Enhancing Productivity of hot metal in Blast furnace - A case study in an Integrated Steel Plant

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Abstract

Studies on applications of lean in a continuous process industry are limited. There is lot of opportunities for improvement in the process industries like steel if lean tools are utilized. This paper addresses the application of Value Stream Mapping as one of the Lean tools to eliminate waste, and improved operational procedures and productivity in a blast furnace of an integrated steel plant. Current state map is prepared and analyzed and suggested to improve the operational process by introducing supplementary raw materials and alternate fuel to increase the productivity. Accordingly the future state map is drawn. The study reveals that there is an improvement in the takt time by implementing the proposed changes if incorporated in the future state map.

Key Words: Lean, Value Stream Mapping (VSM), Current state map, future state map, takt time

1. INTRODUCTION

Globalization is making most of the organizations, sectors more intensely competitive. Many organizations are struggling to improve their operating performance in response to market demands for lower costs, higher-quality products and services, shorter lead times, and higher returns on investment in infrastructure and resources. The case study was carried out to address above issues in iron making of an integrated steel plant and to find out uncover hidden values to increase the productivity. To eliminate the waste and identify the non value added processes from the lean manufacturing perspective, the value Stream mapping is carried out to optimize the process and to increase the productivity.

VSM is the process of visually mapping the flow of information and material as they are preparing a future state map with better methods and performance. It helps to visualize the station cycle times, inventory at each stage, manpower and information flow across the supply chain. VSM enables a company to ‘see’ the entire process in both its current and desired future state, which develop the road map that prioritizes the projects or tasks to bridge the gap between the current state and the future state.

The value stream mapping is used to analyze & map in order to reduce the waste in processes, enable flow, and to make the process for better efficiency. The purpose of value stream mapping is to highlight sources of waste and eliminate them by implementing the future-state value stream that can become a reality. The goal is to build a chain of production where the individual processes are linked to their customer(s) either by continuous flow or pull, and each process gets as close as possible to producing only what its customer(s) need when they need it.

A value stream map is an end-to-end collection of processes/activities that creates value for the customer. A value stream usually includes people, tools and technologies, physical facilities, communication channels and policies and procedures. A value stream is all the actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (a) the production flow from raw material into the hands of the customer, and (b) the design flow from concept to launch.

Standard terminology, symbols, and improvement methods allows VSM to be used as a communication tool for both internal communication and sharing techniques and results with the larger lean community.

2. LITERATURE REVIEW

Hines P and Nick Rich (1997), Rother and Shook (1999), Womack and Jones (1996) and Jessop D et al. (1995) has studied the implementation of Value Stream Mapping effectively.
Lean manufacturing is a production strategy for organizational effectiveness focusing on waste reduction and improving productivity through application of various tools (Mahapatra, 2007). Value Stream mapping technique involves flowcharting the steps, activities, material flows, communications, and other process elements that are involved with a process or transformation. In this respect, Value stream mapping helps an organization to identify the non-value-adding elements in a targeted process (Ramesh, 2008). Hugh (2002) applied VSM to product development. The author proposed general VSA/M method for product development activities. Non-value-added tasks are activities deemed to only support the true value-added tasks (waste – often tasks such as set-ups, reviews, etc.) or that are completely unnecessary in themselves (another type of waste – often “non-tasks” such as waiting in inventory). In the lean manufacturing context, manufacturing cells, just-in-time delivery etc. are applied to create future state map. The future state map drives an implementation plan for improved state and is then used to generate further future states, and (ideally) the process is continuously improved.

Academics such as McDonald et al. (2002), Lian and Landeghem (2002) and Abdulmalek and Rajgopal (2007) have explored the integration of VSM with simulation. A multitude of VSM software (e.g. eVSM) is available over the internet. Such software presents the user with a dynamic view of the value stream (not static), allowing observation of the “real-time” impact of proposed improvements. Essentially it increases flexibility and information available to improvement teams.

Chitturi et al. (2007) discussed practical issues like how to calculate TAKT time, what process improvements can be done and how to handle different process and product families while mapping job shop operations using a standard VSM and also explained while drawing a VSM of a process, all pertinent data should be collected from first to the last operation with respect to it.

Chandradeep Grewal (2008) has explained the methodology of lean and VSM that can be applied for a small company and also stated that it is a powerful tool to identify the inefficiencies and improvement areas. Bhim Singh (2010) implemented Lean to production industry. The author highlighted the benefits from the all the areas of lead time, WIP, processing time, inventory and manpower. Ibon (2008) is considered VSM is suitable tool for redesigning the production systems.

Wong (2009) has studied on adoption of lean manufacturing in the electrical and electronics industry in Malaysia. The author considered the areas viz., scheduling, inventory, material handling equipment, work processes, quality, employees, layout, suppliers, customers, safety and ergonomics, product design, management and culture for implementing.

Petter Solding et al. (2009) have presented in their paper that, the concept for creating dynamic value stream maps of a system using simulation. Creating dynamic value stream maps makes it possible to analyze more complex systems than traditional VSMs are able to and still visualize the results in a language the Lean tools.

3. CASE STUDY

A case study was carried out in an integrated steel plant in India. This plant is having two blast furnaces and hot metal production capacity is around 4 million tons per annum. The volume of each furnace is 3200 m$^3$. Blast furnace is the main and important unit where the raw materials are converting into Hot Metal. There is a lot of scope for study and go for further improvement in the process to enable higher production rate of Hot Metal. Hence this was selected for the case study.

4. METHODOLOGY

VSM is the operational approach to analyze a process of its planning and execution. The mixture of iron bearing materials (iron ore rubble, sinter and/or pellets) and additives (flux material) are known collectively as the “burden”. The burden and the accompanying coke are charged into the top of the furnace either via skips or mechanical conveyor belts. It enters into the furnace via a sealed charging system and move downwards by gravity, which isolates the furnace gases from the atmosphere. Hot reducing gas and heat are generated in the lower part of the furnace by partial combustion of coke and injected fuels with hot blast (pre-heated air) to a gaseous mixture of carbon monoxide, hydrogen and nitrogen. The manner of charging raw materials to the blast furnace affects the distribution of gases that reduce and heat the descending burden materials. The distribution of burden and gases in the stack has a strong effect on the efficiency of gas-solid reactions and on shaft permeability. These in turn have a large influence on furnace performance as measured by fuel rate and productivity. The hearth’s processes are very dynamic and depend on various parameters (Iosif G. Tovarovskiy, 2003). Some of the important parameters considered for productivity in a blast furnace are the volume of the furnace, internal gas flow rate and specific gas volume, burden permeability of the raw materials, smelting indices, RAFT (adiabatic flame temperatures) and type of fuel injected.
To increase the production capacity, the melting time of raw materials should be reduced. Natural gas also increases hydrogen levels, which has more advantages in reducing iron oxide to iron. This can be achieved by direct reduction of iron ore by injecting natural gas as alternate fuel in addition to hot air and oxygen.

First the current state map is drawn based on a set of data collected directly on the shop floor with the help of using the set of standard symbols and is carried out by keeping the view of various lean manufacturing principles. The following diagram represents the current state map. It will give the visualization of the current state process of material flow as well as information of the different activities. From this it is very is to identify and analyze the various activities of value added and non value added. In order to develop the future state map the following steps should be performed.

5. IMPLEMENTATION PROCESS

Tapping et al. (2002) introduced a step by step procedure to perform a VSM analysis. The same is shown in the Fig. 1 below

5.1 SELECTION OF THE PROCESS

For an integrated steel plant to draw as a single unit of the process diagram for the entire activities of steel producing in an integrated Steel plant is very complex and difficult. We have to draw the process diagram for each major production unit/department as a single unit to identify the VALUE ADDED and NON VALUE ADDED processes / activities, and then identify the opportunities to increase the efficiency by modifying/redesigning the new future state map.

As the blast furnace is the main and important unit where the raw materials are converting into hot metal. There is lot of opportunity for the enhancement of the process, hence it was selected for the study.

5.2 DRAW THE CURRENT STATE MAP

The process is thoroughly studied with the help process experts, working people and literature related to the iron & steel manufacturing. The current state map was drawn with data collected from site shown in the following Fig.2.
5.3 ANALYZE THE CURRENT STATE MAP

The current state map was analyzed with respect to screening of raw materials, conveyor system, tapping technology, addition of iron ore pellets and injecting natural gas as alternate fuel to quicken the process.

Screening of raw materials and charging through conveyors are non value added process. But this time cannot be minimized or reduced unless the processing and smelting time of the burden inside the furnace is reduced. This is feasible when burden is added with iron pellets, injecting natural gas as alternate fuel to quicken the melting of burden in the furnace. The hydrogen content in the natural gas has direction reduction of iron in the furnace and there is lot of changes takes in the dynamic conditions of the furnace. Injecting natural gas causes a substantial decrease in the RAFT; this can be eliminated by injecting more oxygen to burn combust. Injecting Natural gas into blast furnace will increase hot metal productivity as well as decrease in coke consumption. These will results in effective utilization of the existing equipment, improve in the process and to get higher production rate at less in production cost.

5.3.1 Screening of raw materials

This process is a non value added process. Here there is no change in properties of the material and done on continuously by batch process. Only to ensure 100% free of fines from raw material of burden. Here sophisticated screening equipment should be introduced to maintain desired quality of burden to decrease the processing time.

To increase the contact between the burden and hot air blast, the burden should be free from fines of the raw material. As the burden moves down through the furnace, it must remain sufficiently permeable to allow the gases to move upward through it. If the fines, which were generated during transportation, were charged to the furnace, the permeability will decrease which affects the reduction process in the furnace and more coke is to be charged to maintain the high temperature of the furnace, which will increase the input cost. In addition, burden and gas distribution have an effect on furnace lining life and hot metal chemistry.

5.3.2 Change in speed conveyor system

Charging of Raw materials is continuous in batches. Coke batch consists of 18 tons of hard coke and 2 tons of nut coke. A mixture batch consists of 15 tons iron ore, 45 tons sinter and other flux materials. First coke batch is charged in to furnace then followed a mixture batch one after another. For each charge total time taken is 10 min. Existing system is capable to supply more number of batches if the furnace is geared up to take the raw materials. This leads to minimize the non value added time.
5.3.3 **Tapping technology**

Now a day’s tapping technology demands high performance machines allowing the use of wear resistant and quick setting clays. There is time gap between tapings of hot metal at furnace for preparation of tap hole (i.e. before opening and after closing of the tapping) and runners. By using special quick-hardening masses to ensure adequate strength, avoid quick erosion of tap hole diameter and runners, ease of drilling at the time of Tap Hole opening and for longer life of the tap hole and runners. Thus, it was not necessary to slow down the blast furnace operation at each casting, whereby a substantial gain was achieved in the daily production.

5.3.4 **Continuous running of Twin Tap holes**

Out of four tap holes in Blast furnace, always a single tap hole will be operated to collect the hot metal from the hearth at regular intervals. To enable the continuity of the process in the furnace the produced hot metal should be taken out continuously. To achieve this, twin tap holes technique may be introduced to collect the hot metal from the furnace.

5.3.5 **Iron ore Pellets**

Pellets are spherical lumps formed by agglomeration of the crushed iron ore fines in presence of moisture and binder. Pelletizing turns very fine-grained iron ore into balls of a certain diameter, which are suitable for direct reduction in blast furnace. The high permeability and reducibility and of sinter and pellets enhances the performance of the blast furnace and efficiently produce hot metal in blast furnaces. With combined blowing of natural gas and oxygen enrichment as a fuel in the furnaces, Pellets have better hightemperature reducibility and that can further increase the productivity and great reduce in processing time. This will increase the input cost of raw materials and it will be compensated by higher production rate by using the same resources.

5.3.6 **Natural Gas**

The primary function of Natural gas is as substitution of Carbon and Hydrogen for coke as reduction agent and alteration of thermal balances in RAFT temperature. Natural gas injection with oxygen enrichment, generally known as combined blasting and with this technology, we achieve coke economy and also increase the productivity. In the combined blowing having different effect in furnace process and depends on temperature of the hearth, direct reduction due to Hydrogen and dynamic conditions of the gas in the furnace. This will also improve the productivity by reducing the processing time in the furnace. In addition to that CO2 savings through use of natural gas are significant. Coal consumption rates better than or comparable to those of the blast furnace, leading to lower carbon dioxide emissions.

5.4 **DEVELOPING THE FUTURE STATE MAP**

After study of current state process the changes were proposed to improve the process and productivity. Based on the changes proposed the future state map was developed with proper notations of value stream mapping. No additional equipment or conveyor system is required for charging of the iron ore pellets to furnace. New equipment is to be installed to store and control the natural gas. But injecting can be done through existing tuyeres, with some modifications in tuyeres before entering the gas mixer to furnace. The future state map drawn and shown in the following Fig 3.
Fig. 3 Future state map

5.5 COMPARE THE RESULTS

<table>
<thead>
<tr>
<th>Data</th>
<th>Actual</th>
<th>Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of hours per shift</td>
<td>8.00</td>
<td></td>
</tr>
<tr>
<td>Break time per shift (in min.)</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>Available time per shift in min.</td>
<td>475.00</td>
<td></td>
</tr>
<tr>
<td>Available time per day in min.</td>
<td>1425.00</td>
<td></td>
</tr>
<tr>
<td>Charging of Raw materials at Blast furnace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time taken for charging Coke Batch( in min)</td>
<td>5.00</td>
<td>4.75</td>
</tr>
<tr>
<td>Time taken for charging Mixture Batch( in min)</td>
<td>5.00</td>
<td>4.80</td>
</tr>
<tr>
<td>Total time for one charge( in min)</td>
<td>10.00</td>
<td>9.55</td>
</tr>
<tr>
<td>Total number of charges per day</td>
<td>144.00</td>
<td>168.00</td>
</tr>
</tbody>
</table>

Table 1
**Table 1**

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Improved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of casts per month</td>
<td>300.00</td>
<td>345.00</td>
</tr>
<tr>
<td>Takt time in hours</td>
<td>2.38</td>
<td>2.06</td>
</tr>
</tbody>
</table>

**Graph 1**

**6.0 CONCLUSIONS**

This paper aims to assess the applicability of value-stream mapping in process industry. It contributes on productivity growth and the role of technological change within the context of global change. Increases in productivity through the adoption of more efficient and cleaner technologies in the manufacturing sector will be effective in merging economic, environmental, and social development objectives.

As the gas reserves are more at Krishna Godavari basin of Andhra Pradesh and assuming continuous gas supply. According to soviet literature the production enhancement after injection of natural gas with oxygen enrichment and adding of iron ore pellets is around 20-25% of the existing capacity of the blast furnace. But considering an improvement is 15% on average on the total number of casts per month.

The paper critically analysis and suggests alternate fuel injection to improve the productivity in a Blast furnace. This process reduces the specific energy consumption and less carbon dioxide emission and reduces the global warming. To attain the results and get the success there should be strong vision with mission at the top management.
References


