	Manufacturing process	High WIP	Unskilled operator /fatigue	7.8889	1	Training the operator and provide break time
Schedule	7. Overproduction	Raw materials Purchasing	High levels of inventory	Lack of standard purchasing schedule	7.1940	4	Pull system, FIFO
	8. Inventory	Manufacturing quantity & delivery format	Finished goods pile up	No proper schedule of delivery	6.9008	6	Standard delivery schedule
	9. Transportation	Layout	Raw materials' long and unnecessary movement	The initial plan of the plant layout	6.3249	8	Facility planning and layout modification
	10. Motion	Workers movement due to the work environment	Internal traffic	Poor workstationarrangements	7.6346	2	Layout modification and facility planning
	11. Inventory	Manufacturing process	High level of WIP	Unbalanced assembly line workstations	5.2222	11	Assembly line balancing
	12. Transportation	Manufacturing process	Unnecessary transportation leads to long lead time	The initial plan of the plant layout	7.5314	3	Layout modification and facility planning

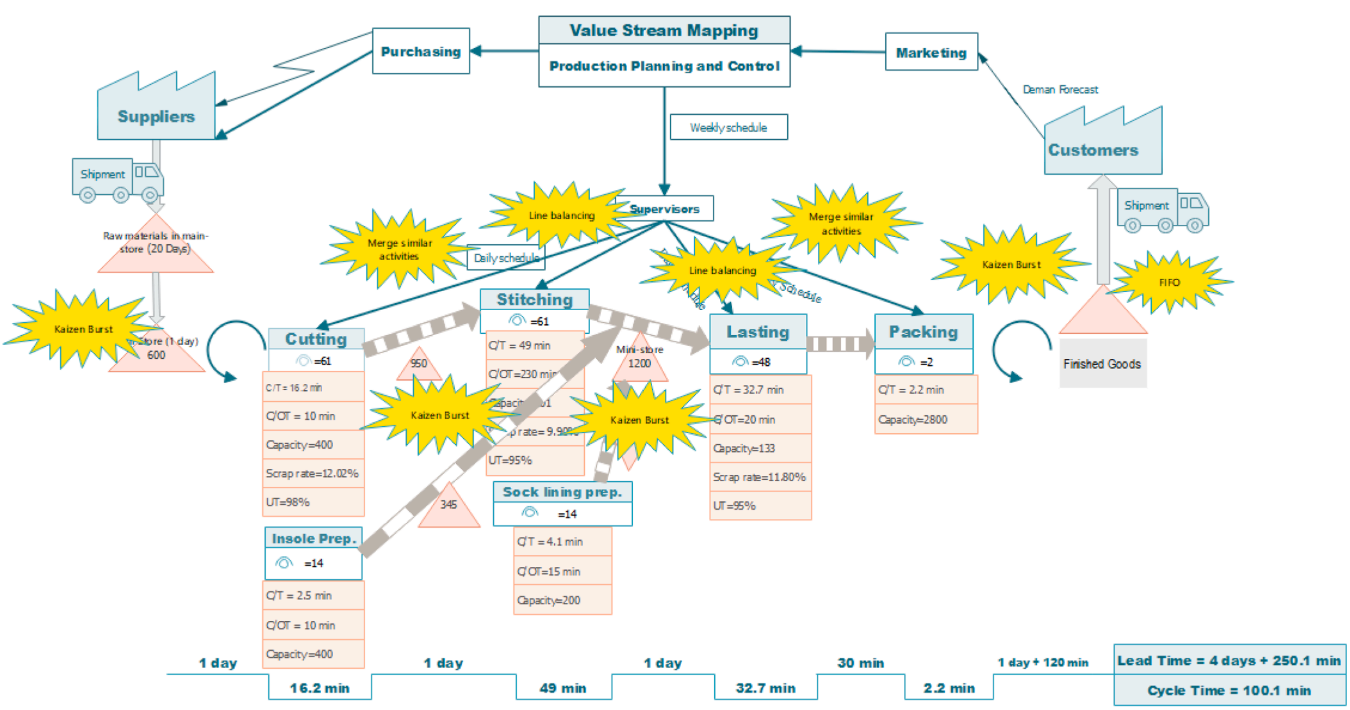

Fig. 6. FSVSM.

work stations is implemented to attain the production flow system. The changes in change over & cycle time, waiting, transportation, NVA, and other modifications are noted in FSVSM.

The proposed modified future plant layout is presented in Fig. 7, where the stitching section replaces the sole preparation and mini store for the lasting area. Consequently, this dramatically reduces waiting time, transportation of raw material, and the number of employees. It also makes the production system to have a flow production system. Alternatively, a conveyor system can be installed from the cutting section to the stitching section and from the stitching section to the lasting section.

5. Results and discussions

The most significant resources (schedule and people) are chosen for an in-depth analysis of the cause and their effects from fuzzy HOQ analysis. The waste sub-elements are evaluated by using the FWGM method, using α-cut values. The failure modes are prioritized using the centroid defuzzification method. After an in-depth analysis of the FMEA, significant lean projects are selected like assembly line balancing, pull system & FIFO, and plant layout modification & facility planning. After the implementation of lean projects, the results are noted from the FSVSM shown in Fig. 6. The key operational performance measures of a manufacturing industry like lead time, cycle time, labor productivity,

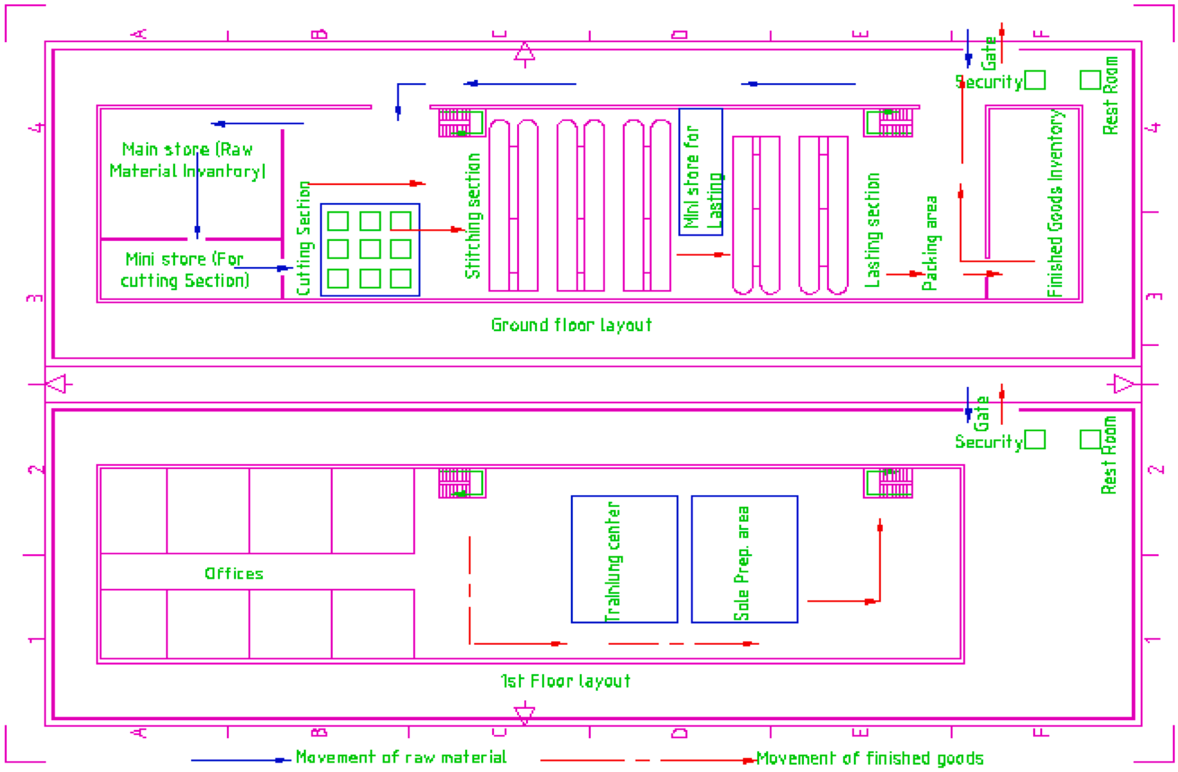

Fig. 7. Proposed modified future plant layout.

Table 8
Comparison of the current and future state.

Key measures	Current state	Future state	Improvements
Total cycle time (min)	228.88	100.1	128.8
NVA time (Including transportation and temporary storage)	14 days and 120 min.	4 days and 150 min.	10 days
Total lead time	14 days and 348.88 min	4 days and 250.1 min	10 days and 98.78 min
Number of workers required (No's)	202	200	2
WIP (pairs)	4650	2750	1900

and WIP for the current and future lean implementation scenarios are shown in Table 8.

5.1. Assembly line balancing (ALB)

ALB problem is a problem of assigning different jobs to workstations while enhancing one or more goals without violating any line constraints. It assists the company in successfully allocating and utilizing available resources. One of the difficulties that ALB should solve is resource optimization. In this study, reduction in cycle time (56.3%) and lead time (69.7%) was obtained as a result of ALB implementation.

5.2. Pull system & FIFO

The use of a pull system aids decision-makers in controlling the flow of resources. It enables the company to set standards for purchasing raw materials and estimating demand in order to satisfy the customers need. And it is a critical tool for the organization to use in order to reduce WIP & finished goods inventory that is held for an excessive amount of time and takes up a lot of space in the plant. In order to dispatch the products to customer on time and confirm that they are not kept in inventory for an extended period of time, FIFO format is used with pull system. This helps to keep the workplace clean and boosts employee satisfaction. According to Isaksson and Seifert (2014), one way to improve the organization's productivity is to reduce the inventory level.

5.3. Plant layout modification and facility planning

Plant layout modifications yield excellent results to achieve the goal of this research. Internal traffic is largely minimized and increases the participation of the worker. This will increase labor productivity. To reduce WIP & waiting time between work stations, every production process section should communicate with the production and planning department internally through intranet. It saves time and energy spent in checking and counting every part and reduces the lead time. The proposed solution will reduce the distance of transportation of materials and transportation activities by more than 75%. This makes the organization have a flow production system. The number of workers required is reduced from 202 to 200. Time, distance, and energy expended on storing and retrieving the WIP are also reduced.

5.4. Implications

Since implementing the lean program is a time-consuming procedure, it desires continuous effort to get significant outcomes. Lean practitioners and managers need to identify critical resources and major waste types before implementing a lean program. This study demonstrates how wastes are identified using VSM by managers and practitioners, fuzzy QFD method to identify critical resources, which creates the major wastes, and fuzzy FMEA method to identify the failure modes. And the sub-elements of the wastes are evaluated using FWGM and α-cut values. Then in prioritizing the failure modes, the centroid defuzzification technique is used. This helps managers and practitioners to select the appropriate lean projects for implementation. To create a lean culture within the company, this has to be done continuously. After attaining the employees to the expected level, more analysis will be done on other resources to remove hidden wastes. For being competitive, managers, decision-makers and practitioners recognized the importance of lean concepts.

6. Conclusions

This research has investigated the combined use of fuzzy FMEA & QFD, plant layout, and VSM empirically. A case study is conducted in the manufacturing firm to validate the proposed model. Experimenting through case study, aids practitioners and decision-makers in identifying the most critical resources, significant waste, and high & less essential activities. This helps practitioners to implement lean projects by making simple changes with fewer resources and integrating the existing system into the LM system. Compared to the conventional selection models, the proposed model provides the following benefits:

- In assessing the failure modes' S, O, and D managers, supervisors, and expert's knowledge & opinion are considered to capture diversified opinions
- The RI of the risk factors is considered while prioritizing failure modes, making the proposed fuzzy FMEA more practical and realistic.
- Since its focus is only on the most critical resources, it saves time to evaluate only the high-priority resources
- Identifying the failure modes, their sub-elements, and the proposed lean projects confirm reliability of the implementation of lean.

The study's' significant contributions are summarized as:

- A fuzzy geometric mean and centroid defuzzification approach addresses most of the criticisms concerning integrated fuzzy models. It prioritizes and ranks the most critical resources' failure modes based on different alpha levels and centroids values.
- This study helps researchers study the fuzzy application in manufacturing industries in-depth and filling the literature gap.

The successful validation of the model is confirmed by comparing the CSVSM with the FSVSM using a case study from the manufacturing organization. The result shows an improvement in the industry's quality, cost, and effectiveness performance.

6.1. Limitations and future research directions

The output of this study is reported from Ethiopian leather shoe manufacturing industry. Apart from its important findings, some study limitations should be acknowledged, as they may lead to further study. The study is conducted in a single case in the leather sector's low-level technology manufacturing industry. Hence, the proposed model can be further investigated by applying it to different organizations and sectors. And also the study has considered managers, supervisors, and expert's opinions by giving different weights. Therefore, assessing the information from a single manager of the organization can be considered future research work. And in the future, various industries can experiment with cost analysis using this approach.

7. Compliance with ethical standards

Funding: This study is conducted without any funding.

CRediT authorship contribution statement

Hiluf Reda: Conceptualization, Methodology, Software, Data curation, Formal analysis, Investigation, Writing – original draft. **Akshay Dvivedi:** Software, Investigation, Resources, Validation, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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