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Application of Value Stream Mapping for Reduction of Cycle Time in a Machining Process

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Abstract

Lean manufacturing initiative is being followed by various organizations in the recent years which mainly focuses on improving the efficiency of operations by eliminating and reducing wastes. This paper aimed to explain the implementation of lean manufacturing techniques in the crankshaft manufacturing system at an automotive manufacturing plant located in south India.. A multi criteria decision making model, analytical hierarchy process is applied to analyze the decision making process in the manufacturing system. The objective of the case industry was to increase the export sales. Lean manufacturing system was selected to meet the company's quality, cost and delivery targets. Crankshaft was manufactured in a single piece flow system with the low cost machines developed indigenously and the results are that the crankshafts have passed the testing, validation and approval by the customer to produce any variant in the company. After implementing lean manufacturing system, the manufacturing lead time reduced by forty percent, defects were reduced, higher process capability achieved, quick response to the customer demand in small lots were achieved.

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Keywords: lean; value stream; Analytical Hierarchy Process; kaizen; production cost

1. Introduction

This Paper is a case study explaining about the successful implementation of lean manufacturing tools and techniques in the development and implementation of crankshaft manufacturing system at the case industry plant.

Crankshaft manufacturing is a critical process and it involves 13 operations starting from facing and centering, where the datum is created to finish grinding of journal diameter and pin diameter, washing and oiling. The vision of the company was to increase the export sales by 30 %. The project findings are that the entire crankshaft manufacturing system was established using lean manufacturing tools.

In 1990 a book appeared by the title, The Machine that Changed the World, often referred *to* as the "MIT study", describes the principles of LP and opens new areas for leanness. Womack J.P et al. (1990). The concept of lean manufacturing was introduced in the Toyota production system and it was the first to use lean practices. Lean manufacturing enhances production processes and boosts the employees job satisfaction Singh, Garg, Sharma , & Grewal (2010). Lean manufacturing believes the simple fact that customers will pay for the value of services they receive, but will not pay for mistakes Rawabdeh (2005).

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Saurin and Ferreira (2009) have presented guidelines for assessing lean production impacts on working conditions either at a plant or a departmental level, which were tested on a harvester assembly line in Brazil. Narahari et al (1999) explored how the lead times can be reduced using scheduling, input control, load balancing and variability reduction. The models are based on single class and multiclass queuing networks and capture important facts of a product development organisation such as concurrent execution of multiple projects, contention for resources, feedback and reworking of project tasks and variability of the new project initiations and task execution times**.** McDonald et al (2000) explained wasteful steps that have to be eliminated and flow can be introduced in the remaining value-added processes. The concept of flow is to make parts ideally one piece at a time from raw materials to finished goods and to move them one by one to the next workstation with no waiting time in between. Pull is the notion of producing at the rate of the demand of the customer. Perfection is achieved when people within the organization realize that the continuous improvement process of eliminating waste and reducing mistakes while offering what the customer actually wants becomes possible. Khaswala et al (2001) explained the basic concepts of Value stream mapping and how to implement them in case of multiple flow value stream mapping that merge in case of a complex product. Abdulmalek and Rajagopal (2006) presented lean manufacturing principles being applied to a steel mill. The lean manufacturing tool of value stream mapping has been used to map the scenarios. The paper also described simulation models which were developed using lean manufacturing principles and also analyzed the possible benefits.

Ward (2007) addressed the confusion and inconsistency associated with "lean manufacturing" concept to clarify the semantic confusion surrounding lean production by conducting an extensive literature review using a historical evolutionary perspective in tracing its main components. Rother (1990) described how Toyota manages continuous improvement, human ingenuity, through its improvement kata and coaching kata. He also explains why typical companies fail to understand the core of lean and make limited progress. The two metrics are the lead time and Percentage value added work. William et al (2011) presented the use of value stream mapping tool in identifying, quantifying and minimizing major wastes in a bread manufacturing set-up. The case study shows how the VSM tool was used to identify and reduce defects, unnecessary inventory, and motion. Gurumurthy and kodali (2011) presented simulation of models which have been modified by using Lean manufacturing principles and elements. The impact of implementation of lean manufacturing elements on the company's performance was also analyzed.

Tapping et al (2000) wrote a book on value sream management system and how it simplifies the planning process for lean implementation, ensuring quick deployment and greater success. Ron Moore (2002) wrote a book on selecting the right manufacturing improvement tools and showed how these tools can be implemented and supported. It also relates to one another and compares their strengths and weaknesses. It also provides an excellent review of the most popular improvement tools and strategies - Lean Manufacturing, Kaizen etc. Salomon et al. (2007) used multiple decision making for supplier selection of assembly line equipments in an automotive industry. Kull and Tallurai (2008) proposed a combination of analytical hierarchical process and goal programming as a decision tool for supplier in the presence of risk measures and product life cycle considerations. The efficiency of the model is tested at a mid –sized, second – tier automotive supplier. Scherrer Rathje et al. (2009) identified the major criteria and conditions that lead to either lean success or failure. They found the sources to failure like the lack of senior management commitment, lack of interest and low acceptability of workers for changes. The sources of success are employee autonomy to make decisions, information transparency, etc.

2. Problems in existing system

The following wastages were identified in the current system of crankshaft production process;

- High additional processing time.
- More number of workers.
- Consumes more resources.
- More inventory.
- More scrap and
- High Cycle time.

3. Methodology

The identified research work was taken for preparation of future state value stream map from the current state value stream map, tools and techniques of Lean Production System were used to establish the single piece flow in the line, by implementing kaizen. Analytic hierarchical process was taken as an aid for justifying the decision taken in the Kaizen improvement and ultimately the required objectives were obtained. Several kaizen were implemented for reducing cycle time, number of workers, inventory and scrap. However only 3 important kaizen are discussed in this paper.

4. Value Stream Mapping

Value stream mapping is a method of lean manufacturing which uses symbols, metrics and arrows to show and improve the flow of inventory and information required to produce a product or service which is delivered to a consumer. A value stream map is a visual representation which enables one to determine where the waste occurs. Value stream maps are utilised to assess current manufacturing processes (figure 1) and create ideal and future state processes Value stream mapping is a tool which enables a company to map the process flow that helps in identifying various factors like;

- Value added time (time taken for producing the end product),
- Non Value added time (time taken which do not contribute to the production of end product),
- Cycle time (time required to perform a process) and
- Changeover time (time required to change tool and programming etc.).

This helps in identifying and eliminating muda (waste), thereby implementing lean principles.

After identifying the non value added steps in the current state, a future state value stream map is developed (Figure 2) which acts as blueprint for lean activities. The future state value stream map often represents a significant change compared to the way the company currently operates. The value stream map team thus develops a step by step implementation strategy to make the future state a reality.

The key elements of the value stream map are shown ;

- The Customer and his requirements.
- Process steps.
- Process Metrics.
- Inventory.
- Supplier with material flows.
- Information and Physical flows.
- Total lead time and Takt time

The cycle time in the figure 3 refers to the time it takes an operator to go through all of their work elements before repeating them. The value added time is the time of those work elements that actually transforms the product in a way that the customer is ready to pay for. The lead time refers to the time it takes one piece to move all the way through the process from start to finish. It is total of all value added time and non value added time. The process ratio is the ratio between the value added times to the production lead time of the process. The takt time is equal to the ratio of effective operating time per shift and the quantity customer requires per shift.

Crankshaft for the domestic market is being produced in batch mode starting with the facing and turning operation to journal rough turning and pin rough operation in turning cell and the turned crankshafts are then moved to oil hole drilling operation and finally the drilled crankshafts are then moved to the oil hole drilling cell for oil hole drilling operation and finally the drilled crankshafts are moved in batches to the grinding cell for finish journal grinding and pin grinding operations. Mapping starts from the customer requirements.

The customer requirement is 12000 numbers per month. The takt time for the demand of 12000 numbers is 126 seconds and the daily requirement is 545 numbers per day. Once the customer informs the 3 months firm schedule requirements through mail, the marketing department informs the production department to plan for the next month's production. The production department informs the forging supplier to plan for the raw material and sends the schedule for the supply of forgings. The production department also informs the value stream in charge of the crankshaft line to plan for the resources including manpower and consumables. The forgings from the supplier arrive at the incoming inspection area and after the sample for inspection the crankshaft forgings are then moved to the turning cell.

Earlier the crankshaft was manufactured at 3 different locations, namely turning cell, oil hole drilling cell and grinding cell. In turning cell, all the turning machines are placed and the movement of material was in zigzag as shown in the figure 1. There was an inventory of 10 numbers in between the machines and 1000 numbers was stored at the end of the cell. There were 2 operators in the turning cell. The turned crankshaft was moved in batches of 1000 numbers to oil hole drilling cell placed at a distance of 10 meters away. Oil drilling machine was operated by one person with the same inventory and storage. The grinding cell was operated by 2 operators and it was 25 metres away from oil drilling machine. The crankshafts movement was in zigzag pattern. An inventory of 10 numbers was maintained and a batch of 1000 crankshafts was moved to the warehouse. The pitfalls were at any point of time, there was an inventory of 1000 numbers maintained between the cells. The rejection rate was high and there was no communication between the turning, oil hole drilling and grinding machine operators to correct the defects. The work content of the operators was not balanced and 5 operators were used as shown in the figure 1

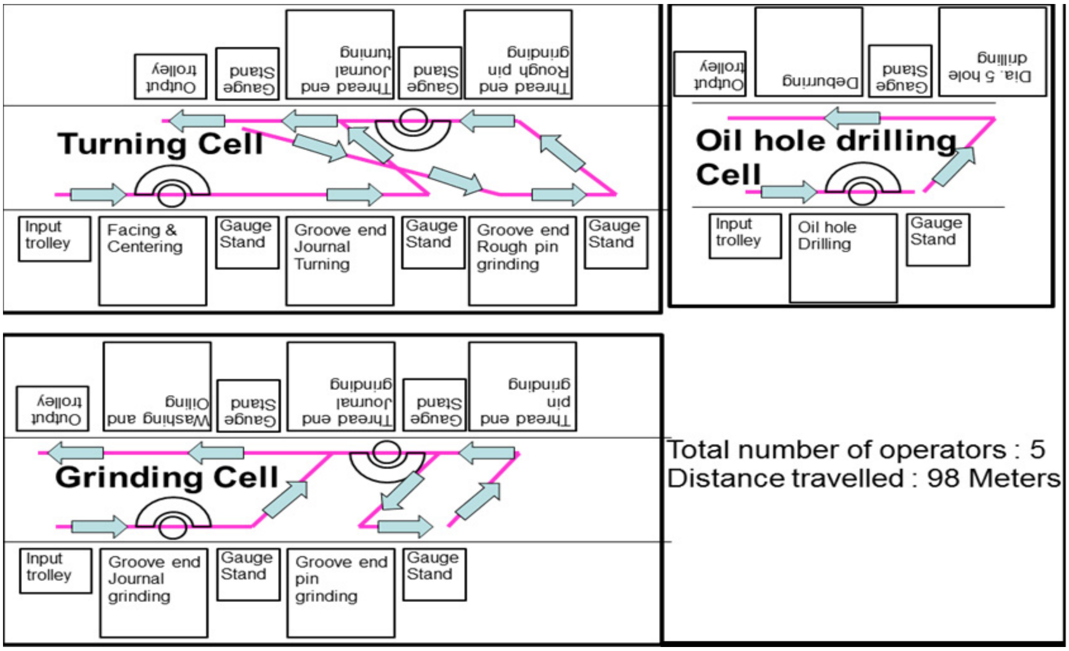

Fig. 1. Turning, Oil hole drilling and grinding cell layout

In the export crankshaft manufacturing cell, the process starts from crankshaft forging receipt at the incoming stores and it is moved in a trolley containing 98 numbers to the facing and centring machine. The datum is created at both the ends of the crankshaft in facing & centring machine and single piece flow transfer to the grooved end journal turning machine, thread end journal turning machine, grooved end pin turning machine, threaded end pin turning machine, oil hole drilling machine, dia 5mm hole drilling machine, deburring, grooved end journal finish grinding machine, thread end journal finish grinding machine, grooved end pin grinding machine, thread end pin grinding machine, deburring, washing and oiling station with a single piece in between the machines. The zigzag flow is eliminated and a unidirectional flow is established as shown in the figure 2. Only 3 operators are used when compared to 5 operators when the crankshaft machining was done in batch mode. The material travelling distance reduced from 98 meters to 50 meters

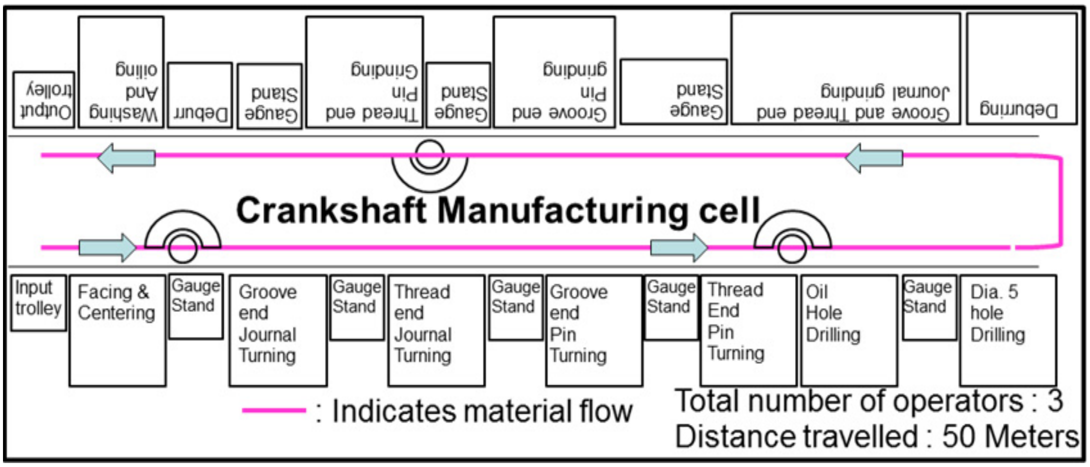

Fig. 2. Crankshaft manufacturing cell

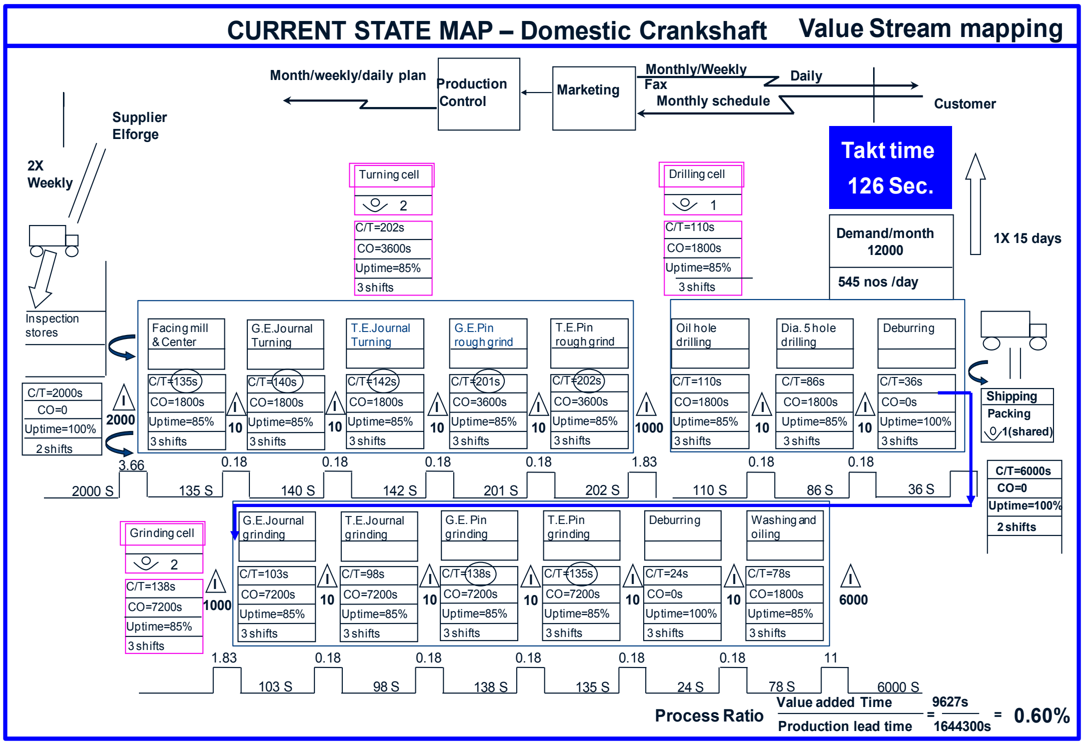

Fig. 3. Current state value stream mapping

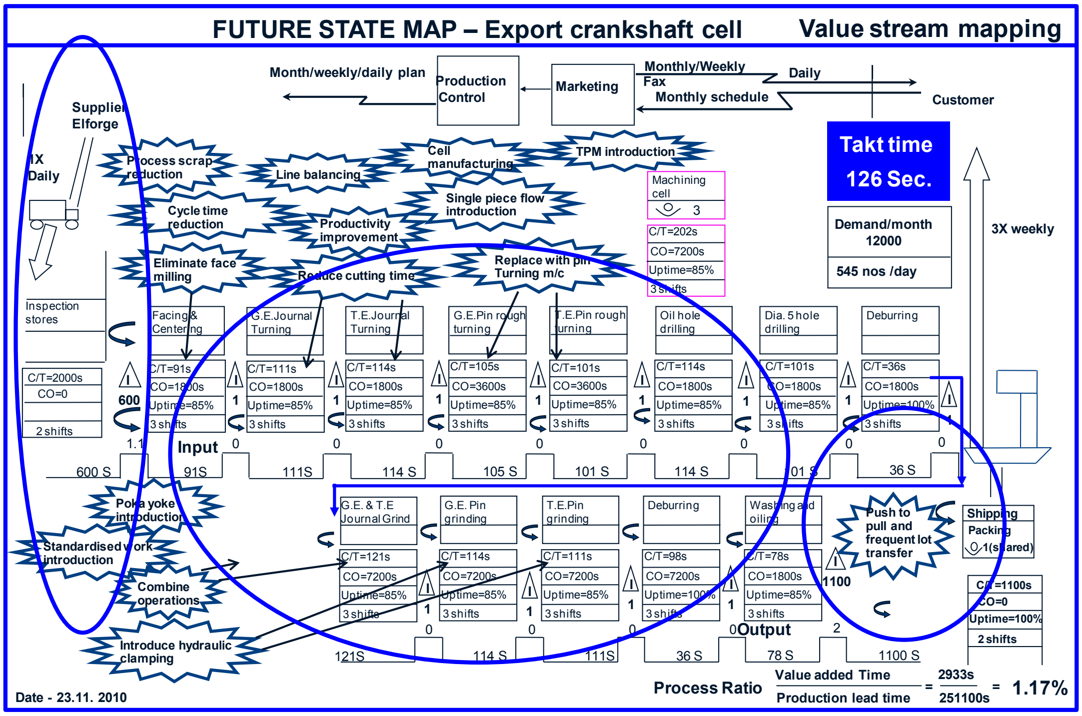

Fig. 4. Future state value stream mapping

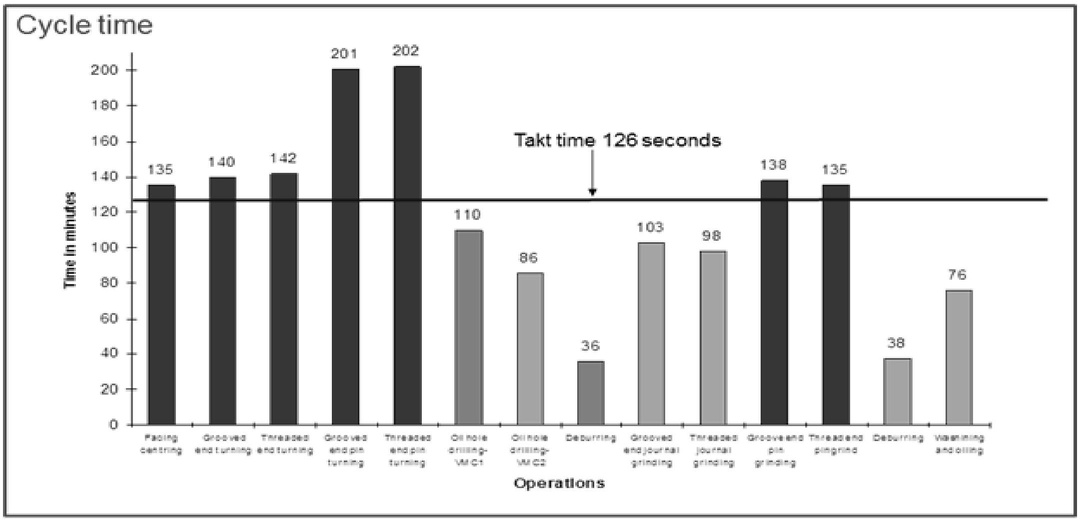

Fig. 5 Cycle time details

Work area : Compressor		Process: Crankshaft				Process cycle time: 1349 Seconds		
Sl.No.	Operation description	Waste elimination				Methods improvement		Investment
		Eliminate operations	Combine operations	Reduce operations	Simplify operations	Introduce new generation tooling	Optimise the machining parameters	Capital Investment machines
1	Facing and centering	●	●					
2	Groove end journal turning					●	●	
3	Thread end journal turning			●		●	●	
4	Groove end pin roughing					●		●
5	Thread end pin roughing					●		●
6	Groove end pin grinding				●			
7	Thread end pin grinding				●			

Fig. 6. Identifying the Opportunities for improvement

KAIZEN 1: Implement the Modified Process by eliminate and combine operations (figure 7)

In facing and centring machine, the cycle time was 135 seconds because milling head and drilling head were used for face milling and drilling operation. The sequence of operation was that the milling head will traverse in y axis to first mill the journal end face and then the drilling head will move in to drill. By developing a special tool with cartridges fitted with inserts mounted on the tool face and a centre drill mounted on the tool centre as shown in the figure 4, the plunge facing and centering operation was completed on both sides of the journal. By this the facing operation was eliminated and plunge facing, facing and centre drilling operations were combined. Due to this kaizen, the cycle time reduced from 135 seconds to 70 seconds and the capital investment for the milling head was also eliminated resulted in a saving of Rs. 0.15 million

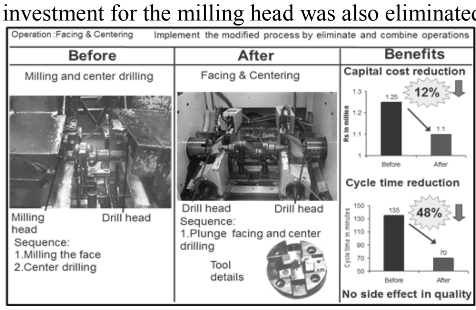

Fig. 7. Eliminate and combined operations

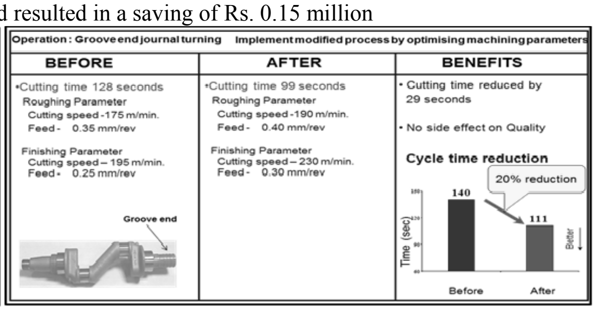

Fig. 8 Optimizing Machining Parameter

KAIZEN 2: Implement the modified process by optimizing the process parameters

The existing process parameters for roughing operation and finishing operation were studied and based on the cutting force calculation; the process parameters speed and feed were optimized for roughing and finishing operations. There was no deterioration on the tool life due to increasing speed and feed. The cycle time reduced from 140 seconds to 111 seconds and there was no side effect on quality. (fig 8)

KAIZEN 3: Implement the modified process by tooling improvement and introduce CNC lathe Historically the crankshaft pin roughing operation was done on a grinding machine to remove material from forging stage to the roughing stage for material removal of 2.5 mm diametrically. As grinding operation is a slow process, the cycle time was also more. Since the pin diameter is eccentric by 25 mm, a special eccentric collet chuck to centralize the pin diameter to the CNC lathe (fig. 10)spindle axis was designed and developed to turn the diameter from the forging stage to the roughing stage by using special new generation neutral, left hand and right hand tool. Due to this the cycle time reduced from 201 seconds to 105 seconds and the capital investment for the groove end pin turning operation also reduced from Rs. 4.57 million to Rs. 2.5 million. There was no compromise on quality.

The cycle time details of the improved processes are shown in figure 9.

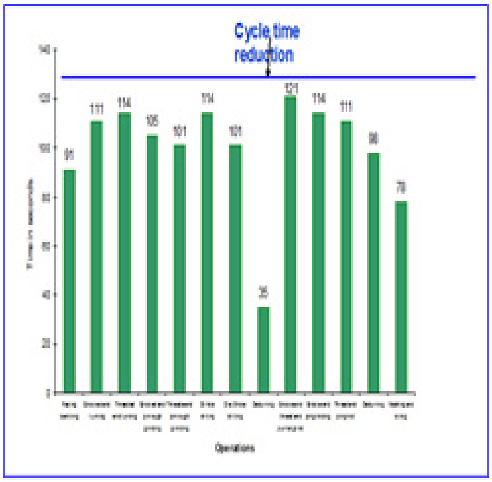

Fig 9. Cycle Time details

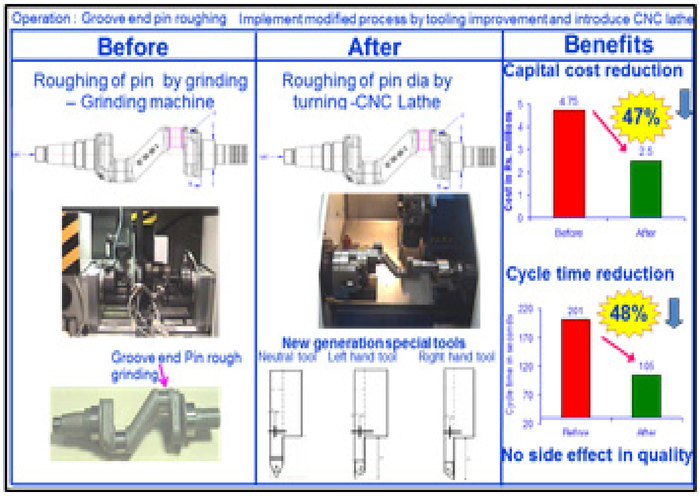

Fig. 10. CNC Lathe Introduction

5. Analytic Hierarchical Process (AHP) for KAIZEN 3

AHP is one of the Multi criteria Decision making methods developed by Saaty (1999, 2008). The basic framework of AHP is based on the innate human ability to make sound judgement for small problems. AHP is a structured technique for complex problems. By using AHP, the decision making will become easy and the decision makers will gain confidence for the selection of suitable assembly method for their company by Vijayaramnath et al. (2010)

Various manufacturing methods were used to achieve the above goals. The most practical method to improve the productivity was selected using analytical hierarchical process. The overall performance matrix, relative value factor are given below, using them overall priority vector is found.

5.1 AHP algorithm

The step by step procedure to carryout AHP is given below (fig 11)

Step 1: Setting up hierarchy.

Step 2: Pair wise comparison of characteristics

Step 3: Establish priority vector

Step 4: Comparison of alternatives

Step 5: Calculate priority vector for alternatives (for various factors considered)

Step 6: Obtain the overall priority vector

The above steps were calculated using AHP, and the values are shown in the following table 1, table 2, and table 3.

Table 1: comparison of characteristics of different machining equipment

	SP	OP	PQ	IMP	RO	CO	LC	TI
Old grinding machine	0.09	0.08	0.15	0.15	0.35	0.10	0.27	0.15
Machining with special purpose machine	0.15	0.48	0.23	0.20	0.12	0.47	0.06	0.23
In-house development of existing CNC machine	0.44	0.25	0.09	0.12	0.20	0.24	0.13	0.12
Turning with conventional machine modified	0.08	0.06	0.41	0.43	0.13	0.06	0.46	0.44
New CNC machine with modified tooling	0.24	0.12	0.11	0.09	0.20	0.14	0.07	0.06

Fig. 11. Hierarchical structure of AHP model

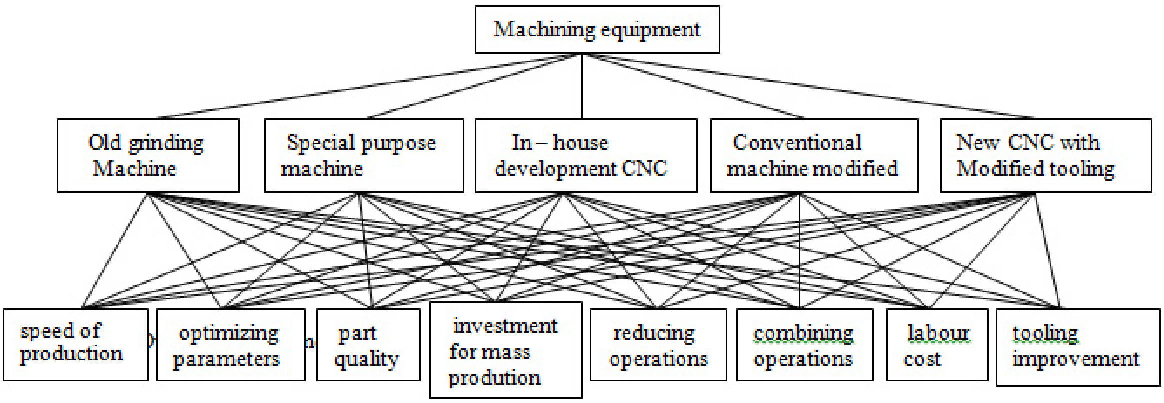

Table 2: Relative value factor

Speed of production (SP)	0.33
Optimizing parameters (OP)	0.19
Part quality (PQ)	0.16
Investment for mass production (IMP)	0.12
Reducing operations (RO)	0.08
Combining operations (CO)	0.05
Labour cost (LC)	0.04
Tooling improvement (TI)	0.03

Table 3: Overall priority factor

Existing Manufacturing Processes	Overall Priority vector %	Rank
Old grinding machining	13.52	5
Machining with special purpose machine	24.39	2
In house development of the existing CNC m/c with special tooling	25.83	1
Turning with conventional m/c with modified tooling	20.0	3
New CNC machine with modified tooling	15.8	4

From the analytical hierarchy process, it can be concluded that the In-House development of the existing CNC machine with special tooling is best method for machining the crankshaft. Hence the statistical tool supports the real time analysis of obtaining the desired production rate.

6. Results and benefits of Lean Systems

- Single piece flow for crankshaft manufacturing system was established.
- The non-value adding activity of having inventory between the machines were eliminated
- Quick response to the customer demand to supply frequently in small lots

- The complete export crankshaft manufacturing cell was established to meet the customer quality, cost and delivery requirements. The results are shown in table 4.

Table 4: Results

Description	Existing manufacturing line	Target – Export crankshaft manufacturing line	Result – Actual in Export crankshaft manufacturing line
Productivity (P)	20/hour	25/hour	28.57/hour
Number of operators	5	3	3
Quality (Q)	8%	5%	5.5 %
Cost (C)	Rs.1000	Rs. 900	Rs. 875
Delivery (D)	80% fill rate	100% fill rate	100% fill rate
Morale (M)	10 suggestion/person/ month	50 suggestions / person/month	
Safety (S)	Zero accidents	Zero accidents	Zero accidents

7. Conclusion.

Lean manufacturing system implemented in this paper is done in a crankshaft manufacturing cell to eliminate the 8 non-value adding wastes like over production, waiting, unnecessary transport movement, defects and unused employee creativity from the manufacturing system and also to create product mix flexibility in the manufacturing cell. The limitation in this research is that the crankshaft manufacturing cell set-up changeover between the crankshaft variants is not within the takt time of 126 seconds and the agreement with the customer is also to produce one variant for one week and changeover to the next variant, will not have an impact on the project. The limitations in this research is that this export crankshaft manufacturing cell can produce only crankshaft variants and there is no flexibility of producing other critical parts of the compressor The future work is to establish lean manufacturing systems for all compressor critical parts machining and supply assembled compressors to customer.

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