QATAR UNIVERSITY

COLLEGE OF ENGINEERING

CAPACITY IMPROVEMENT AND CYCLE TIME REDUCTION USING VALUE STREAM MAPPING AND SIMULATION FOR A PRODUCTION PLANT IN QATAR, A CASE STUDY

BY

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A Project Submitted to the Faculty of

the College of Engineering

in Partial Fulfillment

of the Requirements

for the Degree of

Masters of Science in Engineering Management

January 2017

COMMITTEE PAGE

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ABSTRACT

YAMEEN, MOHAMMAD, A, Masters: January: 2017,

Masters of Science in Engineering Management

Title: Capacity Improvement and Cycle Time Reduction Using Value Stream Mapping and Simulation for a Production Plant in Qatar, a Case Study.

Supervisor of Project: Dinesh Seth.

This Project deals with a real life problem of a construction company, and is about capacity mismatches between different manufacturing modules. This mismatch badly influences the production and results in increased cycle time. Thus the objective of this project is to attempt capacity equalization (reducing mismatch) which if taken care off will improve the capacity and will lead to cycle time reduction. The company owns a stabilizing plant. This company operates in Qatar and specialized in infrastructure projects mainly in road construction and road development. This company is anticipating an increase in demand due to booming road construction activities mainly due to 2022 FIFA World Cup and development of infrastructure in line with Qatar National Vision 2030.

The company executives were interested for a detailed investigation to analyze the problem of capacity mismatch between the different workstations of their plant and wanted to address the higher cycle time as well.

This project was undertaken to investigate the above mentioned problem using scientific and proven process improvement management tools which are in use for such types of problems. For this investigation the student attempted lean based value stream mapping as a major investigation approach. Value stream mapping (VSM) has

been in use for the last 20 years to get more from the existing processes without any significant investment. Besides this, it has been in use for capacity improvement and capacity mismatch analysis based situations also.

The data were collected from the plant during operation, indicating the cycle time and capacity of each workstation and based on these details current state was prepared. This was an eye opening exercise, and this process management based tool proved as a trigger for improvement and the mismatch related problem was pin pointed. Based on this current state, after exposing various pockets of inefficiency several improvement measures were suggested. Based on these suggested improvements the future state is attempted. As the implementation could not be achieved, so to validate the changes simulation was used as tool to demonstrate the impact of these changes on the cycle time. Simulated future state results after incorporating improvements demonstrated the capacity balance problem and resulted in improvement in cycle time and finally a comparison was made between the two states and future scope of work was reported.

DEDICATION

I would like to thank

ALLAH Almighty for His countless blessings…

, My Parents for their Prayers and Encouragements

You spent everything, for us, me and my brothers and sisters...

, My Brothers and Sisters who believed in me...

, My lovely wife Rawan for the endless Support and Love ….

, My little Daughter Jwana, looking into your eyes gave my all hope in Great future...

, And to you; who is giving me your time reading this work …

To all of you this work is Dedicated.

ACKNOWLEDGMENTS

Thanks to ***Almighty ALLAH*** for giving the strength and ability to understand, learn, and complete this Project.

In gratitude and wish sincere thanks to my supervisor ***Dr. Dinesh Seth***, for his help, support and guidance throughout the last year. Your motivation and guidance was the reason for this project to become a reality.

Everlasting thanks to our instructors in ***Qatar University***, for the years we spend together and learned more and more from you.

Great thanks to ***My Company, BOOM CONSTRUCTION*** for the support provided to me.

Special thanks to ***My Colleagues*** and ***My Friends***, who helped me in the difficult times, I couldn't achieve anything without their support …

Thanks All

TABLE OF CONTENTS

COMMITTEE PAGE i
ABSTRACT ii
DEDICATION iv
ACKNOWLEDGMENTS v
List of figures viii
List of tables ix
Chapter 1: Introduction 1
1.1 Problem background 1
1.2 MACRO Level View of Company's Operations 2
1.3 Micro Level View (Stabilizing Plant) 9
1.4 Project Objective 11
1.5 Project Framework 12
1.6 Report Organization 14
Chapter 2: Literature Review 16
Chapter 3: Process Chart and Data Collection 22
3.1 Process Chart 22
3.1.1 Cement feeding: 22
3.1.2 Water feeding: 23
3.1.3 Aggregate feeding: 24
3.2 Assumptions 27
3.3 Data Collection 28
3.5 Current State Value Stream Mapping 38
Chapter 4: Projected Demand Forecasting and Takt Time Calculation 44
4.1 Historical production data for trend 44
4.2 Linear regression for forecasting production demand 45
4.3 Expected additional demand of projects 48
4.4 Total Production planned: 48
4.5 Define Targeted Capacity: 50
4.5 Define *Takt Time*: 50
Chapter 5: Analysis of Current State and Suggested Improvements 51
5.1 Utilization levels 51
5.2 Suggested Improvements 55
5.3 Impact of suggested changes 58
5.4 Future State Mapping 60
Chapter 6: Results Validation using Simulation 62
6.1 Simulation Program 62

6.2 Current State Model 63
6.3 Future State Model 68
Chapter 7: Results Discussion 72
7.1 Process capacity 72
7.2 Workstations Utilization 74
7.3 Workstations Cycle Time 75
7.4 Value Added Time 78
7.5 Non-Value Added Time 78
Chapter 8: Recommendations, Future work, and study limitations. 81
8.1 Conclusions and Recommendations 81
8.2 Future Work 82
8.3 Project Limitations 82
REFERENCES 83
Appendices 86
Appendix A: Production Process flow chart 86
Appendix B: Simplified Process Flow Chart 87
Appendix C: Current State Value Stream Mapping 88
Appendix D: Current State Value Stream Mapping Indicating Potential Improvements 89
Appendix E: Future State Value Stream Mapping 90

List of figures

Figure1: Macro level view of the road construction Process. 3
Figure 2: Material excavation 4
Figure 3: Material Screening. 4
Figure 4: Crusher Plant. 5
Figure 5: feeding different types of material. 5
Figure 6: Different layers of a road. 6
Figure 7: Stabilizing Plant. 7
Figure 8: Aggregate Laying. 7
Figure 9: Asphalt Plant. 8
Figure 10: Asphalt Laying. 9
Figure 11: Stabilizing Plant Process. 10
Figure 12: Project Framework. 13
Figure 13: Process Flow Chart. 25
Figure 14: Simplified Process Flow Chart. 26
Figure 15: Process Workstations. 27
Figure 16: Aggregate Feeding. 29
Figure 17: Collecting Conveyor. 30
Figure 18: Elevator Bucket Conveyor. 32
Figure 19: Mixer. 33
Figure 20: Workstations Cycle Times. 36
Figure 21: Capacity of Workstations. 37
Figure 22: Waste types in a Process. 38
Figure 23: Workstations Timings. 41
Figure 24: Current State VSM 42
Figure 25 : Forcasted data. 47
Figure 26 : Demand Resulting from Getting New Project. 48
Figure 27: Total Forecasted Demand. 49
Figure 28: Workstations Capacity with Planned Capacity. 53
Figure 29: Areas of Improvements. 54
Figure 30: Single Geared Motor Mixer. *Figure 31:* Double Geared Motor Mixer. 57
Figure 32: Stockpiling Conveyor. 58
Figure 33: Suggested future state value stream mapping. 61
Figure 34: Process Simulator 2016 - Free ® by ProModel ® 62
Figure 35: Simulator Main Window. 63
Figure 36: Current State Model. 65
Figure 37: Utilization Levels. 66
Figure 38: Future State Model. 69
Figure 39: Utilization Levels of Future State. 71
Figure 40: Current State and Future State Workstations Capacity. 73
Figure 41: Workstations Capacity Improvements. 73
Figure 42: Current State and Future State Utilization Levels. 75
Figure 43: Workstations CT and Takt Time. 76
Figure 44: Cycle Time Reduction. 77
Figure 45: VAT Improvement. 78
Figure 46: NVAT Reduction. 79

List of tables

Table 1: List of Papers with thier Sectors. 16
Table 2: Application of VSM and Simulation in the Reviewed Literature. 18
Table 3: Feeders Collected Data. 29
Table 4: Material Dosage Data Collected. 32
Table 5: Material Discharge Data Collected. 34
Table 6: Total Forecasted Demand. 49
Table 7: Utilization Levels. 51
Table 8: Implied Utilizations. 52
Table 9: Current state And Future State Capacities. 59
Table 10: Workstations Timings for Current State and Future State. 60
Table 11: Current State Model Simulation Results. 66
Table 12: Utilization Levels Comparison. 67
Table 13: Future State Model Simulation Results. 70
Table 14: Future State Utilization Levels. 71
Table 15: Workstations Capacity Improvements. 72
Table 16: Workstations Utilization Levels. 74
Table 17: Workstations Cycle Time Improvements. 76
Table 18: Workstations VAT Improvement. 78
Table 19: NVAT Reduction. 79

Chapter 1: Introduction

The company owns a stabilizing plant. This company operates in Qatar and specialized in infrastructure projects mainly in road construction and road development and anticipating an increase in demand due to booming road construction activities mainly due to 2022 FIFA World Cup and rise in infrastructure development requirements in view of Qatar National Vision 2030.

In this chapter the macro view of the company operations will be discussed, followed up with micro level view of the processes of the mixing plant that is analyzed in this project. This part will provide clear understanding of company operations.

The next part will discuss the project motivation, where the importance of this project is explained, followed by the project objectives. In this chapter Project frame work is discussed, and finally the contents are also briefly explained.

1.1 Problem background

The stabilizing plant of Company is producing excellent product that satisfies quality requirements and meeting Company's current projects demand. This reputation allows them to get new projects that requires expansion in their production capacity.

As their plant is an old one (more than 10 years in the operation), it is observed that some of the workstations has limited capacity due to the old age and the limitation of spare parts available, while other workstations are running at very low utilization levels while the capacity is available. The current company requirements can be satisfied with the current plant capacity, while getting new project forces the company to evaluate the possibility of resolving the bottleneck / bottlenecks of the current workstations and to see if the company will be able to satisfy the new expanding requirements by using the same plant without the need of capital investments.

So the company executives were interested for a detailed investigation to analyze the problem of capacity mismatch between the different workstations of their plant and wanted to address the higher cycle time issue as well.

1.2 MACRO Level View of Company's Operations

This part explains the general wide view of the company's operations, which gives the understanding of all operations related to road construction. Figure 1 shows the macro level view of the road construction projects as a main function of the company, while the red bordered activity (Product stabilizing) is the scope of this project.

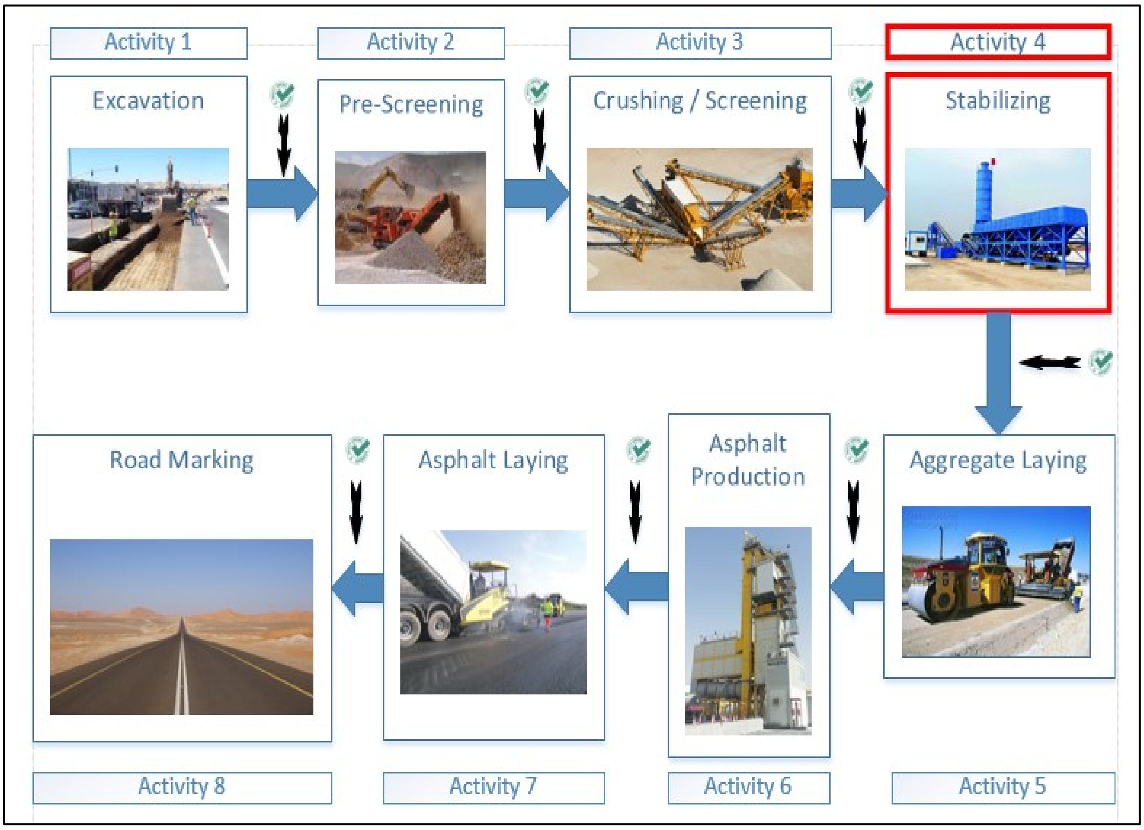

Figure1: Macro level view of the road construction Process.

Brief description of each activity is discussed below:

- *Activity 1:* Company operations starts from site material excavation (figure 2). The excavation is done to a certain width which is defined in the project specifications. The excavated material is transported to the production facility that treats the material in order to modify their characteristics so it can be used again in the construction projects. The treated material can be used after meeting the construction specifications and project requirements that's why the quality checks are there in between all activities.

Figure 2: Material excavation

- *Activity 2:* The excavated material is pre-screened (figure 3) so fine material is separated from the course ones. Both are tested in order to know their nature.

Figure 3: Material Screening.

- *Activity 3:* The course material is crushed using a crusher plant followed up by a screen plant in order to get material sizes required for the next step, See figure 4. This material is also tested against certain parameters to understand the kind of modification required.

Figure 4: Crusher Plant.

- *Activity 4:* The resulted material is transported to the stabilizing plant. The stabilizing plants is the plant used to mix the material by certain percentages defined carefully by the quality control department with out-sourced material that plays a role part of modifying resulted product characteristics and specifications, figure 5 shows different material feeding at a stabilizing plant.

Figure 5: feeding different types of material.

Different types of mixed material are required that is required for the different layers of road construction, see figure 6. The specifications and parameters varies as of the material need to be used for the Sub-Grade, Sub-base or road base. And by using the stabilizer plant the specific quantities of each material needed can be defined.

Some examples of material being added is the cement that increase material bonding and strength, dune sand that improves the plasticity index and liquid limits, while water is been added to improve material mixing and workability at site.

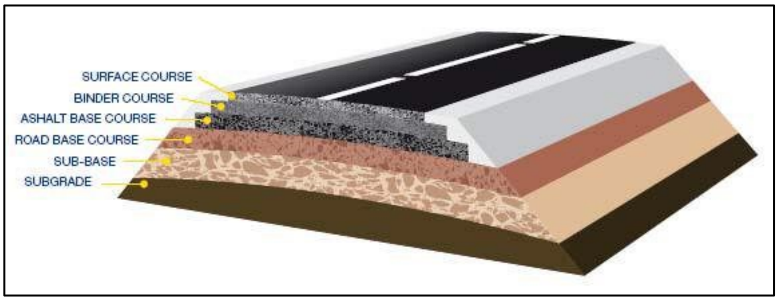

Figure 6: Different layers of a road.

This project deals with the stabilizer plant capacity, while it is be discussed with more details in the micro level view and the current state chapter that follows up. The following Figure 7 shows a stabilizer plant.

Figure 7: Stabilizing Plant.

- *Activity 5:* The mixed material will be tested to confirm quality compliance, then it will be transferred back to work site to be laid up. Figure 8 shows laying activities on site which includes material paving and compaction.

Figure 8: Aggregate Laying.

- *Activity 6:* Asphalt production plants is responsible of providing asphalt pavements which are the top layers in any road, this pavement is done separately under different conditions where the material is heated and mixed with asphalt binder in the asphalt patching plant figure 9.

Figure 9: Asphalt Plant.

- Activity 7: The mixed asphalt is sent to working site to be laid under specific conditions of thickness and temperature. The following figure 10 shows asphalt paving activities.

Figure 10: Asphalt Laying.

- *Activity 8:* The asphalt is laid layer by layer and each one of them is tested before starting the next one, upon completion of the asphalt different layers laying, road is marked and delivered to the owner to be opened for traffic.

It is important to understand the importance of having enough capacity at each and every activity, as any shortage of capacity at any one of them will cause a delay in the project delivery and a lot of wasted resources and cost implications, which will affect negatively company reputation and owner satisfaction, and ability of getting new project as a result.

1.3 Micro Level View (Stabilizing Plant)

After understanding the Macro level of the overall company operation, it is required to go in the Micro level where we zoom in the stabilizing plant which is analyzed in this project in order to know all workstations and the activities related to.

A stabilizing plant, also known as a wet mix plant is an equipment that combines various ingredients to form road base product. This equipment is controlling the quantities of each ingredient in order to produce a product that satisfies the quality requirements, some of these inputs include sand, water, aggregate (rocks, gravel, etc.), and cement.

Here it is explained briefly the main components of a stabilizing plant, while more details are discussed in the process current state mapping which will come later in this report in separate chapter.

The following figure 11 shows the stabilizing plant processes, starting from the feed of the different raw material. The feed of those material is controlled by automatic system that is operated by the plant operator, who program the feed rate along with other production parameters of every type of the raw material being used.

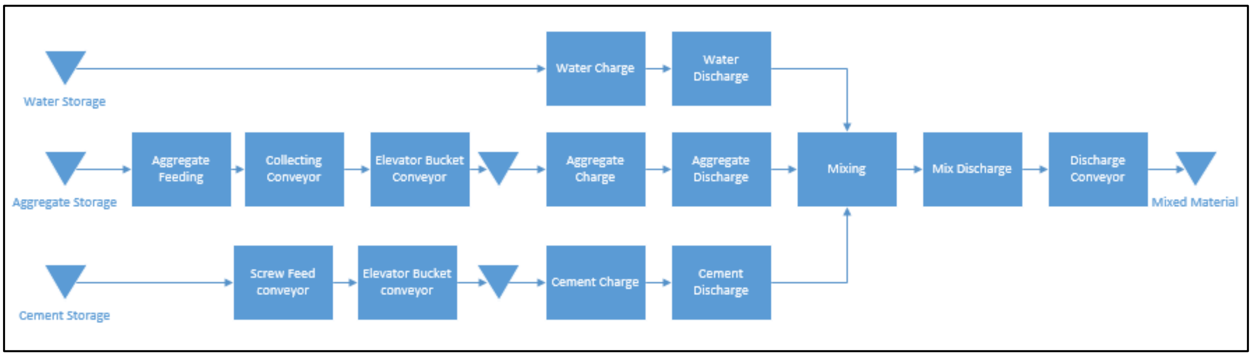

Figure 11: Stabilizing Plant Process.

The aggregate is fed by 5 conveyors installed under the storage hoppers, then it is collected together by the collecting conveyor belt. The material is transported vertically to the mixing tower top by the elevator bucket conveyor, then it is dosed by a mean of weighing scale that reads the amount of material then it is discharged to the mixer to be mixed with the other incoming materials.

The cement is stored separately in vertical silo, the cement is discharged by screw conveyor then it is transported vertically to a small silo that is installed at high level in the mixing tower. The material is weighed in a separate scale by a screw conveyor and the required amount of material is discharged in the mixer.

Water cycle starts from huge storage tanks which is installed near to the plant, the required amount of water is transferred by a motor pump to the dedicated weighing tank that is installed in the mixing tower as well.

Upon having the required quantity of aggregates, cement and water in the weight scales of each, it is discharged into the mixing tower in order to be mixed together. The mixed material is discharged by pneumatic piston to the transporting truck.

Due to the quality requirements, mixed material should be stockpiled and tested prior to site loading, so the role of the trucks is to transport the material to the area dedicated for material stockpiling which is near to the plant.

1.4 Project Objective

Following are the objectives of this project:

- To understand the capacity mismatch in the current state.
- To document and suggest capacity improvements in order to meet desired demand.
- To suggest improved and recommended future state mapping based on suggested improvements.
- To validate future state mapping of the process using simulation.

1.5 Project Framework

The productivity improvement problem of this project is handled in such a way by following the framework shown in the below figure 12:

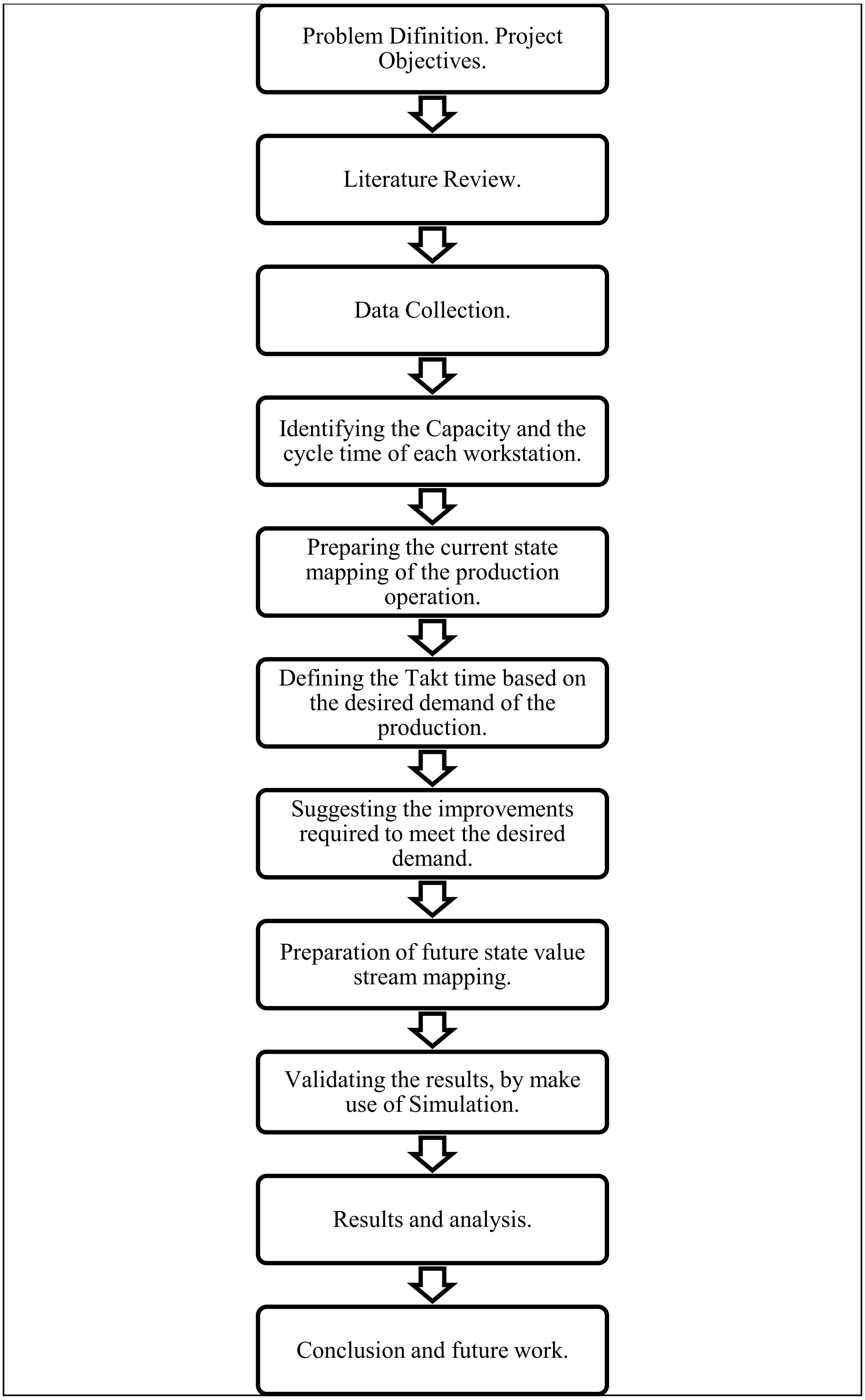

Figure 12: Project Framework.

1.6 Report Organization

Chapter 1 of the report gives brief introduction about company's operations, starting from the Macro level summary and the Micro level description of the operations, this chapter also addresses the project objectives, project framework, and scope of the work.

Chapter 2 of the project provides the summary of studies done in the past on productivity improvement and cycle time reduction problems. It also explains the VSM and its different application and how it is applicable to this problem scenario. It also explains how the various aspects of previous studies were utilized for this case study.

Chapter 3 addresses data collection part, and discuss in details the process flow chart for the stabilizer plant under study, the current state value stream of the process is defined also and analyzed.

Chapter 4 focuses on desired demand forecasting. It considers the demand trend forecasting where the linear regression method is used. It also considers adding the demand of the new project from its schedule of values. The resulting figure are used to calculate the Takt time and the targeted capacity.

Chapter 5 of the projects analyzes the process parameters obtained in the previous chapters considering the calculated takt time and desired capacity. The suggested improvement is discussed in this chapter and the future state value stream mapping is suggested.

Chapter 6 discusses the use of simulation to verify the results obtained from the application of value stream mapping, where both current state and future state is modeled and the resulting data after running the simulation is discussed and compared to the earlier results obtained from VSM.

Chapter *7* focuses on the results obtained from the application of value stream mapping. The resulting data is discussed in term of process capacities, utilization levels, cycle time, Value added and Non-Value added time, and the production volumes.

Chapter 8 discusses the recommendations and conclusion of this project. This chapter also concludes by mentioning how this research project can be extended in future to add further value. It ends up by listing the limitation of this study.

Chapter 2: Literature Review

This chapter provides the summary of studies done in the past on the productivity improvement and cycle time reduction problems. It also explains the VSM and its different applications and how it is applicable to this problem scenario. It also explains how the aspects of previous studies were utilized to be applied in this case study.

Value stream mapping (VSM) has been in use for the last 20 years to get more from the existing processes without any significant investment and besides this it has been in use for capacity improvement and capacity mismatch analysis based situations, an extensive literature discussed the application of VSM on various aspects, table 1 lists the applications of VSM on different industries as reviewed in the literature.

Table 1: List of Papers with thier Sectors.

SN	Author(s) and Year	Sector	Journal
1	António Pedro Lacerda, Ana Raquel Xambre & Helena Maria Alvelos (2016).	Automotive Industry.	International Journal of Production Research
2	D.T. Matt (2014).	Fabrication Industry of large and heavy steel constructions, such as steel structures and facades for civil and industrial architecture	Journal of Manufacturing Technology Management
3	Haider, A, Mirza, J and Ahmad, W. (2015).	Manufacturing industry, A tool room of armored manufacturing organization	Advances in Production Engineering & Management Journal
4	Naga Vamsi Krishna Jasti Aditya Sharma (2014).	Automotive Components Industry.	International Journal of Lean Six Sigma
5	Taho Yang, Yiyo Kuo, Chao-Ton Su and Chia-Lin Hou (2014).	Fish net Manufacturing.	Journal of Manufacturing Systems
6	V. Ramesh, K.V. Sreenivasa Prasad and T.R. Srinivas (2008).	Manufacturing Industry for the manufacture of Machining centre	Journal of Industrial and Systems Engineering

7	Anand Gurumurthy Rambabu Kodali (2011).	Manufacturing Industry of large integrated steel mill.	Journal of Manufacturing Technology Management
8	Jaiprakash Bhamu, J.V. Shailendra Kumar and Kuldip Singh Sangwan (2012).	Automotive Industry.	Int. J. Productivity and Quality Management
9	Dinesh Seth & Vaibhav Gupta (2005).	Automotive Industry.	Production Planning & Control, The Management of Operations
10	Fawaz A. Abdulmaleka, Jayant Rajgopal (2006).	Manufacturing industry, process sector for application at a large integrated steel mill.	Int. J. Production Economics
11	Ibon Serrano, Carlos Ochoa & Rodolfo De Castro (2008).	Production Industry, of disconnected flow lines based environment.	International Journal of Production Research
12	Jafri Mohd Rohania, Seyed Mojib Zahraee (2015).	Colour Industry.	*2nd International Materials, Industrial, and Manufacturing Engineering Conference**
13	M. Braglia , G. Carmignani & F. Zammori (2006).	Production industry, electro-domestic manufacturing firm of refrigerator production	International Journal of Production Research
14	Parthana Parthanadee & Jirachai Buddhakulsomsiri (2014).	Batch production system of the roasted and ground coffee.	Production Planning & Control The Management of Operations
15	Rahani AR, Muhammad al-Ashraf (2012).	Automotive Industry.	*International Symposium on Robotics and Intelligent Sensors 2012.*
16	Thomas McDonald, Eileen M. Van Aken & Antonio F. Rentes (2002).	Manufacturing industry of high-performance motion control products.	International Journal of Logistics Research and Applications

The VSM is used in this project to improve the productivity and to reduce the cycle time of the workstations within the process, it is proved the use of VSM for such an application, the following table 2 lists main contribution done in this direction. The utilization of simulation is also recorded in order to verify the results of VSM and to move from the static view provided by VSM to a dynamic view when the application of the findings was not achieved in reality, which is also listed in the below table.

Table 2: Application of VSM and Simulation in the Reviewed Literature.

SN	Author(s) and Year	Paper Title	Application of VSM	Simulation Utilization
1	António Pedro Lacerda, Ana Raquel Xambre & Helena Maria Alvelos (2016).	Applying Value Stream Mapping to eliminate waste a case study of an original equipment manufacturer for the automotive industry	Production improvement and cost reduction, by identifying various wastes within the process and suggesting improvements that eliminates the wastes.	Not used as Lean wastes have been identified and solutions proposed to eliminate them has been implemented.
2	D.T. Matt (2014).	Adaptation of the value stream mapping approach to the design of lean engineer-to order production systems	Identify best practice guidelines for the adaptation and use of value stream mapping (VSM) in the design of lean engineer-to-order (ETO) production systems as a complex system.	Not Used.
3	Haider, A, Mirza, J and Ahmad, W. (2015).	Lean capacity planning for tool room: An iterative system improvement approach	Manage production imbalances, improves productivity and cost reduction by waste elimination.	Used, to prove that improved system can meet production needs and the capacity needs.
4	Naga Vamsi Krishna Jasti Aditya Sharma (2014).	Lean manufacturing implementation using value stream mapping as a tool: A case study from auto components industry	Improve overall productivity, quality and performance of the manufacturing line.	Not Used, as the future state of VSM has been implemented in the production line and performed data collection for next six months to finalize the future state of VSM, which was later successfully incorporated in the production line
5	Taho Yang, Yiyo Kuo, Chao-Ton Su and Chia-Lin Hou (2014).	Lean production system design for fishing net manufacturing using lean principles and simulation optimization	Cost reduction by eliminating non-value adding activity.	Used to optimize production factors in order to define Future state mapping of the process.

6	V. Ramesh, K.V. Sreenivasa Prasad and T.R. Srinivas (2008).	Implementation of a Lean Model for Carrying out Value Stream Mapping in a Manufacturing Industry	Proposed measures to reduce cycle time and improve the process of manufacture.	Not Used.
7	Anand Gurumurthy Rambabu Kodali (2011).	Design of lean manufacturing systems using value stream mapping with simulation: A case study	Line Balancing, VAT and NVAT evaluation in order to reduce production lead time and improve the process.	Simulation studies were carried out for different scenarios such as “before LM” (current state VSM) and “after LM” (future state VSM). It was found that the case organisation can achieve significant improvement in performance and can meet the increasing demand without any additional resources
8	Jaiprakash Bhamu, J.V. Shailendra Kumar and Kuldip Singh Sangwan (2012).	Productivity and quality improvement through value stream mapping: a case study of Indian automotive industry	Productivity and quality improvement by implementation of VSM	Not used, as the improvements has been applied on the process.
9	Dinesh Seth & Vaibhav Gupta (2005).	Application of value stream mapping for lean operations and cycle time reduction: an Indian case study	Use VSM as a technique to achieve productivity improvement at supplier end for an auto industry	Not Used.
10	Fawaz A. Abdulmaleka, Jayant Rajgopal (2006).	Analysing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study	Value stream mapping was the main tool used to identify the opportunities for various lean techniques.	Used to illustrate to managers potential benefits such as reduced production lead-time and lower work-in-process inventory.

11	Ibon Serrano, Carlos Ochoa & Rodolfo De Castro (2008).	Evaluation of value stream mapping in manufacturing system redesign	Proved the real applicability of VSM to redesign disconnected flow lines based on manufacturing environments with a diversity of logistical problems to improve productivity.	Not used.
12	Jafri Mohd Rohania, Seyed Mojib Zahraee (2015).	Production line analysis via value stream mapping: a lean manufacturing process of color industry	Improving the manufacturing system's productivity and quality enhancement of the product.	Not Used.
13	M. Braglia , G. Carmignani & F. Zammori (2006).	A new value stream mapping approach for complex production systems	Use of VSM for complex production processes.	Not Used
14	Parthana Parthanadee & Jirachai Buddhakulsomsiri (2014).	Production efficiency improvement in batch production system using value stream mapping and simulation: a case study of the roasted and ground coffee industry	Use of value stream mapping (VSM) and simulation to improve the efficiency of the batch production system commonly found in small and medium enterprise.	Used to verify results and is used also to optimise the levels of resources required for the bottleneck operations without disturbing the production.
15	Rahani AR, Muhammad al-Ashraf (2012).	Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study	Both value added and non-value added, are analysed and using VSM as a visual tool to help see the hidden waste and sources of waste in order to eliminate and improve the process.	Not used, as the improvements has been implemented and proved on the process.
16	Thomas McDonald, Eileen M. Van Aken & Antonio F. Rentes (2002).	Utilising Simulation to Enhance Value Stream Mapping: A Manufacturing Case Application	Eliminating non-value-adding work and waste by VSM application.	Utilised with VSM, to verify the results.

This literature highlighted the various applications of Value stream mapping that are being used for, therefore it helped to confirm the possibility of using the value stream mapping in such applications as been used in this project.

More over the researchers has defined a certain guideline for the application of this lean management tool. This report has followed these guide lines and it was explained in the project framework.

Chapter 3: Process Chart and Data Collection

In this chapter the value stream of the current state will be defined and analyzed. This will be done after explaining the flow chart of the current process where the data collection will be explained and the process as well.

3.1 Process Chart

The first step for improving a process is to understand clearly the process itself. And we can do so by following the process inputs and trace them through the process ending up with the finished product.

Figure 13 shows the process flow chart, here below it is explained for each component being used, this will give a clear idea about all the stages and the workstation inside, the three paths shown will be discussed below:

3.1.1 Cement feeding:

- The cement is stored in a vertical type storage silo that is suitable for cement storage and is equipped with filling pipe and a filter to clean exhausted air during filling in order to reduce the waste and pollution. The bottom cone of the silo is equipped with fluidification devices that prevent cement from being jam and provides with continues flow.

- The discharged cement is transferred by screw feed conveyor to the next stage where we have elevator conveyor that moves the cement from the ground level to the top of mixing tower, where it is been stored in a small silo. The feed silo is taking place at the level of weighing scales and it is equipped with electrical high level indicator that stops the screw conveyor when the level inside is high.

- The cement is weighed by small screw conveyor connected to the weighing scale. It is controlled by the computer that stop it once the set value is been reached.

- The discharge from the weighing hopper to the mixer is done by pneumatic cylinder that is controlled by the computer. In order to allow weighing of new material.

3.1.2 Water feeding:

- The water is stored in a huge storage tank that is located beside the plant.
- Electrical Motor pump transfers the water from the storage tank to the weighing tank. The water weighing pump is controlled by the computer to give exact quantity required of water.
- The water is discharged by gravity from the weighing tank by opening the discharge butter fly valve moving the water to the mixer.

- This cycle is controlled by the computer in parallel with other components.

3.1.3 Aggregate feeding:

- The raw material is stored separately near to the plant, wheel loader is used to fill the storage hoppers.
- Five storage feeders been filled with different types of aggregate that is required for the mix. The speed of discharge conveyor is controlled by the computer to give the required percentage from each type.
- Collecting conveyor belt is located under the discharge conveyors that collects the material discharged from each one of the hoppers and transport them to the next workstation.
- The material is transported to the mixing tower by bucket conveyor that moves the material vertically.
- The material is collected in storage hopper that is equipped with electrical level indicator so the material flow will be stopped if the hopper is full.
- The aggregate material is charged to a weighing hopper by mechanical gate controlled by pneumatic cylinder that is controlled by the computer.
- Once the required amount of aggregate will be collected in the weighing hopper it will be discharged to the mixer together with the other components (water and cement).
- All of the material is mixed together and then it is discharged to the transporting trucks to be sent to the stockpiling area. If no truck is

available, the cycle should be stopped and the whole system will be waiting for the next truck arrival.

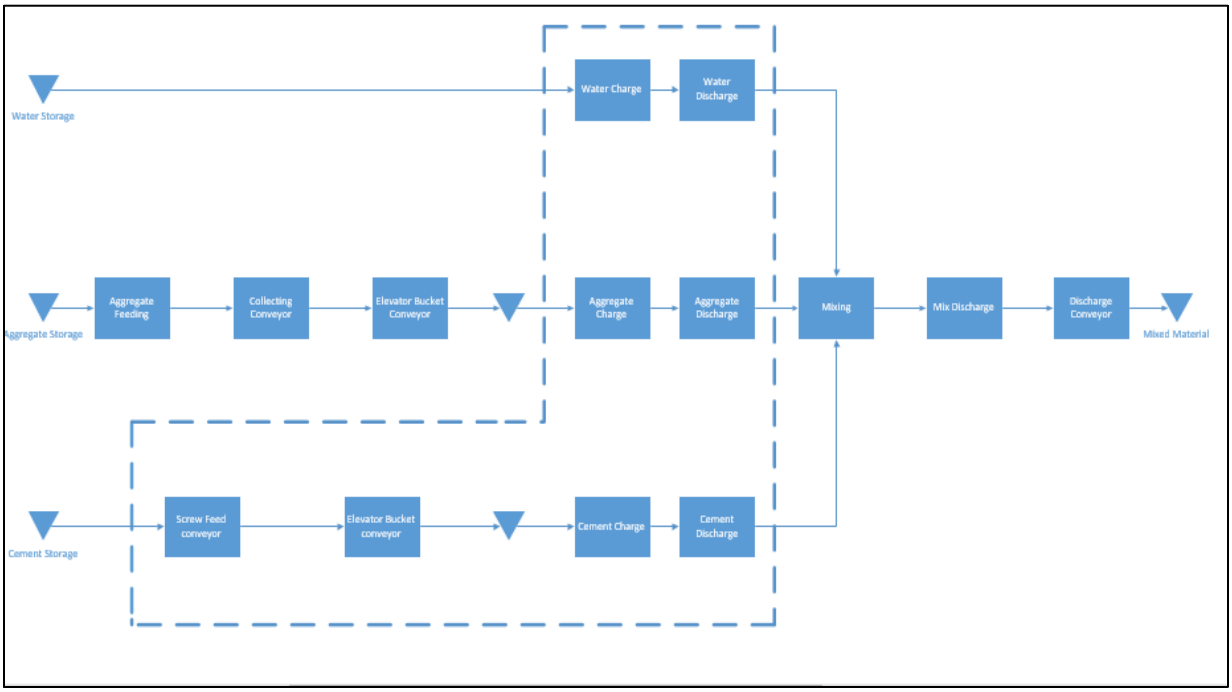

Figure 13: Process Flow Chart.

All of these workstations is controlled by the control system installed in the control room, and the plant operator is assigned to operate and monitor the system.

The process map shown above is complicated one and we can see that it includes three parallel processes, and in order to apply the value stream mapping we will convert it to a simplified model, see figure 14.

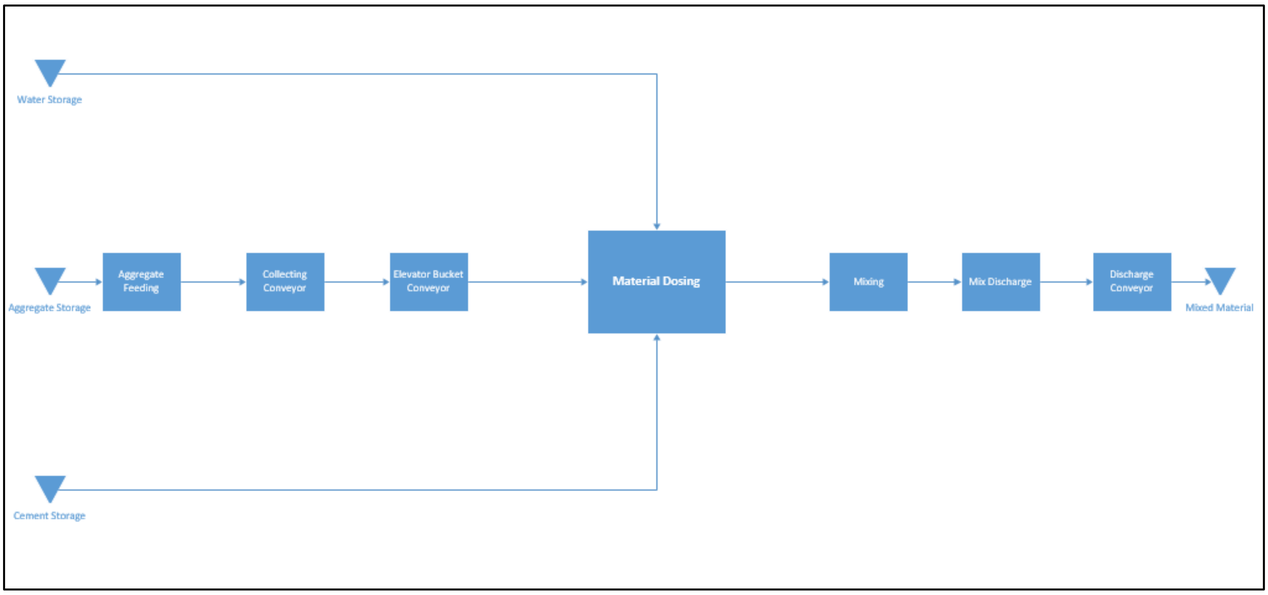

Figure 14: Simplified Process Flow Chart.

In order to come up with the simplified model, we took the most constrained work stations, that lays in the longest path with the highest cycle time, and we combine the dosing-discharging stages of aggregate together in one workstation that will deal with it as a unit and will define its cycle time and capacity separately that will be used in all following analysis.

We will build later on in this chapter the VSM of the current state by using the simplified model that will contain these workstations shown in figure 15.

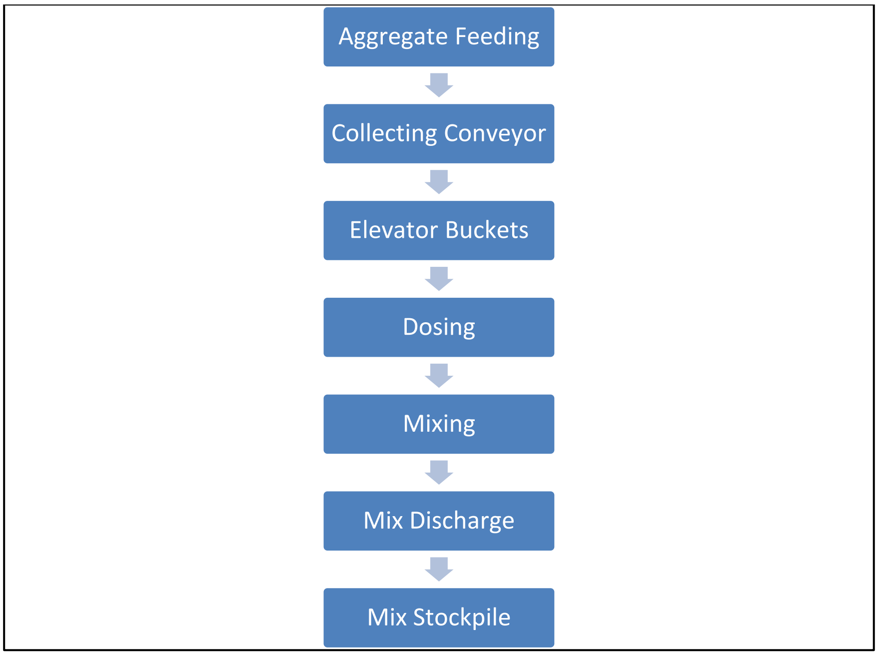

Figure 15: Process Workstations.

3.2 Assumptions

The following assumption has been considered during the work on this project:

- It is assumed to have enough demand for the production from this plant.
- The plant is able to produce different type of mixes by changing the mix receipt from the computer, for ease of analysis the most common mix was considered for all the analysis.
- It is assumed to have enough supply of all types of raw materials from the suppliers, this is applicable for the cement, water and all types of aggregate and sand materials.

- The production of one truck capacity of 25 tons of material is considered for the calculation of cycle times, even though different truck capacity is possible.
- Single shift operation is assumed with 12 working hours, while the active production work is assumed to be 10 hours after deducting 2 hours, one for break and one for plant service and maintenance.
- It is assumed under the previous assumption that the plant will be operational during 10 working hours, and there will be no break down during the said time.
- It is assumed 26 working days each month.

3.3 Data Collection

In order to build the current state model data inputs were collected. Two ways were used for the data collection and to understand the activities. The first is manufacturer manuals and data sheets of all components that has been reviewed. Second is the data collected from the plant to determine the timings of all workstations. Time study was performed using these data, resulting in getting the cycle times and capacity of each work station. Below discussed briefly for each workstation:

1. Aggregate feeding: the manufacturer data sheet of the feeders (5 identical feeders) states that running the feeder on the full speed will discharge 45 tons of material in 1 hour. In order to confirm this during site visit, an aggregate feeder calibration has been done to come up

with actual situation details of the feed capacity, figure 16 below shows the plant feeders.

Figure 16: Aggregate Feeding.

The calibration process is done by running the feeder on 50% speed for 2 minutes, then the material is collected and weighed (WT) using calibrated scale and the capacity is then calculated:

$$Hourly\ Total\ Capacity = Material\ collected\ weight\ (\text{WT}) * \frac{Total\ Capacity}{Running\ Capacity} * \frac{Available\ Time}{Running\ Time}$$

$$Hourly\ Total\ Capacity\ = WT * \frac{100\ \%}{50\ \%} * \frac{60\ Min}{2\ Min} = WT * 2 * 30$$

The following table 3 list up the collected data:

Table 3: Feeders Collected Data.

Feeder	Running	Running time	Collected	Hourly	Total

Number	speed	(Minuets)	material weight (Kg)	Capacity (Ton/hour)
1	50%	2	747	44.82
2	50%	2	751	45.06
3	50%	2	749	44.94
4	50%	2	750	45.00
5	50%	2	750	45.00

As we can see that the data collected proves the same capacity listed in the data sheet with acceptable error, so the ideal data is considered in our calculations later on.

2. Collecting Conveyor: the manufacturer mentioned a capacity of 220 tons/hour as the maximum capacity that can be transported by the conveyor (figure 17).

Figure 17: Collecting Conveyor.

To confirm the workability on the rated capacity the feeders speed was set to 97.7% each one, which is resulting in total material of 220 ton/h as per the calibration done earlier. The material discharged is collected over the running time of 2 minutes and weighed using calibrated scale. During the material discharge the load current of the motor is monitored in order to confirm it is in the allowable limits.

The material collected over 2 minutes found as 7334 kg, which is equal to 220 tons per hour after multiplying by 30. So the nominal capacity is used in our calculations.

3. Elevator buckets: this part of the plant is very old, therefore no manufacturer manuals were available, so the capacity was identified using the calibrated feeders, so all work stations was started to operate without stating the material. Then material is started on 40% speed for 5 minutes and the elevator was observed to confirm workability. Then 1% speed was increased after every 5 minutes only if the running condition in confirmed until we reach a point that the elevator is full of material and the no further increase can be done.

   By doing this practice it was noticed that the elevator can handle up to 54.5% of the feeders speed, actually it was reported by plant operator to be the bottleneck as he observed during his operation, so the 54.5% equally to 122.6 ton/hour which is rounded to 122 for our calculations.

Figure 18: Elevator Bucket Conveyor.

4. Dosing system: by using a stop watch and during visits to the site several trials were done in order to obtain the time required for material dosing. As we are focusing on the aggregate part, then the time starting from material charging to the scale till the material is discharged to the mixer was collected

   30 trial were done and the average time for material dosage is obtained, see below table.

Table 4: Material Dosage Data Collected.

Trial Number	Observed time	Trial Number	Observed time	Trial Number	Observed time	Trial Number	Observed time
1	14.6	9	15.2	17	14.5	25	14.7
2	15	10	15.3	18	14.2	26	14.7
3	14.7	11	14.7	19	15.8	27	15.5
4	14.2	12	15.5	20	14.3	28	15.7
5	13.9	13	15.8	21	14.4	29	15
6	14	14	15.6	22	15	30	15.5
7	13.6	15	13.5	23	14.9	**Data Average**	
8	14.8	16	14.5	24	14.8	**14.797 Seconds**	

Based on the observed timings 14.8 seconds for each patch of 0.6 ton, so using below equation the cycle time is calculated:

$$Dosing\ Cycle\ time = \frac{Cycle\ weight}{Patch\ wieght} * Average\ time$$

$$Dosing\ Cycle\ time = \frac{25\ Tons}{0.6\ Tons} * 14.8 = 616.7\ Sec = 10.28\ Minuets$$

While the capacity is calculated as per below:

$$Material\ Dosing\ Capacity = \frac{Available\ time}{Cycle\ time} * cycle\ quantity$$

$$Material\ Dosage\ Capacity = \frac{60\ Minuets}{10.28\ Minuets} * 25\ Tons = 146\ Tons/\ hour.$$

5. Material Mixing: the manufacturer listed a nominal capacity of 133 tons/ hour in the product sheet, and it was considered in the calculations.

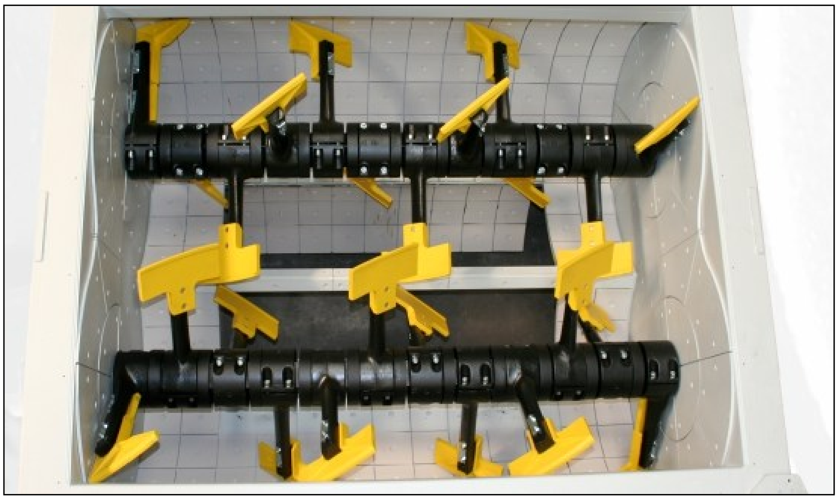

Figure 19: Mixer.

6. Mixed material discharge: by using stop watch and while visit to the site several trial was done in order to calculate the time required to discharge the mixed material from the mixer.

    30 trial was done and the average time for material discharge is calculated, see table 5.

Table 5: Material Discharge Data Collected.

Trial Number	Observed time	Trial Number	Observed time	Trial Number	Observed time	Trial Number	Observed time
1	2.9	9	2.8	17	2.9	25	2.6
2	2.8	10	3.1	18	2.8	26	3
3	3.1	11	2.9	19	3	27	2.8
4	3	12	3	20	3.1	28	2.9
5	2.8	13	3	21	2.9	29	2.8
6	3.1	14	3.1	22	2.9		
7	2.7	15	2.7	23	3	**Data Average**	
8	2.7	16	2.6	24	2.8	**2.88**	

Based on the observed timings 2.88 seconds for each patch of 0.6 ton, so using below equation the cycle time is calculated:

$$Discharge\ Cycle\ time = \frac{Cycle\ weight}{Patch\ wieght} * Average\ time$$

$$Discharge\ Cycle\ time = \frac{25\ Tons}{0.6\ Tons} * 2.88 = 120\ Sec = 2\ Minuets$$

7. Mixed material loading: the mixed material is directly loaded into a truck which is stopped under the mixer door, so the truck cycle time is calculated by summing the hauling, dumping, return, spotting and loading time.

$$Truck\ Cycle\ time = th + td + tr + ts + tl$$

Where;

th: Truck hauling time.

td: Truck dumping time.

tr: Truck return time.

ts: Truck Spotting time.

tl: Truck loading time.

Alternatively, it is also possible to calculate the observations from the time truck start to be loaded to the time when it is back and loaded again which will give the total of above. For lack of simplicity the total time is considered and the observations are listed in below table 6.

Table 6: Mixed Material Loading Data Collected.

Trial Number	Observed time (Seconds)	Trial Number	Observed time (Seconds)
1	1205	11	1188
2	1220	12	1185
3	1170	13	1220
4	1182	14	1192
5	1210	15	1207
6	1190	16	1209
7	1202	17	1193
8	1195	18	1212
9	1210	19	1214
10	1190	20	1200
	Data Average	**1199.7 Seconds**	

So average cycle time is considered to be 1200 seconds which is equal to 20 minutes, knowing that 2 truck are allocated for this work, then the capacity is calculated as per below:

$$Mixed\ Material\ Loading\ Capacity = \frac{Available\ time}{Cycle\ time} * truck\ capacity * Number\ of\ truck$$

$$Mixed\ Material\ Loading\ Capacity = \frac{60\ Minuets}{20\ Minuets} * 25\ Tons * 2 = 150\ Tons/\ hour.$$

The following table 7 summarizes the results obtained for the various workstations:

Table 7: Workstations Cycle Times.

WorkStation	Capacity	CT (minuets)
Aggregate Feeding	225 ton/hour	6.67
Collecting Conveyor	220 ton/hour	6.82
Elevator Buckets	122 ton/hour	12.3
Dosing	146 ton/hour	10.28
Mixing	133 ton/hour	11.28
Mix Discharge		2
Mix loading	150 ton/h	10

It is also observed the variation in cycle time and the capacity of all work station, see figure 20 and figure 21 respectively.

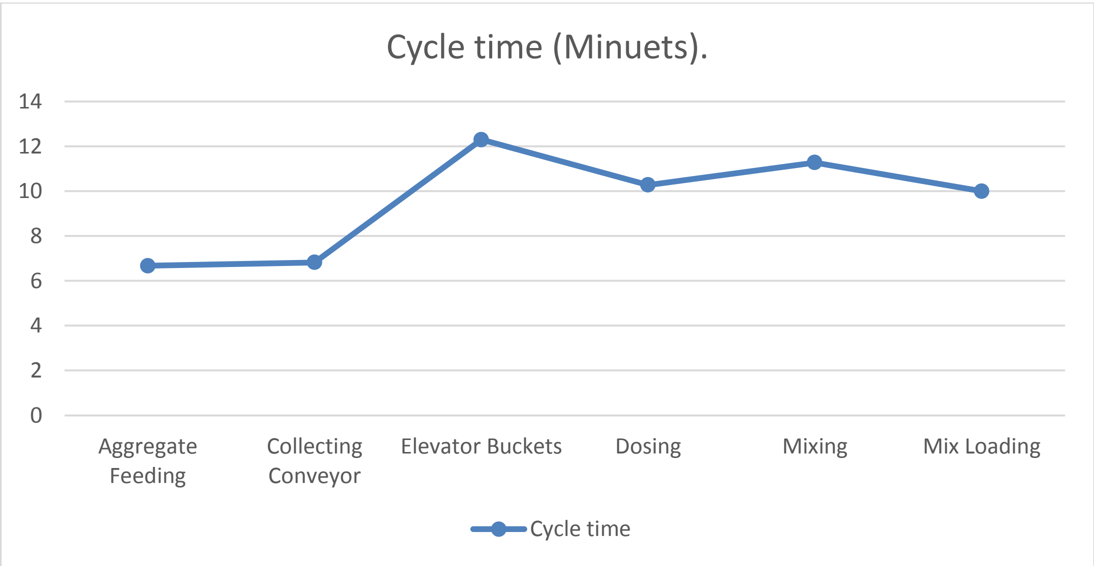

Figure 20: Workstations Cycle Times.

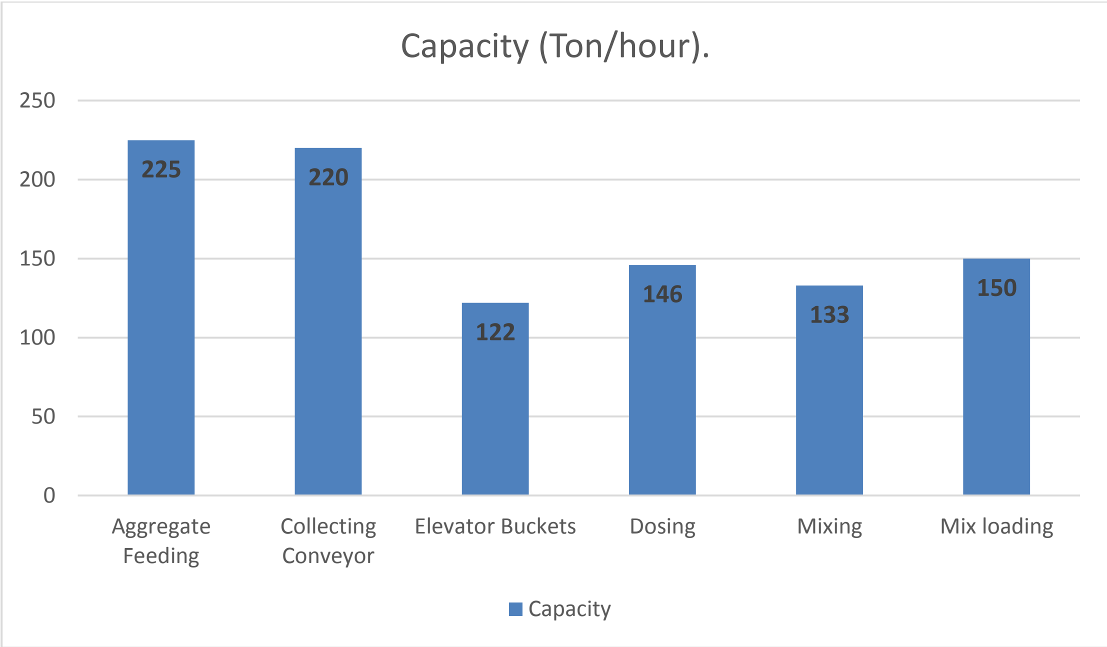

Figure 21: Capacity of Workstations.

3.5 Current State Value Stream Mapping

Based on the data collected earlier for the capacity and the cycle time, the next step is to come up with the current state value stream after estimating the value added time and Non-Value added time for each workstation.

Keeping in mind that added value time is the part that adds value to the final product and the customer is willing to pay for, while the non-added value time is the time which is wasted in the process, and the does not add any value to the final product while the customer is not willing to pay for. Figure 22 below shows the main classification of waste that is considered as Non-value added to any process. Based on these definitions and the below explanation how we come up with these figures for each workstation.

Figure 22: Waste types in a Process.

1. Aggregate Feeding: as we have excess capacity in this workstation so it is noticeable that with the current working capacities and the multiple bottlenecks available the feeders will run for 6.67 minutes for every cycle it has to wait for 5.63 minutes for the next patch. In other words it will be operational with a percentage capacity of 54% capacity.

2. Collecting Conveyor: Similarly to the feeders with the current production rates the collecting conveyor has to run for 6.82 minutes (VAT) while it will be idle for 5.48 minutes (NVAT).
3. Elevator Buckets: here is the main bottleneck in the whole process that will be always running on the maximum capacity and the whole cycle time is considered therefore as a VAT with zero NAVT.
4. Dosing: this work station is running at higher utilization levels, but it is noticeable the value adding of the dosing system, so the Cycle time of 10.28 Minuets is considered as VAT, while the waiting time of 2.02 Minuets is considered as NVAT.
5. Material Mixing: the cycle time of the mixer is accounted as VAT (11.28), while the waiting time while the mixer is empty and waiting for new patch is considered as NVAT = 1.02 minutes.
6. Mixed Material Discharge: in this workstation it is only a material transportation from location to other that's why it is all considered as NVAT of 2 minutes.

7. Mixed Material loading: in this workstation the whole cycle time in considered as VAT equalling to 10 minutes, while the excess capacity that is not used equalling 2.3 minutes as NVAT.

It is important to mention that all of these processes are running in series that's why the successor workstation can't start if the preceding workstation is done.

Table8 below summarizes these results, while the value added time and non-value added times are displayed as a percentage for each workstation in the below figure23.

Table 8: Workstations VAT and NVAT.

WorkStation	Capacity	NVAT	VAT	CT (minuets)
Aggregate Feeding	5 Feeders X 45 ton/hour each = 225 ton/hour	5.63	6.67	6.67
Collecting Conveyor	220 ton/hour	5.48	6.82	6.82
Elevator Buckets	122 ton/hour	0	12.3	12.3
Dosing	146 ton/hour	2.02	10.28	10.28
Mixing	133 ton/hour	1.02	11.28	11.28
Mix Discharge	-	2	0	-
Mix loading	150 ton/h	2.3	10	10

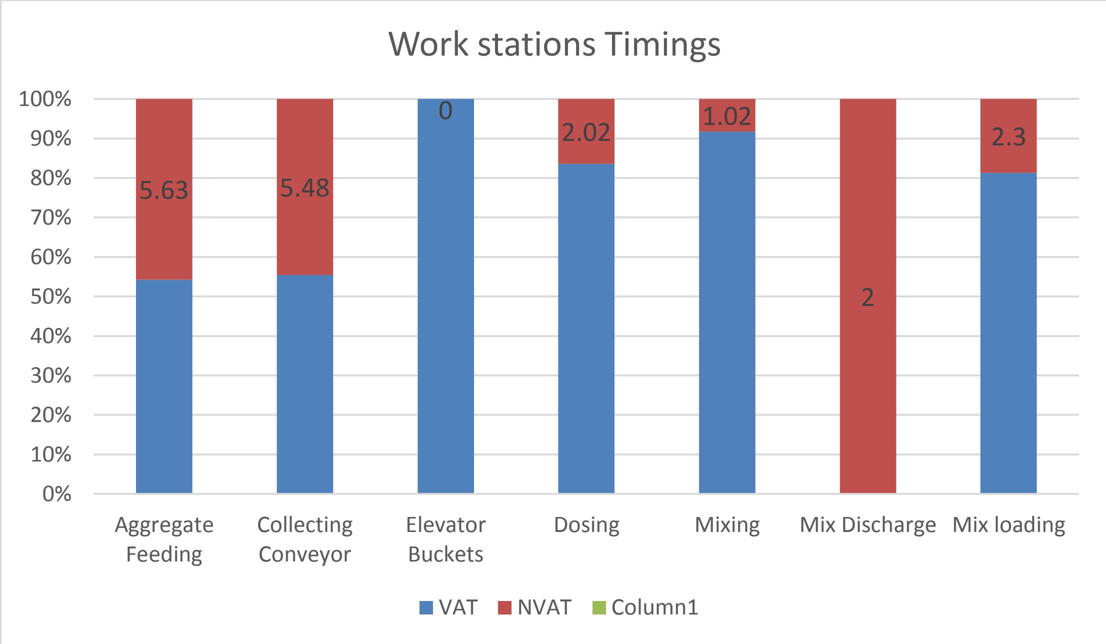

Figure 23: Workstations Timings.

Using the data collected earlier, the value stream mapping of the current state is defined accordingly, see figure24.

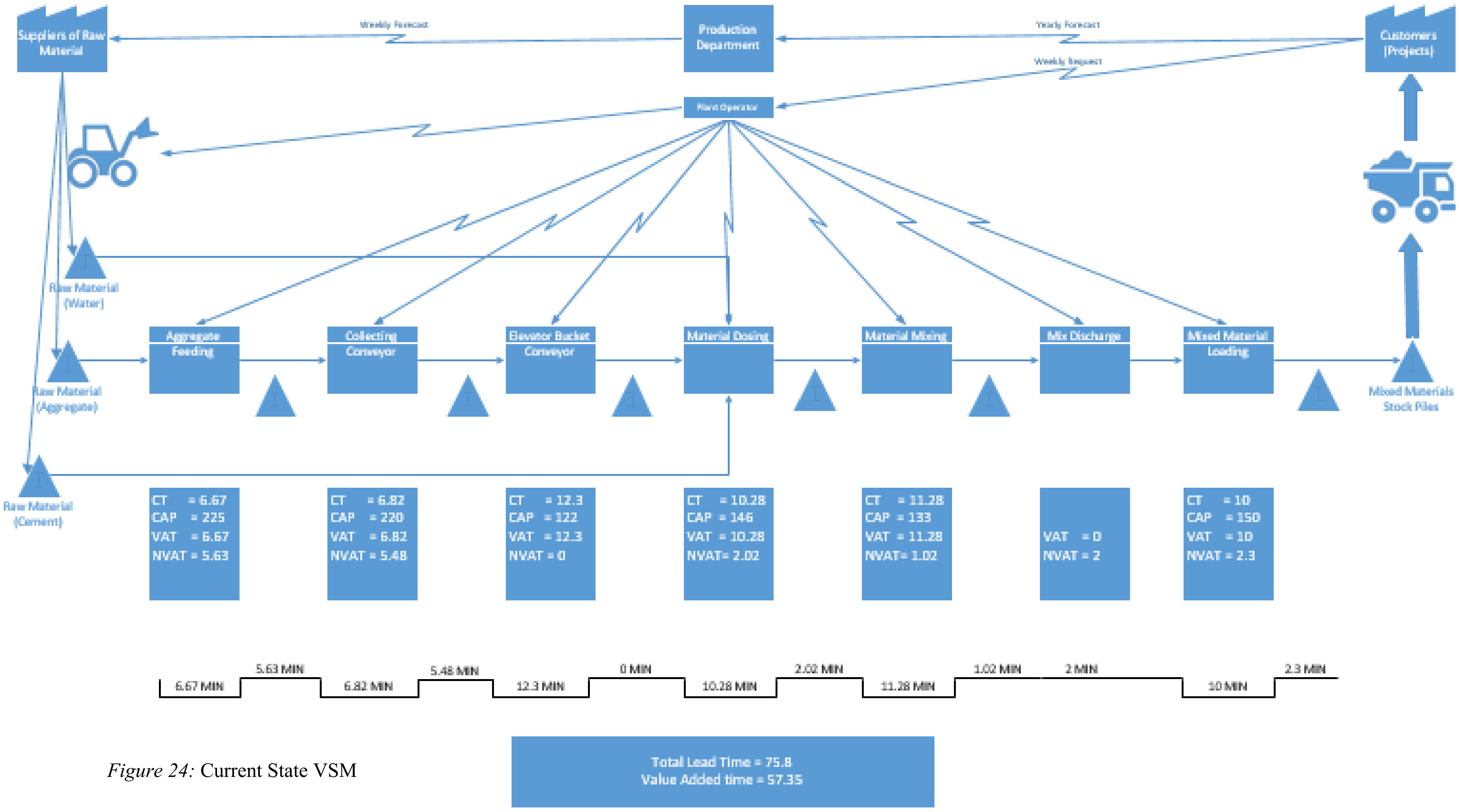

Figure 24: Current State VSM

The following chapter will discuss the demand of production forecast, which is used to calculate the Takt time and the desired capacity.

Chapter 4: Projected Demand Forecasting and Takt Time Calculation

In this chapter the future demand is projected based on the historical production data and the future demand. Then the takt time is calculated based on these data that is used in the next chapter to come up with the value stream map of the future state.

The projected demand includes the two parts of Demand Company is dealing with: the desired demand, and the demand of the new project required supply.

4.1 Historical production data for trend

The historical production data is collected from the company's records, Shown in table9. The information collected is quarterly production data starting from the 2^{nd} quarter 2014 up to the 2^{nd} quarter of year 2016. The production was done based on single shift (8 hrs of production + 2 hrs for maintenance and breaks), every month 26 working day is considered. The hourly production rate of the plant is then calculated resulting in (114 – 122) Tons/hour. It is worth mentioning that these production data is considered as a trend of serving the supply to various construction projects already in hand and the supply to the market.

Table 9: Historical Production Data.

	Period	Production (Tons)
1	Q2/2014	71198
2	Q3/2014	75059
3	Q4/2014	76299
4	Q1/2015	72714
5	Q2/2015	72083
6	Q3/2015	73308
7	Q4/2015	72635

8	Q1/2016	72120
9	Q2/2016	75903

The planned demand assumes to have continuous demand that will follow the same trend, therefore the linear regression model will be used to predict the future requirements.

4.2 Linear regression for forecasting production demand

The collected production data is used in order to come up with "*Linear Regression Formula"* that is used to forecast the production for the coming periods, which will be the first component of the future demand.

The general use of the least square method is to come up with the formula that will follow the same pattern of historical data in order to predict the future data. It is trying to fit all data to one line that minimizes the sum of the squares of the difference between the original data and the resulting line.

The lease squares equation for linear regression is

$$Y = \alpha + bt$$

Where:

Y = Dependent variable computed by the equation.

y = the actual dependent variable data point.

α = Y intercept.

b = Slope of the line.

t = Time period.

If a straight line is drawn through the general area of the difference between the point and the line is y- Y. The sum of the squares of the differences between the historical data point and the line points is

$$(y_1 - Y_1)^2 + (y_2 - Y_2)^2 \cdots + (y_{12} - Y_{25})^2$$

The drawn line which better accommodate the data is the one that minimizes this total.

In the least squares method, the equations for α and b are

$$\alpha = \bar{Y} - b * \bar{t}$$

$$b = \frac{\sum ty \ - n\bar{t}.\bar{y}}{\sum t^2 - n\bar{t}^2}$$

Where:

α = Y intercept

b = slope of the line

$\bar{y}$ = Average of all y's

$\bar{t}$ = Average of all t's

t = t value at each data point

y = y value at each data point

n = Number of data point

Y = value of the dependent variable computed with the regression equation.

INTERCEPT and *Slope* functions in Microsoft excel is used to come up with α and b values explained earlier.

α = 73207.47

b = 54.48333

Simultaneously we will forecast for the coming periods, strictly based on the equation, "Y= α + b.t " forecasts the periods from 3rd Quarter-2016 to 2nd Quarter-

2020 would be as in the following table 10 :

Table 10: Desired Forecasts.

Period	Time Period	Historical Production	Linear Regression
Q2-14	1	71,198	73,262
Q3-14	2	75,059	73,316
Q4-14	3	76,299	73,371
Q1-15	4	72,714	73,425
Q2-15	5	72,083	73,480
Q3-15	6	73,308	73,534
Q4-15	7	72,635	73,589
Q1-16	8	72,120	73,643
Q2-16	9	75,903	73,698
Q3-16	10		73,752
Q4-16	11		73,807
Q1-17	12		73,861
Q2-17	13		73,916
Q3-17	14		73,970
Q4-17	15		74,025
Q1-18	16		74,079
Q2-18	17		74,134
Q3-18	18		74,188
Q4-18	19		74,243
Q1-19	20		74,297
Q2-19	21		74,352
Q3-19	22		74,406
Q4-19	23		74,461
Q1-20	24		74,515
Q2-20	25		74,570

Figure25 below illustrate those data compared with the historical data:

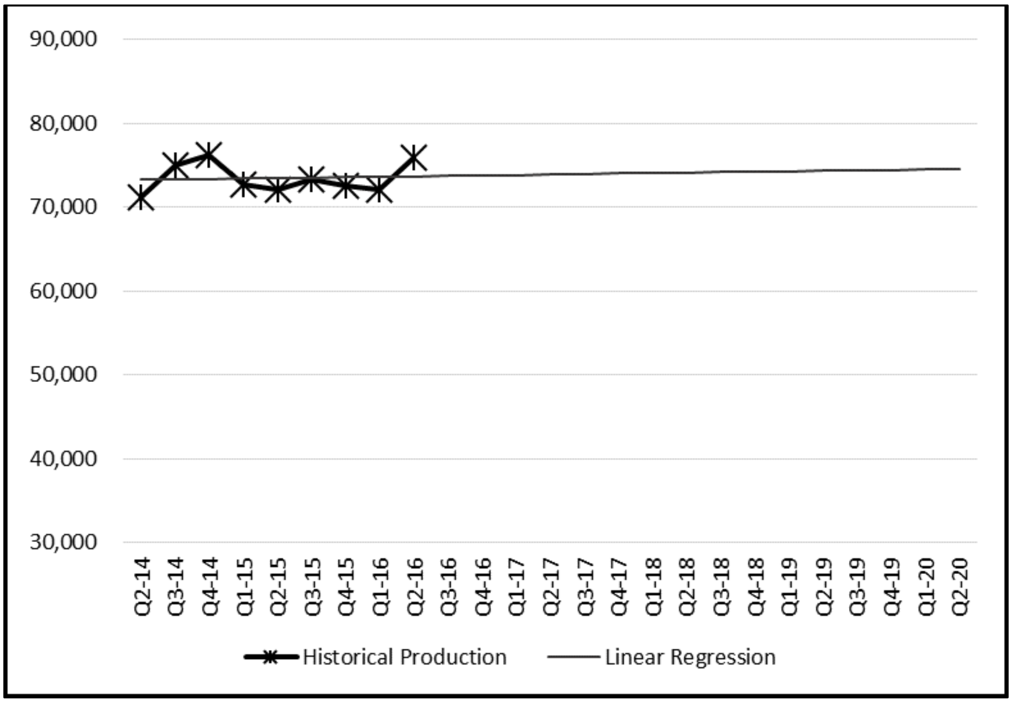

Figure 25 : Forcasted data.

As noted earlier, the results obtained follows the same trend.

4.3 Expected additional demand of projects

The second portion of the demand to be forecasted is the one coming from the new project schedule of quantities, and in this case simply the data is been obtained from the project data that shows the quantity needed over project period. The execution of the project is scheduled to start on the 3rd quarter of year 2017 ending on 1st quarter of year 2020. See figure26 below.

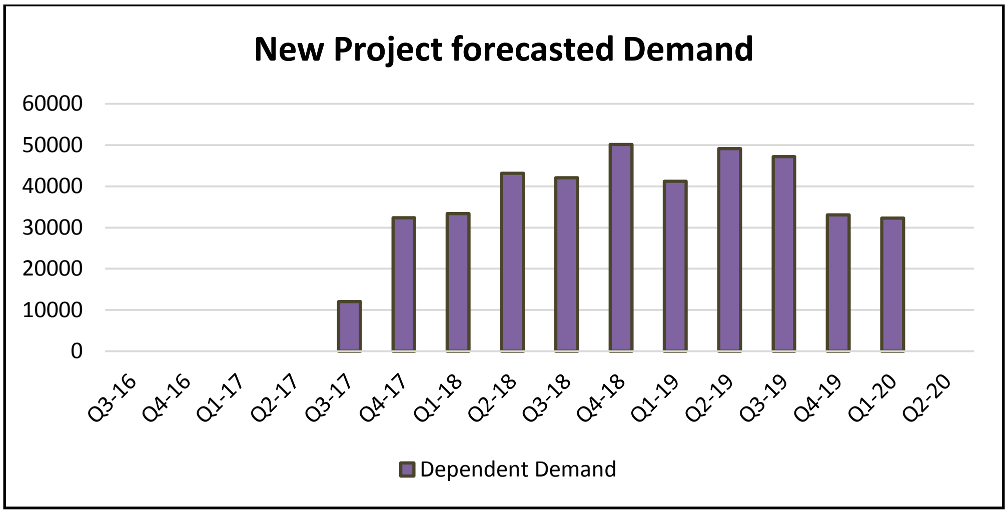

Figure 26 : Demand Resulting from Getting New Project.

These data are used to plan the total desired demand and to define the takt time as well the targeted plant capacity.

4.4 Total Production planned:

The resulting sum of both demand forecasts is tabulated below table 11.

Table 6: Total Forecasted Demand.

Period	Time Period	Trend Demand	Expected Additional Project Demand	Total Forecasted Demand
Q3-16	10	73,752		
Q4-16	11	73,807		
Q1-17	12	73,861		
Q2-17	13	73,916		
Q3-17	14	73,970	12,005	85,975
Q4-17	15	74,025	32,345	106,370
Q1-18	16	74,079	33,410	107,489
Q2-18	17	74,134	43,128	117,262
Q3-18	18	74,188	42,107	116,295
Q4-18	19	74,243	50,110	124,353
Q1-19	20	74,297	41,230	115,527
Q2-19	21	74,352	49,100	123,452
Q3-19	22	74,406	47,200	121,606
Q4-19	23	74,461	33,050	107,511
Q1-20	24	74,515	32,304	106,819
Q2-20	25	74,570	-	74,570

From those data we see the production planned over the time period using all data collected, figure27 below shows the total forecasted demand noting the peak value occurs in 4th Quarter 2018 that is used to calculate the planned capacity and takt time required:

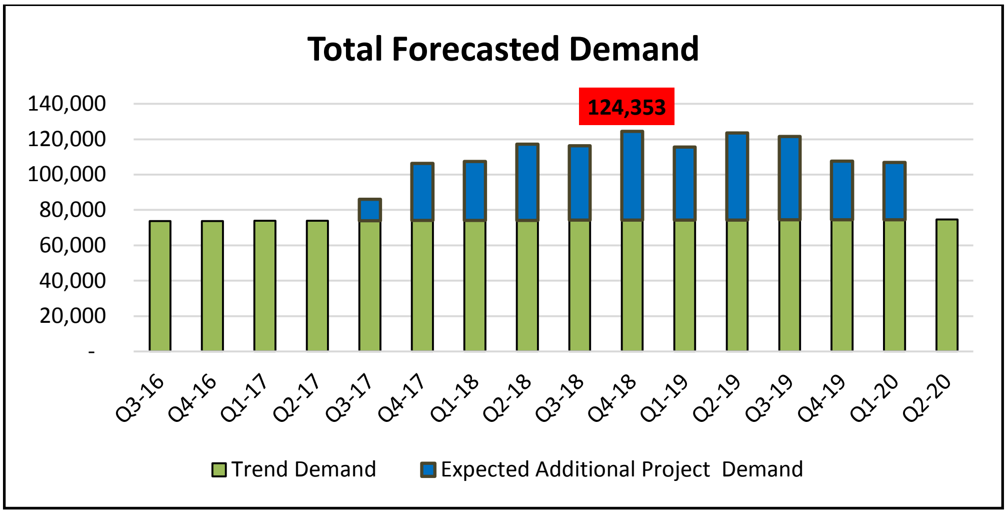

Figure 27: Total Forecasted Demand.

4.5 Define Targeted Capacity:

The peak value of “124,353 “Tons @ Q4, 2018 is used for the calculations, so the formula below is applied:

$$Targeted\ Capacity = \frac{Production\ Target}{Available\ Time}$$

Assuming 8 working hours daily, 26 days per month and for 3 months.

So $Hourly\ Targeted\ Capacity = \frac{124{,}353\ Tons}{3*26*8} = 199.3\ Tons\ /Hour$

Considering some cushion Capacity (10%) to absorb the chance of break down and Demand variations, then the targeted capacity will be **219.3 Tons/hour.**

4.5 Define *Takt Time*:

Considering a delivery of one truck (25 tons) to calculate *Takt time*.

$$Takt\ time = \frac{Cycle\ Quantity}{Hourly\ Targeted\ Capacity} * 60\ Minutes$$

$$Takt\ time = \frac{25\ tons}{219.3\ t/h} * 60\ Minutes = 6.84\ Minutes$$

After the takt time is calculated, next chapter will discuss the future state of the value stream and the suggested improvements.

Chapter 5: Analysis of Current State and Suggested Improvements

The value stream of the current state is defined earlier. The takt time and the desired capacity is defined also earlier. In this chapter the process parameters obtained will be analyzed considering the calculated takt time and desired capacity. The suggested improvement is discussed in order to come up with the future state value stream mapping.

5.1 Utilization levels

The capacity of the current workstations shows capacity mismatch, which results in high variation in the cycle times and the utilization levels of the work stations as we can see in Table 12. Knowing that the utilization is calculated based on the overall process capacity with is the bottleneck capacity (The capacity of elevator buckets 122 Ton/hour). And calculated based on the following equation:

$$Utilization\ \% = \frac{Process\ Capacity}{Workstation\ capacity}$$

Table 7: Utilization Levels.

WorkStation	Capacity	Utilization
Aggregate Feeding	225 ton/hour	54.2%
Collecting Conveyor	220 ton/hour	55.5%
Elevator Buckets	122 ton/hour	100%
Dosing	146 ton/hour	83.6%
Mixing	133 ton/hour	91.7%
Mix loading	150 ton/h	81.3%

So we can see that the process is running at very low utilization levels, see for instant the utilization of the aggregate feeders and collecting conveyors.

Other term we can look into is the implied utilization if we look to the desired capacity calculated earlier which is equal to 219.3 tons/hour.

So

$$Implied\ Utilization\ \% = \frac{Desired\ Capacity}{Workstation\ capacity}$$

And it is summarized in the following table12.

Table 8: Implied Utilizations.

WorkStation	Capacity	Implied Utilization
Aggregate Feeding	225 ton/hour	97.5%
Collecting Conveyor	220 ton/hour	99.7%
Elevator Buckets	122 ton/hour	179.8%
Dosing	146 ton/hour	150.2%
Mixing	133 ton/hour	164.9%
Mix loading	150 ton/h	146.2%

It is clear that the first two work station is having enough capacity that can accommodate the planned capacity while it is needed to work on the other workstations in order to upgrade their capacities in order to be able to increase the overall process capacity in order to reach the desired capacity, see figures 28 and figure 29 that highlights the suggested workstations for improvement.

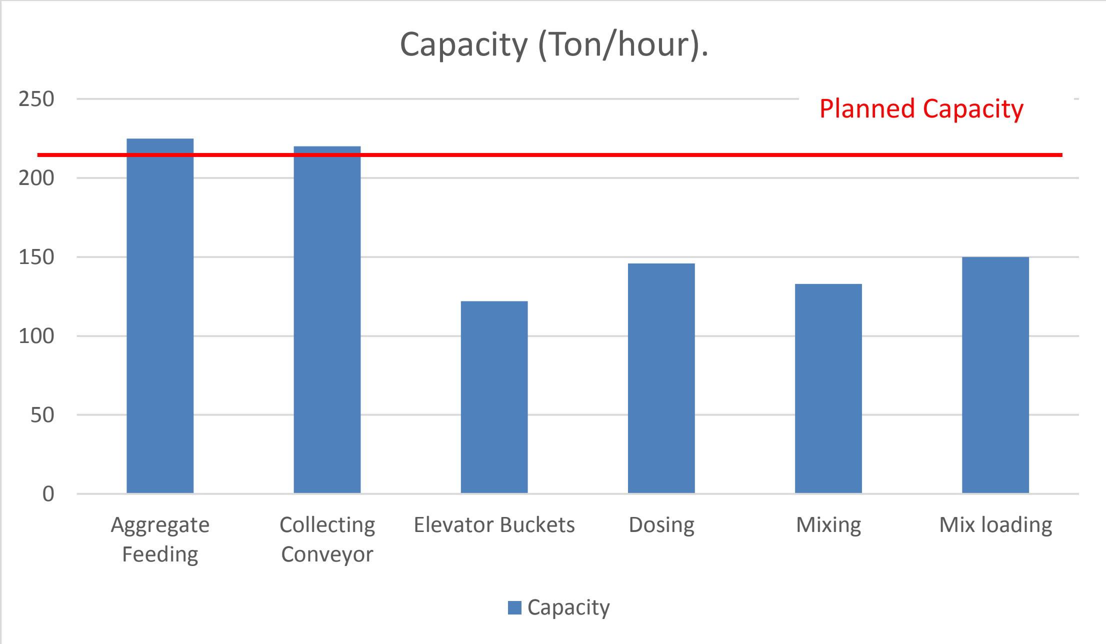

Figure 28: Workstations Capacity with Planned Capacity.

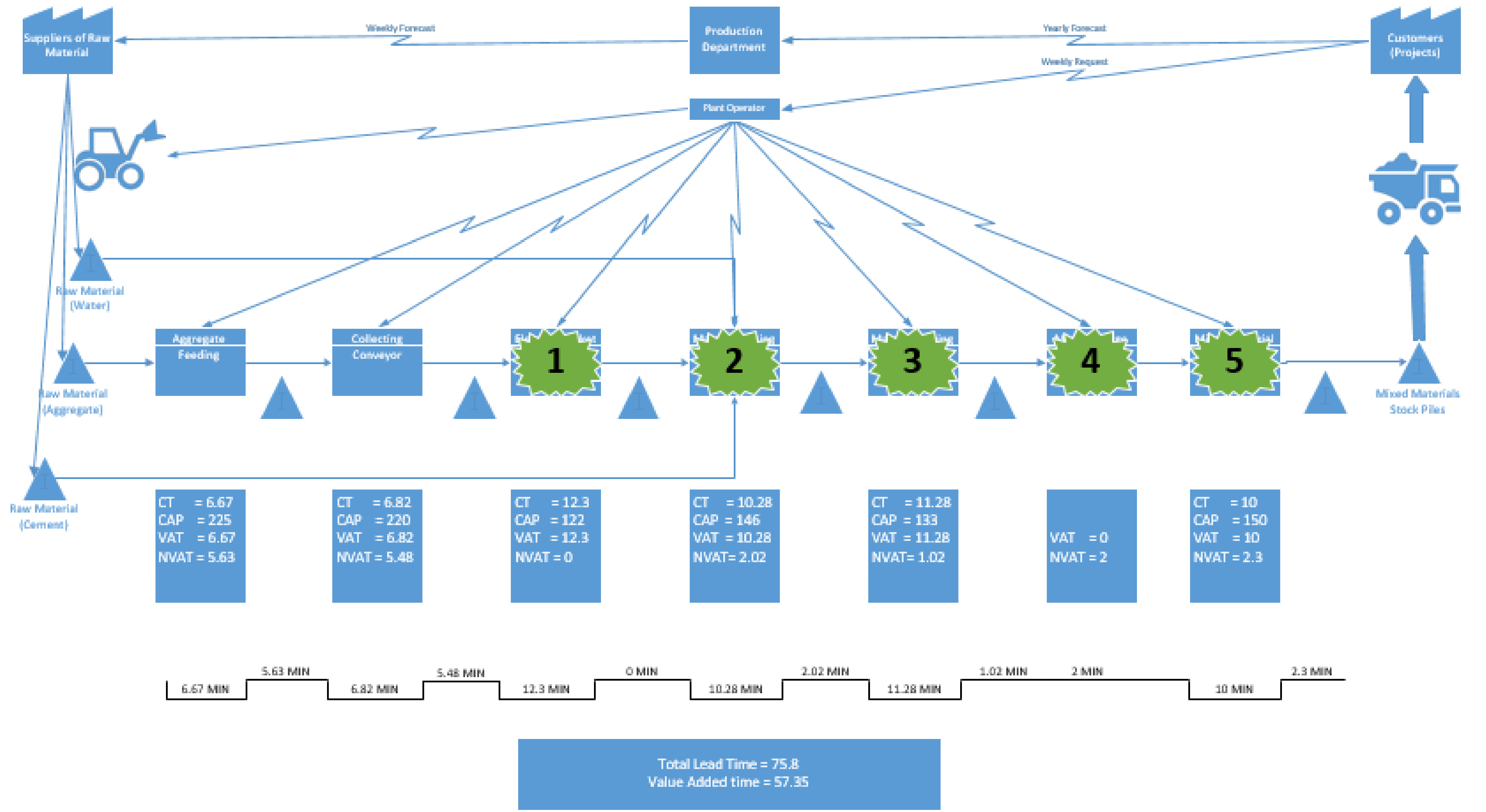

Figure 29: Areas of Improvements.

5.2 Suggested Improvements

Here below we will discuss the suggested improvements, in order to meet the planned capacity, so we will discuss each one of them one by one as follows:

1. *Elevator Buckets*: this work station is the process bottleneck is it is having the least capacity compared to other workstations, and it is forcing all other workstations to wait as a result of that.

   Using the current system of the elevator buckets is limited in term of capacity and it is very old which results in spare parts availability problem, while belt conveyor is very simple system that can replace easily the current one with minor cost implications compared to increasing the motor and buckets capacity of the current elevator. It is also proved system that is already used in the collecting conveyor (capacity 220 tons/ hour).

   So it is suggested to change it with identical belt conveyor similar to the one installed for the collecting belt conveyor as that will increase the capacity to 220 tons/hour.

2. *Dosing system*: it is observed that the time required for aggregate charging to the weight scale is quite high due to the weighing gate size, so with minor modification in the opening of the weighing gate the material weighing speed can rapidly improve. While the discharge time is reasonably acceptable.

The current gate opening is 20cm X 80cm that allows the flow of 170 tons/ hour, the area of the opening can be linked to the material flow by dividing these quantities by each other. And the proposed change can be calculated by linking this factor with the required flow of material.

$$Proposed\ Gate\ area = \frac{Required\ Aggregate\ Flow}{Current\ Aggregate\ Flow} * Current\ Gate\ Opening$$

$$Proposed\ Gate\ area = \frac{250\ Tons/hour}{170\ Tons/hour} * 20 * 80 = 2165\ cm\ square$$

And as we are limited with the hopper length with is 85 cm, so we keep the same gate length and we calculate the suggested gate width can be rounded to 30 cm.

With these changes the capacity will be increased to be 230 tons/hour.

3. *Material Mixing*: The mixer is currently driven by single motor (figure 30) that is connected to double shaft gearbox. And as per the supplier of this equipment it can be retrofitted to a double geared motor system (figure 31), with this upgrade it is only required to change the geared motors with having the same mixer without any change.

Figure 30: Single Geared Motor Mixer.

Figure 31: Double Geared Motor Mixer.

The cost of this upgrade is limited to the price of the new tow geared motors which is acceptable, and the capacity will be improved to almost double, as per the manufacturer the capacity of the new system will achieve 235 Tons/hour.

4. *Mixed Material discharge*: it is totally considered as non-value added activity, as it is only a material discharge from mixer to the loading mechanism, therefore it is suggested to increase the discharge cylinder to a bigger one, as a result the time required for opening/closing will be reduced by 15% because of the higher speed of the new proposed cylinder as per the manufacturer.
5. *Mixed material loading*: Currently tipper trucks is used to transfer the material to be stockpiled in order to be tested. It is possible to increase the number of tipper trucks to be used in order to accommodate the increased capacity but is will have a complications related to the traffic and management of the trucks and the drivers and the continuous movement under the plant. In order to avoid these complications it is

advised to use stockpiling conveyor (figure 32) that can transport the materials and stockpile it near to the plant.

Figure 32: Stockpiling Conveyor.

Even though the cost is considered out of the scope of this project, but is also noticeable that the use of this conveyor is more feasible than using 4 trucks (double to what is been used currently).

As per the manufacturer of this conveyor, it can handle easily the suggested capacity of 219 ton/hour. As the capacity of this conveyor is varying between 260 and 225 depends on the height of the stockpile constructed. So for our calculations of the future state we will consider the minimum which is 225 tons/hour.

5.3 Impact of suggested changes

The following table number 13 summarizes the capacity of the current state and the future state after considering the proposed improvements. And after calculating the future state cycle time as per below equation, noting that all of the calculation is done based on one load of material (25 tons).

$$Future\ State\ CT = \frac{load\ quantity}{Future\ State\ Capacity} * 60\ Minutes$$

Table 9: Current state And Future State Capacities.

WorkStation	Current State Capacity (t/h).	Current State CT (minute).	Future State Capacity (t/h).	Future State CT (minute).
Aggregate Feeding	225	6.67	225	6.67
Collecting Conveyor	220	6.82	220	6.82
Elevator Buckets	122	12.3	220	6.82
Dosing	146	10.28	230	6.52
Mixing	133	11.28	235	6.38
Mix Discharge	-	2	-	1.7
Mix loading	150	10	225	6.67

5.4 Future State Mapping

The value stream of the future state is defined based on the earlier calculated data. The takt time and future state cycle time and capacity is recorded as well. The value added and non-value added times are listed in the below table 14.

Table 10: Workstations Timings for Current State and Future State.

WorkStation	Future State Capacity (t/h).	Future State CT (minute).	VAT (minutes).	NVAT (minute).
Aggregate Feeding	225	6.67	6.67	0.15
Collecting Conveyor	220	6.82	6.82	0
Elevator Buckets	220	6.82	6.82	0
Dosing	230	6.52	6.52	0.3
Mixing	235	6.38	6.38	0.44
Mix Discharge	-	1.7	-	1.7
Mix loading	225	6.67	6.67	0.15

The below figure 33 shows the future state value stream mapping as proposed.

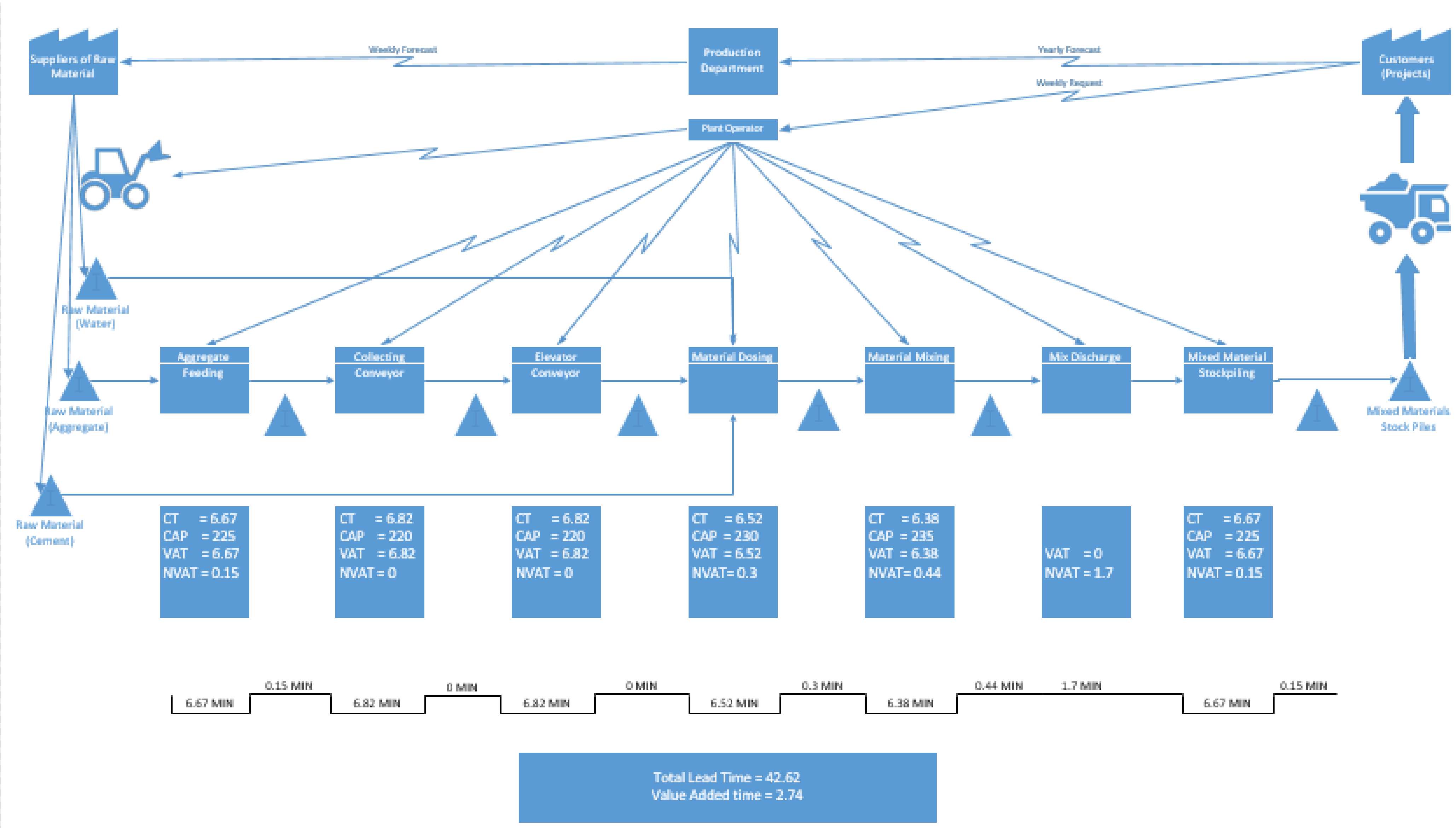

Figure 33: Suggested future state value stream mapping.

Chapter 6: Results Validation using Simulation

The value stream of the current state and the value stream of the future state was defined earlier in this report, while the resulting data is discussed in the next chapter. Given that the Value stream mapping is providing us with static view of the process and the resulting output needs to be verified in order to have the dynamic view of the process and to validate the results collected earlier

In this chapter the used simulation program is introduced, afterwards the current state model is built up using the parameters obtained earlier, the model is simulated to get the results. The results obtained from the simulation is compared to earlier calculated data. Then the parameters is updated as per the future state in order to come up with the future state model and the new model is simulated to come up with the results which is also compared with earlier data collected. Both resulting data is compared and discussed as well.

6.1 Simulation Program

Process Simulator 2016 - Free ® by ProModel Corporation, is used in this project to generate models and simulate them, see figure 34.

Figure 34: Process Simulator 2016 - Free ® by ProModel ®

Process simulator runs as add on under the environment of Microsoft ® Visio ® software, see figure 35.

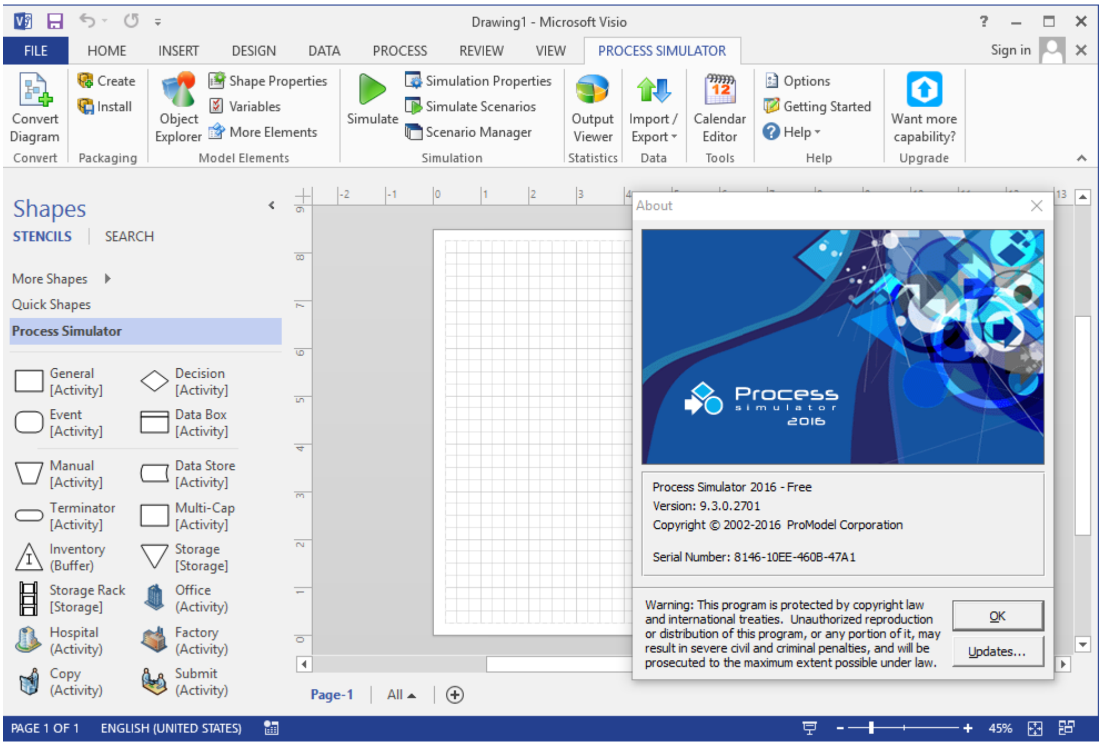

Figure 35: Simulator Main Window.

Process Simulator provides solutions for Capacity Planning and Throughput Analysis, Hospital Patient Flow, Lean Six Sigma / CI, Project Portfolio Planning, and Supply Chain and Logistics. It is used in the industries of Academic/Education, Aerospace and Defense Manufacturing, Government and Department of Defense, Healthcare, Manufacturing, Pharmaceutical, and Services industries as well.

In addition of availability of free version, it is selected due to the graphical interface, ease of use and possibility to generate graphical reports.

6.2 Current State Model

The flow chart of the current state is implemented in the simulation software, as per the mapping done based on site visits, See below figure 36. it is important to mention that cycle times has been converted to minuets per 1 ton of production in order to normalize the data in the simulation software, instead of having the cycle time per 25 tons (1 load) of product which is followed all over the project.

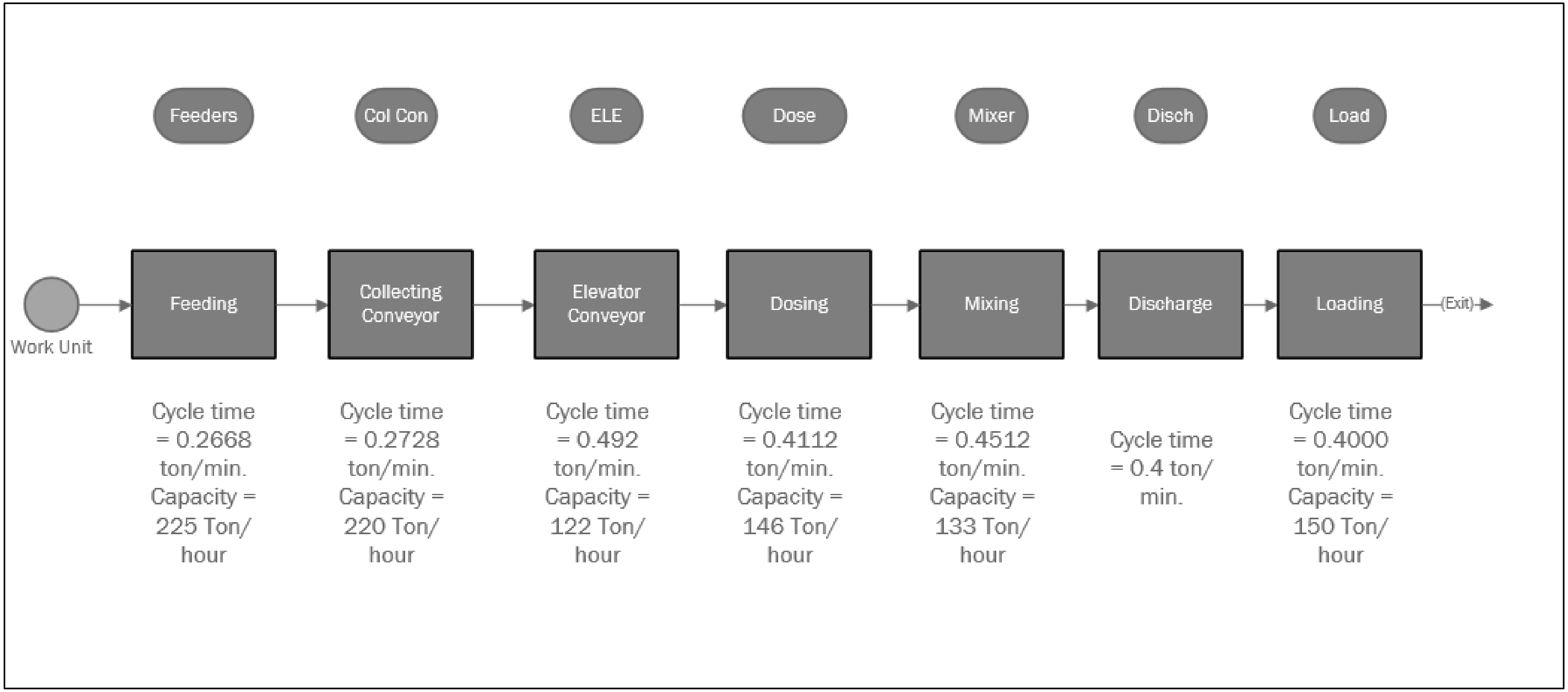

Figure 36: Current State Model.

Text captions were added in the figure to indicate stored parameters, as shown in previous figure, this model is run for 10 hours which is the working hours for 1 day, and the resulted data are listed in the following table 15.

- Total output quantity = 1215 working units (while each working unit represents 1 ton of material).
- Average time in operation = 2.69 minutes per 1 ton of production.

Table 11: Current State Model Simulation Results.

Scoreboard

Name	Total Exits	Average Time In Operation (Min)	Average Cost
Work Unit	1,215.00	2.69	0.00

- The Utilization level of the workstations as in the following figure 37.

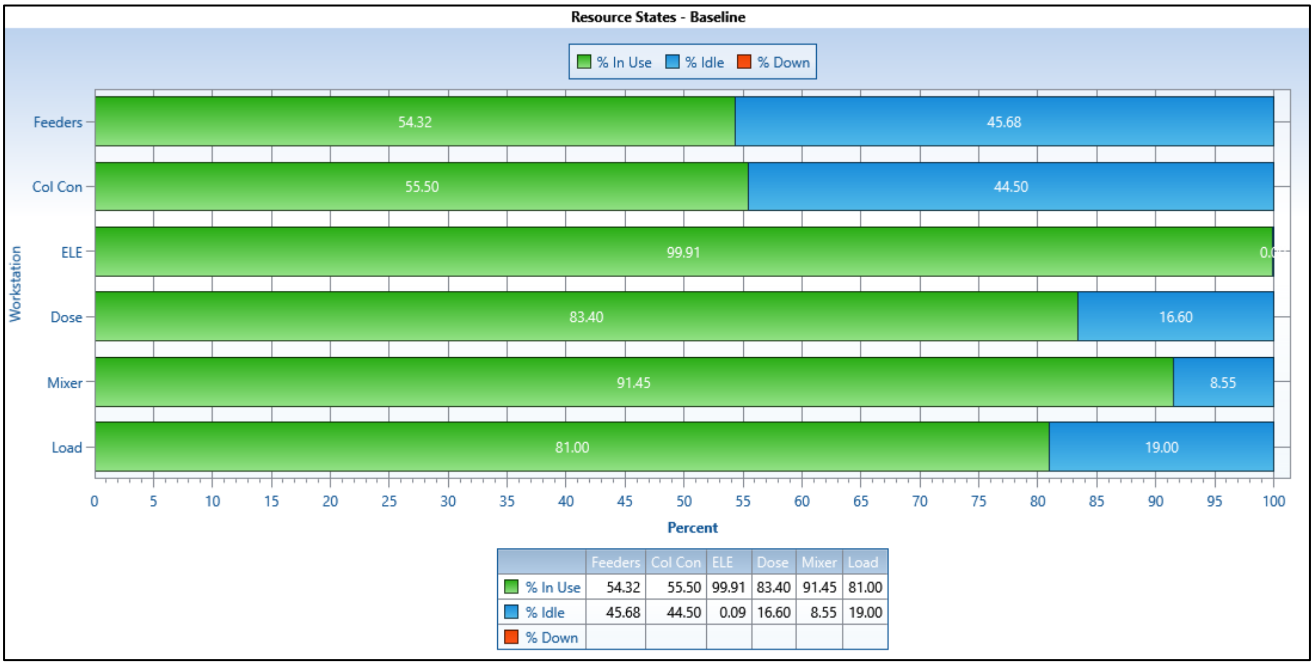

Figure 37: Utilization Levels.

Comparing these data resulted from the simulation with the ones resulted from the VSM calculations, it is concluded tables 16 below.

Table 12: Utilization Levels Comparison.

WorkStation	Utilization % (Simulation Based)	Utilization % (VSM Based)	Difference
Aggregate Feeding	54.32	54.2%	0.12
Collecting Conveyor	55.5	55.5%	0
Elevator Buckets	99.91	100%	0.09
Dosing	83.4	83.6%	0.2
Mixing	91.45	91.7%	0.25
Mix loading	81	81.3%	0.3

It is confirmed from these figures that the difference between is very minor between the data calculated earlier and the simulation results.

6.3 Future State Model

The flow chart of the future state is implemented in the simulation software, as per the mapping done earlier based on site visits, See below figure 38. Similar to the earlier model, the cycle times has been converted to minuets per 1 ton of production in order to normalize the data in the simulation software.

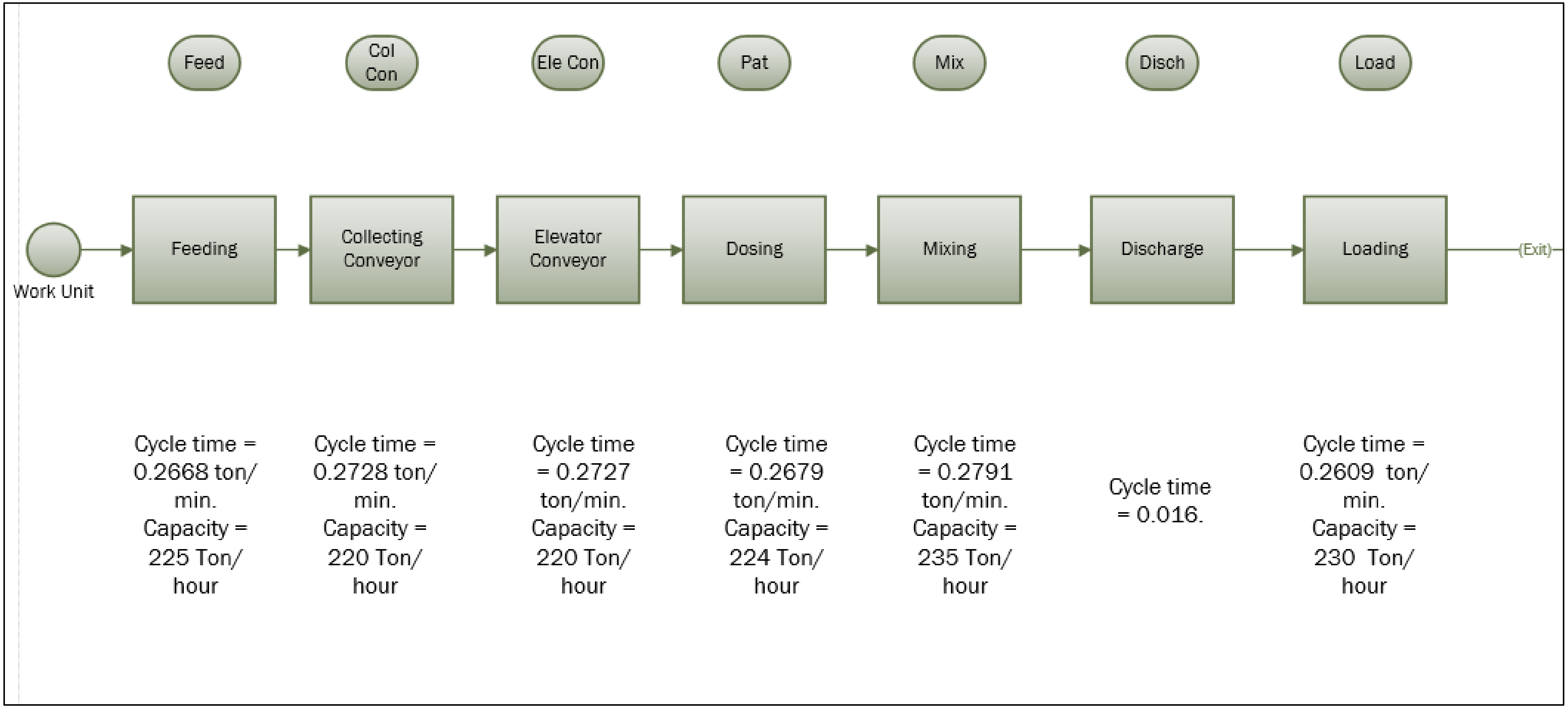

Figure 38: Future State Model.

The suggested improvements were integrated in the new model parameters by changing the cycle times of workstations 3,4,5,6, and 7 as below:

1. *Elevator Buckets* is transformed to an *elevator conveyor* with a cycle time of 6.82 minutes per 25 ton, which is converted to a minutes per ton been divided by 25, resulting Cycle time of 0.2727 minutes/ton.
2. *Dosing system*: the improved cycle time of 6.82 minutes / load was stored instead of the current state cycle time. Similarly it is divided by 25 to get the cycle time of 1 ton production (0.2679 minuets/ton) which is used in the model.
3. *Material mixing*: the earlier stored current state cycle time is changed to the suggested improved cycle time of 0.2791 minuets/ton.
4. *Mixed material discharge* improved cycle time of 0.016 minuets/ton is used in the future state model as suggested earlier.
5. Mixed material loading: the reduced cycle time of 0.2609 minuets/ton is inserted in the model replacing the earlier CT.

The resulted model is simulated for 10 hours (1 day production time) and the main results were as below:

- Total output quantity = 2145 working units (while each working unit represents 1 ton of material).
- Average time in operation = 1.64 minutes per 1 ton of production, See below Table 17 shows the simulation results.

Table 13: Future State Model Simulation Results.

Scoreboard

Name	Total Exits	Average Time In Operation (Min)	Average Cost
Work Unit	2,145.00	1.64	0.00

- The Utilization level of the workstations as in the following figure 39.

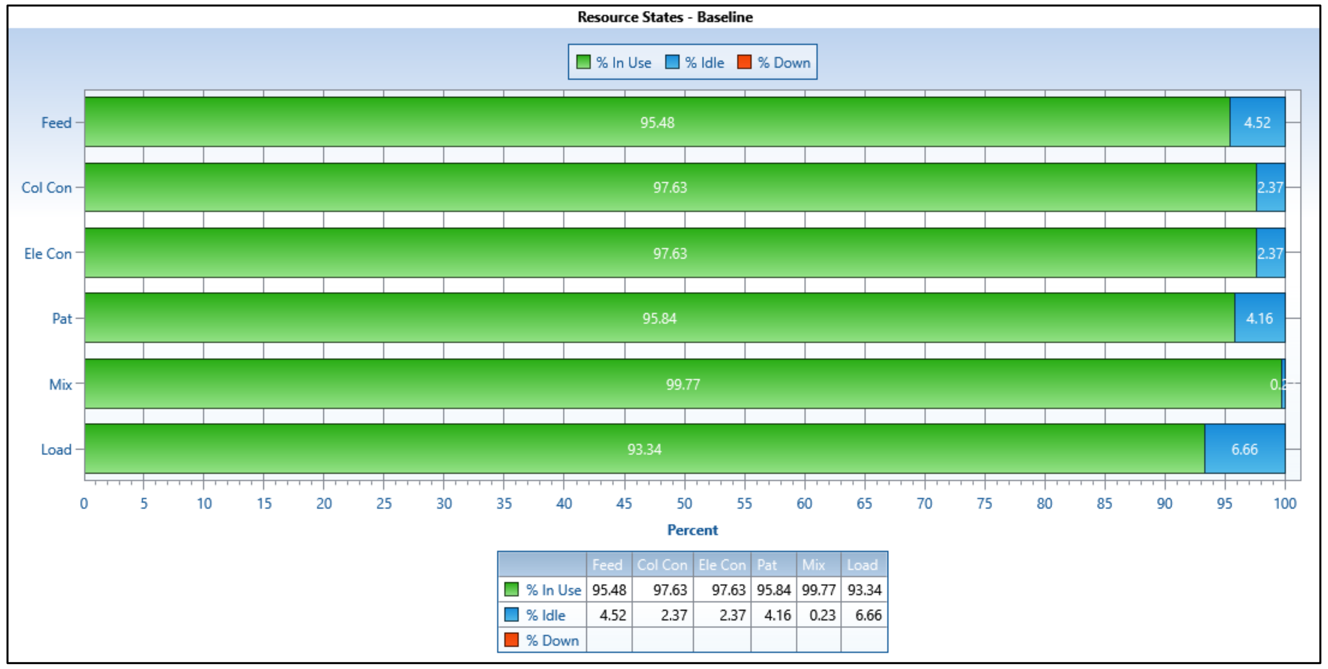

Figure 39: Utilization Levels of Future State.

Table number 18 below compares these data resulted from the simulation with the ones resulted from the VSM calculations of the future state.

Table 14: Future State Utilization Levels.

WorkStation	Utilization % (Simulation Based)	Utilization % (VSM Based)	Difference
Aggregate Feeding	95.48	97.78%	2.3%
Collecting Conveyor	97.63	100%	2.37%
Elevator Buckets	97.63	100%	2.37%
Dosing	95.84	95.65%	0.19%
Mixing	99.77	93.61%	6.16%
Mix loading	93.34	97.78%	4.44%

The difference in the utilization levels between the calculated and the simulation results are varying between (0.19% and 6.16%), which is due to the time required to empty the system after finishing the production, which was not considered in the VSM calculations and considered as negligible due to the high production volume.

Chapter 7: Results Discussion

The value stream of the current state and the value stream of the future state were defined earlier in this report. This chapter offers comprehensive comparison between present and future states of the process. It tries to capture the improvements in term of:

- Process Capacity.
- Utilization levels.
- Value added time.
- Non-Value added time.
- Production volumes.

7.1 Process capacity

It is confirmed the process capacity improvement comparing the current state and future state of the work stations and the entire process, see the below table number 19 that lists the resulted data.

Table 15: Workstations Capacity Improvements.

WorkStation	Current state Capacity (Ton/hour)	Future State Capacity (Ton/hour)	Capacity improvement (%)
Aggregate Feeding	225	225	0
Collecting Conveyor	220	220	0
Elevator Buckets	122	220	80.3
Dosing	146	230	57.5
Mixing	133	235	76.7
Mix loading	150	225	50

The maximum improvement percentage (80%) is recorded for the elevator conveyor as it is the bottleneck of the production and it requires changing the workstation from using the bucket elevator to a conveyor elevator belt. Then relatively high improvement in the capacity of the material mixing (76.7%) by suggesting minor upgrade of the running mechanism by using double geared motors instead of one, this is based on manufacturer recommendation that is proved (as per the manufacturer) in other similar plants.

The dosing workstation recorded 57.5% improvement in the capacity by suggesting minor modification in the weighing mechanism, while the mixed material loading recorded 50% improvement by introducing the usage of stockpiling conveyor belt.

These capacity improvements is illustrated in the following figures that compares the current state capacities with the future state ones (figure 40), and comparing the improvement percentages (figure 41).

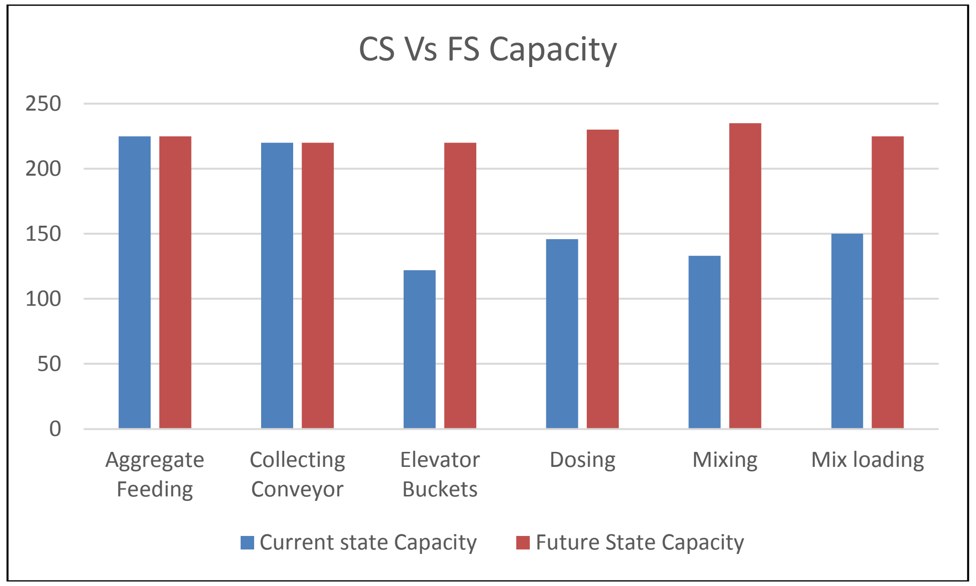

Figure 40: Current State and Future State Workstations Capacity.

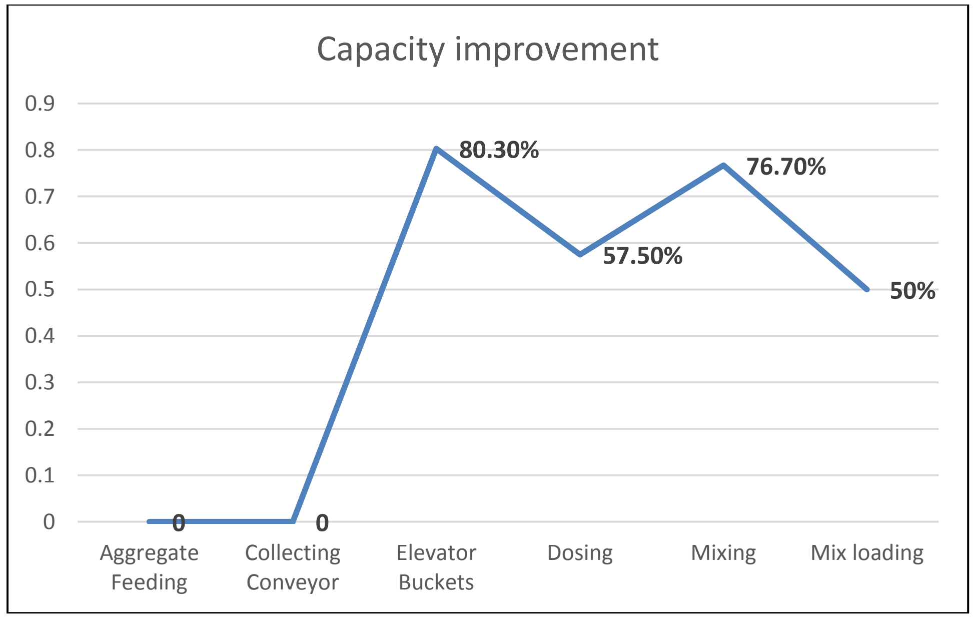

Figure 41: Workstations Capacity Improvements.

It is recorded that the process capacity is improved from 122 tons/hour to 220 tons/hour with percentage increment of 80.2%.

This was achieved not only by improving the bottleneck capacity but also by improving the other workstations capacities, as if we deal only with the bottleneck workstation then we will end up with moving only the bottleneck to other workstation (in our case was the material mixing with 133 tons/hour capacity), and from this point we see how important s to look at the overall process and the use of powerful tool as of the value stream mapping. That allow us to have the overall process improvement instead of having moving bottleneck problem.

7.2 Workstations Utilization

The utilization levels of the workstations was improved as a result of applying the value stream mapping, the following table number 20 lists up the utilization levels for both the current state and future state of all workstations.

Table 16: Workstations Utilization Levels.

WorkStation	Current State Utilization	Future Sate Utilization	Improvement Percentage
Aggregate Feeding	54.20%	98%	80%
Collecting Conveyor	55.50%	100%	80%
Elevator Buckets	100%	100%	0%
Dosing	83.60%	96%	14%
Mixing	91.70%	94%	2%
Mix loading	81.30%	98%	20%

It is noted that the utilization levels is improved rapidly for the first tow workstations (Aggregate feeding and collecting conveyor), as it was earlier running at very low level of utilization (around 55% for both). While it is improved by 20% and 14% for the mixed material loading and the dosing of the aggregate respectively. For the material mixing 2% improvement is recorded and the elevator conveyors remains at full utilization level after the increase in the capacity.

The collecting conveyor and the elevator conveyor is running on full utilization levels (100%) that means that the process is running as per their capacity levels.

All workstations will be running on very high utilization levels (94% to 100%) which indicates the capacity balancing in the process as an overall, while it is important to note that 10% cushion was considered during the calculations that will absorb any expected demand variation or down time required during the starting which was neglected due to high production volume compared to the first patch time. In other words the utilization levels will be around the level of 90% with the designed demand levels and case assumptions made earlier.

The following figure number 42 shows bar chart for the utilization levels of the current state and the future state of the process.

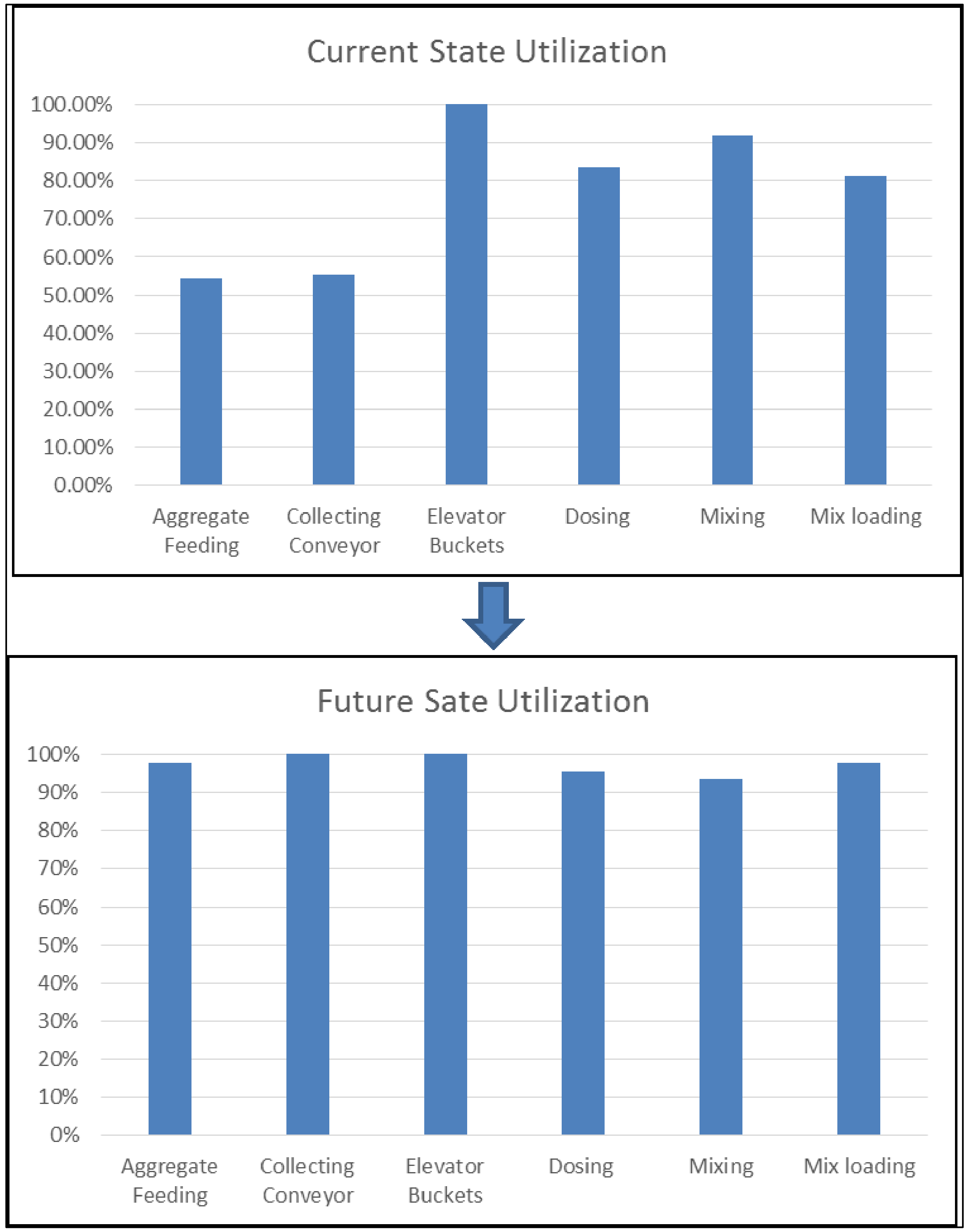

Figure 42: Current State and Future State Utilization Levels.

7.3 Workstations Cycle Time

Value stream mapping is proved tools for cycle time reduction, and in the project it is noted the rapid improvement in the cycle times of each workstation, below table 21 lists up the cycle times of the all workstations before and after the application of value stream mapping and the improvement percentage.

Table 17: Workstations Cycle Time Improvements.

WorkStation	Current State CT (Minute).	Future State CT (Minute).	Improvement Percentage
Aggregate Feeding	6.67	6.67	0.0%
Collecting Conveyor	6.82	6.82	0.0%
Elevator Buckets	12.3	6.82	44.6%
Dosing	10.28	6.52	36.6%
Mixing	11.28	6.38	43.4%
Mix loading	10	6.67	33.3%

The Cycle time of first tow workstation has remain without any change, while repaid reduction is reported in all other workstations (33% to 45%), while the balancing in the production line is notified in the future state cycle timing of all workstations as all f them is very near to the defined Takt time (6.84 Minutes). Below figure 43 shows the future state cycle time and the Takt time.

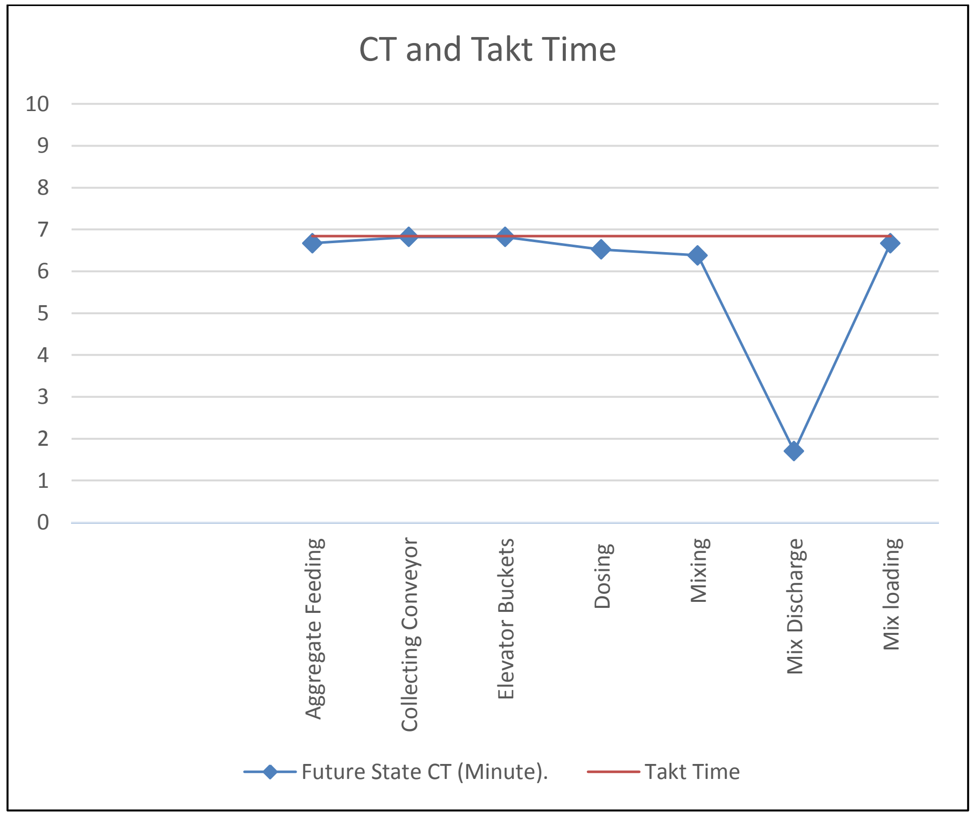

Figure 43: Workstations CT and Takt Time.

The following figure 44 shows the reduction in the cycle time in both the current state and future state value stream.

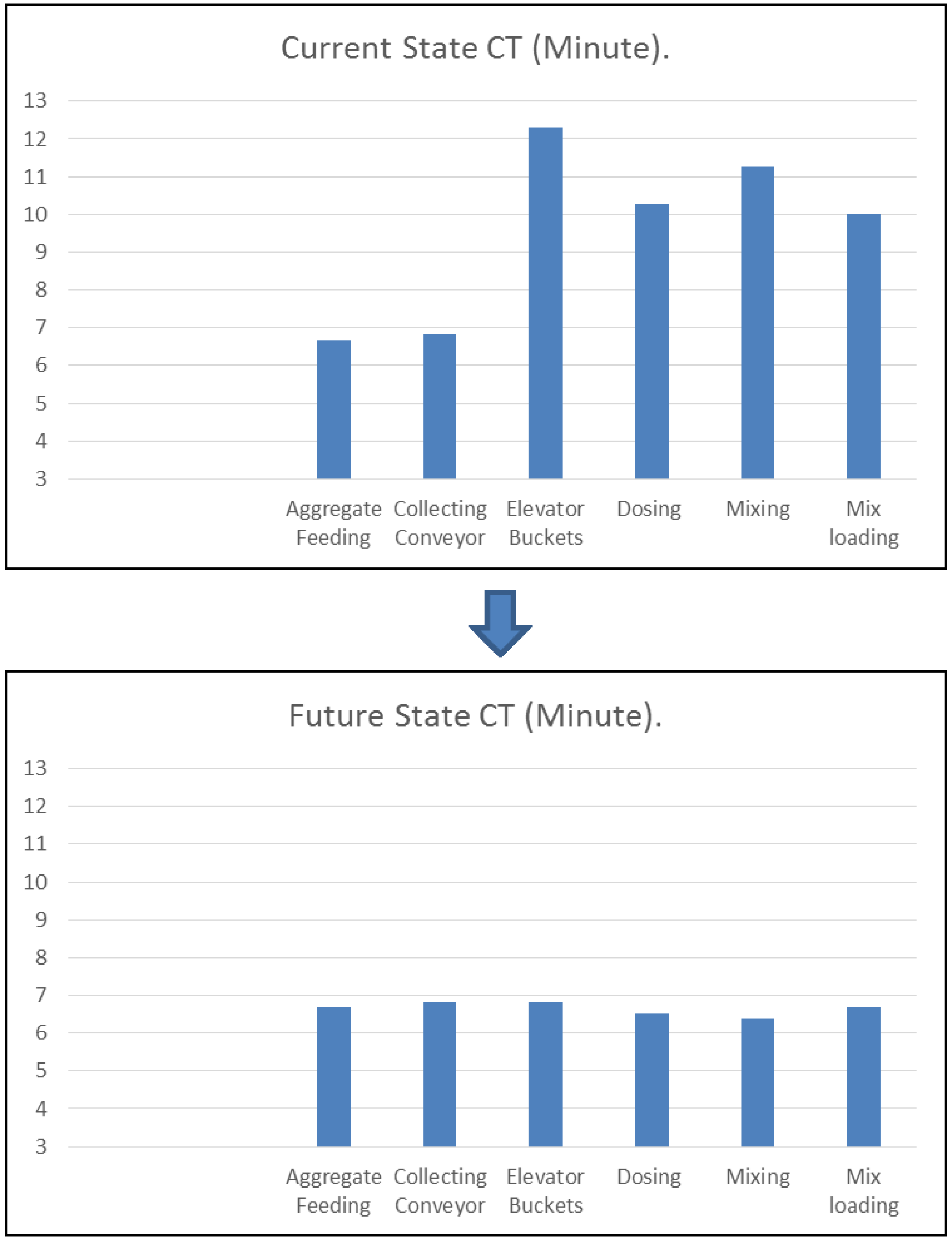

Figure 44: Cycle Time Reduction.

7.4 Value Added Time

Improvement in the Value added time of most of the work station is reported comparing the current state and the future state of the value stream. See table 22 below.

Table 18: Workstations VAT Improvement.

WorkStation	Current State VAT (Minutes).	Future State VAT (Minutes).	Improvement Percentage.
Aggregate Feeding	6.67	6.67	0%
Collecting Conveyor	6.82	6.82	0%
Elevator Buckets	12.3	6.82	45%
Dosing	10.28	6.52	37%
Mixing	11.28	6.38	43%

In the below figure number 45 the value added timings are drawn for all the workstations for the current and future state value stream.

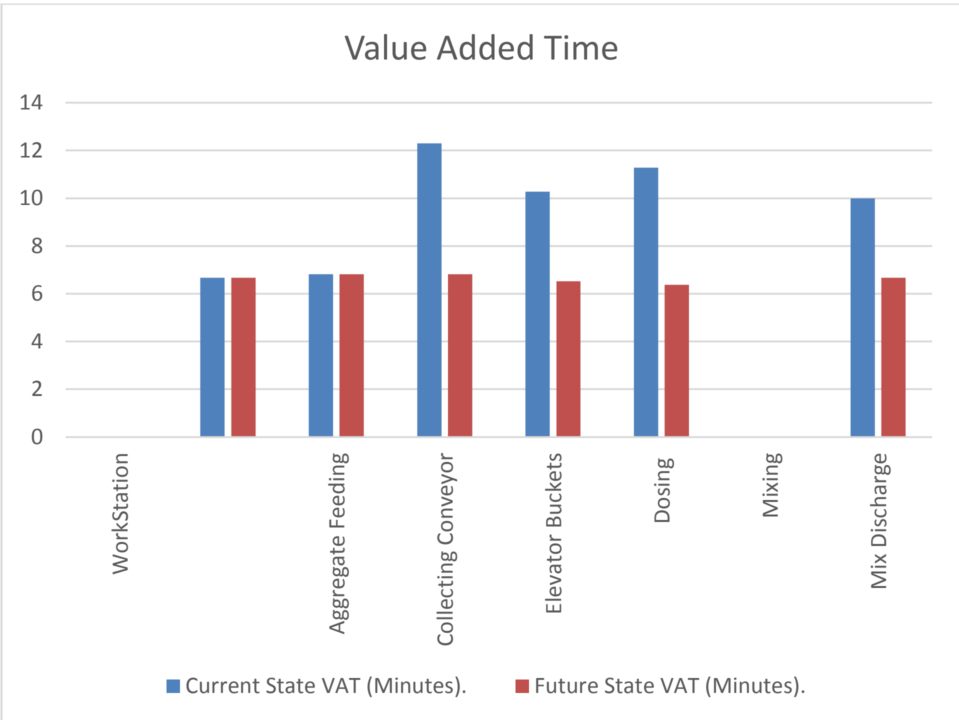

Figure 45: VAT Improvement.

7.5 Non-Value Added Time

Reduction in the Non-Value added time of all work station is reported comparing the current state and the future state of the value stream. See table number 23 below.

Table 19: NVAT Reduction.

WorkStation	Current State NVAT (Minutes).	Future State NVAT (Minutes).	Reduction Percentage.
Aggregate Feeding	5.63	0.15	97%
Collecting Conveyor	5.48	0	100%
Elevator Buckets	0	0	0%
Dosing	2.02	0.3	85%
Mixing	1.02	0.44	57%
Mix Discharge	2	1.7	15%
Mix loading	2.3	0.15	93%

The reduction percentages are rapidly high due to the waiting time removed by increasing the capacity, so it is noticeable the elimination of the NVAT of the collecting conveyor, while the reduction percentages of other workstations varies from 15% for the mixed material discharge and 97% for the aggregate feeding, the below bar chart 46 shows the earlier NVAD of the current state and the proposed future state NVAT.

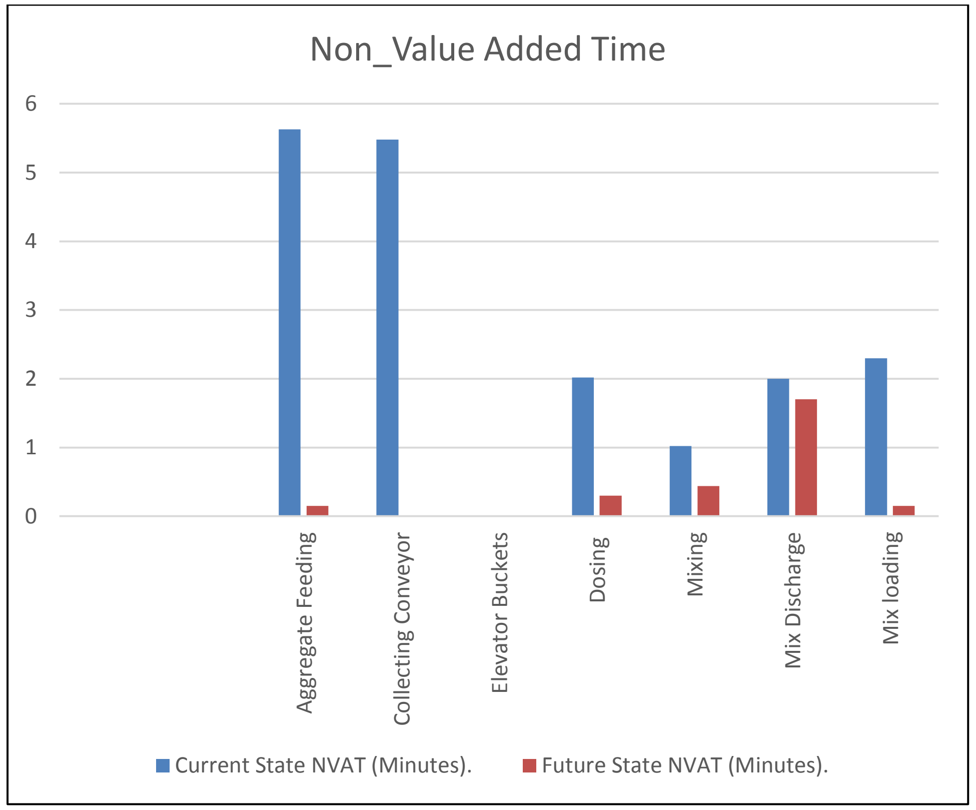

Figure 46: NVAT Reduction.

Chapter 8: Recommendations, Future work, and study limitations.

In line with the project objectives said earlier, this chapter summarizes recommendations and the conclusions of this project. It also concludes by mentioning how this research project can be extended in future to add further value. Ending by listing the limitations of this study.

8.1 Conclusions and Recommendations

This Project is a serious attempt to address the application of value stream mapping to a real life problem based on case study, it analyses the capacity improvement possibility and the cycle time reduction opportunity that will results is high benefits to the company.

It shows that a chance of improvement is there and valid by applying a lean production tool of value stream mapping, in order to evaluate the whole stream of the process so it can give wide view of the process resulting in providing a set improvements suggested that will increase the whole process capacity instead of moving the bottleneck from a workstation to other one.

The workstations with higher cycle time that the takt time was identified and for these workstation appropriate actions are suggested to reduce their cycle times, as results the cycle time of the process is reduced from 12.3 minutes per load to 6.82 minutes per load.

As a result also it is recorded that the plant production rate was increased from 122 ton/hour to 220 tons/hour.

In order to have these implemented, the following set of actions is suggested to be applied on the plant:

1. Replace the current system of the Elevator Buckets workstation to a conveyor belt system, this enables provides the enough capacity required and allow the cycle time of this work station to meet the takt time calculated.
2. To increase the capacity of the Dosing system it is advised to increase the gate opening of the aggregate weighing, this will allow the supply of enough material that will lead to meeting both the planned capacity and cycle time of this workstation.

3. Double geared-motor system for the material mixer is suggested in order to increase the available capacity at this workstation,
4. Reduction of material discharge time is possible by changing the discharge cylinder to a bigger one, 15% reduction in the cycle time is achievable by doing so.
5. Make use of stockpiling conveyor at the discharge point of the plant, instead of the current practice of trucking the material, this will allow meeting both capacity needs and cycle time of the process.

It is verified by the simulation that the application of these suggested improvements will results in meeting the production demand and the capacity required.

8.2 Future Work

The work done in this project is limited to a case study in the production environment, and could be extended in the future in order to include the whole supply chain of the process. It results in set of technical suggestions for the capacity improvements that is to be applied on the plant. Despite this technical focus of the case and the associated limitations of the findings, it is also possible to improve this work by considering the quality impact of this improvements and the cost impact of applying those improvements.

8.3 Project Limitations

This project evaluates the capacity improvement and the cycle time reduction in the stabilizing plant, while it was limited in term of the followings:

- The project focused only on the stabilizing plant only, and other stages influencing capacity within this company were not considered.
- The findings are based only on this plant of this company, the conformance with other stabilizing plants can't be considered.
- The cost implications was under placed in the evaluation. While it is valuable to mention that implementing the suggested improvements in this project will enable the company to use the current plant for satisfying their demand without the need of buying a new additional plant, which is more cost saving.
- The manpower aspects was not considered.

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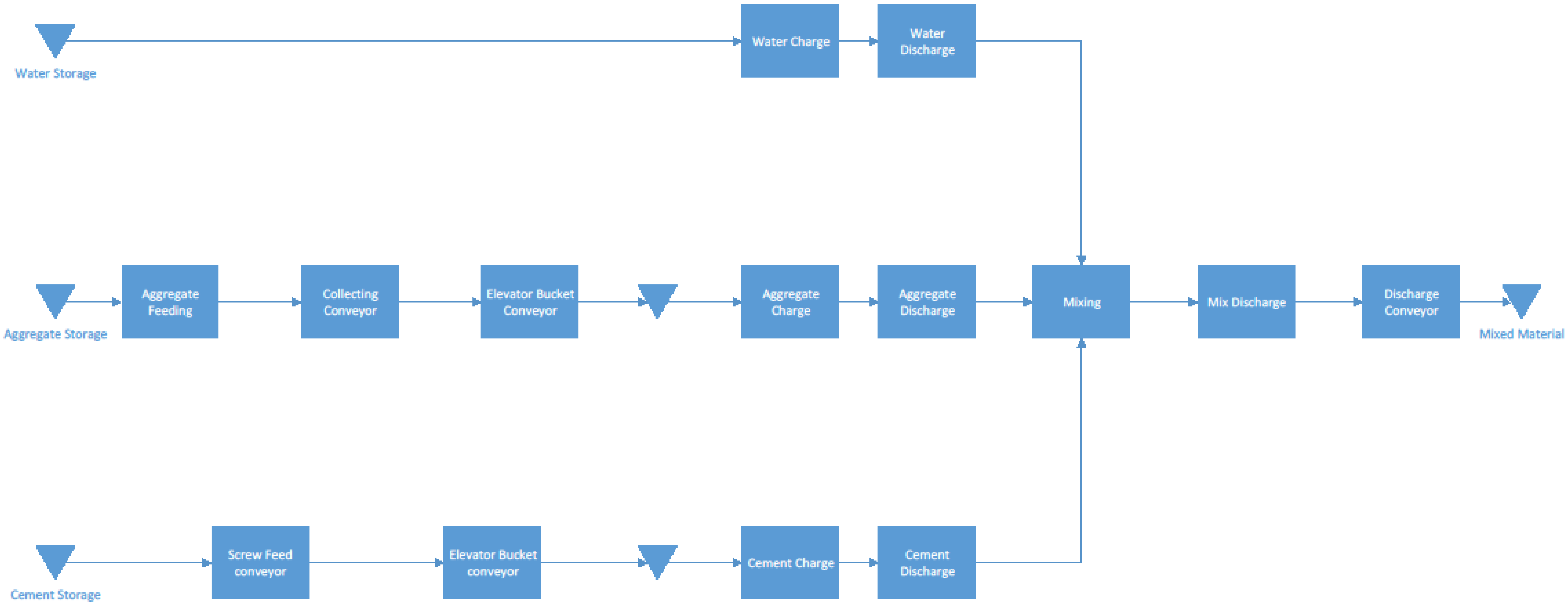
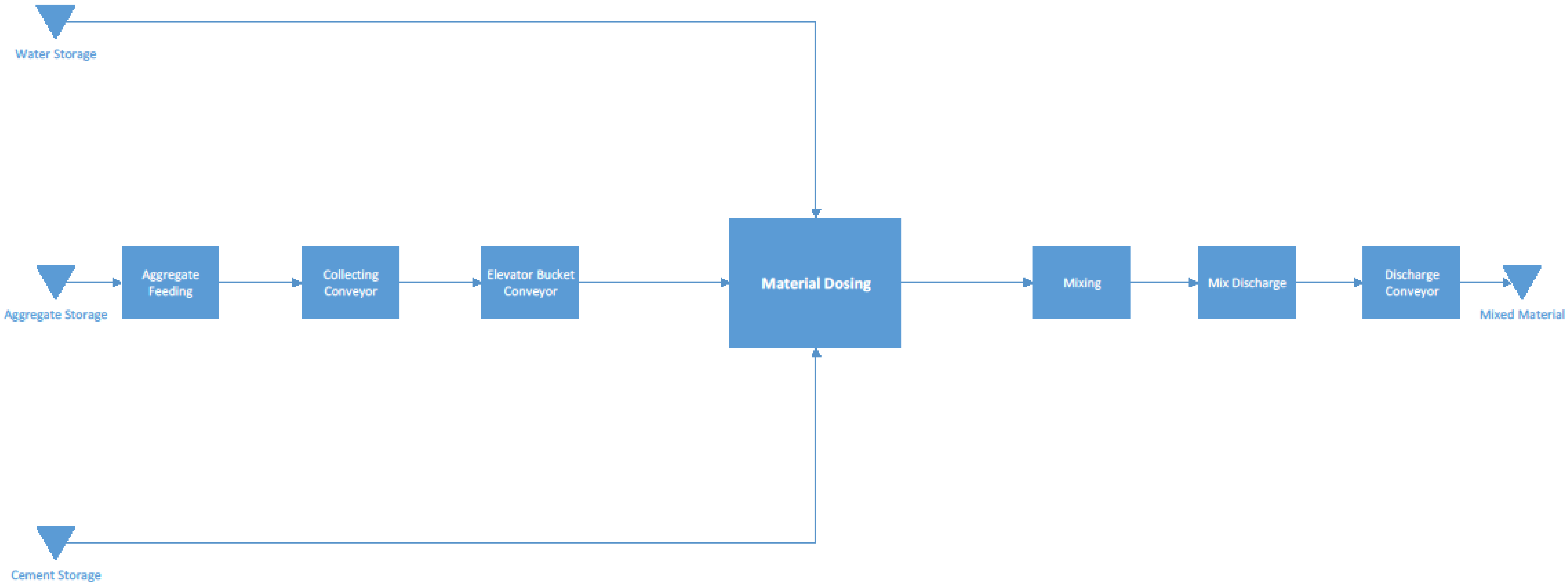
Appendices

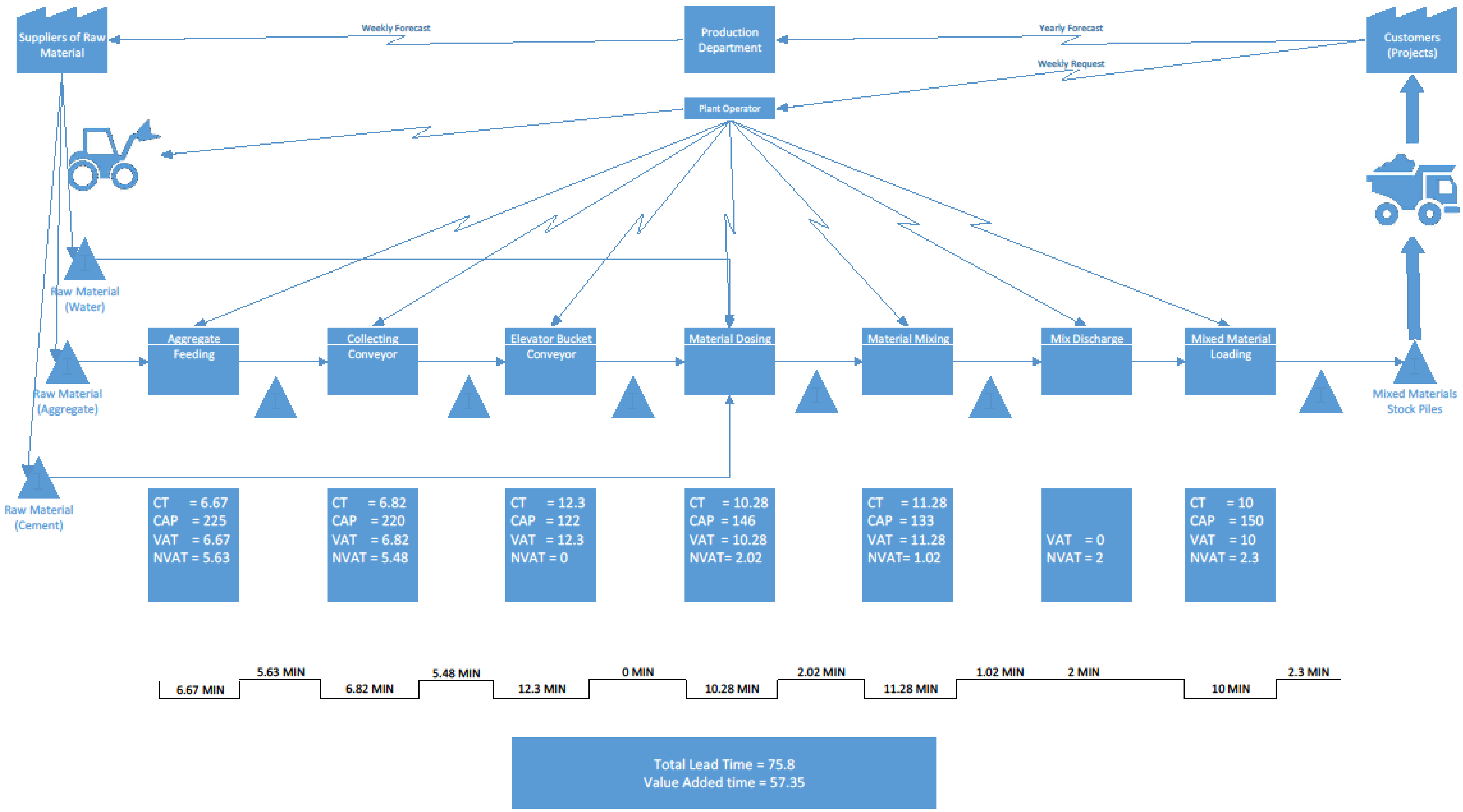
Appendix A: Production Process flow chart



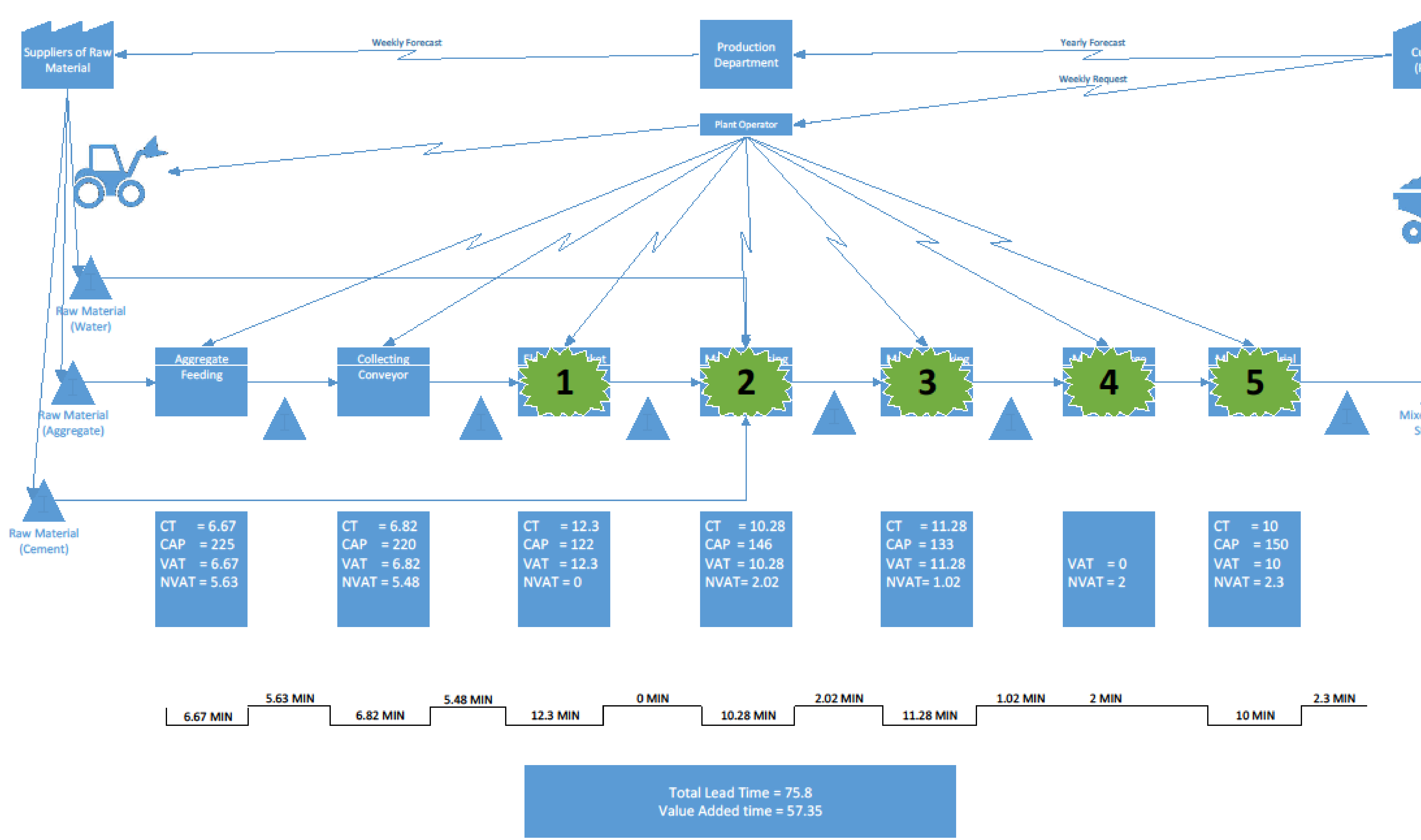
Appendix B: Simplified Process Flow Chart



Appendix C: Current State Value Stream Mapping



Appendix D: Current State Value Stream Mapping Indicating Potential Improvements



Appendix E: Future State Value Stream Mapping