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Implementation of Lean Manufacturing to Minimize Waste in the Fire Ring Production Process †

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Abstract

Enggal Jaya MSME is a small-scale enterprise specializing in metal casting and the production of fire rings, with a monthly capacity exceeding 15,000 units. Currently, its production process exhibits significant inefficiencies across the seven wastes of lean manufacturing: overproduction, defects, inventory, motion, transportation, overprocessing, and waiting. This study aims to map the information and production workflows for fire ring components, analyze the types and root causes of waste, and propose actionable solutions to improve shop-floor efficiency. Value Stream Mapping (VSM) and the Waste Assessment Model (WAM) were utilized as the primary methodologies. The current-state VSM revealed a Process Cycle Efficiency (PCE) of 69%, whereas the proposed future-state VSM demonstrates an improved PCE of 73%. Furthermore, Waste Assessment Questionnaire (WAQ) calculations identified five major types of critical waste: overproduction (19.2%), defects (18.0%), inventory (16.1%), motion (15.2%), and transportation (13.3%). Proposed countermeasures include systematically recording production activities, developing Standard Operating Procedures (SOPs), integrating appropriate material handling tools, and implementing rigorous production forecasting and scheduling.

Keywords: lean manufacturing; value stream mapping; waste assessment model; ring fire product

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1. Introduction

In the highly competitive modern manufacturing landscape, Micro, Small, and Medium Enterprises (MSMEs) face mounting pressure to enhance productivity, capacity, and product quality. To maintain viability, MSMEs must cultivate competitive advantages through superior quality, competitive pricing, timely delivery, and operational flexibility [1], thereby generating greater economic value than their competitors. The evolution of the manufacturing sector, particularly in metal casting, necessitates production optimization, increased value addition, and strict cost efficiency [2]. Consequently, many companies are driven toward adopting lean manufacturing principles [1,3,4].

Lean manufacturing is a simple, well-structured, and continuous approach to eliminating waste, which encompasses both material wastage and non-value-added activities [5–7]. Because consumers do not subsidize process inefficiencies, eliminating these wastes is crucial for minimizing costs and maximizing customer value [7]. This approach is highly

adaptable, allowing companies to implement it according to their specific capabilities and resources to achieve greater efficiency [8].

The first step in a lean transformation involves identifying and mapping operational workflows to detect inefficient, waste-generating activities [9–11]. Value Stream Mapping (VSM), pioneered by the Toyota Motor Corporation [12], is a dynamic tool used to visualize the entire production system, from raw material procurement to final product distribution [1]. A primary advantage of VSM is its ability to illustrate both material and information flows. This comprehensive visibility enables practitioners to analyze the underlying logic of the production system, allowing them to focus on systemic process improvements rather than isolated product modifications [13–15].

Numerous studies have demonstrated the versatility of VSM across a wide array of industries. In the service sector, it has been successfully applied to map material and information flows [2] as well as to identify waste and improve service processes in shoes care enterprises [16]. Within the apparel and footwear manufacturing sectors, researchers have utilized VSM alongside Process Activity Mapping (PAM) to minimize the seven types of waste in shoe production [11]. Similarly, VSM has been deployed to address suboptimal production targets and eliminate non-value-added activities in the manufacturing of golf gloves [17] and sports shoes [18].

The applicability of VSM extends to broad manufacturing and food production environments. For example, productivity enhancements in small and medium-sized enterprises (SMEs) have been achieved by integrating VSM with Kaizen methodologies, as demonstrated in the batik industry [15]. Furthermore, VSM has been utilized to streamline operations in the production of aluminum pans [5], snack food industry [19] and in a four-wheel vehicle manufacturing company [20]. Collectively, these studies demonstrate that VSM-driven improvements not only enhance production efficiency but also maximize customer responsiveness and build sustainable competitive advantages [21]. Consequently, VSM is widely recognized as a highly effective operational tool within the manufacturing industry [22].

In addition to VSM, complementary methodologies such as the Waste Assessment Model (WAM) are frequently employed. WAM is an analytical method used to identify operational waste [13]. As a lean manufacturing tool, it consists of the Seven Waste Relationship (SWR) [13], followed by the Waste Relationship Matrix (WRM) and the Waste Assessment Questionnaire (WAQ). The primary advantage of the WAM method is its simple, standardized matrix and questionnaire, which yield highly accurate results when identifying critical waste [15,23]. Following this identification, further waste analysis is typically conducted using fishbone diagrams, the 5W + 1H framework [24], and Failure Mode and Effects Analysis (FMEA) [25].

This research was conducted at Enggal Jaya MSME. Established in 1991, the enterprise manufactures various metal equipment products. Its highest-volume product is the Fire Ring, which has a production capacity of 15,000 pieces per month. Preliminary observations revealed several unrecognized sources of waste on the shop floor. These include poor layout design (specifically, the excessive distance between the molds and the melting station), a lack of dedicated storage for raw materials and finished goods, defective products requiring reprocessing, delays during the melting and hardening stages, and insufficient material handling equipment that exacerbates waiting times.

To address these inefficiencies, this study implements lean manufacturing principles using VSM tools. The primary goal is to identify current waste on the Fire Ring production floor and propose targeted improvements to minimize it. Reducing this waste is expected to subsequently increase both production capacity and overall company profitability. Fur-

thermore, a root-cause analysis will be conducted using fishbone diagrams to ensure the proposed solutions facilitate a more efficient production process.

2. Research Methods

2.1. Object and Time of Research

This research was conducted at the Enggal Jaya MSME in Central Java, Indonesia, from January to March 2024. The study observed the entire production process. Data was collected by distributing questionnaires to two owners and one operator, while process time measurements were recorded by observing five operators.

2.2. Research Stages

The research consisted of five primary stages, utilizing the following methodologies [13]: (1) Value Stream Mapping (VSM): Mapping the production and information flow to identify both value-added and non-value-added activities at the total production level [8]. (2) Value Stream Analysis Tools (VALSAT): Mapping waste in detail within the value stream, focusing on the value-adding process [16]. (3) Waste Relationship Matrix (WRM): Analysing measurement criteria to evaluate the relationships between different types of waste [13]. (4) Waste Assessment Questionnaire (WAQ): Identifying and allocating waste occurring on the production floor [23]. (5) Process Activity Mapping (PAM): Mapping all activities in detail to eliminate waste, inconsistency, and irrationality in the workplace, ultimately aiming to improve product quality, accelerate processes, and reduce costs [13].

3. Research and Discussion

3.1. Production Process

The fire ring production process consists of five main activities. First is the mold-making process, which involves creating patterns and pouring sand into the mold, taking 2–3 weeks. This is followed by the smelting process, where raw materials (metal and charcoal) are melted in a cupola furnace for 6–7 h until ready for pouring. The third step is pouring the liquid metal into the mold using a cintung—a specialized tool designed to withstand high temperatures—which takes 6–7 h.

The subsequent stage is the demolding phase. The liquid metal requires 2 h to harden, after which the mold is dismantled using an iron rod over a period of 6–7 h. The product is then left to rest for 24 h until fully solidified. The final step is finishing, which takes 7 days and involves cutting the fire ring into four sections and smoothing the edges with a grinder to achieve the required precision. An image of the finished fire ring is shown in Figure 1.



Figure 1. Fire Ring Product.

Observations of process time were conducted using a stopwatch. Table 1 presents the cycle times from five observations of 20 activities carried out across five Fire Ring manufacturing workstations.

Table 1. Fire Ring Production Process Time.

Workstation	Process	No	Activity	Code	Activity Time (Minutes)				
					1	2	3	4	5
1	Mold Making	1	Making Mold Patterns	A.1	0	1.93	2.5	2.0	2.03
		2	Inserting Sand into the Mold	A.2	0.8	1.03	1.02	0.79	0.96
		3	Compacting the Sand	A.3	1.05	1.4	0.94	1.18	1.0
		4	Leveling the Sand	A.4	0.25	0.32	0.41	0.36	0.46
		5	Giving Waterproof Powder	A.5	0.4	0.28	0.3	0.3	0.38
		6	Making Holes	A.6	0.38	0.5	0.49	0.41	0.56
		7	Inserting Sand into Other Side	A.7	2.1	2.75	2.37	2.33	2.42
		8	Removal of Mold Box	A.8	1.4	1.48	1.23	1.6	1.99
2	Smelting	9	Preparation of Smelting Area	B.1	2.19	2.07	2.12	2.31	2.35
		10	Raw Material Retrieval	B.2	0.39	0.5	0.51	0.56	0.49
		11	Smelting Process	B.3	5.22	5.01	4.92	5.13	5.01
3	Pouring	12	Preparation of Pouring Area	C.1	1.11	1.01	0.92	1.2	1.01
		13	Metal Liquid Retrieval	C.2	3.49	3.71	3.42	3.91	3.89
		14	Pouring Process	C.3	3.48	3.95	3.94	3.65	3.76
4	Demolition	15	Mold Unloading	D.1	4.11	4.34	4.72	4.38	4.4
		16	Retrieving the Metal that has been shaped	D.2	0.25	0.33	0.4	0.4	0.36
		17	Putting the Metal into the Container	D.3	0.38	0.44	0.41	0.6	0.23
5	Finishing	18	Separating the Fire Ring	E.1	0.24	0.36	0.32	0.33	0.34
		19	Smoothing the sides of the ring with Grinders	E.2	1.36	1.49	1.29	1.96	2.04
		20	Putting the ring into the sack	E.3	3.02	3.33	3.34	3.03	2.7

Work in process (WIP) refers to the inventory of semi-finished materials on the production line awaiting further processing. Table 2 shows the quantity of WIP at each Fire Ring manufacturing workstation. The WIP data, number of operators per workstation, and available working time are the data required to construct the VSM.

Table 2. Work in Process Inventory, Number of Operators, and Available Time.

No	Workstation	Inventory (kg)	Number of Operators (People)	Available Time (Minutes)
1	Mold Making	5400	4	33,600
2	Smelting	1400	5	660
3	Pouring	625	11	660
4	Demolition	625	10	720
5	Finishing	500	4	28,800

3.2. Data Sufficiency and Uniformity Tests

In this study, the data sufficiency test employed a confidence level of 95% and an accuracy level of 5%; that is, a 5% risk of rejecting a correct hypothesis was accepted, with 95% confidence in the decision, and data were deemed sufficient if $N' < N$. The data uniformity test used the same accuracy and confidence levels to determine the upper control limit (UCL) and lower control limit (LCL). Table 3 presents the results of the data sufficiency and uniformity tests, which confirm that the production time data are both sufficient and uniform.

$$\text{Process Cycle Efficiency} = \frac{\text{Value Added}}{\text{Lead Time}} \times 100\% = \frac{4864}{7026.0058}\% = 69\%$$

The current VSM yields a value added of 4864 min and a lead time of 7026.0058 min, giving a PCE of 69%. The higher the PCE percentage, the more efficient the production process.

Table 3. Recapitulation of Data Sufficiency and Uniformity Test Calculations.

No	Workstation	N	N′	Description	UCL	LCL	Average	Description
1	Mold Making	5	4.37	Sufficient Data	10.860	7.619	9.24	Uniform Data
2	Smelting	5	0.76	Sufficient Data	8.324	7.187	7.76	Uniform Data
3	Pouring	5	1.53	Sufficient Data	9.372	7.607	8.49	Uniform Data
4	Demolition	5	4.73	Sufficient Data	6.089	4.210	5.15	Uniform Data
5	Finishing	5	3.58	Sufficient Data	5.828	4.231	5.03	Uniform Data

3.3. Waste Assessment Model (WAM) Evaluation

The WAM evaluation was derived from discussions and completed questionnaires from the owner and operators. After determining the Waste Relationship Matrix (WRM) scores, the WRM questionnaire results were processed by converting the input into the output in the WRM table. Table 4 presents the WRM calculation. The weightings were obtained from the respondents' answers to determine the relationships between waste types, ranging from absolutely necessary to unimportant.

Table 4. Weighting of Waste Relationship Matrix Questionnaire Answers.

F/T	Waste						
	O	I	D	M	T	P	W
O	10	17	6.5	9	11.5	0	12.5
I	7	10	6	3	12	0	0
D	5	10.5	10	6.5	4	0	6
M	0	2.5	8	10	0	9.5	17.5
T	6	6	8.5	12.5	10	0	11.5
P	7.5	9	13.5	15	0	10	7.5
W	5	3	3	0	0	0	10

These answers were then processed and converted into relationship strength symbols. The conversion ranges were as follows: 17–20: absolutely necessary (symbol A, value 10); 13–16: especially important (symbol E, value 8); 9–12: important (symbol I, value 6); 5–8: ordinary closeness (symbol O, value 4); 1–4: unimportant (symbol U, value 2); 0: no relationship (symbol X, value 0) [13]. The symbols were subsequently converted into numerical values with reference to A = 10, E = 8, I = 6, O = 4, U = 2, and X = 0. The WRM conversion into numerical values is shown in Table 5.

According to the WRM questionnaire calculation, the waste from overproduction (19%) had the highest percentage, indicating that this waste exerts the greatest influence on other wastes. Meanwhile, the waste to inventory column (18%) had the highest percentage value, meaning that inventory waste is the waste type most frequently caused by other wastes. Following the WRM calculation, the Waste Assessment Questionnaire (WAQ) was calculated. The initial step of the WAQ is grouping the questionnaire items, as presented in Table 6.

Based on the 80/20 Pareto principle, five waste types require prioritisation, namely overproduction, defects, inventory, motion, and transportation. Their cumulative percentages are: overproduction 19%, defects 35%, inventory 53%, motion 69%, and transportation 82%. These wastes were therefore selected for further analysis and improvement (see in Table 7).

Table 5. Waste Matrix Value of Fire Ring Product.

F/T	Waste							Score	(%)
	O	I	D	M	T	P	W		
O	10	10	4	6	6	0	6	42	19
I	4	10	4	2	6	0	0	26	12
D	4	6	10	4	2	0	4	30	14
M	0	2	4	10	0	6	10	32	14
T	4	4	6	6	10	0	6	36	16
P	4	6	8	8	0	10	4	40	18
W	2	2	2	0	0	0	10	16	7
Score	28	40	38	36	24	16	40	222	100
(%)	13	18	17	16	11	7	18		100

Table 6. WAQ Question Grouping.

No	Questions Type	Total (Ni)
1	From Overproduction	3
2	From Inventory	6
3	From Defect	8
4	From Motion	11
5	From Transportation	4
6	From Process	7
7	From Waiting	8
8	To Defect	4
9	To Motion	9
10	To Transportation	3
11	To Waiting	5
	Total Questions	68

Table 7. WAQ Calculation Percentage.

Waste Type	Total	Cumulative	Percentage (%)
O	19.2487633	19.24876334	19
D	16.1156651	35.36442848	35
I	18.0343792	53.39880767	53
M	15.2024139	68.60122155	69
T	13.3220946	81.92331613	82
P	8.74218742	90.66550355	91
W	9.33449645	100	100
Total	100		

From the VALSAT tool calculations, PAM achieved the highest total score; consequently, PAM was selected for a more detailed investigation of waste (see Table 8).

The overproduction waste observed is attributed to the absence of production forecasting, resulting in a lack of certainty regarding the quantity of products to be manufactured within a given period. Furthermore, overproduction waste arises from the implementation of a make-to-stock production system, which, when combined with limited space, leads to inefficient utilisation of storage areas (warehouses). The necessary steps include proper production forecasting to determine production scheduling. The SME should: (1) record all production activities, including order quantities, quantities produced, sales data, income data, and employee wage data; (2) develop a Standard Operating Procedure (SOP) for the production process so that operators have guidelines for each production activity, as also recommended in [13,26] through product recapitulation records.

Table 8. Valsat Tools for Fire Ring Product.

Waste	Weight	Mapping Tool						
		Process Activity Mapping	Supply Chain Response Matrix	Production Variety Tunnel	Quality Filter Mapping	Demand Amplification Mapping	Decision Point Analysis	Physical Structure Mapping
Production	19.249	20.249	57.746	0	19.249	57.746	57.746	0
Inventory	16.116	48.347	145.041	48.347	0	145.041	48.347	16.116
Defect	18.034	18.034	0	0	162.309	0	0	0
Motion	15.202	136.822	15.202	0	0	0	0	0
Transportation	13.322	119.899	0	0	0	0	0	13.322
Process	8.742	78.680	0	26.227	8.742	0	8.742	0
Waiting	9.334	84.010	84.010	9.334		84.010	28.003	
Total		506.041	302.000	83.908	190.300	286.798	142.839	29.438

Defect waste arises primarily from insufficient operator precision during the mould-making process. For instance, inadequate sand compaction can create cavities that lead to leakage, while substandard pouring of molten metal may result in density inconsistencies during solidification. Furthermore, improper material handling can cause physical damage to the final product.

To address these issues, several improvements are recommended: (1) the establishment and strict implementation of standard operating procedures (SOPs) covering mould quality, pouring processes, dismantling, finishing, and material handling; and (2) the adoption of semi-automatic machinery to enhance product consistency and improve production efficiency. In addition, prior research [27] emphasises the importance of conducting routine maintenance and ensuring proper machine settings to minimise defects.

Inventory waste stems from the lack of a dedicated space for raw materials and finished goods, causing the pathways between production lines to become narrow. Moreover, large quantities of WIP are not immediately dismantled. Proposed improvements are: (1) providing a dedicated area for raw materials and finished goods in accordance with production capacity; (2) re-laying out the facility so that space can be adjusted to needs; (3) reducing WIP to avoid delays between activities; (4) reducing the accumulation of finished goods through direct delivery processes. According to [13], applying forecasting can minimise inventory waste, while [27] adds the creation of a list of items to be used, proper inventory management, and the application of 5S techniques. Furthermore, reducing or eliminating non-value-added (NVA) activity time [28] can decrease waiting time and increase the Value Added (VA) Ratio from 16.24% to 29.42% [29].

Motion waste primarily results from the disorganised placement of tools, such as hoes and cintung, as well as from an inefficient production layout that creates excessive distances between workstations. Several improvements are therefore recommended: (1) arranging production equipment in clearly designated locations to ensure ease of access; (2) labelling each tool to indicate its proper storage location after use; (3) reconfiguring the workspace layout so that all tasks can be performed within convenient reach; and (4) developing visual displays of company rules and policies to guide employee practices.

Ineffective factory layout, identified through Focus Group Discussions (FGD) [30], has been recognised as a significant source of waste. In line with [27], appropriate solutions include designing an organised raw material storage layout and establishing a systematic raw material display. Furthermore, research by [31] employing VSM demonstrated improvements in the line balancing rate and a substantial increase in line productivity, from 1500 units per week to 3000 units per week.

Material transfer occurs primarily during the demolition and finishing processes; for example, the transport from demolition to finishing takes approximately 5.21 min. Another issue is the absence of material handling tools, so movement is performed manually and repeatedly, resulting in long durations, risk of injury, and operator fatigue. The proposed improvements are: (1) repairing the production floor by casting cement and widening the material handling pathways; (2) providing tools such as wheelbarrows or hand trucks (see Figure 2). The improvement steps taken by [17] include the application of 5S and the enhancement of material handling facilities for optimal performance.



(**a**) (**b**)

Figure 2. Material Handling (**a**) Wheelbarrows, (**b**) Hand Truck.

3.4. PAM Improvements

Activities within the Process Activity Map (PAM) are classified into three categories: value-added (VA), non-value-added (NVA), and necessary non-value-added (NNVA). To optimize production efficiency, VA activities must be enhanced while NVA and NNVA activities are minimized. An analysis of the current PAM revealed several redundant NVA and NNVA tasks. Consequently, the process must be improved by eliminating or consolidating these inefficiencies. Applying Kaizen principles can effectively facilitate the reduction of these NVA activities [32].

Table 9 presents the improved PAM for the Fire Ring product, comprising 38 activities, and distinguishes between activities that can be eliminated and those that can be combined. It also indicates whether each activity is VA, NVA, or NNVA. Table 10 then summarises the number of repair activities and post-repair activities related to operation, transportation, inspection, storage, delay, VA, NVA, and NNVA.

Table 9. PAM Fire Ring Product Improvements.

No	Sub Activity	Distance	Time (Minutes)	Number of Operators (People)	Activity Symbol					VA/NVA/NNVA
					O	T	I	S	D	
1	Picking up the pattern that will be used for the mold	0	3.25			X				NNVA
2	Putting the pattern on the mold	0	1.296		X					NNVA
3	Scooping sand using shovel	2.25	12.94			X				NNVA
4	Moving the sand into the mold	2.25	0.333						X	NNVA
5	Putting down the shovel	0	6.234		X					NVA
6	Compacting the sand in the mold		720		X					NNVA
7	Picking up waterproof powder with shovel	0	0.087			X				NVA
8	Spreading the waterproof powder into the mold		63.4	4	X					NNVA
9	Picking up a pipe to make a hole	1.5	0.233			X				NVA
10	Inserting the pipe into the mold	0	10.55		X					NNVA
11	Putting sand into the mold	1.12	52.71		X					NNVA
12	Compacting the sand in the mold	0	87.12		X					NNVA
13	Leveling the sand in the mold	0	55.5		X					NNVA
14	Removing the hole pipe	0	5.75		X					NVA
15	Removing the mold	0	2.156					X		VA

Table 9. *Cont.*

No	Sub Activity	Distance	Time (Minutes)	Number of Operators (People)	Activity Symbol					VA/NVA/NNVA
					O	T	I	S	D	
16	Checking that the kupola furnace is ready for use	5.2	5.57	5			X			NVA
17	Taking raw materials	4.15	10.33			X				NVA
18	Moving raw materials to the furnace	4.15	2.33						X	NNVA
19	Putting raw materials into the furnace	0	15.45		X					NNVA
20	Waiting for the melting process to finish	0	300						X	NVA
21	Making sure the mold is ready to use	0	5.33	11			X			NVA
22	Taking the cintung for the pouring process	1.25	1.074			X				NNVA
23	Aiming the cintung into the furnace	1.25	0.3167						X	NNVA
24	Taking liquid from the kupola furnace	0	8.33		X					NNVA
25	Aiming the cintung to the mold	10.5	5.33			X				NNVA
26	Pouring metal liquid into the mold	1	0.087		X					VA
27	Waiting for the metal liquid to harden	0	180						X	NVA
28	Picking up the hook stick	3.5	1.654	10		X				NNVA
29	Aiming the stick to the mold	3.5	0.3178						X	NNVA
30	Unloading the mold	0	2.23		X					VA
31	Taking the finished mold	0	360					X		VA
32	Putting the fire ring into the container	5.3	300					X		NNVA
33	Demolishing the fire ring	0	1440	4	X					VA
34	Picking up the grinder	3.2	1.36			X				NNVA
35	Aiming the grinder at the fire ring	3.2	0.29153333						X	NNVA
36	Grinding the fire ring	0	2880		X					VA
37	Putting the fire ring into a sack	2.2	180.00					X		VA
38	Putting the sack into the warehouse	5.2	120					X		VA

Description: : Activity can be eliminated; : Combining activities.

Table 10. Recapitulation of Results Before and After PAM Improvement.

	Before Improvement		After Improvement	
	(Sub-Activity)	(Minutes)	(Sub-Activity)	(Minutes)
Operation	16	5350	15	5349
Transportation	11	39	9	36
Inspection	2	11	2	11
Storage	5	962	5	962
Delay	7	664	7	484
VA	8	4864	8	4864
NVA	9	695	9	514
NNVA	24	1347	21	1344
Total Time (minutes)	6906		6722	
%VA	70.44%		72.37%	
%NVA	10.06%		7.64%	
%NNVA	19.5%		19.99%	

3.5. Preparation of Future Value Stream Mapping

Following the description of the current VSM and the identification of waste, the activities requiring improvement can be determined so that the production system aligns with the lean manufacturing concept (see Figure 3).

$$\text{Process Cycle Efficiency} = \frac{\text{Value Added}}{\text{Lead Time}} \times 100\% = \frac{4984}{6841.556}\% = 73\%$$

The Process Cycle Efficiency (PCE) result compares a Value-Added (VA) time of 4964 min to a total lead time of 6841.56 min. The Future Value Stream Mapping (VSM) indicates a PCE of 73%, reflecting a 4% improvement over the Current VSM. This higher PCE percentage demonstrates that the process is running more efficiently. Based on the Pareto chart analysis, the primary wastes requiring further investigation and mitigation are overproduction, defects, inventory, motion, and transportation.

To address these inefficiencies at the Enggal Jaya SME, the following improvements are recommended: (1) Recording and accounting for all production activities; (2) Developing Standard Operating Procedures (SOPs) for all workstations to establish uniform operational standards; (3) Employing semi-automatic machines and integrating additional material handling tools; (4) Providing warehouses for raw materials and finished products that match current production capacity; (5) Modifying the production floor layout to optimize workflow efficiency (6) Levelling the production floor and widening material handling pathways to ensure safe and efficient transit.

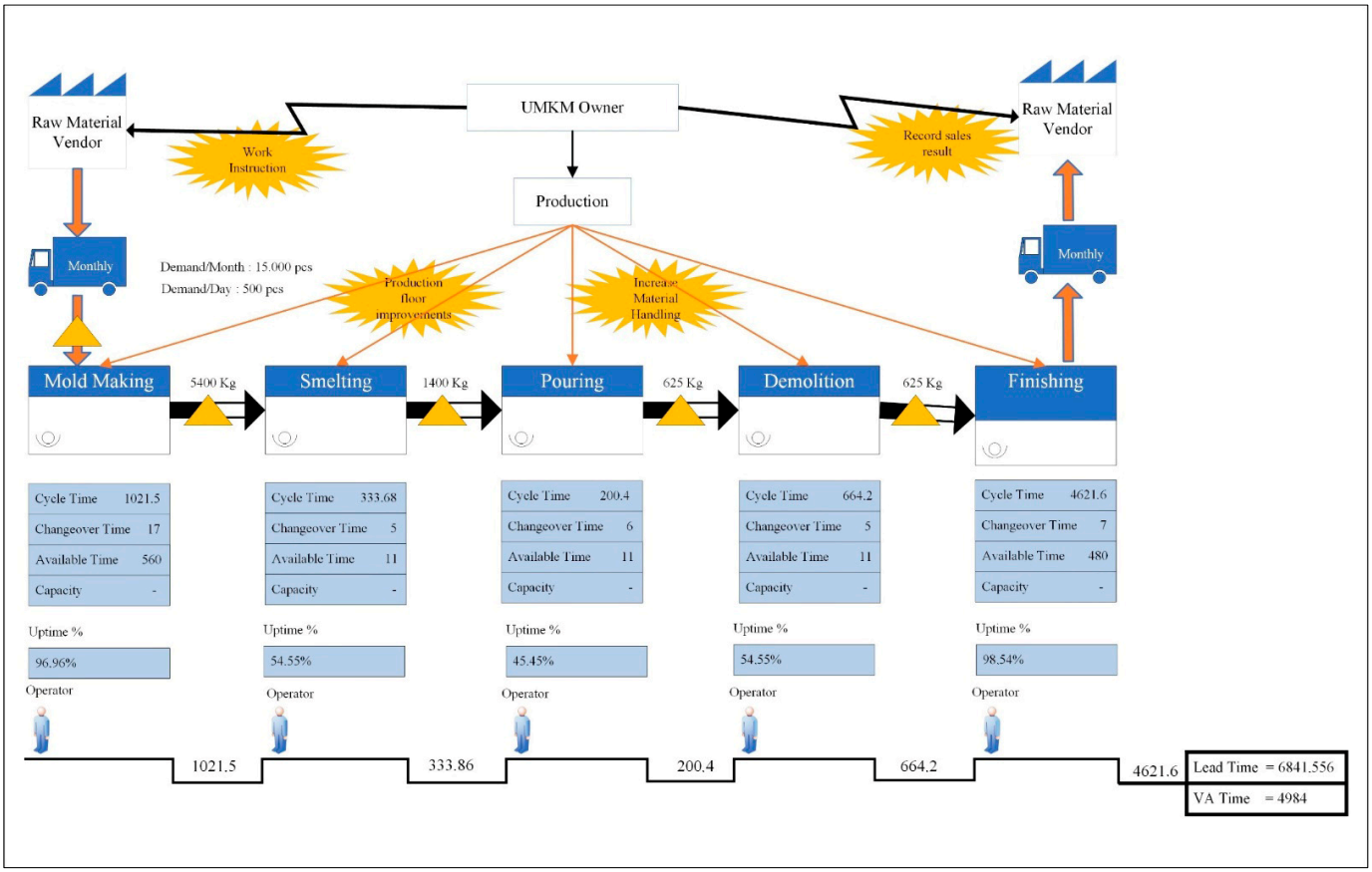

Figure 3. Future Value Stream Mapping of Fire Ring Production.

4. Conclusions

Waste identification using the WRM indicates that overproduction yields the highest 'from' percentage (19%), signifying that it exerts the greatest influence on other waste categories. Conversely, inventory shows the highest 'to' percentage (18%), indicating that it is the waste most frequently generated by other factors. Furthermore, WAQ calculations identify the five most dominant waste types as overproduction (19.2%), inventory (18.0%), defects (16.1%), motion (15.2%), and transportation (13.3%). To mitigate these issues, several operational improvements are recommended: recording and accounting for all production activities, creating standard operating procedures, redesigning the facility layout to optimise material handling, reducing work-in-process, transitioning to semi-

automatic machinery, providing additional material-handling tools such as wheelbarrows or hand trucks, establishing formal production scheduling, and accurately forecasting consumer demand to prevent overproduction.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author due to the presence of personal information.

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Abbreviations

The following abbreviations are used in this manuscript:

VSM	Value Stream Mapping
WAM	Waste Assessment Model
PCE	Process Cycle Efficiency
WAQ	Waste Assessment Questionnaire

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