Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management
Bali, Indonesia, January 7 – 9, 2014

Innovative Implementation of Several Lean Principles in a Flat Steel Plant: a Case Study

Sameh M. Fahmi, Tamer M. Abdelwahab, Yaseen Amin, Mohamed S. Emam, Haytham Youssef & Ahmed Ragab
Al Ezz Dekheila Steel Co. (EZDK), Alexandria
Al Dekheila, Alexandria, Egypt

Abstract

This paper describes innovative methods used to overcome the challenges for applying several lean principles in flat steel production. Enhancement of production leveling was achieved through a mix of make-to-order and make-to-stock. A smart allocation method was applied based on small lot production/shipment. In addition, innovative cooling method was developed and implemented in order to decrease the cycle time and help discover defects early. The results show that the percentage of contracts shipped within 3, 6, 9, 12, and 15 days of contract issuance date increased by 97%, 76%, 55%, 44%, and 41% respectively. The average time from start of production to shipping was reduced by 17%. Better utilization of yards, early discovery of defects, smooth operation during lack of customer orders were results of those practices. This case study shows that innovation is essential in implementing lean principles in specific industries and work environment where it seems usually not possible to apply them.

Keywords
Lean manufacturing, production planning, steel industry, mixed model production**,** delivery time, flat steel, forced cooling, small lot size, lead time, Heijunka, group technology

1. Introduction
The positive results of lean manufacturing has been reported in many studies (e.g. Fullerton and McWatters, 2001; Fullerton, McWatters, and Fawson, 2003; Huson and Nanda, 1995) such as: less cycle time (sometimes called throughput time), less work-in-process, less rework and defects, less plant troubles, shorter time to respond to market changes, increase in on-time-delivery, increase in employees morale, and improvement of financial measures on the long term. These results encouraged companies from different sectors and in different parts of the world to implement lean manufacturing (e.g. Huson and Nanda, 1995, Sakakibara, Flynn, and Schroeder, 1997).

Lean manufacturing consists of many elements (principles) such as set up time reduction, pull system, production leveling (Heijunka), small lot size, quality control circles, group technology, total quality control, and total productive maintenance. Those elements support each other (e.g. Schonberger, 1982, Liker, 2004, Fahmi and Hollingworth, 2012). Lean manufacturing elements are implemented through a culture of waste elimination, root cause analysis, mistake proofing, visualization (visual plant), respect for employees, simplification, focus on shop floor (Gemba), and standardized work.

There is a limited number of studies on implementing lean manufacturing in steel plants. Most of them are proposing how to implement lean manufacturing in steel industry rather than showing the results of real implementation. . Abdallah (2003) explained that steel industry can reduce lead time and work-in-process by applying lean manufacturing. Abdelmalek and Rajgopal, (2006) suggested that 5S, visual systems, and value stream mapping are applicable in steel industry, while set up time reduction, production leveling, total productive maintenance, and just-in-time are partially applicable. Dhandapani, et al. (2007) showed how a steel plant at India can reduce production cost and lead time by implementing lean principles.

Fahmi and Abdelwahab (2012) described a case study of applying several lean manufacturing elements in the production planning of a steel plant (EZDK). Those elements included: production leveling, pull production, creating flow, and Gemba. They presented results which included reduction of work-in-process (WIP) and Lead time besides less variability in downstream plants loading.

This paper deals with more innovative steps towards applying lean manufacturing at the same steel plant in Egypt (EZDK). In the next section, EZDK flat steel plants and the production planning challenges are described. Section 3 describes the implemented lean steps: Common Market Demand, smart allocation, and forced water cooling. Results are presented in section 4. Finally, a brief introduction to future work is presented.

2. Production Planning of Flat Plants

The main process of EZDK flat production is a continuous process consisting of one Electric Arc Furnace, one Caster, and one Hot Strip Mill. The raw materials are melted in the Electric Arc Furnace, and then the molten steel is cast in the Caster into slabs with the required width and a thickness of 52 mm. Those slabs are rolled in the Hot Strip Mill to reduce their thickness and produce Hot Rolled Coils (HRC) with the required width, thickness, steel grade and weight. This plant produces coils with width from 900 mm to 1600 mm, thickness from 1.2 mm to 12.7 mm, dozens of steel grades, and coil weight from 8 t to 27 t. The plant produces about one million tons of HRC per year.

The Electric Arc Furnace has a capacity of 160 t which means that it operates with batch production of 160 t of molten steel known as “heat”. Each heat consists of one steel grade only. The continuous process (sequence) lasts for more than 10 consecutive heats (more than 1,600 t) then the Caster has to stop to get prepared for the next sequence. Decreasing the sequence length increases the production cost because some expensive materials have to be changed each sequence. There are several constraints for the products included in the same sequence such as: coils should not have width difference more than 100mm, sequence should start with larger width to smaller one, and sequence should start with a high thickness 3 or 4 mm and then, if needed, it can be reduced from coil to the next through certain steps. Furthermore, not all grades can be produced in the same sequence.

Table 1 shows a simplified example of the first three heats of a sequence. Each heat has a weight of 160 t of the same steel grade. Each heat is divided into several coils with specific weight based on the customer request. For example heat number 3 has a steel grade M and is divided into 8 coils with the same weight (20 t) for two contracts C15 and C4. In order to produce a steel grade, there should be a customer order (contract) of 160 t or its multiples. In some cases, the production of a customer order will be delayed until there is another customer requesting the same grade. For example, if there was one order for 120 t of steel grade M, then we would have either to postpone production or to produce it now and keep 40 t in our stock for unknown period and may eventually sell it at discount.

Table 1: Simplified example of the first three heats of a sequence

<table>
<tr><td>Heat #</td><td colspan="12">1</td><td colspan="9">2</td><td colspan="8">3</td></tr>
<tr><td>Heat Weight (t)</td><td colspan="12">160 t</td><td colspan="9">160 t</td><td colspan="8">160 t</td></tr>
<tr><td>Steel Grade</td><td colspan="12">A</td><td colspan="9">A</td><td colspan="8">M</td></tr>
<tr><td>Coil Weight (t)</td><td>16</td><td>16</td><td>16</td><td>16</td><td>16</td><td>12</td><td>12</td><td>12</td><td>12</td><td>12</td><td>10</td><td>10</td><td>21</td><td>21</td><td>21</td><td>19</td><td>19</td><td>11</td><td>14</td><td>17</td><td>17</td><td>20</td><td>20</td><td>20</td><td>20</td><td>20</td><td>20</td><td>20</td><td>20</td></tr>
<tr><td>Contract#</td><td colspan="5">C9</td><td colspan="5">C1</td><td colspan="2">C23</td><td colspan="3">C30</td><td colspan="2">C17</td><td>C2</td><td>C8</td><td colspan="2">C18</td><td colspan="6">C15</td><td colspan="2">C4</td></tr>
</table>

The flat steel is produced in the form of Hot Rolled Coils at a high temperature (around 600 ^{o}C) and then left for few days to cool down naturally. After cooling, more than 60% of the coils need to be processed in one or more of the downstream processes. There are several downstream plants: Skin Pass, Pickling, Slitting, Light Cut To Length, and Heavy Cut To Length. The coil takes one route or another through those different plants based on the customer demand.

The planning team of the flat steel plants has to satisfy customer needs including: steel grade, thickness, width, type of processing, packing type, coil weight range, and short delivery time. In addition, they have to consider all plants technical constraints. Dealing with all these complications while trying to minimize stock is very challenging.

Local and export sales contracts differ in their specifications and pattern of shipping. Regular local customers make requests on monthly basis and most of them request the same specifications each month. They transport their products from EZDK several times every month and pay the company prior to shipping. In some cases, the customer may keep his products at EZDK for several weeks which may lead to problems in the storage yards. On the other hand, foreign customers’ requests are shipped as one batch and they vary from one contract to another except for few products which are requested regularly.

The flat production planning team at EZDK consists of five engineers. Recently, this team has applied several lean principles and achieved positive results (Fahmi and Abdelwahab, 2012). In order to go further in the lean journey, the team took further steps by moving from make-to-order to a combination between make-to-order and make-to-stock to level the production, and by applying small lot size in the allocation from company stock to customer order, besides decreasing the cycle time from 6 days to 1.5 day for specific family of products. The rest of this paper explains the implementation of those steps and the results of this case study.

3. Description of the Lean Steps

3.1 Common Market Demand (CMD)

Production leveling by applying Mixed Model Production has been applied by Toyota and described in the literature (e.g. Ohno, 1986; Shingo, 1988; Liker, 2004). The basic idea is to level production by volume and mix so that there is no sudden demand on the upstream processes to produce large batch of any product. Such sudden demand will cause disturbance to the pull system, some processes stoppage, and delay in delivery. Mixed Model Production means that the plant produces a mix of products each day with quantities equal to the average daily demand of each product. For example, if the expected weekly demand of products A, B, C, and D is 70, 140, 35, and 14, then the plant should produce every day 10 of A, 20 of B, 5 of C, and 2 of D.

Production leveling by mix is not an easy task for a flat steel plant with infinite number of products based on the mix of thickness, width, steel grade, weight, and special processing that the customer request. This big number of products forced the plant to work with make-to-order production. Thus the plant had to produce whatever products ordered at that time. Although production planning team tried to reduce batch size, apply pull system, and apply production leveling by producing a variety of products each day starting from mid-2011 (Fahmi and Abdelwahab, 2012), yet, in some cases they did not have the opportunity to produce a variety of products due to limitation of ordered products. This led to a production of certain products at certain times which, in turn, led to overload of some downstream processes and/or high demand on specific raw material additives at those times.

In November 2012, the production planning team decided to search for products which are requested frequently by more than one customer. The team called this idea Common Market Demand (CMD). The basis of the study was a period of one year. Products that were requested in 80% of the months by several customers were considered as CMD products. The team was surprised to find dozens of products that are requested every month. It was also found that some products can be grouped and produced as the same product. For example, if the products share the same dimensions and grade but differ in the downstream process then those products can be produced as the same product and processed later differently based on the customer request. In other cases, the products are similar except in the coil weight range requested by every customer. In this case, a coil weight range that satisfies most of the customer requests was specified for the CMD product.

The team wanted to apply Kanban in producing those CMD products; however, it had to be electronic Kanban which needs a sophisticated programming. In addition, the minimum order quantity in a flat steel plant is, in reality, a dynamic value because it depends on other available products to be produced with the same steel grade and almost the same width. Finally the team decided to apply the idea with a more simple approach. A maximum stock of each product was defined as:

*Maximum Stock = (Average Daily Demand * Lead Time of Production in days) + Minimum Order Quantity*

Lead time was assumed as 8 days for all products. Minimum order quantity was different from one product to another and was generally controlled by the size of the heat (160 t) unless there are other CMD products with the same grade. In 2013, the minimum order quantity was reduced gradually for several products. When the stock of a product is less than the maximum stock, the planning engineer tries to compensate the shortage in the coming days.

The result was identifying 55 products that are requested frequently. Later, the number increased to 75 products which constitute about 75% of the local demand and 50% of the total demand. The CMD products are produced frequently regardless of the existence of customer's order. The planner tries to replenish the stock of each product up to the maximum stock of it. The demand of each of those products was checked periodically and resulted in eliminating some products and changing the maximum stock quantity of others. Other products were added to the list based on recent demand from customers. The maximum stock of all CMD products is less than one week of production and the average stock is about four days of production.

3.2 Smart Allocation Method

Applying production leveling is easier when the demand is leveled. It would have been very useful if the customers ship the product in small quantities every day or every week. Unfortunately, this is not easy to achieve at the moment due to several reasons related to economy, contract terms, customer manufacturing process, customer culture … etc. Customers used to request large quantities which they may need in one/two/three months and without a clear partial shipment plan. As a result, large quantities were produced and waited for customer to ship them. Increased stock means loss of opportunity to generate cash and sometimes a plant stops due to lack of space in its yard. Later, this method was modified by producing a certain percentage of the contract and resuming the production after the customer starts shipping. This led to delay in reacting to customer sudden shipment. The production planning team faced a challenge to minimize stock, improve cash flow, and deliver on shorter time under those conditions.

In light of lean principles of small lot size and producing/delivering Just-In-Time, the production team developed a smart method to match customer stochastic demand, apply production leveling, and shorten delivery time. Instead of producing large quantities for specific customer, many products were produced for stock (Common Market Demand) and then allocated (assigned) to customer contracts with small quantities. For example, if the customer requests 1,000 t of specific product, the production team allocates 200 t only, and when they get shipped then another 200 t will be allocated. Smart allocation Method tries to match allocation with the shipping rate so that we are creating a pull system and allocating stock to as many customers as possible. Figure 1 describes the main concept of smart allocation where small quantities are allocated from CMD to several contracts, while in the traditional large batch allocation the old contracts gets large batches of final product while the most recent contracts have no product ready for shipping. In smart allocation, the shipping is the signal for more allocation, while in the traditional way the allocation is not related to the shipping rate.

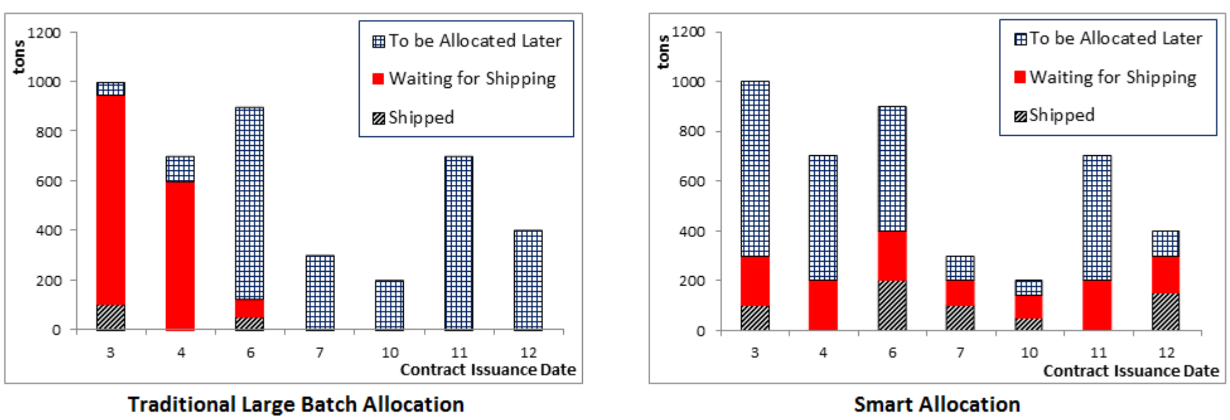


Figure 1: Comparison between traditional large batch allocation and smart allocation

The implementation was not easy because it is against the traditional culture of sales representatives and planning engineers themselves. Sales representatives did not like to have small quantity allocated on large contract and they wanted to have large quantity allocated. Planning engineers used to produce the entire contracts and get done with them. Gradually, sales representatives started trusting the smart allocation and planning engineers liked the smart allocation because they saw its results on decreasing stock and satisfying several customers' demand.

3.3 Forced Water Cooling

Flat steel is produced as coils at temperature of about 600ºC. It takes 4 days in winter and 6 days in summer to get the coil cooled from 600ºC to 40ºC in order to be inspected/processed at the next step. This means that it takes 4 to 6 days in order to discover any quality problem and/or to get the coils processed at the downstream plants. This led, sometimes, to delay in delivery because the cycle of discovering defect and reproduction is long.

In order to minimize the lead time and discover any defects earlier, the team tested and implemented a new cooling method. Since the measurements of the cooling curve showed that it takes less than 24 hours to get the temperature down to 200ºC, the team started thinking about forced cooling from 200ºC to 40ºC which may save 3 days in winter and 5 days in summer (see Figure 2 below). An experiment was conducted, in October 2012, to test the forced water cooling of a coil after about 17 hours of production time. The results showed that the coil was cooled to 40ºC in few hours. All mechanical and metallurgical tests did not show any negative effect of this cooling method.

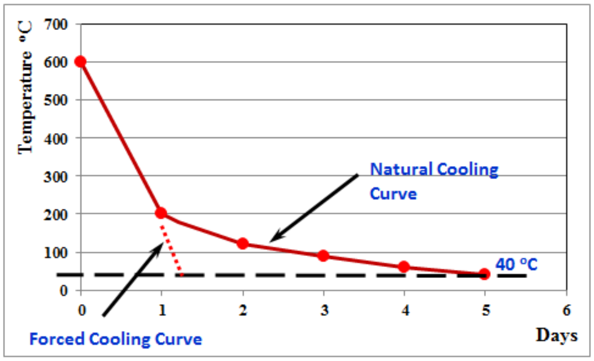


Figure 2: Cooling curve with/without Forced Water Cooling

A small cooling basin, which can cool three coils at the same time, was fabricated and waste water was used as a cooling liquid. With a water flow of about 70 m^3/hour, three coils are cooled down from 200ºC to 40ºC in less than 2 hours instead of 4 to 5 days. This resulted in processing coils after 24 hours of production. This cooling method was put into operation in February 2013 and is used only with coils that will be pickled after cooling.

4. Results

The results of applying Common Market Demand, smart allocation, and forced water cooling are presented in this section. Since the idea of Common Market Demand (CMD) was applied starting from November 2012, the results of 2013, which includes the last two months of 2012, is compared with previous years. So, the results of 2012 do not include November and December 2012, as they are included in the results of 2013.

4.1 Reduced Delivery Time

A comparison between the percentages of local contracts accumulated weight shipped within a number of days after the contract issuance shows how this percentage increased significantly after applying production leveling and smart allocation method. Figures 3 and 4 show the percentage of local contracts accumulated shipping after 3, 6, 9, 12, and 15 days of contract issuance date. In average, this percentage increased by 62.4% in 2013. The percentage of increase was inversely related with the number of days. For example the percentage of increase for 3 days was 97% while the percentage of increase for 15 days was 41%. This is expected because the lead time of production is 6 days which means that any allocation prior to 6 days is not possible unless the coil was already produced as CMD product and then allocated to the contract when the contract was issued.

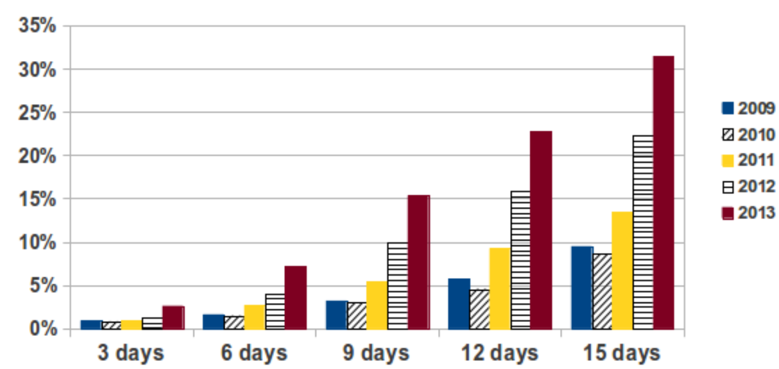


Figure 3: Percentage of local contracts shipped within 3, 6, 9, 12, and 15 days

It is obvious that the percentage of shipping started improving in 2011 and 2012 due to the basic implementation of

Heijunka and pull production from mid-2011 which resulted in shorter lead time, and this was enhanced in 2013 by applying CMD and smart allocation. The greatest improvement in 2011 and 2012 was in the percentage of shipping after 9 days and 12 days of contract issuance because the average lead time was reduced at that time from 10 days to 6 days (Fahmi and Abdelwahab, 2012). It is worth mentioning, that the total quantity shipped for local/export contracts did not have effect on this improvement because the correlations between the average monthly shipping of local/export contracts from 2009 to 2013 with the percentage of shipping in 3, 6, 9, 12, and 15 days are very small (less than 0.17). The changes of the shipping percentage every month are presented in Figure 4 below.

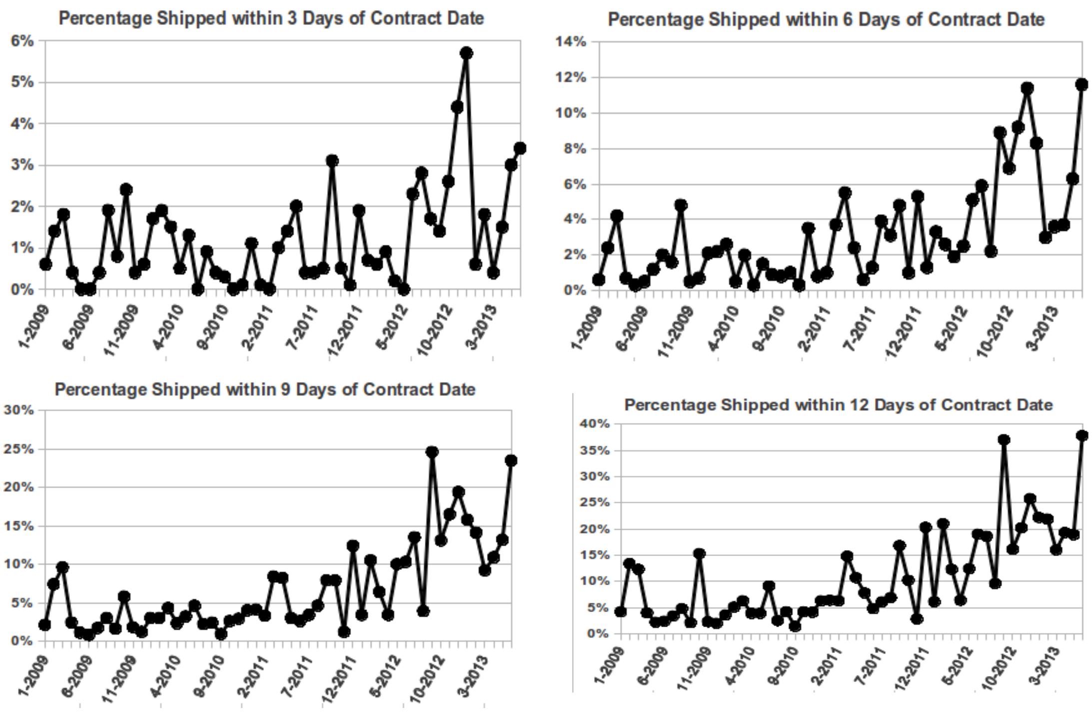


Figure 4: Change of the percentage of local contracts accumulated shipping within 3, 6, 9, and 12 days

4.2 Improved Cash Flow

By using the smart allocation method together with CMD, the number of days between start of production and shipping was reduced by 16.9% as shown in Figure 5. The average time from start of production to shipping (Jan 2010- October 2012) was 21.4 days and after applying smart allocation and CMD (November 2012- June 2013) it reached 17.8 days with a reduction in standard deviation by 16.2%. Decreasing the number of days from start of production to shipping improves cash flow because the local customers pay at the time of shipping. Moreover, it leads to better utilization of final product yards.

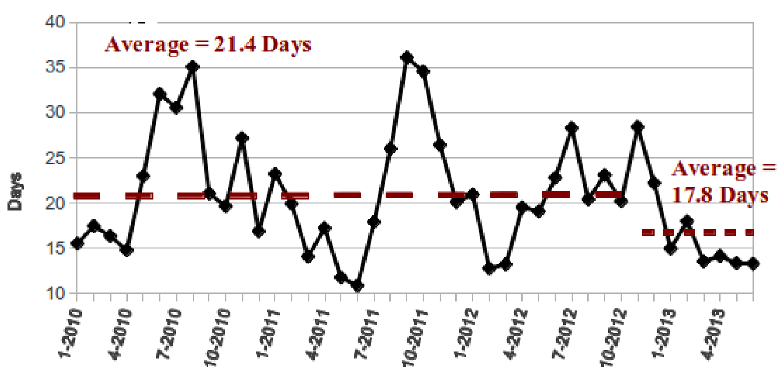


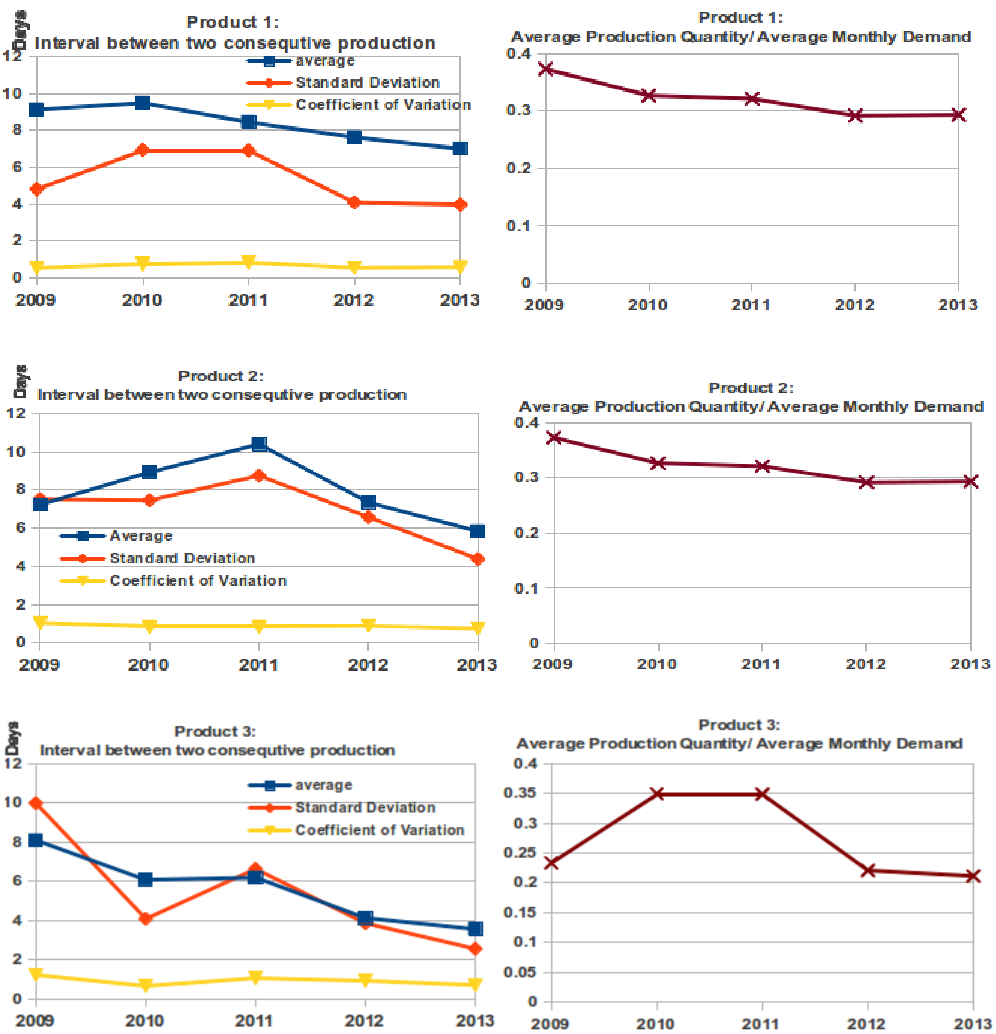
Figure 5: Average Number of Days from start of production to shipping

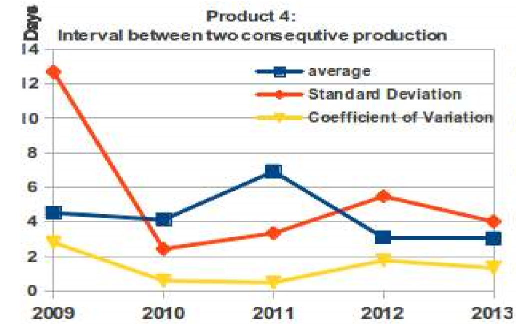
4.3 More Leveling of Production by Product Mix

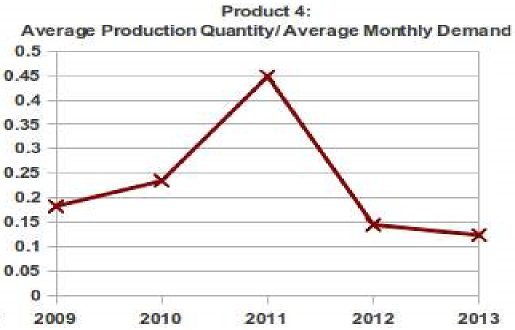
By having 75 products to be produced frequently, it was easier to level the production by producing a variety of products each day. In previous days, this leveling was limited by the available contracts which may or may not allow producing various products daily. The reduction in the interval between two consecutive production batches of the same product is used as a measure of production leveling. The ratio between the batch size (average production quantity) and the average monthly demand is used as a measure of small lot production.

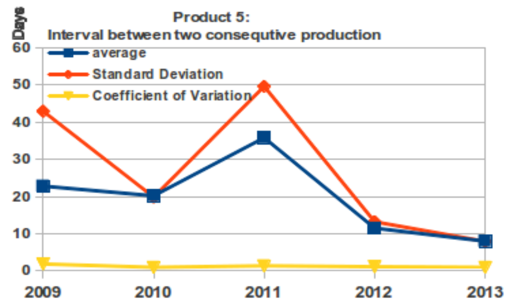
Figure 6 shows a sample of 8 products of the largest demand of the 75 products. The first graph (left) of each product shows the average interval between two consecutive production batches, the standard deviation of this interval, and the coefficient of variation (ratio between standard deviation and the average). The second graph (right) shows the ratio between the batch size (average production quantity) and the average monthly demand.

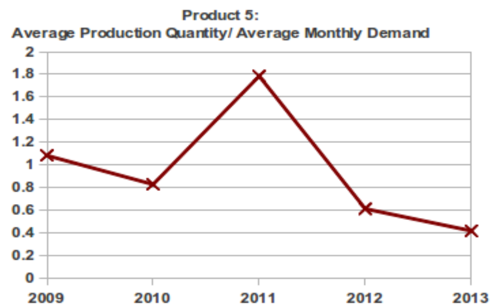
The average number of days between two consecutive production batches and the ratio of the batch size (average production quantity) to the average monthly demand decreased in 2013 for all products, except for product 6, with an average reduction of 14% and 11% respectively. Table 2 shows that there was a dramatic decrease in the demand on product 6 in 2013 and this led to the increase of the batch size and decrease in number of batches per month. The standard deviation of the interval between two production batches and the coefficient of variation of all products decreased in 2013 by an average of 30% and 19% respectively except for product 1 where the coefficient of variation increased slightly. These results show that these products are produced in smaller batches and more frequently than before applying CMD. In addition, the reduction in the variation of the interval between two consecutive batches shows more production leveling than before.

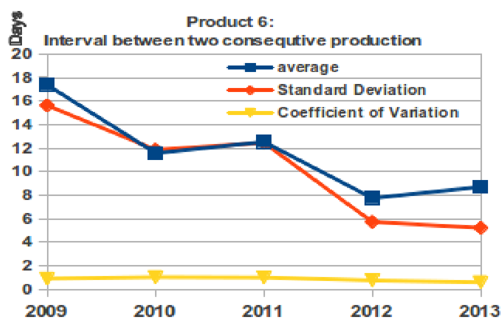


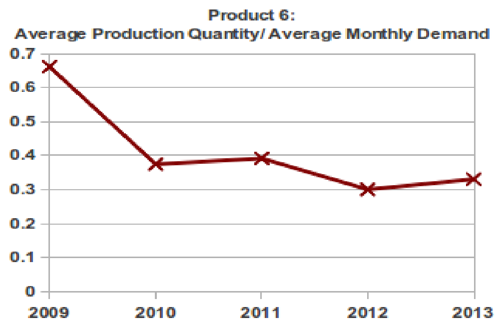

Product 4:
Interval between two consequtive production
Days
average
Standard Deviation
Coefficient of Variation
2009
2010
2011
2012
2013

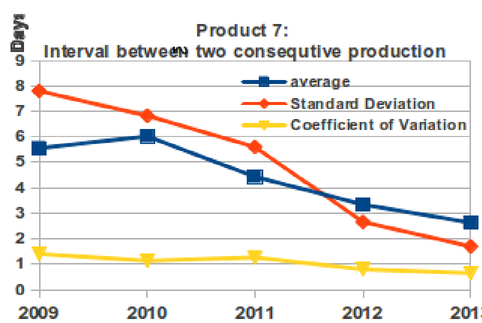

Product 4:
Average Production Quantity/ Average Monthly Demand
2009
2010
2011
2012
2013

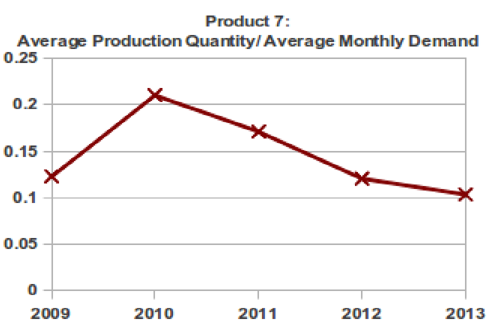

Product 5:
Interval between two consequtive production
Days
average
Standard Deviation
Coefficient of Variation
2009
2010
2011
2012
2013

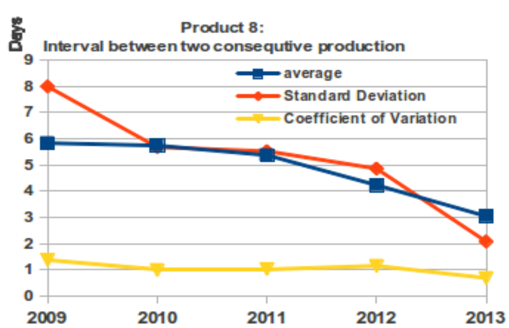

Product 5:
Average Production Quantity/ Average Monthly Demand
2009
2010
2011
2012
2013


Product 6:
Interval between two consequtive production
Days
average
Standard Deviation
Coefficient of Variation
2009
2010
2011
2012
2013


Product 6:
Average Production Quantity/ Average Monthly Demand
2009
2010
2011
2012
2013


Product 7:
Interval between two consequtive production
Days
average
Standard Deviation
Coefficient of Variation
2009
2010
2011
2012
2013


Product 7:
Average Production Quantity/ Average Monthly Demand
2009
2010
2011
2012
2013


Product 8:
Interval between two consequtive production
Days
average
Standard Deviation
Coefficient of Variation
2009
2010
2011
2012
2013

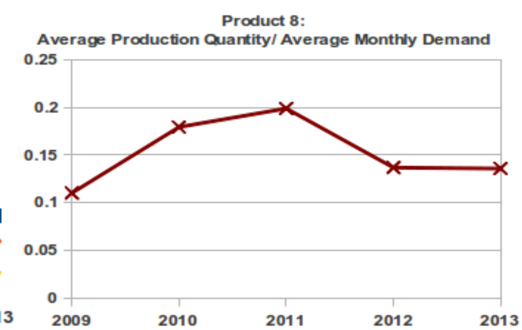

Product 8:
Average Production Quantity/ Average Monthly Demand
2009
2010
2011
2012
2013

Figure 6: Changes in production interval and quantity per batch for products 1-8

Table2: Average monthly demand in tons of products 1-8

	Product							
Year	1	2	3	4	5	6	7	8
2009	3,605	1,824	1,756	5,378	475	967	626	606
2010	4,292	760	1,459	5,388	879	2,413	399	488
2011	3,554	773	1,761	2,991	388	1,612	801	417
2012	3,146	780	2,630	6,540	785	2,268	935	528
2013	4,789	1,240	2,420	8,544	1,006	1,450	1,253	532

4.4 Flexibility to Produce Almost any Family of Products at any Time

Before applying CMD, it was impossible sometimes to produce a customer request because the plant operates on a large batch (about 1,600 t) of a width range of about 100 mm and there may not be enough customer orders to produce that batch or even half of it. Furthermore, there may not be enough orders to produce 160 t of specific steel grade. After applying CMD, this case has almost disappeared because there is, almost always an opportunity to produce CMD products of different widths and grades. For example, Table 3 shows an example of the first three heats of a sequence where CMD products are produced with different grades allowing the production of current orders (contracts) such as: C2 in heat 1, C19 and C5 with grade S, and C4 with grade N.

Table 3: Simplified example of the first three heats of a sequence where CMD is used as part of the heat

<table>
<tr><td>Heat #</td><td colspan="12">1</td><td colspan="9">2</td><td colspan="8">3</td></tr>
<tr><td>Heat Weight (t)</td><td colspan="12">160 t</td><td colspan="9">160 t</td><td colspan="8">160 t</td></tr>
<tr><td>Steel Grade</td><td colspan="12">P</td><td colspan="9">S</td><td colspan="8">N</td></tr>
<tr><td>Coil Weight (t)</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>14</td><td>10</td><td>10</td><td>14</td><td>14</td><td>14</td><td>19</td><td>19</td><td>19</td><td>19</td><td>21</td><td>21</td><td>18</td><td>18</td><td>18</td><td>18</td><td>18</td><td>18</td><td>26</td><td>26</td></tr>
<tr><td>Contract#</td><td colspan="10">C2</td><td colspan="2">CMD</td><td colspan="3">C19</td><td colspan="4">C5</td><td colspan="2">CMD</td><td colspan="6">C4</td><td colspan="2">CMD</td></tr>
</table>

4.5 Plan Adjustment Based on Customer Requests and Plant Condition

Sometimes, a customer has urgent need for a certain product. In other instances, the plant may need to add more heats to the sequence due to any technical reason. In other cases, sudden plant stoppage may cause the molten steel chemical composition to change so there will be a need to cast this molten steel for another steel grade. It was difficult to respond positively to those situations in the past leading to delay of delivery, higher production cost, and more stock (inventory). By applying CMD, there are always alternatives for these cases. Heats are added from CMD, urgent requests may be produced by adding CMD to customer request to form a heat or two, and, finally, CMD is used an alternative steel grade. Unfortunately there is no record of those cases, but they usually happen several times per month.

In the past, whenever there was a lack of contracts, the plant would produce large quantities of few products. This would result in final product stock increase for long time. With the Common Market Demand method, the plant produces small quantities of dozens of products which increases the shipping probability. This condition was faced several times during summer 2013 when there was a lack of local contracts, but the plant was operating smoothly because CMD products were produced frequently. All this is accomplished while the CMD stock is in average about 3 to 4 days of production.

4.6 Reduction of Cooling Time for a Limited Number of Coils by 75%

By using forced water cooling the cooling time was reduced from 4 to 6 days to one day only. Although, this method is used only for a limited number of coils, for inspection purposes and fulfilling an urgent customer need, it is securing the supply for a very critical sector. Instead of discovering a defect after 6 days, it is discovered after one day. On the other hand, in case of shortage, plant can produce today to deliver tomorrow evening. Since the start of Forced water cooling in February 2013 till end of June 2013, 132 coils were cooled using this method. Some of those coils have helped discover defects early, and some of them were used to fulfill urgent need of customer. Although the number of coils is small, most of them were inspection samples for thousands of tons.

5. Discussion and Future Work

This case study shows how lean principles can affect delivery time. It has been shown that the Supermarket idea, as Ohno (1988) called it, can be applied at a flat steel plant with thousands of products. It took some time to get the discipline to replenish the stock of the supermarket. The forced water cooling and smart allocation method show

how innovation and lean spirit can work together.

The implementation of leveled production can be improved in the future by marketing the CMD products and by encouraging customer to ship in small batches on short intervals. The forced water cooling can be more effective if it can be used for other products. The smart allocation and CMD are still in their elementary phase and need enhancement to shorten the time from production to shipping by higher percentage. The lean journey needs more efforts to apply lean practices at the plant such as Single Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), and a pull culture everywhere.

6. Conclusion

Further implementation of lean principles at a flat steel plant in Egypt shows that steel industry can gain competitive advantage in delivery time and fast response to market. Because of the nature of the technology used in such heavy industry, we cannot copy/paste the principles of lean production as they are implemented in other industries, yet we can always make use of the core of lean ideas like waste elimination, pull, flow, small lot, and production leveling in an innovative way.

This paper shows the effect of production leveling through a mix between make-to-order and make-to-stock, and through smart allocation. It proves that the idea of "supermarket" (Ohno, 1988) is applicable in flat steel production. The forced water cooling is basically an application of waste elimination and cycle time reduction. More cases on implementation of lean principles in steel industry can help us understand how to create a lean steel organization.

Acknowledgements

The authors would like to thank Mr. Nelish Arora, ADDValue Consulting, who during his training course at EZDK in 2012 inspired this team with the idea of the supermarket which, eventually, led to the CMD. The authors appreciate TATA Steel Ijmuiden, Netherlands and SMS help during the development of the forced water cooling system. The authors would like to thank Mr. Hamdy Fathy, Mr. Reda Abdelshafy, Mr. Mohamed Ali, and Mrs. A. Ayad for their support and encouragement.

References

Abdullah, F., Lean manufacturing tools and techniques in the process industry with a focus on steel, *PhD dissertation*, University of Pittsburgh, 2003.

Abdelmalek, F., Rajgopal, J., Needy, K., A classification model for the process industry to guide the implementation of lean, *Engineering Management Journal*, 18 (1), pp. 15–25, 2006.

Dhandapani, V., Potter, A., and Naim, M., Applying lean thinking: a case study of an Indian steel plant, International *Journal of Logistics Research and Applications*, Volume 7, Issue 3, 2004

Fahmi, S. and Hollingworth, D., Revisiting the roots of JIT and Lean Manufacturing, *Journal of Supply Chain and Operations Management*, Volume 10, Number 2, September , pp. 29-49, 2012.

Fahmi, S. and Abdelwahab, T., Case Study: Improving Production Planning in Steel Industry in

Light of Lean Principles, *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management*, Istanbul, Turkey, July 3 – 6, pp. 2489-2497, 2012.

Fullerton, R.R., and McWatters, C.S., The production performance benefits from JIT implementation, *Journal of Operations Managemen*t, (19)1, pp. 81-96, 2001.

Fullerton, R.R., McWatters, C.S., and Fawson, C., An examination of the relationships between JIT and financial performance, *Journal of Operations Management*, (21)4, pp. 383-404, 2003.

Hopp, W. and Spearman, M., Factory Physics: Foundations of Manufacturing Management, IRWIN, p. 232, 1996.

Huson, M. and Nanda, D., The impact of Just-in-Time manufacturing on firm performance in the U.S., *Journal of Operations Management*, (12)3/4, pp. 297-310, 1995.

Liker, J., The Toyota Way: 14 Management principles from the world's greatest manufacturer, McGraw-Hill, 2004

Ohno, T., Toyota Production System: Beyond large scale production, Productivity Press, 1988.

Ohno, T., Workplace Management, Productivity Press, p. 96, 1988.

Sakakibara, S., Flynn, B.B., Schroeder, R.G., and Morris, W.T., The impact of Just-In-Time manufacturing and its infrastructure on manufacturing performance, *Management Science*, (43)9, pp. 1246-1257, 1997.

Schonberger, R., Japanese Manufacturing Techniques, Free Press, 1982

Shingo, S., A Study of Toyota Production System from an Industrial Engineering Viewpoint, Productivity Press, 1989.

Biography

Sameh M. Fahmi is a Production Planning Section Manager at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Mechanical Engineering from Alexandria University, Egypt, MSc in Advanced Mechanical Engineering from Imperial College, UK, and MBA from Rensselaer Polytechnic Institute, USA. He has published at several conferences and at JSCOM on lean, TPM, and simulation. Mr. Fahmi has experience in utilities plants' maintenance and operation, process improvement, production planning, and lean implementation.

Tamer M. Abdelwahab is a Production Planning Manager at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Production Engineering from Alexandria University, Egypt and Professional Certificate in Advanced Management from AUC, Egypt. Mr. Abdelwahab has more than 10 years of experience in steel production planning.

Yaseen Amin is a Production Planning Manager at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Mechanical Engineering from Alexandria University, Egypt and Diploma in Metal Forming from Moscow Institute for Steel and Alloys, Russia. Mr. Amin has long experience in production planning and rolling mill plants operations.

Mohamed S. Emam is a Production Planning Engineer at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Production Engineering from Alexandria University, Egypt. In addition, Mr. Emam holds MBA from Arab Academy of Science and technology, Egypt. Mr. Emam has several years of experience in production planning of flat steel production.

Haytham Youssef is a Production Planning Engineer at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Production Engineering from Alexandria University, Egypt. Mr. Hayhtam has several years of experience in production planning and manufacturing engineering.

Ahmed Ragab is a Production Planning Engineer at Al Ezz Dekheila Steel Co- Alexandria, Egypt (EZDK). He holds BSc in Production Engineering from Alexandria University, Egypt. Mr. Ragab is an MSc student at Alexandria University, Egypt.