Value Stream Mapping and Theory of Constraints its Role in Enhancing Total Equipment Effectiveness

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Abstract
The current study seeks to employ the tools of analyzing and improving industrial processes represented by the Value Stream Map (VSM) and the Theory of Constraints (TOC) with the aim of enhancing the overall equipment effectiveness (OEE) in the gasoline production line at the South Refinery/Shuaiba. The case study approach was adopted as the most appropriate to analyze the phenomenon within its realistic context, as the study is based on a field reality that indicates the presence of a decline in operational performance indicators, especially in light of operational bottlenecks and production losses that are not precisely defined.

Keywords: Value stream map, Theory of Constraints, total equipment effectiveness, South Refinery/Shuaiba

Introduction

Operational efficiency and performance improvement represent one of the most significant challenges facing industrial organizations in the modern era, amidst a production environment characterized by rising costs and increasing competition. In this context, industrial organizations are no longer focused solely on increasing production capacity, but are now seeking to achieve the maximum possible effectiveness in their current resources, especially equipment, as it represents a crucial element in stabilizing production and achieving the required quality, The concept of total equipment effectiveness has emerged as the latest key indicator for measuring equipment performance and its ability to achieve operational objectives within the specified time and with the least possible waste, downtime or defects, The current study addresses the analytical aspect of improving the gasoline production line at the South/Shuaiba refinery, which is one of the most prominent oil facilities in Iraq and is also a vital production route within the crude oil refining chain. Initial results indicate the presence of variations in the performance of the line phases and bottlenecks that limit the efficiency of production flow and low indicators of Total Equipment Effectiveness in some phases.

Research methodology

The Problem of The Search

Many industrial facilities suffer from a decline in the overall efficiency of equipment due to bottlenecks, poor distribution of resources, and a failure in analyzing operational processes due to the absence of comprehensive analysis tools that reveal sources of waste within the overall system The need for a value stream map, process analysis, and identification of factors that negatively affect the overall performance of the total equipment is highlighted. As a result of interviews with specialists, the field problem of the study can be limited to an important and fundamental question, which is: Can value stream mapping and Theory of Constraints be used to enhance Total Equipment Effectiveness in an industrial environment plagued by bottlenecks and inaccurate data?

Search Objectives

- It provides an integrated analytical framework that helps the management of the South/Shuaiba Refinery diagnose waste in the gasoline production line.

- B. It contributes to improving equipment efficiency by proposing solutions based on accurate data and analysis, rather than partial estimates or observations.

The Importance of The Search

1. Diagnose waste in the gasoline production line by drawing a current value stream map and analyzing the production process.
2. Calculate the overall equipment efficiency for the current situation based on the value stream map and Theory of Constraints outputs.
3. Design a future value stream map and propose possible improvements to increase efficiency and eliminate or reduce waste as much as possible.

Hypothetical outline of the study

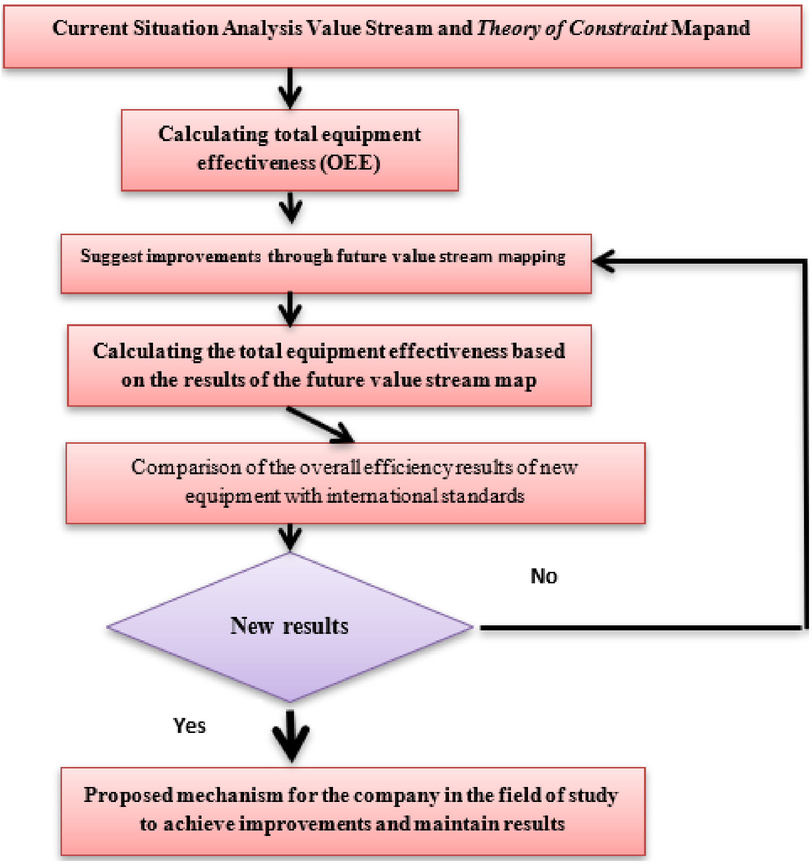

Fig 1: The hypothetical scheme of the Search

Research community and sample

The South Refinery represents the study site (study field), while the study community represents all production lines such as (liquid gas, gasoline, white oil, gas oil, fuel oil, marine fuel oil, fats, and jet fuel). The study sample represents the gasoline production line.

The theoretical framework of the search

Value stream mapping

Value stream mapping concept

The term value stream was first used in a book called The Machine That Changed the World in the 1990s, written by James Womack, Danielle Jones, and Daniel Ross. It was also simplified in another book titled "Lean Thinking" in 1996 by James Womack and Danielle Jones, where it was known as the flow of materials and information (Duah & Nadarajah, 2020: 52), A pictorial method that describes the flow of raw materials and the values provided by customers, showing the main phases of the operating process, as well as data related to material flow, quality, order fulfillment time, and production rhythm (Nguyen *et al*, 2023:33).

Importance of Value Stream Mapping

Value stream mapping offers many benefits, the most important of which are: (Royce, 2020: 6) (Narkhede & Chaple, 2017: 55-56) [4] (Xiaoqili, 2014: 12), (Allows a broad view of the entire flow, helps identify waste, shows the relationship between material flow and information).

Value Stream Map Dimensions

Completing the current value stream map requires a set of the following steps (Locher, 2008: 23-32) [10]:

Determine current customer needs

We mean the external customer, the final consumer of the products being developed. Various aspects of customer needs must be considered.

Determine the main processes

In this step, the processes are determined in order, for example, what level of detail is required, when the first process ends and the second and third processes begin, etc. In addition, the waiting time for each process is determined.

Determine process parameters

Testing the appropriate process metrics for any development process is confusing because most development processes do not include standard performance metrics that reflect cost, quality, and service within the value stream.

Theory of Constraints

Theory of Constraints Concept

A tool that helps analyze the production process from different perspectives. It is an approach to operational excellence that helps managers and practitioners address the complexities and potential challenges in supply chain operations (Neisyafitri *et al*., 2023:112) [24].

Stages of Applying the Theory of Constraints

(Chyi Chou *et al*. 2012:4687-4688), (Aryanezhad *et al*, 2010:5075-5077) [26]. Identifying system constraints, determining how to exploit system constraints, monitoring and support, lifting or removing system constraints, returning to step 1 if any changes occur.

Benefits and uses of the Theory of Constraints

(Kadhim *et al*, 2020:764) [27] (Horngren *et al*, 2009:707) [28]

Reducing production time, improving product and service quality, and increasing inventory profitability

Total Equipment Effectiveness

Total Equipment Effectiveness Concept

Total equipment effectiveness was first proposed by Nakajima in the late 1980s as a comprehensive tool for measuring machine performance, According to Nakajima, total equipment effectiveness is applied to measure the performance of equipment in terms of availability, performance and quality (Wudhikarn, 2013:351). A process performance measurement tool that has been widely used in industry and has established itself as one of the primary metrics for measuring performance in manufacturing organizations (Hautakangas,2023:2).

Total Equipment Effectiveness importance

Total Equipment Effectiveness has many advantages, including (It helps increase productivity, reduce scrap rate, extend equipment life, reduce labor costs, and improve process efficiency).

Total Equipment Effectiveness dimensions

There are three factors of Total Equipment Effectiveness, to calculate which equation is used:

Availability rate

It is the availability rate (machine availability), as the Japanese Institute of Factory Maintenance has set the standard that shows the standard availability rate of 90%, and availability is the percentage number that shows the number of times the machine is available when it is needed for production (Djunaidi *et al*, 2022: 163) [5].

Availability can be calculated using another operating equation (Zubair *et al*, 2021:4) [23].

$$\text{Availability} = \text{Runtime} / \text{Loading Time} * 100\%$$

Performance rate

Defines (Amperajaya *et al*, 2022:323) [1] the performance ratio as a ratio that shows the ability of machines to produce the product (performance describes the ability of the machine to produce good products).

The performance rate equation is calculated as follows (Haddad *et al*., 2021: 57) [7].

$$\text{Performance rate} = \text{Production quantity} * \text{Ideal cycle time} / \text{Process time} * 100\%$$

Quality rate

It is mentioned (Ohno, 2002: 5) that it is providing and offering conviction, satisfaction and comfort to the customer, or it is achieving and accomplishing the value entitlement. We can obtain a quality equation by applying the following equation (Ramadhani *et al*, 2022: 26) [17].

$$\text{Quality Rate} = \text{Production quantity} - \text{Defective Product} / \text{Production quantity} * 100\%$$

The practical side of the search

An introductory overview of the south refinery

Southern Refineries Company (a public company) was established in 1969 and is a government company affiliated to the Iraqi Ministry of Oil based in Basra - Shuaiba, where the company's activities since its establishment included crude oil refining operations to produce oil derivatives and is one of the major manufacturing companies in the country, where it produces oil derivatives using the latest scientific and technological advanced methods of production that are comparable in quality to foreign products and meet the requirements of consumers South Refineries Company provides petroleum products (liquid gas, gasoline, white oil, gas oil, fuel oil, marine fuel oil, base fats, diesel fuel.

Current process flow and current value stream map

The gasoline production sequence starts from the first phase, which is the pre-processing phase, to the last phase, which is the gasoline optimization phase to complete the finished product.

A. Primary processing phase of crude oil

At this phase, crude oil enters the southern refineries after it has been prepared by the Basra Oil Company. Table (1) shows a summary of the current process activity for the initial processing phase of crude oil, and Figure (2) indicates the current value flow map for the initial processing phase of crude oil.

Table 1: Summary of current process activity for the primary processing phase of crude oil.

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		9	137	
Transition		3	180	730
Delay		1	35	
Screening		1	12	
Storage		1	5	

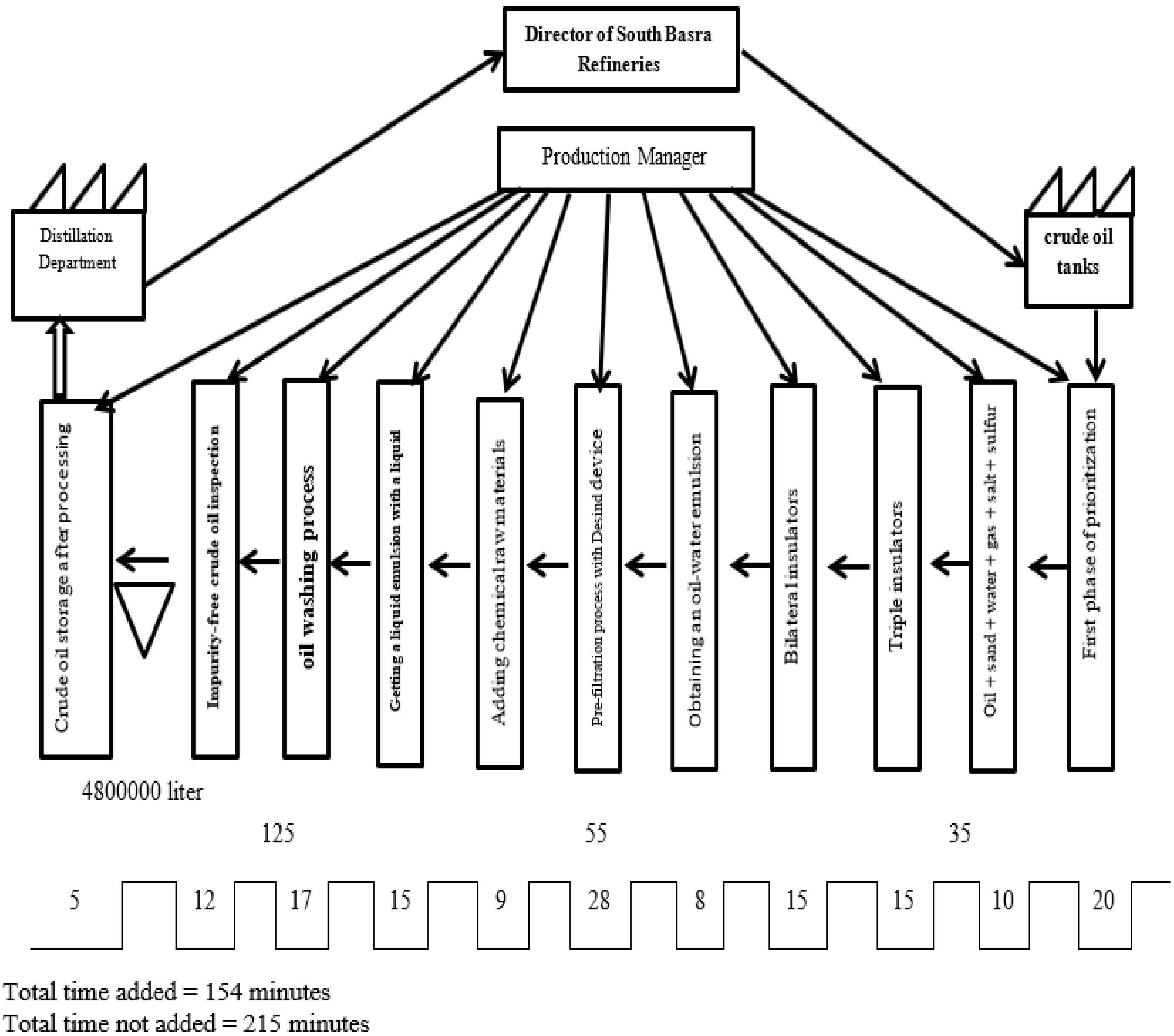

Fig 2: Current value flow map for the primary processing phase of crude oil

It was calculated as follows:

Total value addition time = Operation time + Inspection time + Grievance time

= 137 + 12 + 5 = 154 minutes

Total non-value-added time = Commute time + Delay time

= 180+35 = 215 minutes

Total Waiting Time = Total Value Adding Time + Total Non-Value Adding Time

=154 + 215 = 369 minutes

B. Crude oil distillation phase

At this phase, the distillation process is carried out, which is one of the semi-manufactured parts needed in the hydrogenation section. Table (2) shows a summary of the current process activity for the crude oil distillation phase, and Figure (3) indicates the current value flow map for the crude oil distillation phase.

Table 2: Summary of the current process activity for the crude oil distillation phase

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		8	83	
Transition		4	145	1000
Delay		1	35	
Screening		1	20	
Storage		1	3	

It was calculated as follows:

Total value addition time = Operation time + Inspection time + Grievance time

= 83 + 20 + 3 = 106 minutes

Total non-value-added time = Commute time + Delay time

= 145 + 35 = 180 minutes

Total Waiting Time = Total Value Adding Time + Total Non-Value Adding Time

= 106 + 180 = 286 minutes

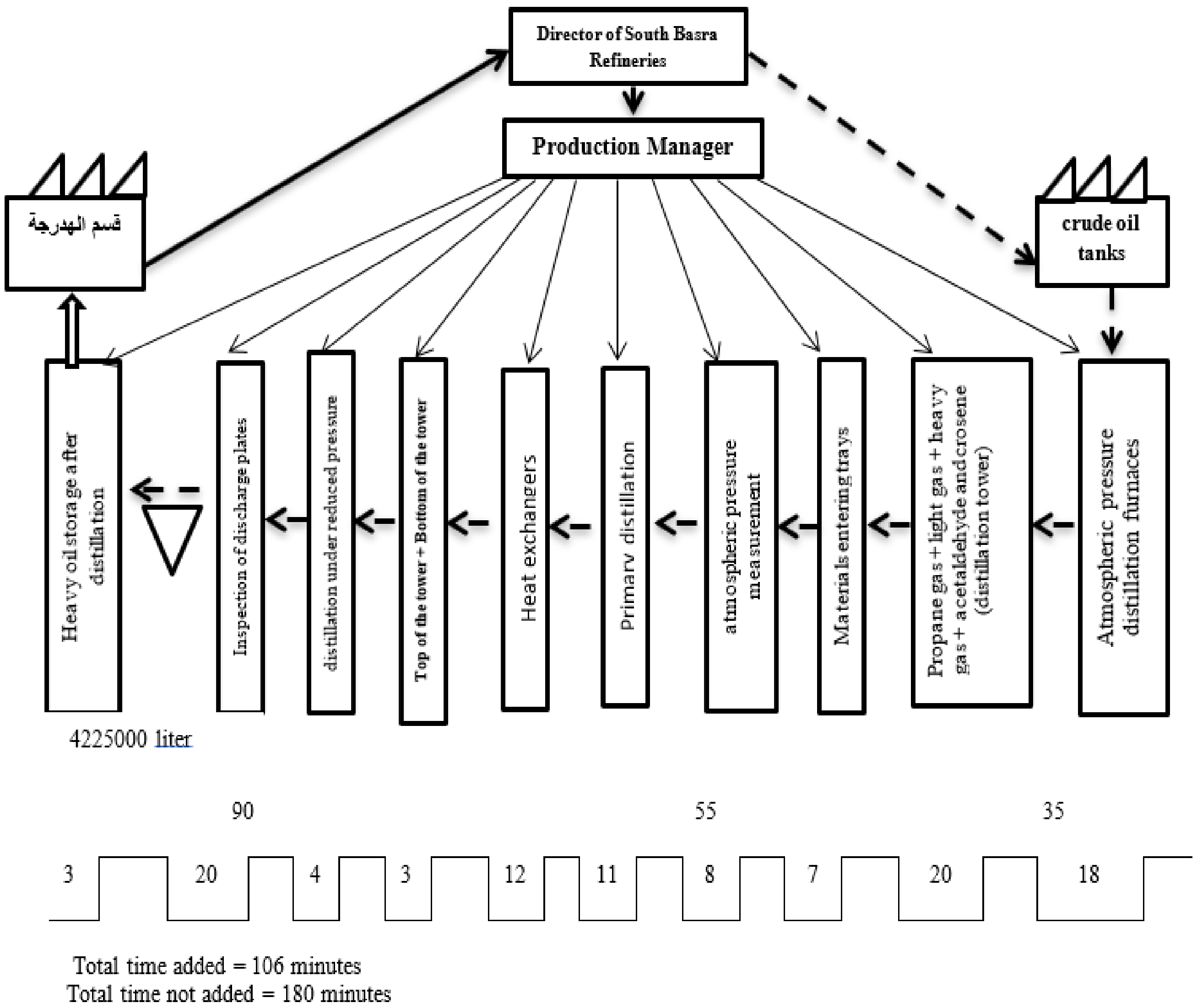

Fig 3: Present value flow map for the distillation phase of crude oil

C- Hydrogenation phase

At this phase, crude oil (heavy oil) is hydrogenated, which determines one of the semi-manufactured parts needed by the hydrogenation department. Table (3) shows a summary of the current process activity for the heavy oil hydrogenation phase, and Figure (4) indicates the current value flow map for the heavy oil hydrogenation phase.

Table 3: shows a summary of the current process activity for the heavy oil hydrogenation phase.

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations	◯	5	35	
Transition	⇨	4	100	525
Delay	D	1	35	
Screening	▭	1	30	
Storage	▽	1	5	

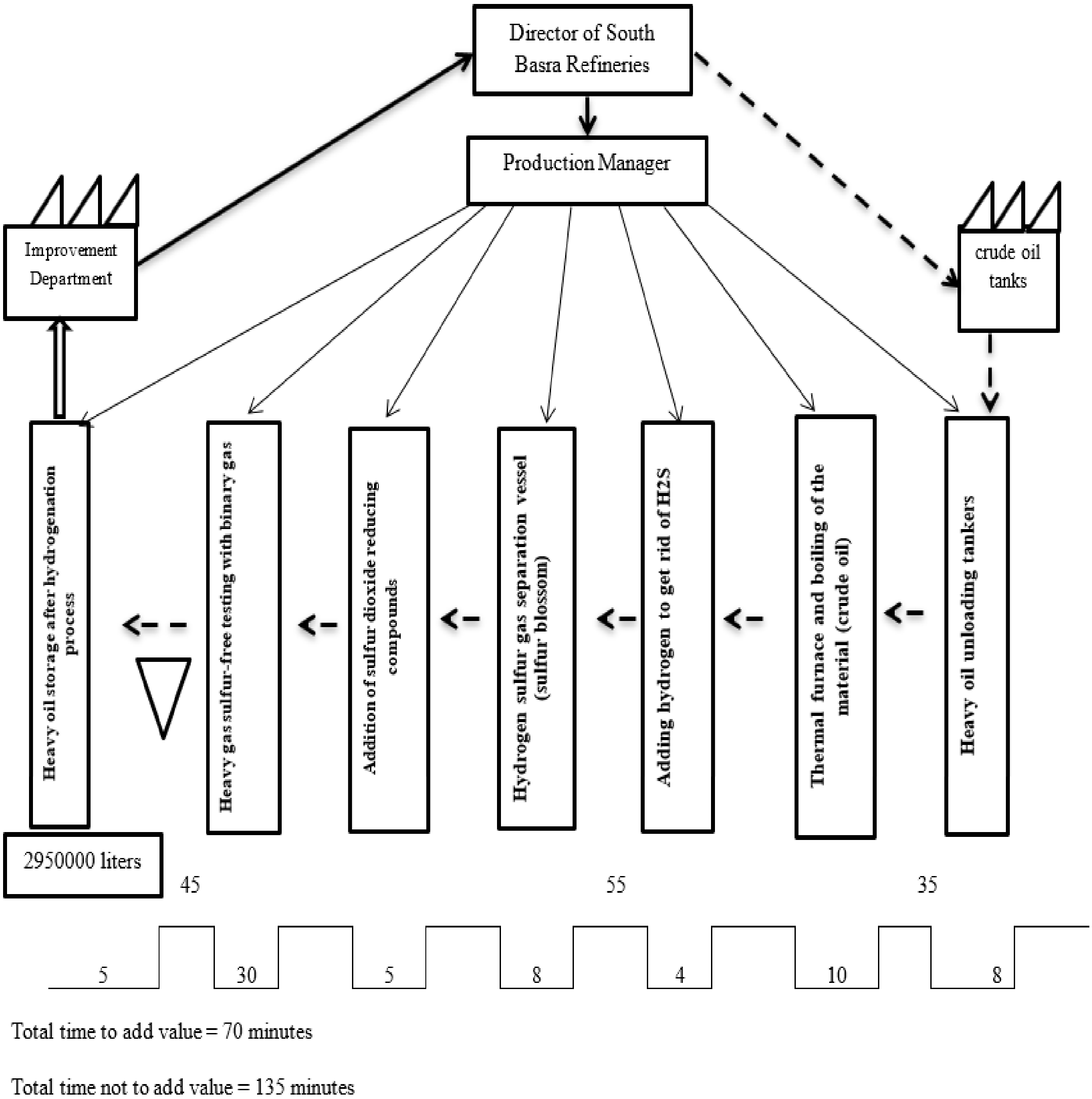

Fig 4: Current value flow map for the hydrogenation phase of crude oil

It was calculated as follows:

Total value addition time = Operation time + Inspection time + Grievance time

= 35 + 30 + 5 = 70 minutes

Total non-value-added time = Commute time + Delay time = 100 + 35 = 135 minutes

Total Waiting Time = Total Value Adding Time + Total Non-Value Adding Time

= 70 + 135 = 205 minutes.

D. Improvement phase

In this final phase, heavy oil is refined after the hydrogenation process, which is the final product in the refinery section. Table (4) shows a summary of the heavy oil refinery process activity, and Figure (5) shows the current value flow chart for the heavy oil refinery phase.

Table 4: Summary of the current process activity for the heavy oil improvement phase

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations	⬭	7	67	
Transition	⇨	4	100	800
Delay	D	1	35	
Screening	▭	1	20	
Storage	▽	1	5	

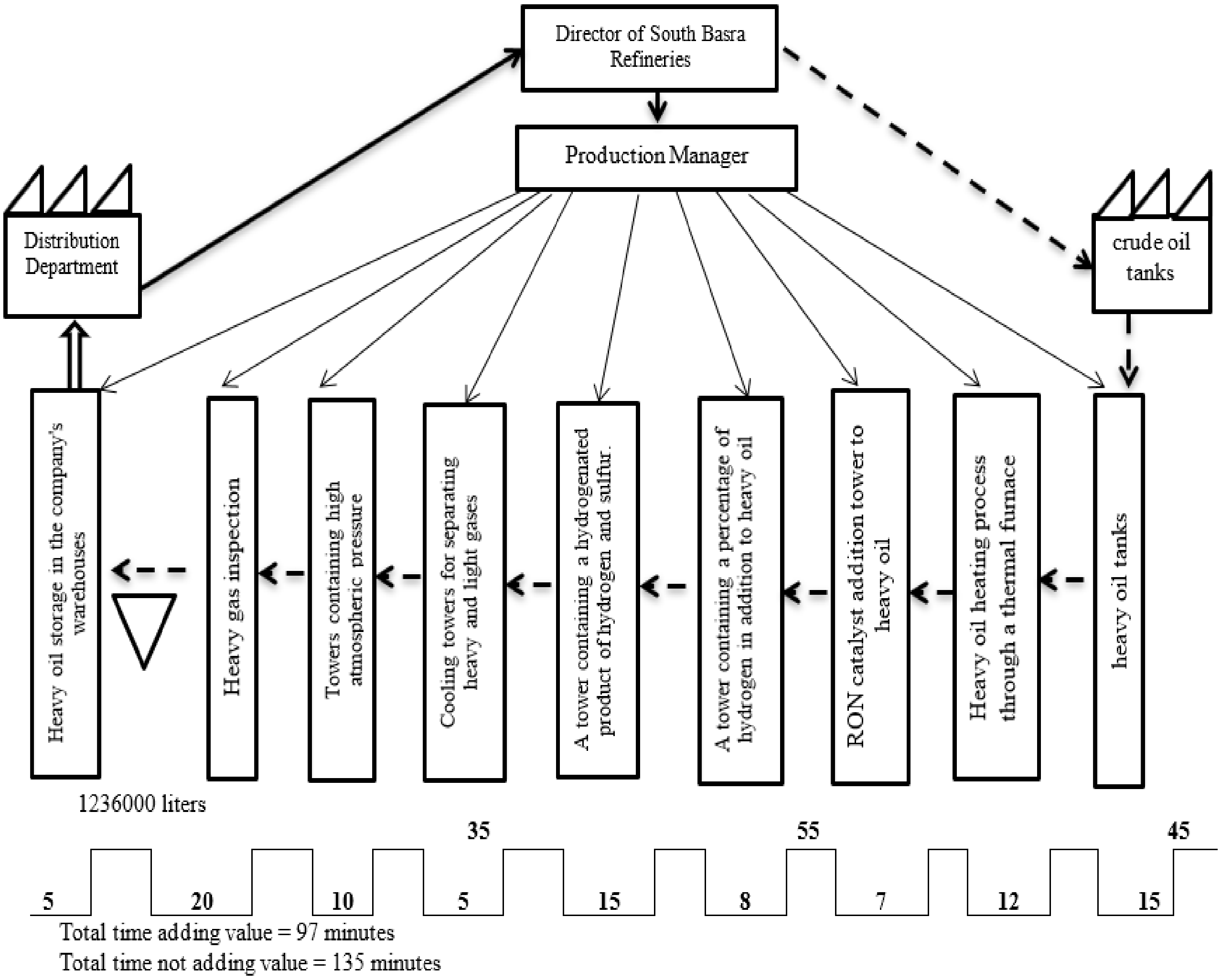

Fig 5: Current value stream map for the improvement phase

Total value addition time = Operation time + Inspection time + Grievance time

= 72 + 20 + 5 = 97 minutes

Total non-value-added time = Commute time + Delay time

=100 + 35 = 135 minutes

Total Waiting Time = Total Value Adding Time + Total Non-Value Adding Time

= 97 + 135 = 232 minutes.

Methods for identifying bottlenecks

Utilization rate method

Review the design capacity, actual daily production, and number of workers for each stage of gasoline production, noting that the percentage of spoilage is 0.05% of the final product.

Table 5: Design capacity, actual and planned daily production, and number of workers for each stage of gasoline production

T	Stage	Design energy for three meals/liter	Design energy for one meal/liter	Planned daily production (liters(	Actual daily production (liters) per meal	Number of workers per meal
1	Primary Treatment	16000000	5333333	5000000	4800000	26
2	Distillation	15400000	4833333	4500000	4225000	30
3	Hydrogenation	11000000	3666667	3200000	29500000	20
4	Improvement	4500000	1500000	1400000	1263500	19

Calculating the utilization rate for each stage of gasoline production and for each worker and equipment.

Table 6: Total utilization rates and number of workers and equipment

T	Stage	Actual utilization rate	Worker utilization rate	Equipment utilization rate
1	Primary Treatment	30%	3.46%	90%
2	Distillation	29.1%	2.91%	87.4%
3	Hydrogenation	26.82%	4.02%	80.5%
4	Improvement	28.08%	4.43%	84.23%

Table 7: Usage rate according to the times of adding value and not adding value (one meal)

T	Stage	Value Added Time/Minute	Value Not Added Time/Minute	Usage Rate
1	Primary Treatment	154	215	41.7%
2	Distillation	106	180	37.1%
3	Hydrogenation	70	135	34.1%
4	Improvement	97	135	39.3%

Waiting Time Method

Table 8: Usage rate Waiting times for each stage of gasoline production

T	Stage	Non-value added ratio
1	Primary Treatment	58.3%
2	Distillation	62.9%
3	Hydrogenation	65.9%
4	Improvement	60.7%

Calculating the Total Equipment Effectiveness indicators according to the current status of the gasoline production station

Availability rate

Availability can be calculated as follows:
Available production time: 480 minutes, planned downtime: 60 minutes, unplanned downtime (15) days per year (converted to minutes) through

15 days * 24 hours * 60 minutes = 21,600 minutes per year

21600 / 360 days = 60 minutes per day (unplanned breaks) for the main morning shift

Availability = Uptime / Load Time x 100%.

Operating time = available production time - (planned downtime + unplanned downtime).

= 480 - (60 + 60) = 360 minutes

Loading time (planned production time) = Available production time – Planned downtime.

= 480 - 60 = 420 minutes

Therefore, the performance rate = 360 / 420 = 85.7% approximately 86%

Performance rate

The performance rate can be extracted through the following: Planned daily production (one working session) 1,400,000 liters/day, actual daily production 12,635,000 liters/day

Performance Rate = Actual Output / Planned Output x 100%.

Daily performance rate $=\frac{1400000}{1263500}$ x 100 = %90.25%

Actual cycle time = [Available production time / Actual output] x 100%

$=\frac{480}{1263500}$] x 100 = %0.0380 minute

Ideal cycle time = [Available production time / Planned output] x 100%

$=\frac{480}{1400000}$] [x 100 = %0.0343 minute

Quality rate

The quality rate is calculated after calculating the percentage of defectiveness, which is (0.05)% of the actual output of the work station as a whole (gasoline production station). The actual daily output of the gasoline station for three meals amounted to (3,990,000) liters/day, and the defective units are calculated as follows:

$$\text{Quality rate} = \frac{\text{Total Good Outputs - Defective Outputs}}{\text{Total output produced}} \times 100\%$$

Defect ratio = Actual output of 3 meals * Spoilage ratio
Good output for three meals 3,990,000 liters * 5% = 199,500 liters/day

3,990,000 liters – 199,500 liters = 3,790,500 liters/day

Total good output for one meal = 3790500/(3) = 1263500 liters/day

Good output for one working meal = 1,330,000 liters/day

If the quality rate$=\frac{1263500}{1330000}=95\%$

Or quality rate $=\frac{3990000-199500}{3990000} * 100\% = 95\%$

Total equipment effectiveness for current situation = 86% * 90.25% * 95% = approximately 73.7% 74

Future process path and future value stream map (proposed) for gasoline production phases

Primary processing phase of crude oil

At this phase, crude oil enters the southern refineries after being prepared by the Basra Oil Company. Table (9) shows a summary of the future process activity for the primary processing phase of crude oil, and Figure (6) shows the future value flow map for the primary processing phase of crude oil.

Table 9: Summary of the future process activity for the primary processing phase of crude oil

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		9	110	
Transition		3	85	730
Delay		1	20	
Screening		1	10	
Storage		1	5	

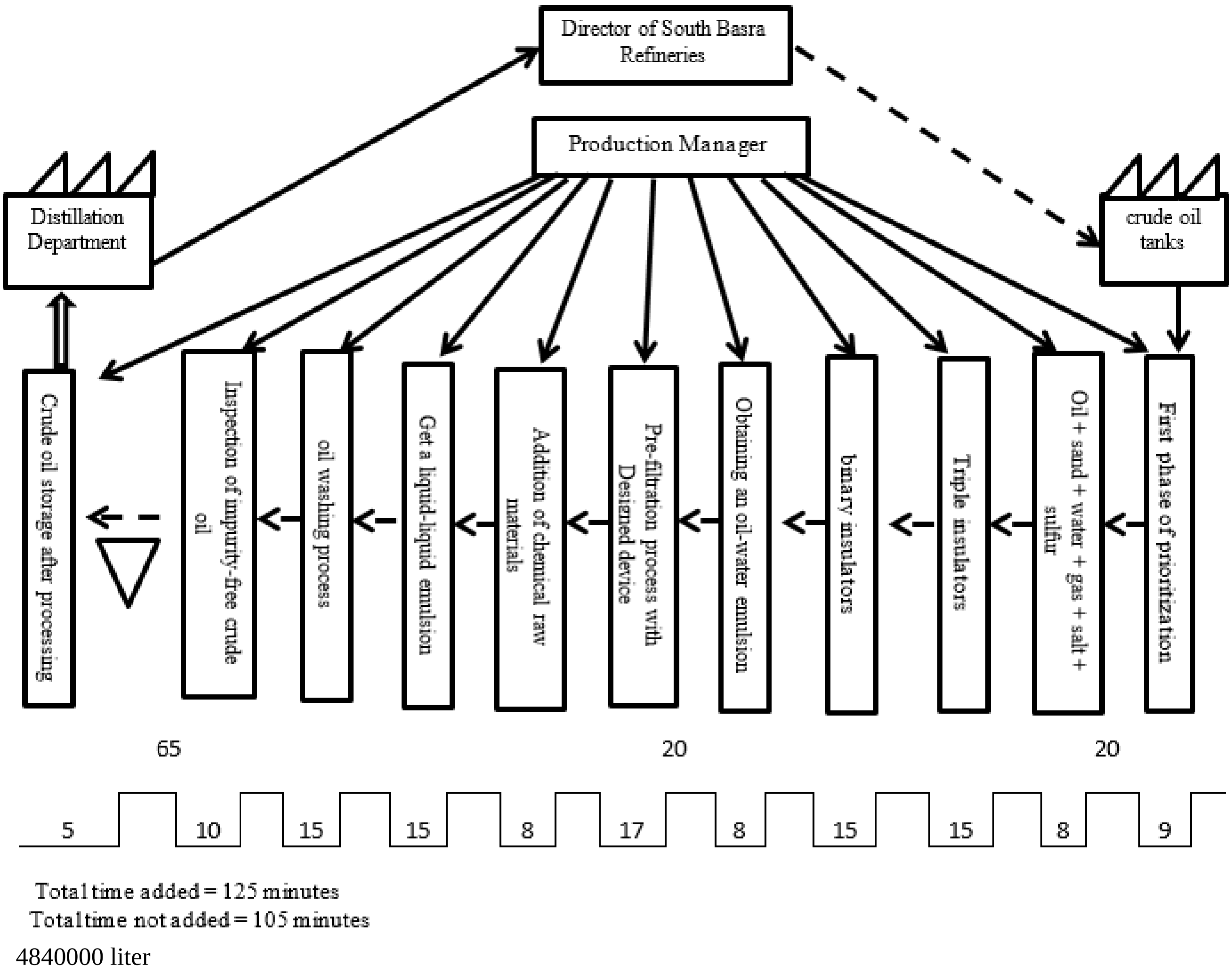

Fig 6: Future value flow map for the primary processing phase of crude oil

Total value addition time = Operation time + Inspection time + Grievance time

= 110 + 10 + 5 = 125 minutes

Total non-value-added time = Commute time + Delay time

= 85 + 20 = 105 minutes

Total Waiting Time = Total Value Adding Time + Total Non-Value Adding Time

=125 + 105 = 230 minutes

Crude oil distillation

At this phase, the distillation process takes place, which is one of the semi-finished parts required in the hydrogenation section. Table (10) shows a summary of the future process activity for the crude oil distillation phase. Figure (7) shows the future value stream map for the crude oil distillation phase.

Table 10: Summary of the future (proposed) process activity for the crude oil distillation phase

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		8	78	
Transition		4	59	1000
Delay		1	20	
Screening		1	18	
Storage		1	3	

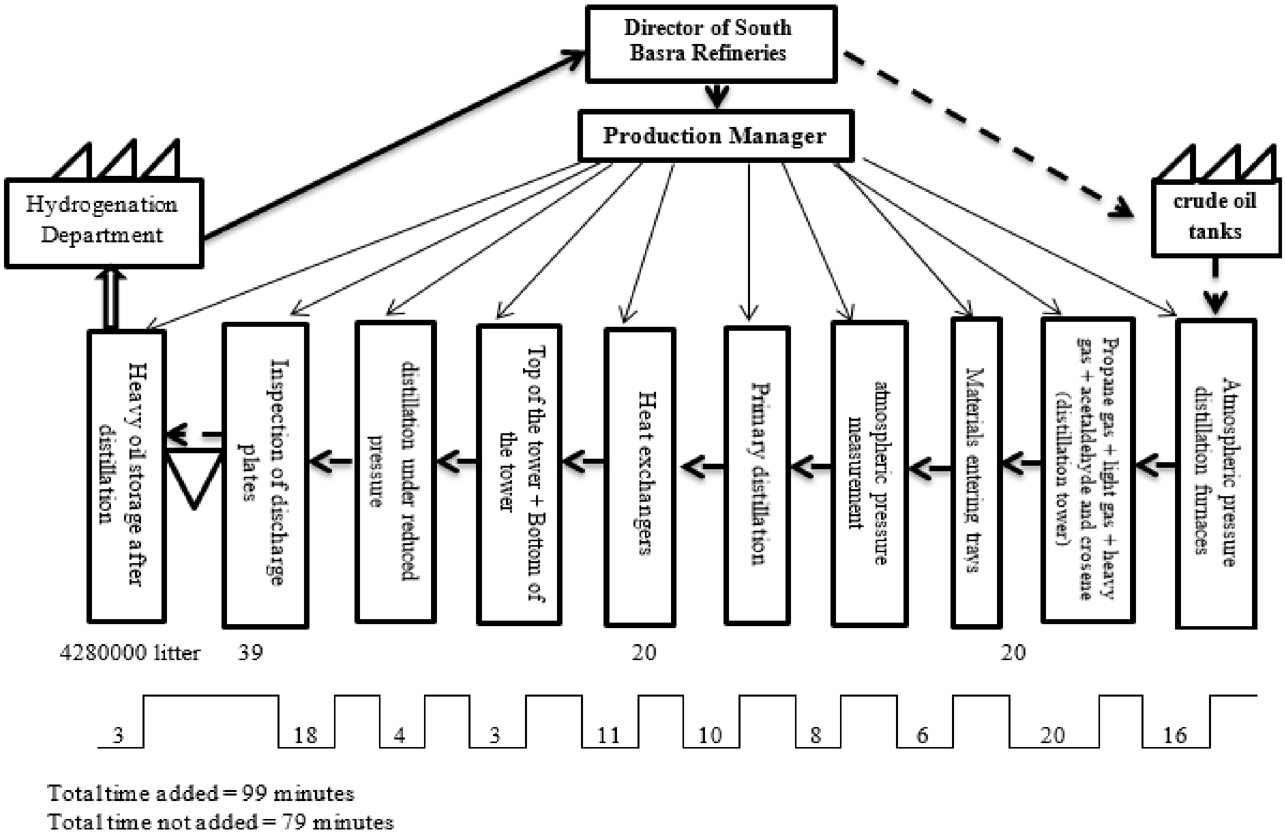

Fig 7: Future value flow map for the distillation phase of crude oil

Total value addition time = Operation time + Inspection time + Grievance time

= 78 + 18 + 3 = 99 minutes

Total non-added time = Travel time + Delay time
= 59 + 20 = 79 minutes

Total waiting time = Total added time + Total non-added time

= 99 + 79 = 178 minutes

Hydrogenation phase

At this phase, crude oil (heavy oil) is hydrogenated, which determines one of the semi-finished parts needed by the improvement department. Table (11) shows a summary of the future process activity for the heavy oil hydrogenation phase, and Figure (8) indicates the current value flow map for the heavy oil hydrogenation phase.

Table 11: shows a summary of the future process activity for the hydrogenation phase.

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		5	33	
Transition		4	38	525
Delay		1	20	
Screening		1	27	
Storage		1	5	

Which was calculated as follows:

Total Value Added Time = Operation Time + Inspection Time + Storage Time

= 33 + 27 + 5 = 65 minutes

Total Non-Value Added Time = Travel Time + Delay Time = 38 + 20 = 58 minutes

Total Waiting Time = Total Value Added Time + Total Non-Value Added Time

= 65 + 58 = 123 minutes

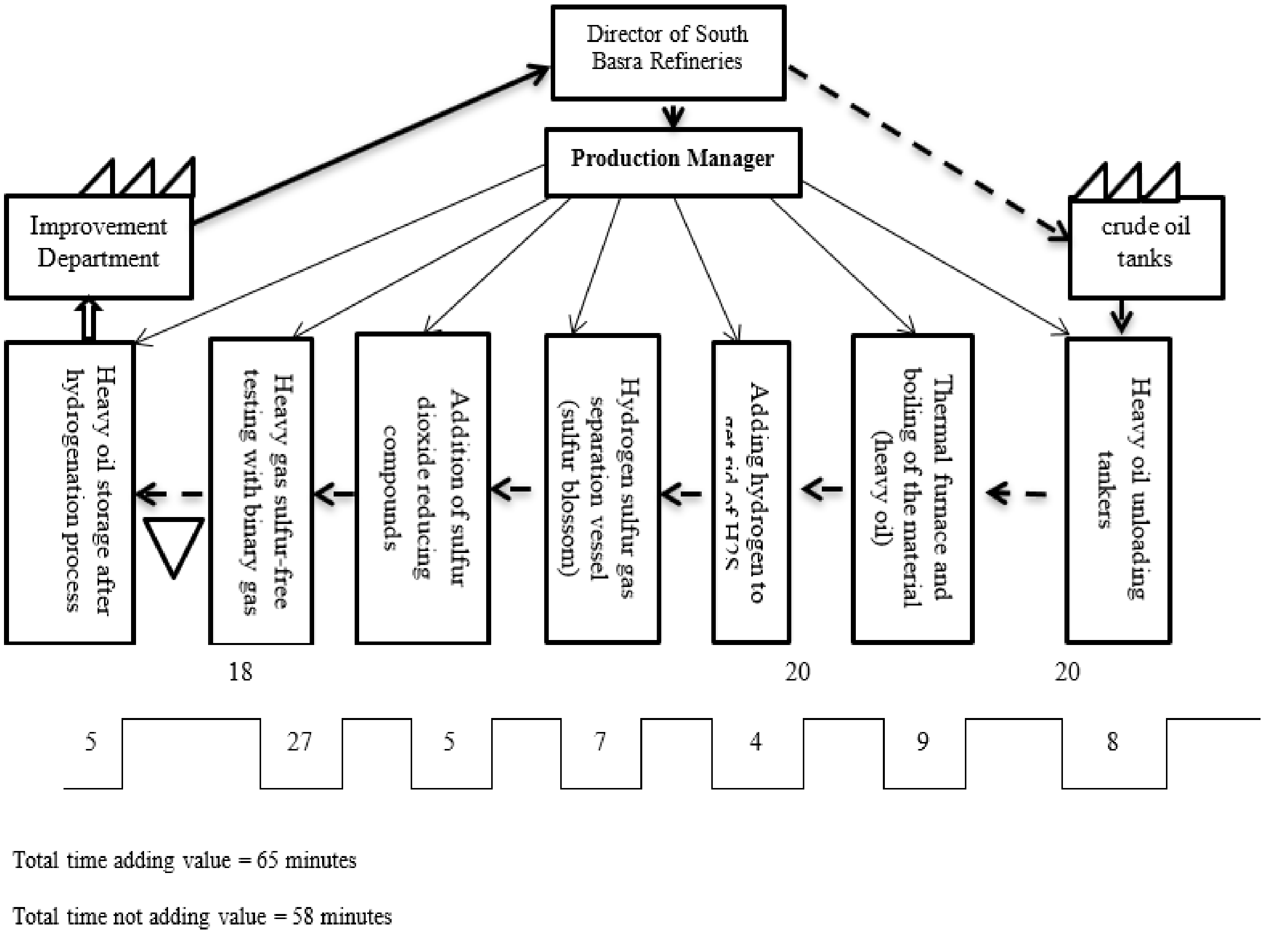

Fig 8: Future value flow map for the hydrogenation phase

D- Improvement phase

In this final phase, heavy oil is improved after the hydrogenation process, which is the final material manufactured in the improvement section. Table (12) shows a summary of the activity of the heavy oil improvement process, and Figure (9) indicates the future value flow map for the improvement phase.

Table 12: Summary of the future process activity for the improvement phase

Activities	Symbols	Number of symbols	Total time (minutes)	Distance (meters)
Operations		7	89	
Transition		4	40	800
Delay		1	20	
Screening		1	10	
Storage		1	5	

Which was calculated as follows:

Total Value Added Time = Operation Time + Inspection Time + Storage Time

= 66 + 18 + 5 = 89 minutes

Total Non-Value Added Time = Travel Time + Delay Time = 40 + 20 = 60 minutes

Total Waiting Time = Total Value Added Time + Total Non-Value Added Time

= 89 + 60 = 149 minutes

Calculating the Total Equipment Effectiveness indicators in light of the proposed (future) situation

Availability rate = 480 - (60+40) = 380 minutes (due to reducing failures)

Loading time 480 - 60 = 420 minutes

If the availability rate $=\frac{420}{348}*100\% = 90.5.\%$

Planned daily production performance rate = 1,400,000 liters/day

Actual daily production = 1,358,000 liters/day

$=\frac{1358000}{1400000}*100\% = 97\%$

Actual cycle time $=\frac{480}{1358000}*100\% = 0.0353$ minute

Ideal cycle time $=\frac{480}{1400000}*100\% = 0.0343$ minute

By comparing the actual cycle time of the future position, which is (0.0353) minutes, with the actual cycle time of the current position, which is (0.0380) minutes.
We note that it has decreased by (0.0027) minutes, which indicates the impact of improvements on the process.

Quality rate

The quality rate is calculated after calculating the percentage of damage of (3%). If the percentage of damage is reduced from (3% - 5%) by reducing the malfunctions and waiting times that lead to an increase in the temperature of the equipment, which causes an increase in the percentage of damage, as follows:
In terms of the actual daily outputs of gasoline production after the proposed improvement in the future value flow map (1,400,000) liters/day for one meal, and since the spoilage is calculated for three meals, therefore:

1,400,000 * 3 = 4,200,000 liters/day for three meals

4,200,000 * 3% = 126,000 liters (defective)

So 4,200,000 - 126,000 = 4,074,000 liters/day

$\frac{4074000}{\text{Meals } 3}$ = 1358000 Liters/day serving of one meal of good products

So the quality rate $=\frac{126000-4200000}{4200000}$ = 97%

Or quality rate $=\frac{1358000}{1400000}*100\% = 97\%$

So, the overall equipment efficiency in light of future proposals = 90.5% * 97% * 97%

= 85%

Conclusions and recommendations

Conclusions

The most important conclusions reached by the study were:

- The benefit of the value stream map is not limited to production processes only, but it can also be used to analyze administrative and service processes, and thus it is in line with modern trends in applying (Lean) in various types of organizations.
- The value stream map reflects the future, as it enables organizations to design waste-free production processes and identify improvement opportunities based on the standard data collected and analyzed.
- The theory of constraints embodies a comprehensive framework for continuous development, as it seeks to identify constraints (bottlenecks) in the production or administrative system, and deal with them in a way that ensures raising performance efficiency and increasing overall achievement.
- The overall efficiency of equipment is directly affected by improvements in the value stream map, as removing bottlenecks through value stream mapping analysis contributes to increasing productivity rates, performance efficiency, and quality, thus improving OEE indicators.
- OEE reveals the "hidden energy" in production facilities. It clarifies the difference between the current performance and the optimal capabilities of equipment, and precisely identifies waste and bottlenecks in the production system.

Recommendations

- Employing (Root Cause Analysis) tools to identify the causes of low OEE and address them from the root, not just dealing with apparent symptoms such as downtime or defect.
- Enhancing employee capabilities through training programs geared towards OEE and TPM to build an industrial culture based on measurement, continuous improvement, and shared accountability.
- TOC implementation procedures must be adopted within production and service organizations by identifying implementation obstacles, diagnosing the main factors affecting overall achievement, and working to resolve them according to the theoretical steps
- Redesigning processes to reduce non-value-adding times using Lean Manufacturing techniques and Future VSM to reduce waste and improve efficiency.
- Increase equipment efficiency and preventive maintenance to ensure machine readiness and reduce unplanned downtime, while monitoring Total Equipment Effectiveness (OEE) indicators.

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