

Material and Energy Wastes Reduction in Steel Production through the Application of Lean Manufacturing Tools

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Abstract

The iron and steel industry plays a major role in the growth and development of modern societies, and is an intensive consumer of energy. Manufacturers facing fierce market competition and increased customer awareness about environmental problems and efficient use of natural resources and energy for sustainability, strive for material, energy, and costs reduction to maintain competitiveness. Implementing lean manufacturing methodology is a sound way to achieve this aim. This study investigates the prospective effect of lean practices on improving productivity within a deformed rolled bar steel manufacturing facility. The adopted methodology is data-driven based on various lean and quality tools as Value Stream Mapping (VSM), the 5 Whys technique, and Pareto Analysis. The application of lean tools aid in identifying the major causes of losses and may help in increasing productivity and reducing waste in energy consumption. Recommended actions may also contribute in decreasing the stoppage time and the risk of equipment damage. By applying the same approach to the whole production line, additional waste reductions in both material and energy are expected.

Keywords

Lean Manufacturing, Energy Value Stream Mapping, and Steel Industry.

1 Introduction

The iron and steel industry is considered a primary industry as it provides input for different other dependent industries such as construction, housing, infrastructure, consumer goods and automotive. According to the World Steel Association, by 2050, steel usage is expected to be 1.5 times higher than the present levels in order to meet the needs of a growing population (Worldsteel 2018). Steel production is a chain of major processes applied to scrapped steel or iron ore in order to get deformed bars or wire rod coils. Rolling process is used for mass production of long steel products as rebar, wire rod, sections, rails, angles and flat products. Cobble is considered a major defect causing a large amount of losses in steel production. It occurs due to abnormalities in rolling conditions. This defect causes loss in production, equipment damage, and major delays in the mill.

Lean manufacturing is a philosophy of production that targets minimizing the use of resources throughout the manufacturing process. It involves identifying and eliminating waste, which is defined as any activity that does not add value from the customer's perspective. There are 8 types of wastes: overproduction, waiting, unnecessary transportation, over processing, excess inventory, unnecessary movement, defects, and unused human potentials (Khaba and Bhar 2018). The most commonly used lean manufacturing tools are: value stream mapping (VSM), standardized work, 5S (sort, set in order, shine, standardize, sustain), single minute exchange of dies (SMED) (Cudney and Elrod 2011). Not all lean manufacturing tools lend themselves to the application to continuous production processes. VSM is a versatile tool that highlights the source of waste and helps making target area of improvements visible. It uses a flow diagram to depict every step of a process. VSM focuses mainly on identifying waste, reducing manufacturing time and making the manufacturing process more efficient. Recently, VSM scope has been extended to include energy and water to reflect the objective of sustainable manufacturing (Cheung 2017). Furthermore, the 5 Whys technique is considered an effective lean tool used to determine the root cause of a problem.

This paper focuses on identifying and reducing waste in material and energy in the steel industry with the help of lean manufacturing tools. The remainder of this paper is structured as follows: Section 2 presents a review of the applications of lean manufacturing tools within various industries; Section 3 describes the proposed methodology;

Section 4 presents the case study; Section 5 discusses the overall result and finally the conclusion and future work are presented in Section 6.

2 Literature review

Lean manufacturing has been applied in all sectors from manufacturing to service sector; mass production to high variety and small volumes production; construction industry to assembly industry. The lean tools are considered powerful tools for the identification and elimination of all types of activities and processes that do not add value to customers (Davim 2018). Researchers found that lean tools significantly enhance manufacturing performance (Wickramasinghe et al. 2017).

VSM is the most frequently used approach (Bhamu and Sangwan 2014). It is an effective tool to identify which process is more important to the customer (Rocha 2014). Some lean manufacturing tools have been applied based on VSM in the steel industry (Rocha 2014). It resulted in significant cost reduction and a high increase in company competitiveness. Zuraidah et al. (2014) integrated VSM and simulation modeling for the metal manufacturing industry. It resulted in 70.7% reduction in production lead time and 10% decrease in the process time. Oliveira et al. (2017) used VSM to detect wastes through the production of mechanical equipment and suggested several lean tools to gain the required improvements. Kumar et al. (2018) used VSM to eliminate rework time. They achieved reduced lead time and improved productivity. Verma and Sharma (2016) focused on using VSM in reducing energy and making the process more energy efficient. Adithya (2015) found that energy value stream mapping is an efficient tool for the non-value-added energy management. A 3.5% reduction in energy consumption in electrical instrument manufacturing industry was achieved (Adithya 2015). However, VSM cannot be used by itself, that is why for obtaining these improvements other tools like Kaizen, Total Productive Maintenance are required. It is noted that limited number of papers from the developed, emerging, and underdeveloped countries address lean manufacturing. So, this work aims at applying lean tools to the steel production industry in a developing country in order to reduce the gap of the case studies in this field.

3 Methodology

The proposed framework shown in Figure 1 aims to facilitate the implementation of lean tools. It suggests the use of a selected set of lean tools to identify, prioritize, and reduce wastes. First, data about the processes are collected. These include raw material usage, utilities, production rate, number of workers and cycle time for each process. Using these data, the current value stream (CVSM) is constructed and different types of losses are quantified and allocated to specific processes. These losses are prioritized based on some criterion defined by the decision maker (e.g. quantity, cost, weight, ...)

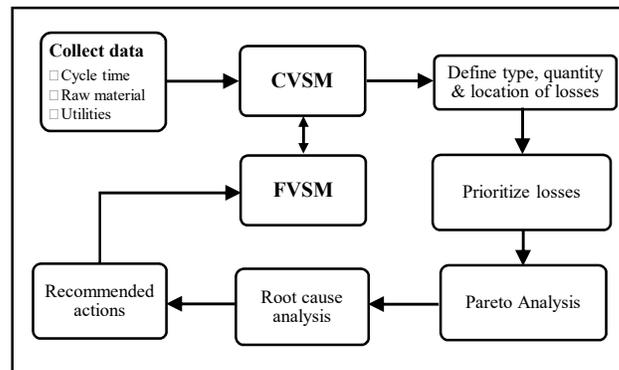


Figure 1. Applied methodology.

The losses with highest priority are then selected for investigation using Pareto Analysis. Then the 5 whys technique is applied to identify the causes of wastes in both material and energy. Based on the root cause analysis, actions are recommended to reduce or eliminate losses. New data for material and energy consumption are then obtained, these are used to draw a Future VSM (FVSM). Finally, the FVSM and CVSM are compared to identify improvement. After

implementing the recommended actions, the process starts over again, the FVSM becomes then the CVSM and prospective improvements are further investigated to ensure continuous improvement of the process.

4 Case study

4.1 Production Process Description

The proposed framework is applied to a steel manufacturing process for producing deformed rolled bar. The rolling mill plant consists of three main areas as shown in Figure 2: Reheating furnace (RF), milling line, and finishing area. Billets are transferred from storage yard to the receiving bed by overhead cranes in order to be charged inside the RF to reheat billets from 37 to 1050°C. Then billets are discharged to mill line to be rolled through three stages (roughing, intermediate, and finishing mill trains) with a total of 18 stands (six stands per stage). Two cropping (top and tail cut, and emergency cropping in case of cobbles) and two cutting shears are also used to size the final product. After that the final produced rebar is subjected to Quenching and Tempering process (QTB). The rolled bars are then transferred to the inspection conveyor in order to separate short length bars and scraped bars, then batches are transferred to the bundling station. It is assumed that the process operates on a 24 hr. basis with a machine availability of 88%. A monthly production quantity of 40,000 tons is assumed to illustrate the concept.

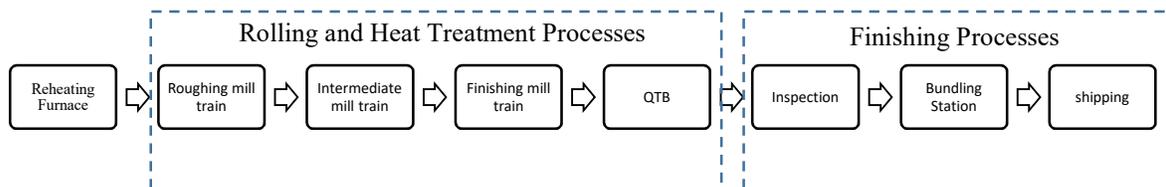


Figure 2. Sequence of deformed rolled bar production processes.

4.2 Current Value Stream Map

The CVSM shown in Figure 3 identifies waste types and quantities throughout the rolling mill production line. The value stream map depicts the consumption of material, water, and natural gas. It illustrates three areas with losses: reheating losses, rolling and heat treatment, and finishing losses. The average percentage of losses from reheating furnace present 1% of the total material input. These are scale losses. The rolling and heat treatment losses amount to 1276.59 ton per month, representing 3% of total material input and may be broken down to three types of losses: shear 1 and 2 crops, cobble, and scrap contributing to 8.33%, 75%, and 16.67% of this stage losses, respectively. Finally, the finishing processes cause crops and short lengths, initiating a loss of 0.75%, and 1.25% of input material, respectively. Thus, the highest amount of losses arises from rolling and heat treatment process, and among these cobbles have the highest contribution. Therefore, losses due to cobbles are selected to be the focus of this study. According to applied methodology (Figure 1) a Pareto analysis has been performed. Figure 4 displays the amount of losses between every two consecutive stands of the 18 stands of the milling line. The Pareto chart identifies that 8 areas cause 80% of the losses. Yet, it can be noted that the highest losses may be categorized into three levels. The areas between stand #17-18, stand #16-17 present 23.8%, 21.6% of losses, respectively. QTB and stand # 15- 16 cause around 13.4%, 8.1% of the losses, respectively, while all the remaining areas contribute to 33% of the losses. To identify the causes of the losses, it is necessary to consider each area separately.

Therefore, it was decided to start the analysis by considering the highest losses present between stands #17-18. Nevertheless, the other locations are to be considered in the future to identify possible waste reductions. Next, the root causes of the losses under study are identified. Through interviews with production and maintenance managers and thorough investigations the 5 whys technique was carried out to illustrate the various causes that affect the rolling process and result in cobble between stand #17,18 as shown in Figure 5.

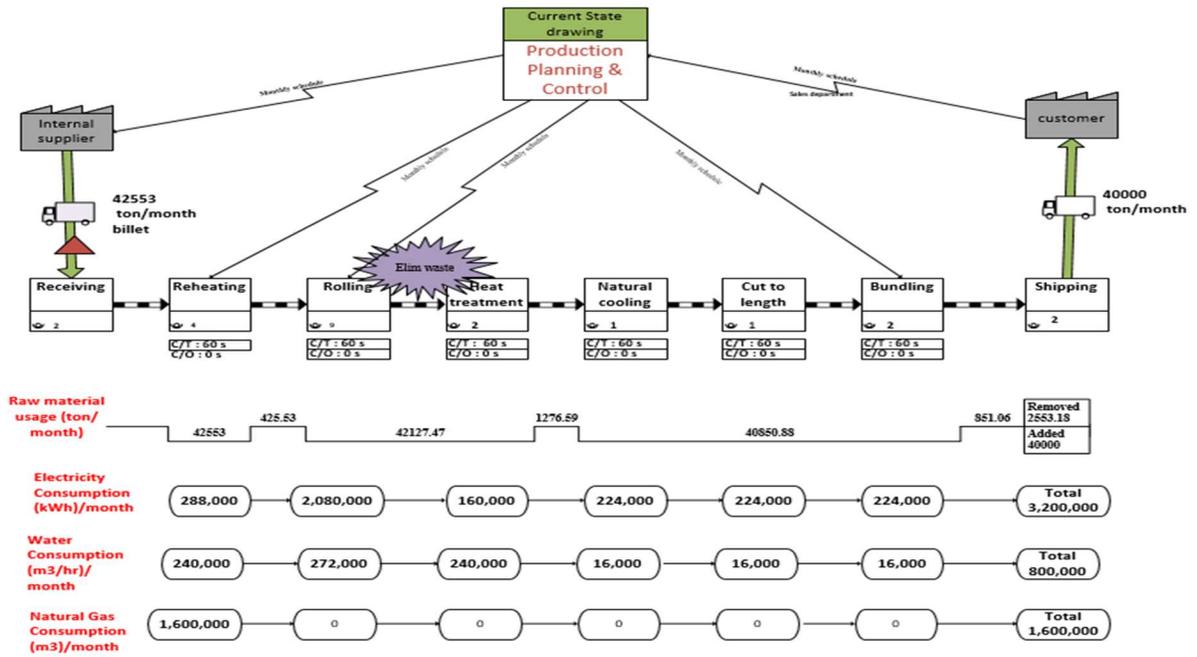


Figure 3. Current Value Stream Map (CVSM)

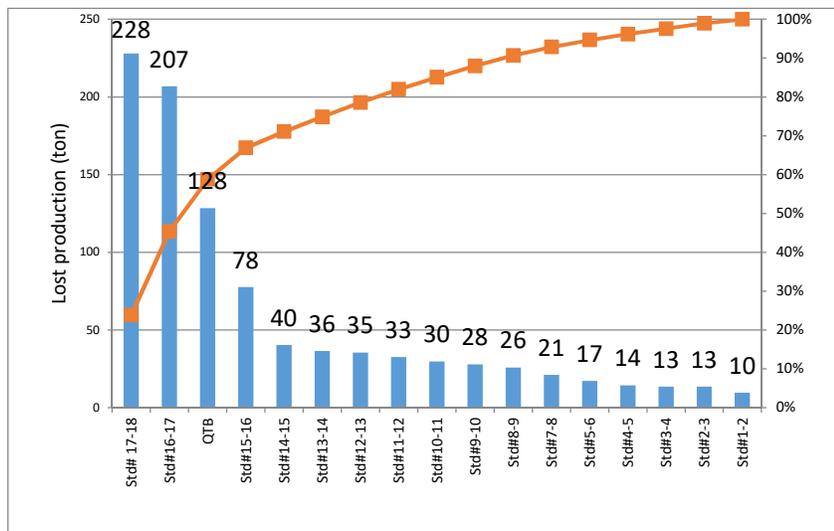


Figure 4. Pareto Analysis

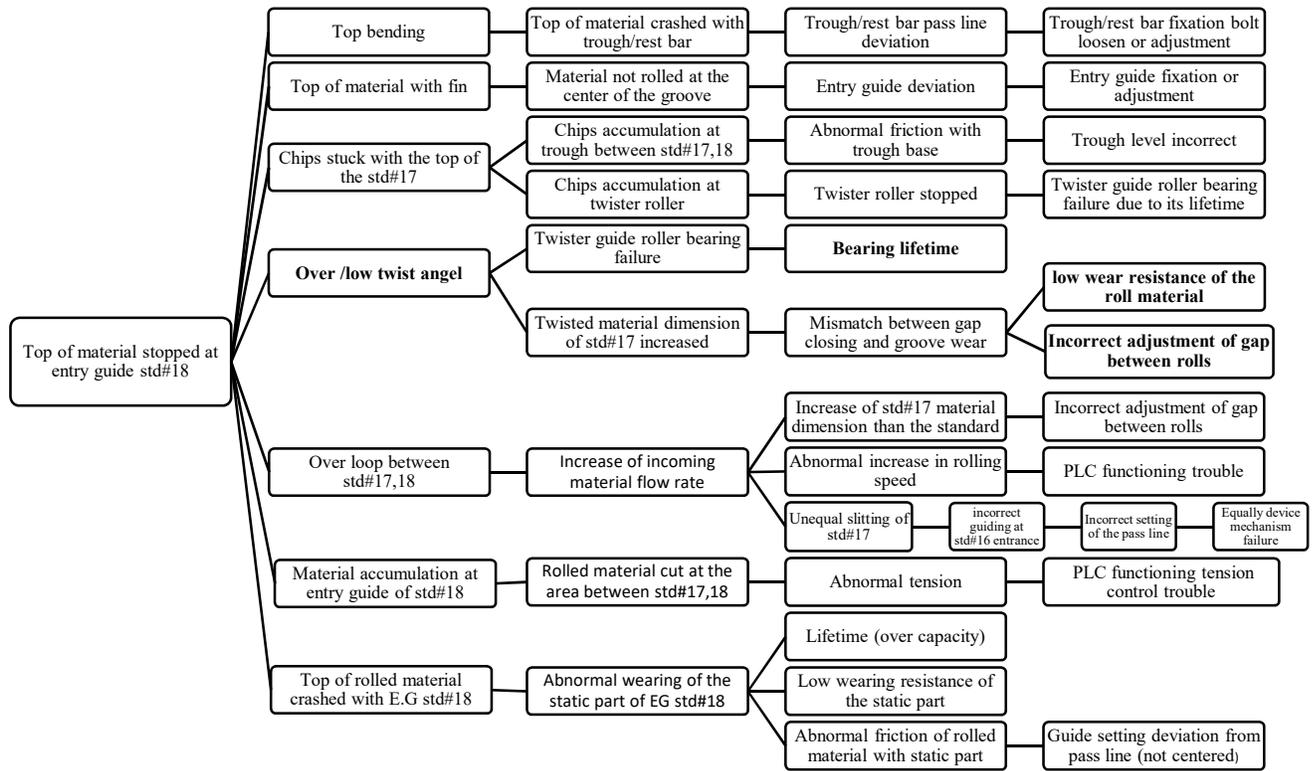


Figure 5. The use of the 5 whys Technique to analyze the root causes for losses between stand #17 & 18.

5 Recommended actions and expected results

According to the 5 whys technique (Figure 5), it is obvious that the root cause for over and low twist angel is bearing life time of the guide, low wear resistance of the roll material and incorrect adjustment of gap between rolls. Also, the root cause for top bent is rest bar level adjustment, and for top of rolled material with fin is entry guide adjustment. This study focuses in suggesting actions to decrease these root causes.

5.1 Planned stoppage for changing guides

It is evident that one of the root causes for over twist angel is bearing lifetime. The current situation is that the bearings are changed when a failure occurs. In order to define the improvement actions to prevent the root cause, first we studied the behavior of the entry roller guides of std#17,18 (two guides with same bearing type). Frequency of bearing failure at different lifetimes has been recorded over a period of two months as shown in Figure 6. It is obvious that the failure occurs most probably after running for 8 hours. Currently, the bearings operate on a run to failure basis, thus bearing replacement occurs 3 times per day. There are 9 guides between stand #17,18. Using the binomial distribution, the expected downtime for replacing the nine bearings is estimated at 19.64 minutes/shift (58.92 min/day). Additionally, one ton of material is wasted at each stoppage due to cobble, the expected number of stoppages is 8 stops/day leading to 211.2 ton/month of wasted material.

The recommended action is to replace all nine bearings every 6 hours, i.e. before their expected failure time at 8 hr. This is to cause an expected downtime of 10.33 minutes/shift (30.99 min/day), i.e. a saving of 27.9 min/day in downtime. This may result in an increase in monthly production by 737.35 ton, besides a saving of 211.2 ton/month due to cobble which would occur in the run to failure scenario. Thus, a potential increase in monthly production by 1.84 % and a 0.53 % saving of total monthly production may be achieved.

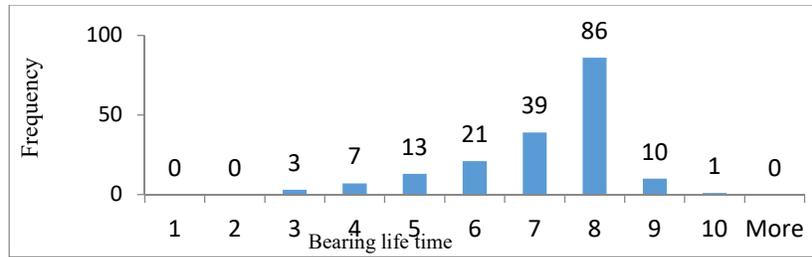


Figure 6. Histogram for the frequency of bearing failure

5.2 Replacing current bearing type with longer life time type

It is recommended to replace the currently used bearing type (Type A) which has an average lifetime of 8 hrs by another type (Type B) having an average lifetime of 48 hrs. The basis of comparison is 2 days, which is equal to the life time of bearing type B. During the period of 2 days, the Type A bearing will cause an estimated stoppage time (= expected changing time × no of changes/day × 2 days) of 117.84 min. In addition to waste of one ton of material due to cobble generated at each stop resulting in 211.2 ton/month. Type B bearing will be changed only once during the 2 day period, thus the planned stoppage policy will require a stoppage time of 30 min. Hence, a saving in downtime of 87.84 min may be achieved by using Type B bearing. This will result in increasing the production by 87.84 ton/day, representing 6.88% of total daily production.

It is necessary to further investigate the economic feasibility of the proposed action. The costs of type A and type B bearings are \$5 and \$50, respectively. The increase in daily costs due to using a higher life time bearing is estimated at \$180 (= (cost of type B - (cost of type A × no of changes /day × 2 days)) × no of bearings)/2).

Assume the product selling price to be \$600/ton, and the net profit of 15% of selling price (\$90/ton). Thus, the saving of 87.84 ton/day, will lead to an increase in profit by \$7,905.6/day (saved production tons × profit). Deducting the extra bearing cost of \$180/ day will lead to a net daily savings of \$7,725.6. The current daily profit with Type A is estimated at 114,030 \$/day (net profit × production/hr × hr/day × availability). Thus a 6.77% increase in daily profit may be achieved in addition to saving in material presenting a 1.78 % of total monthly production.

Comparing the results obtained from the planned stoppage for changing guides and replacing the current bearing type with a longer life time type, it is better to adopt the recommended action of using a bearing with a longer life time to achieve higher production.

5.3 Replacing Chilled rolls with HSS rolls

One root cause for low twist angel is low wear resistance of the roll material. It is recommended to use high speed steel (HSS) rolls with higher wearing resistance instead of the currently used type (Chilled type). The total production throughout the life time of the rolls is estimated at 5,000 ton and 1,500 ton for HSS and chilled rolls, respectively. The prices for the HSS and Chilled rolls is \$120,000 and \$50,000, respectively. For a one-month production, the chilled rolls is used which cause a number of stoppages of 27 stops (monthly production / production of the roller through its lifetime). Each stoppage requires a duration of 15 min, i.e. 405 min/month. For the HSS rolls, the number of stoppages will be only 8, with an estimated total monthly stoppage of 120 min. Thus, a saving of 285 min/month may be achieved which may result in increase of 0.7% in total monthly production.

5.4 Reducing losses due to cobble occurrence

When cobble occurs additional billet is cut as scrap because it is already discharged between stand #1,2. This is an additional loss besides the cobble. Some modifications were implemented to stand #1 to stop individually until cobble removal of the previous billet. The cooling system was modified to separate cooling system for stand #1 to prevent cooling the top of the existing billet. It resulted a reduction in losses (crops) by 0.9 %. It results in saving material by 0.03% of total monthly production.

5.5 Reduction of natural gas (NG) consumption

The RF was designed to discharge billets after reheating them to 1050°C -1100 °C using NG. However, billets are received by transfer cars with a temperature of 300°C - 350 °C, the RF charging equipment is designed to charge cold

billets with a temperature of 25°C-80°C. Hot charging from transfer car to RF directly to utilize heat energy of received billet had been implemented and resulted in a saving of 26.9% of NG consumption.

5.6 Future Value Stream Map (FVSM)

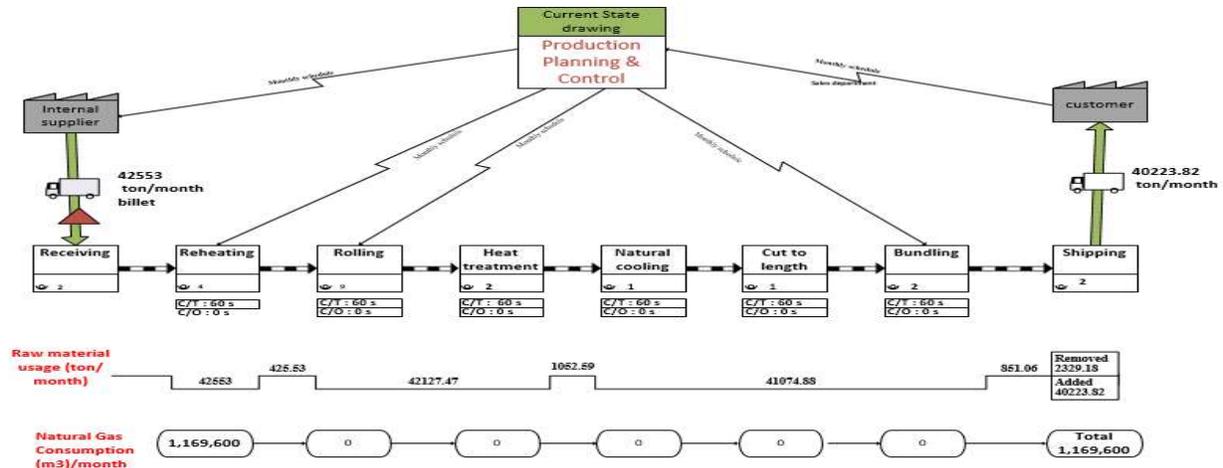


Figure 7. Future Value Stream Map (FVSM)

Based on the recommended actions, the FVSM has been developed to illustrate the material and energy savings achievable. It is obvious from the FVSM in Figure 7 that losses of material may be reduced from 1276.59 ton/month to 1052.59 ton/month and a potential reduction of NG consumption from 1,600,000 m³/month to 1,169,600 m³/month is expected.

5.7 Other recommended actions

5.7.1 Adjustment of gap between rolls

Another root cause for low and over twist angel is incorrect adjustment of gap between rolls. Currently, the gap adjustment is manually controlled through the measurement of the rolled bar weight. A weight per unit length greater than a specified threshold value, indicates that the gap between rolls has increased due to wear. Operator then manually decreases the gap by a specific amount. It is recommended to use sensors for non-contact on-line measurement of the cross-sectional area and weight-per-meter of hot rolled bar. These sensors can measure round, oval and rebar profiles in real time. This results in an immediate warning when product out of tolerance. Continuous measurements of the rolled bar is expected to lead to further reductions of work roll wear and reduction of cobbles.

5.7.2 Using new technology

The adjustment of rest bar and entry guide are among the root causes for losses in stand #17 and 18. The current adjustment method is done visually and depend on the human accuracy which may lead to misalignment of guides to the pass line and misalignment of guide rollers. The following actions are recommended to overcome this problem:

- (1) Using motorized movable rest bar. The movement of the guide is done by means of a small pitch worm screw thanks to brushless motor with high gear ratio.
- (2) Using a new system based on the image acquisition of the shadow produced by the pass rings and guide rollers when these intercept the band of light is diffused by the light source. Starting from this image, the processing system reconstructs the pass shape and compares it with the design drawing retrieved from the device database. It is easy to make any correction to the position of the rollers of the guide or the finishing pass mounting base.

6 Conclusion and Future work

Lean manufacturing has been extensively used to identify and eliminate waste in industrial facilities. The application of VSM in conjunction with the 5 whys technique and other quality control techniques may result in savings in material and energy in steel plants. The proposed methodology results in identifying the main causes of losses and thus may help in saving 0.56 % of total monthly production from the lost billets as a result of cobbles that occur at one of the most critical locations in the rolling line. Furthermore, a potential saving of 26.9% of natural gas consumption, an increase in production by 7.58%, and a decrease in stoppage time may be achieved. These results obtained by recommended actions between 2 guides only. By applying the same approach to other rolling guides, additional savings are expected. The approach is data-driven, yet no extra data collection is needed, it relies on data collected for production and quality control which is readily available. The future work is to extend the value stream map to account for all types of energy and water consumption.

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