Lean manufacturing implementation in iron and steel industries: effect of wastes management on the production costs

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Abstract
Purpose – This study aims to improve the market competitiveness of iron and steel manufacturers in developing countries by reducing their production costs.

Design/methodology/approach – The research methodology relies on a case study-based approach. The study relies on six steps. The first is the preparation, then the five steps of the six-sigma – define, measure, analyze, improve, control. The qualitative and quantitative data were considered. The qualitative analysis relies on the experts’ judgment of internal status. The quantitative analysis uses the job floor data from three iron and steel manufacturers. After collecting, screening and analyzing the data, the root causes of the different wastes were identified that increase production costs. Consequently, lean manufacturing principles and tools are identified and prioritized using the decision-making trial and evaluation laboratory method, and then implemented to reduce the different types of waste.

Findings – The main wastes are related to inventory, time, quality and workforce. The lean tools were proposed with the implementation plan for the discovered root causes. The performance was monitored during and after the implementation of the lean initiatives in one of the three companies. The obtained results showed an increase in some performance indicators such as throughput (70.6%), revenue from by-products (459%), inventory turnover (54%), operation availability (45%), and plant availability (41%). On the other hand, results showed a decrease of time delay (78%), man-hour/ton (52.4%) and downgraded products (63.3%).

Practical implications – The current case study findings can be utilized by Iron and Steel factories at the developing countries. In addition, the proposed lean implementation methodology can be adopted for any other industries.

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1. Introduction

Globalization is one of the factors that increase market competition and poses challenges to companies’ survival. Industries in general, particularly the iron and steel industry face many problems. One of these problems is the increase in manufacturing costs, negatively affecting the firms’ competitiveness. Where it hinders export operations and increases the market share of imported products. Besides, the selling price cannot be set without considering the international prices of competitors. Manufacturing cost is one of the most important determinates of the price (Tanwar, 2013). Thus, reducing manufacturing costs permits the company to achieve some advantages compared to the competitors. This strategy is known as the cost-leadership strategy. Cost-leadership strategy is one of the strategies adopted by companies to achieve production efficiency. According to (Porter, 1997), it is used basically to gain an advantage over competitors by reducing operating costs compared to others in the same industry. If competitors fail to achieve the same reduction in operating costs, the company that has succeeded in reducing costs can gain competitive advantages through cost leadership. This is probably the case with the competitive advantages of international iron and steel products over local steel products. Importing products from international markets and offering them at lower prices, leads to satisfying a high proportion of the local market demand. Consequently, these imported products reduce the capacity utilization of
the local iron and steel factories and threat to stop their production. Accordingly, local iron and steel firms should adopt initiatives that reduce manufacturing costs.

On the other side, lean production/manufacturing has been applied in many international industries (Kumar Chakrabortty and Kumar Paul, 2011). Its main concept is to produce at lower costs by using the lowest level of resources without affecting the quantity or quality of the products (Seleem et al., 2020). This target can be achieved by eliminating the wastes that represent the sources of cost increases. These wastes include transportation, inventory, motion, waiting, overproduction, over processing, defects and neglecting workforce creativity (Wilson, 2010). The lean production system identifies and removes wastes from system bottlenecks through continuous improvements that meet customer demand at the highest levels of quality and efficiency (Seleem et al., 2016).

Responding to this importance and effectiveness, the current work provides a set of contributions for the scientific and practical communities. The research uses a holistic framework that integrates qualitative and quantitative analysis to investigate the lean implementation levels and the associated manufacturing wastes. First, a qualitative analysis was performed based on the internal assessment of the industry experts. The analysis investigates the implementation level of lean principles/tools in iron and steel manufacturing in one of the developing countries. This work explores the main root causes of the different wastes that directly increase costs. The quantitative real data are gathered from three iron and steel producers in Egypt. Relying on the discovered deficiencies, lean tools were proposed and implemented. The performance improvement plan treats all the discovered problems simultaneously. The proposition of a holistic framework for lean implantation is an effective practice, especially for the iron and steel industry that shows a clear shortage of such implementations. On the practical level, the research proposes a complete case study for overcoming one of the major problems facing iron and steel producers in developing countries. By reducing their manufacturing costs, they can reduce prices and interring new markets or put barriers in front of steel importers from global markets. This target is the main solution for the national industries, particularly the iron and steel industry. In iron and steel factories, the working capital amounts are about 30% of the fixed assets, which means high opportunities for waste and losses occur during the various stages of the supply chain system. Reducing wastes will have a significant impact on improving the companies’ competitiveness.

2. Literature review
According to Ohno (1982), the main concept of Toyota production system (TPS) is eliminating wasteful practices. In his work, Taiichi Ohno relies mainly on two pillars for reducing waste: just in time and automation. After that, Shigeo Shingo succeeded in developing the will-know setup waste reduction tool “SMED” in TPS (Dillon and Shingo, 1985; Shingo, 1988). The waste elimination concept is then named as the “lean manufacturing” by Womack et al. (1990). They named five principles for lean which are specify value, identify value stream, value flow, pull system and perfection. Academics and practitioners agreed that by implementing lean manufacturing principles and tools, firms can improve many performance attributes related to deliveries, productivity, yield, waste elimination, inventories, costs, defects and demand management (Panwar et al., 2018; Seleem et al., 2020). These good achievements led to the implementation of lean philosophy by many global companies to achieve high levels of efficiency (Vienazindiene and Ciarniene, 2013). According to Durakovic et al. (2018), lean principles are good source for achieving competitive advantages. They also showed that researchers gave high consideration to lean topics for the previous two decades for more than 30 different engineering areas in more
than 40 countries. Egypt takes the 34th rank while the USA, India, United Kingdom, Brazil, Malaysia, Italy, Germany, Spain, Canada and Poland, respectively, take the first 10 rankings. Relying on quantitative forecasting, they expected that this attention from researchers will be continued for the coming decades. Regarding the less developed countries, Belhadi et al. (2018) investigated the current level of lean implementation and the need in small and medium enterprises relying on qualitative analysis. They concluded that the level of lean implementation is very weak and there is a tremendous need for its implementation. Recently, Mbambala and Telukdarie (2019) investigated the impact of adopting world-class manufacturing (WCM) in the steel industry. WCM relies on implementing three pillars: lean tools to reduce costs, TQM to enhance quality and proactive maintenance to increase system reliability. To show its impact, they compared two production sites of the same steel company; the first implements WCM whereas the second one does not. The numbers show the site’s superiority that implements WCM over the second in many criteria, including production efficiency, defective material and plant reliability. For example, fuel rate is smaller due to the high usage of the by-product and better process control. The mean time between failures is higher in reasons of the implementation of full autonomous maintenance. Moreover, the unplanned stoppage time is smaller in reasons of the implementation of the preventive maintenance besides the autonomous maintenance. The literature provides many review works for lean implementation in different industries (Negrão et al., 2017), and for metal and engineering industries (Goshime et al., 2018).

These positive results encouraged researchers/practitioners to implement lean in iron and steel factories. However, most of these implementations are limited to applying few lean initiatives based on a set of analysis tools, e.g. VSM, 5-Why, Ishikawa diagram or FMEA. Saced et al. (2019) used VSM, Pareto-chart, 5-Why in the analysis of a deformed rolled bar steel plant. Relying on the discovered root causes, the performance improvement initiatives were suggested. With the same concept, Indrawati et al. (2019) used VSM to identify the main wastes in hot strip mill production. The production delay is found as the major losses, they proposed to implement maintenance programs to overcome the time losses. Chowdary and Fullerton (2019) investigated the effect of lean implementation in a Caribbean steel manufacturing company. Their methodology relies on using VSM, 5-Why analysis, Ishikawa diagram, Pareto-chart and simulation. The results indicate that the company can achieve a reduction percentage of lead time = 37%, processing time = 7.5%, work in process = 71% and change over time = 38%. These out-comes can be achieved by implementing the total productive maintenance, 5S, Kanban and SMED. Recently, Horuz et al. (2021) implemented only 5S in one of the iron and steel factories in Hatay in Turkey. The potential improvements of implementing 5S were highlighted. However, implementing only one lean tool is insufficient (Malysa and Furman, 2021).

Such trials suffer from the incomplete implementation of the lean success factors with the sustainability programs to achieved outcomes. It supports the opinion of Negrão et al. (2017), who said “lean practices application still occurs in a fragmented way.” Kareem et al. (2017) showed that management commitment, workforce training, resources allocation and ethical instructions are important factors for the lean implementation success. In discrete manufacturing, Seleem et al. (2018) showed that “Education and training,” “Top management involvement and commitment,” “Leadership” and “Cultural change” are the most important factors to be reinforced before implementation. A similar finding was presented by Singh et al. (2020) for the success of green lean implementation. For achieving continuous development and sustainability of outcomes, a continual development cycle can be adopted, e.g. the
standard PDCA, six-sigma approaches like DMAIC/DMADV or any sophisticated continual cycle. Moreover, the leanness degree depends on how many lean tools have been implemented. It can be measured relying on the qualitative data or quantitative data. According to Panwar et al. (2018), such empirical studies are needed. Recently, Akarte et al. (2021) reviewed the different industrial engineering tools that can be used in the iron and steel industry to improve productivity and competitiveness. Planning, scheduling, total quality management, logistics management, safety and human factor, procurement and process optimization are the important topics that were highlighted and highly applied in this industry for the recent period. However, these topics are treated separately in the literature and there is a gap for a unified framework that gathers most of the performance improvement tools in a continual development cycle.

According to Patel and Patel (2021) lean manufacturing has system change tools, whereas six-sigma has a continuity improvement nature. The combination of lean and six-sigma integrates the elimination of the non-value added tools and variability reduction techniques that achieves cost reduction (Vinodh et al., 2014). For implementing LSS, Flor Vallejo et al. (2020) selected a set of five roadmaps as reference models for developing their proposed one. Most of these roadmaps rely mainly on some stages, including initiation/preparation, identification of resources and areas for improvements, execution/implementation and evolution stage. The implementation and evolution stage is carried out under the DMAIC process (Felizzola Jiménez and Luna Amaya, 2014). Based on the reference roadmaps, Flor Vallejo et al. (2020) proposed five stages: prepare, plan resources and select projects, implement, sustain and expand. Trakulsunti et al. (2020) proposed a similar roadmap containing only three phases:

1. readiness;
2. preparation, initialization and implementation; and
3. sustainability.

The DMAIC process itself was considered as roadmap for implementing LSS. Kumar et al. (2006) adopted the five steps of DMAIC process to implement LSS in SME. The initiation and project charter were included in the define phase. Identifying the improvement areas was considered in the analysis phase after collecting the required data in the measure phase. Then comes the implementation of the lean tools in the improve phase. The cycle is then completed by the control phase that achieve sustainability. In addition Patel et al. (2019) proposed a roadmap with five steps that maps DMAIC steps with the lean principles/tools of (Value, VSM, Waste reduction, Kaizen, 5S and Perfection). Sreedharan et al. (2020) started their case study with “management approval”, team forming and problem selection, then they implemented the DMAIC. After the analysis phase, they suggested to present the process map of the manufactured part. And after the control phase, they proposed to implement the “sustain phase.” We found “process map” and “sustain phase” are redundant and they could be integrated, respectively, with the “analysis” and “control” phases of the DMAIC. Sunder et al. (2020) improved the customer satisfaction in the healthcare case study using LSS roadmap based on the traditional DMADV. Based on the literature, Alexander et al. (2022) proposed a four steps conception model: assess, create, execute and sustain. The assess phase is mainly to understand the current status. The second phase is to create the LSS implementation plan considering the business different attributes. The third phase is to execute the developed plan. The fourth phase is to sustain the improvement gained. Based on these roadmaps, LSS can be implemented by starting with a preparation phase before the DMAIC process.
3. Research methodology
In this study, a case study-based research approach was adopted to improve the performance of an iron and steel manufacturer. The methodology starts with the preparation phase. In such phase, the top management agreement and commitment should be obtained and deployed. After that, the main team of the performance improvement project should be identified and allocated with the specified hierarchy and authorities. After the preparation phase, DMAIC process was adopted as shown in Figure 1. It represents mainly, the main steps conducted by the organized teamwork. It starts with the define

![Figure 1. The DMAIC methodology for the implementation of lean tools in the case study](Source: Authors’ own creation)
phase; it identifies the main problem(s) and objectives through the organization of workshops with the industry experts. The second phase integrates the measure and analysis into only one phase. Two methods are adopted in this phase: the qualitative and the quantitative methods.

The qualitative method explores the experts’ opinions about the different system deficiencies, managerial policies, strategies, employees’ practices, policies of treating defects, etc. The performance improvement is everyone’s responsibility and the results are gain from the contribution of the whole employees. Employees’ opinions and evaluations cannot be ignored and should be considered. Employees’ opinion can be investigated via surveys with statistical analysis. Investigating the employees’ opinions can highlight massive root causes of the problems. First, a questionnaire was developed; it contains three sections. The first section gathers the participant profile, e.g. general information, company name, position, gender, age, experience, qualifications, lean training and attending conferences. The second section gathers the questions related to the lean implementation. It contains mainly the five lean principles and tools. The principles include “specify a value from a customer perspective,” “identify the value stream for processes with steps,” “value flow without interruption or wastes,” “customer pull system” and “perfection.” The tools include empowerment and root causes analysis. The third section contains a set of questions for the generic wastes: time-losses, defects, inventory and manpower. The Likert scale with five points was adopted. Academics and industrial experts validated the questionnaire. After that, it was distributed to the participant from the three companies (known here as C1, C2 and C3). The selection of the specific participant from each category was done randomly. Afterward, the responses were gathered. A number of 260 questionnaires were validated. The internal consistency of the responses was investigated using Cronbach’s $\alpha$. The Cronbach’s $\alpha$ was 0.835 for all responses that confirms the high internal consistency and the reliability of the data. The analysis relies on the responses’ mean, standard deviation, coefficient of variation and confidence interval plot.

The quantitative analysis is then adopted for sizing these root causes and prioritizing them. The shop floor metrics were collected from the three companies. The data was then analyzed using a set of statistical analysis tools using Minitab® software. For the major root causes, the performance improvements can be proposed to reduce or eliminate wastes. There is no generic lean tool. For each type of system deficiency, a specified lean tool can be proposed. The integration of these tools can make a great performance improvement. The interrelationships between the identified lean tools should be analyzed for prioritizing the initiatives that should be implemented first. The DEMATEL method can effectively perform such analysis (Seleem et al., 2018). For the prioritized lean tools, the lean implementation plan can be developed to identify the associated timeline. The followed step is to implement the suggested initiatives on the shop floor level. The monitoring and controlling phases are mandatory for preventing system from backsliding to old status and assuring the accurate execution of the lean processes. Finally, the results should be reviewed using suitable KPIs. A repetitive cycle can be required according to the satisfaction level.

4. Define problem and objectives
Due to globalization and open markets, local iron and steel producers are struggling to provide products at competitive prices. The prices of their products are often higher than those of the imported ones. However, most of these companies claim to adopt lean manufacturing and reduce wastes. The main objective is to improve the cost leadership strategy of iron and steel manufacturers by reducing production costs. Consequently, they...
can offer iron and steel products at competitive prices. The main problem can be defined by the following questions:

- **Q1.** What is the extent of the current implementation of lean principles/tools in the local plants?
- **Q2.** What are the main types of wastes in the iron and steel plants?
- **Q3.** What lean tools are required to eliminate/reduce production waste?
- **Q4.** What is the effective implementation plan for the proposed lean tools?

5. **Measure and analysis**

To achieve the previous objectives, a lean implementation methodology was proposed as illustrated in Figure 1. It is proposed to consider all the demographical nature of employees and their opinions. Accordingly, the significant variation between employees' evaluations in reasons of demographic changes should be investigated. The analysis is performed relying on real data from three companies that meet the following conditions:

- They are working in the field of steel “rebars.”
- Their aggregated local market share exceeds 50% of the production and sales volume.
- Factories with integrated production lines starting from melting to producing finished products.
- These factories were newly constructed. They are compatible with global technology.

5.1 **Qualitative analysis**

The extent of lean implementation in the specified companies was covered by 21 queries. Relying on the responses overall mean, the disagreement of the application of lean principles and tools is concluded. Where, the obtained average < (µ = 3 on Likert scale). That indicates a disagreement of responses with about 51.61%. For the inventory wastes, a set of 25 queries were used to investigate the inventory-related wastes and their root causes. The responses show an overall agreement with \( \bar{x} = 3.49 > \mu \) and \( \bar{x} = 0.41 \) at 88.19% for many inventory related-aspects. These aspects can be used to characterize the inventory of the iron and steel industry. For example, there is a delay between the purchase requisition and supply due to the increased period of:

- having offers from suppliers;
- technical evaluation of bids;
- financial evaluation;
- issuing supply orders and preparing contracts; and
- customs clearance and logistics.

The inventory level increases according to the increased consumption level and increased lead-time. The stores have stagnant stock. Purchase requisitions require multiple signatures. Relying on such characteristics, the lean is not implemented in the inventory system of iron and steel industries.
The different factors related to time waste were also investigated using 20 queries. These factors gather different aspects e.g. management practices, maintenance planning and implementation, resources availability, problem analysis, lesson learned and feedback, communication, coordination, information accuracy and information technology. The agreement is concluded for the existence of time losses where $\bar{x} > \mu$. The analysis highlights some characteristics for the iron and steel firms: The planned downtime can be reduced by good communication and effective coordination between stakeholders during planning, execution and monitoring. The planned downtime can be reduced by lessons learned and feedback. The unplanned downtime occurred in reasons of shortage of material or energy, or lack of effective maintenance programs. The maintenance downtime represents one of the major time losses in the firm. The equipment downtime can be reduced by adopting the scientific methods of failure analysis, treatment of failure root causes, forming multidisciplinary authorized teamwork. There work implantation process follows a bureaucratic system with many signatures and authorizations. There is a lack of having the right information at the right instance. Based on these characteristics, one can conclude that the investigated companies start to implement lean however there are many time losses.

In addition, wastes of the defective outcome can present in the form of material, energy, utilities, production time, workforce capacity, etc. The increase in the defective outcomes increases the production costs. The different defects and their reasons in iron and steel companies were investigated using 18 quires. The questions show an overall agreement with an $\bar{x} = 3.68 > \mu$. Besides, it shows practical implications with wastes for many divisions. As example, the rejected or recycled portion of the final products represents a loss for the company. The imported scrap may contain dust, rubber, plastic, concrete/stones, wood [..] etc., which forms a loss percentage. A proportion of the final products is lost due to non-conformity to specifications. The rejected and recycled products can be reduced. The low yield of inputs is due to the non-conformity of steel scrap or sponge-iron and increased by-products during the production stages. Accordingly, the iron and steel firms have many defective related wastes.

The manpower losses were investigated using 17 queries. Many business aspects were investigated include recognition manpower, training, talent management, overtime, absenteeism, lateness, sick leave, job rotation and availability of working tools. The responses show an overall agreement with $\bar{x} = 3.47 > \mu$. The agreement is obtained for many manpower losses. For example, the excess overtime is produced due to the bad distribution of the workforce. Leaves due to injuries is one of the company losses. The factory uses overtime due to the poor employment of the available workforce. Employees’ lateness is one of the elements of loss in the company. Sick leaves are a form of the elements of loss in the company. In conclusion, there are many faces of the underutilization of the workforce. The reasons behind them could be related to management, cultural and social aspects.

5.2 Quantitative analysis
According to the analysis of experts' opinions, the application of lean production is weak in the considered local iron and steel companies. It is also confirmed that there are many wastes in the form of inventory, time-losses, defects and manpower. The data were collected from the three companies over five successive years for the quantitative analysis. For benchmarking, IBM is considered. These IBMs are taken as the best numbers among the three companies. Consequently, the differences between metrics of the three companies and that of IBM can be noticed. Meanwhile the researcher is expecting a higher difference compared to the international benchmarking.
5.2.1 Inventory metrics. The inventory contains many items e.g. spare parts, consumable materials/items and tools. These parts are critical for the continuity of the production processes. The different inventoring data were collected from the three companies over five years represent:

- Lead time: the total time from requisitioning of the part until its availability for use on the shop floor.
- Purchasing time: the period between the part requisition and the issue of the purchasing order.
- Part receipt time: the period between issuing of the purchasing order and receiving part at warehouse.
- Inspection time: the time interval between having a part in the warehouse and end-inspection.

These metrics are illustrated in Figure 2 for spare parts, consumables and tools. As shown in Figure 2(a), the lead time of spare parts for C2 can be considered the best value (IBM). Consequently, there is a big difference between the lead-time of C3 and IBM (115 days), and that of C3 and IBM (121 days). As shown in Figure 2(b) and (c), the performance of C2 is better than C1 and C3 in almost all criteria. These noticed differences are produced due to many reasons, e.g. the increase in the period between issuance of purchase requisition and issuance of the purchase order. The increase of the period between the issuance of the purchase order and the receipt of items in warehouse. The increase of the period between items receipt in warehouse until completion of the technical inspection. These gaps should be eliminated to reduce costs:

In such industry, there are many other materials, parts or utilities used e.g. refractories, graphite electrodes, high carbon ferro manganese (HC FeMn), silicon manganese (SiMn), ferro silicon (FeSi), carbon, burnt lime (calcium oxide), ladle furnace, oxygen, electricity for the electric arc furnace (EAF) and natural gas. The consumption rates of these ingredients should be optimized for reducing wastes. Figure 2(d) presents the comparison between consumption's results of the three companies and the best metric (IBM). As shown, there are gaps in the different consumption rates for many reasons such as long process time and low quality of materials. From the technical practice, increasing scrap mix affects positively the operating conditions and consumption rates. These gaps represent the volume of waste that negatively affects the volume of inventory investment and increases costs.

5.2.2 Time metrics. As plotted in Figure 3, the investigated time metrics are scheduled stoppage, unscheduled stoppage and the time delay due to equipment breakdowns. In addition, the two metrics for availability were investigated (plant availability and operations availability). As shown C2 represents the best results in almost all-time metrics, can be considered as the IBM. The differences between metrics of C2 and that of the other companies represent the gaps of time performance. These gaps reflect the level of waste due to time losses during the production stages because of losses between the later stages, power cuts, stock out and poor maintenance of machinery and equipment, plus underutilization of the plant production capacities due to finished products imports from the foreign market; all these issues increase costs.

5.2.3 Quality metrics. For the quality metrics, the data collected include scrap impurities, defective production, by-products, scraped production, the yield of the used metallic and the yield of the total deliveries. First, Figure 4(a) shows that there is a gap (higher impurities) between supplied scrap impurities and IBM. There is also an increase between the defective production ratio and the generation rate of by-products. Besides, there is high scrap generation in one company. Figure 4(b) shows different gaps (low yield) between the yield of
inputs before/after scrap segregation and IBM. These gaps represent the volume of wastes due to supplied scrap impurities, scrap production and defective production. This situation negatively affects productivity, yield and costs and confirms the waste hypothesis due to defects.

**Notes:** (a) Spare parts; (b) consumables; (c) tools; (d) materials

**Source:** Authors’ own creation

Figure 2. Comparison of inventorying metrics for the three companies
5.2.4 Manpower metrics. Overtime, vacation time and average labor efficiency are used to investigate manpower. Labor efficiency is the average number of hours required to produce one ton of steel rebars. Other metrics were considered e.g. sick leave, absenteeism, lateness and left time due to work-related accidents or injuries. Figure 5 shows the different percentages of these metrics for the three companies. The figure shows low personnel efficiency compared to an average of 2 h per ton for American iron
and steel companies, while many American companies achieve 1 h per ton (Elliott et al., 2013). High man-hours/ton increase costs due to methods, training and weaknesses of management techniques. The low worker efficiency is due to low-capacity use of the factories because of imports from foreign markets that cover more than 20% of domestic consumption (World Steel Association, 2017) due to the low efficiency of the local product compared to the global products. Underutilized manpower is not limited to physical utilization as well as intellectual and innovative, and these results confirm the waste of manpower.

5.3 Major root causes
Based on the analysis above, the internal reasons behind high production costs at local iron and steel products can be identified as listed in Table 1. It includes mainly four sectors: inventory, time-losses, quality and manpower:

- The inventory wastes are appeared in long lead-time and increased inventory levels. Delays in supply stages initiate the long lead-time, the complex warehouse operations of inspection, the decision for rejected items, the bureaucratic system, complex bidding and variation in consumption rates. Together, the high inventory levels are formed due to the weak utilization of by-products and the stagnant stock of spare parts, consumables, tools or by-products.

- Time-losses can be found as idle time, setup, downtime or waiting times. These losses are due to less communication, coordination, monitoring, slight use of analytical tools, lesson learned and feedback, bureaucratic system, long supervision line, information quality, shortage of material/spare parts, shortage of energy elements and equipment breakdown due to lack of the effective maintenance programs. These causes produce complex procedures, imbalance of production processes and long response time, resulting in loss of production time.

- Quality problems are produced due to inefficient quality management systems. The production wastes are produced due to defects resulting from increased scrapped products, downgraded products sold at low price and defected products that require additional processing, wastes of raw materials and repeated errors.

- The wastes associated with manpower are formulated for reasons of employees’ lateness, injuries, sick leaves and use of overtime. On the other side, many wastes are formulated for reasons of the management systems, e.g. lack of exploiting

![Figure 5. Different metrics of the manpower for the three companies](image)

*Source: Authors’ own creation*
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<tr>
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<td>Hoshin Kanri (link strategies to shop-floor operations)</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Lack of feedback from the lesson learned</td>
<td>Propagation of lesson learned and knowledge sharing</td>
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<tr>
<td></td>
<td>• Setup-time</td>
<td>Lack of employees training for reduction of setup time</td>
<td>Provide training program</td>
<td>TLI-9</td>
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<td></td>
<td></td>
<td></td>
<td>Single-minute exchange of die (SMED)</td>
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<td></td>
<td></td>
<td></td>
<td>Theory of constraints (TOC) with “drum buffer rope”</td>
<td>TLI-11</td>
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<tr>
<td></td>
<td>• Idle-time</td>
<td>Imbalance between the production processes</td>
<td>Perform line balancing</td>
<td>TLI-12</td>
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(continued)
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<thead>
<tr>
<th>Focus area</th>
<th>Constraints</th>
<th>Root causes</th>
<th>Proposed improvement/lean tool</th>
<th>Symbol</th>
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<tr>
<td>Waiting-time</td>
<td>Bureaucratic system with long supervision line and many signatures</td>
<td>Standardization of administrative processes Process analysis for simplification Single-line authority with short supervision Self directed work teams Andon system Management commitments Hoshin Kanri</td>
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<td>Set specification for the steel scrap</td>
<td>QLI-3</td>
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<tr>
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<td>Increased by-product</td>
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<td>Poka-Yoke</td>
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<tr>
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<td>Work analysis and load balancing</td>
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<td>Injuries</td>
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<td>Review health and safety</td>
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<td>Fatigue, moral, social etc.</td>
<td>Set recognition and motivation programs</td>
<td>MLI-11</td>
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<td>Illness and lateness</td>
<td>Set disciplinary rules for absences</td>
<td>MLI-12</td>
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**Source:** Authors’ own creation
workers' innovative skills, lack of multiskilled workforce, inadequacy workplace, lack of training and insufficient working tools.

After measuring all these wastes, it became very important to provide suitable lean tools to eliminate these sources of wastes and to implement a cost leadership strategy. Accordingly, the next section presents the proposed framework for implementing lean manufacturing.

6. Improvement and lean implementation
After system diagnosing and highlighting the main root causes of the problem, lean tools can be proposed. However, three generic prerequisites are proposed to be implemented first as a preparation. The first is the management commitment. It is important to define the performance improvement teamwork, identify the responsibilities, identify the level of authority and provide the required support. The top management adopts the application of the lean production system by achieving stability, uniformity and discipline, and forming a specific workgroup responsible for implementation. The second is manpower rehabilitation. It is necessary to perform the necessary orientation and provide training programs, workshops or visits for workers and employees. These programs motivate workers to participate in performance improvement programs and overcome the problem of resistance to change or backsliding to old methods of work. The third prerequisite is the identification and mastering of the different lean tools. Adopt the principles of the lean production system, which include value determination, value stream flow, continuous flow, pull system, the pursuit of perfection, etc. After implementing these prerequisites, lean tools can be proposed and implemented.

6.1 Improvement initiatives
The quantitative analysis highlighted some constraints for performance improvement in the inventory, working time, quality and manpower. Table 1 shows the detailed constraints for each dimension and the assigned improvement initiative(s).

6.2 Implementation plan
First, the proposed lean initiatives are analyzed to have a feasible sequence. The interrelationship between them was analyzed using the DEMATEL method (Seleem et al., 2018). The lean tool that has a great effect on others is proposed to be implemented first. In addition, the implementation period for each activity was estimated by factory experts. Consequently, the Gantt chart of the project was developed and the initiatives in the proceeding phase are selected to support the implementation success of the successive phase for each direction (inventory, time, quality and manpower).

6.3 Control phase
The suggested performance improvement initiatives have been started for implementation at the beginning of 2019. Many KPIs are used to control and monitor the implementation process as shown in Figure 6.

7. Results and discussions
According to the agreement of data confidentiality that was conducted with the company, only a sample of the data can be published. According to the agreed sample, Figure 6 is developed. It compares the average values of a set of KPIs before implementing the lean and the corresponding records at the end of 2019 and 2020. As shown by Figure 6 and after
Figure 6. The impact of lean manufacturing implementation on (a) inventory turnover (b) by-product (c) availability (d) production time losses (e) throughput (f) scrap and downgraded quantities (g) man-hour/ton and (h) workforce losses.

Source: Author’s own creation
24 months of starting lean practicing and implementing many initiatives, several achievements can be highlighted. For example, the average inventory turnover was improved by about 54%. One of the high achievements is the revenue from by-products as shown by Figure 6(b). The average revenue from by-products was increased by about 459% compared to the average revenue before lean implementation. Initiatives are implemented in the third phase; their impact is not yet documented. These initiatives include the recycling of the by-products internally, the establishment of an effective budgeting system, and the effective usage of the ERP system. Regarding the implantation of the just-in-time and Kanban system, until the moment, the company fails to implement it for many reasons e.g. more than 80% of steel inputs were imported from foreign markets. Besides, the local suppliers have a low capability to fulfill their commitments.

The availability was improved remarkably as noticed from Figure 6(c). The average operation availability after lean implementation was increased by about 45%, while the average plant availability increased by about 41%. Regarding the time losses, a set of good achievements was noticed for example the average delay was reduced by about 78% compared to the average values before lean implementation. The unplanned maintenance activities were reduced by about 51% from the average values before implementation of workers training, effective management programs, reduction of the six big losses, team-working use of information systems and CMMS that lead to a reduction of the time needed to perform maintenance activities.

Moreover, the scheduled downtime is increased by about 13%. This slight increase had been explained by the high usage of equipment (operating them with full capacities). On the other side, the average delays were 30% from the calendar time before lean application, decreased to 4% in 2019, and increased to 9% in 2020 due to plant operation with full capacities for a long time. Besides the OEE, FMEA analysis and total productive maintenance are planned to be performed in the third phase that focuses on reducing unplanned downtime.

Another good achievement is the remarkable increase in factory throughput. As shown in Figure 6(e) an average increase of about 70.6% was achieved for the throughput. The average percentage of downgraded products was also reduced by a satisfactory percentage of 63.3% compared to the average percentage before lean implementation as shown in Figure 6(f). On the other side, there is a fluctuation in the average percentage of scape. It increases in 2019 to 0.17% then reduced in 2020 to 0.12% compared to an average value of 0.09% before lean implementation. This behavior could be explained by adopting multi-disciplinary teams and job rotation that disrupted the production system at the beginning. Another reason is the late implementation of the Poka-Yoke and the Jidoka.

Concerning the workforce, a good achievement was noticed after the implantation of the second phase. For example, the average man-hour/ton was reduced by about 52.4% compared to the average value before implementation, as shown in Figure 6(g). The reduction of man/ton is achieved due to the implementation of motivation, training programs, forming of working groups, job rotation and load balancing. Besides the commitment of workers and employees were increased. As shown in Figure 6(h) the average percentage of employees who make tardiness was decreased from 1.07% to 0.00025%. Moreover, the average percentage of employees who make absenteeism is reduced from 0.18% to 0.1% with a reduction percentage of about 44.4%. The increase of the commitment level is produced in reasons of implementing the disciplinary rules. On the other side, the average percentage of employees who take sick leave is increased from 1.6% to 2.1% compared to an increasing percentage of about 31.3%. The utilization of overtime was not changed during the first two phases. On an average basis, it remains around 8% of the total time worked. The reason behind this constant overtime is the late implementation of
initiatives that can reduce overtime, e.g. load balancing with redistribution of the workforce, value stream mapping, lean thinking and Kaizen. Conversely, the unchanged overtime percentage is a good result considering that the throughput was almost doubled in 2020.

8. Conclusions
The current research presents a case-based analysis for implementing lean manufacturing in iron and steel plants. Based on the facts discovered, the following problems can be concluded: the main wastes in iron and steel manufacturing are related to inventory, time, quality and workforce. Before the implementation of lean six-sigma, the preparation step should be conducted to assure management commitment and forming of an authorized work team. The management committee should allocate sufficient implementation time for each lean tool. For effective investigation of a manufacturing system, using qualitative analysis besides the shop-floor data is an effective way to listen to the voice of industry experts. All company sectors should participate in the performance development programs, to reduce production wastes effectively. The effective implementation of lean tools is capable of reducing/eliminating most of the production wastes in the iron and steel industry. After identification of the improvement lean initiatives, the interrelationships between them should be investigated to identify their effect on each other. The causals lean initiatives should be implemented before the results ones. As perspectives, the uncertainty of expert evaluations can be considered in the quantitative analysis and DEMATEL analysis, e.g. fuzzy judgement could be considered. Besides, the current authors are motivated to implement the lean 4.0 in iron and steel industries.

References


Further reading


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