A Framework for Improving Productivity of SMEs Economically

By

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Outline

• Introduction
• Problems in SME
• Literature review
• Framework
• Case study
Introduction

• SMEs Play major role in countries GDP and employment
• 37.2% of India's manufacturing output with 40% of India’s workforce
• Contributes 7.28% of countries GDP*
• Empirical study on several industries near Kanpur reveals that, most of the SMEs are plagued with:
  ➢ Unorganized process flow
  ➢ Improper layout
  ➢ Inadequate planning
  ➢ Overtime production

*Annual report 2013-14, Ministry of micro, small, and medium industries.
Problems in SME

• Nenzhelele (2009), SMEs in South Africa
  ▪ Less educated workers
  ▪ Limited technological know-how
  ▪ Improper productivity improvement implementation strategies or plan

  1. Short term priorities
  2. Internal operational focus and lack of external orientation
  3. Tacit knowledge
  4. Looking for flexibility
  5. Poor managerial skills
  6. Entrepreneurial orientation
  7. Command and control culture
  8. Limited resources
Empirical study in the similar industry reveals a few more:

- Shared utilization of man and machine
- Enormous use of makeshift approach
- Limitation in space
- Unwillingness to adopt change
Literature Review

• Case based

• Framework development

### Case based

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Year</th>
<th>Industry</th>
<th>Approach</th>
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<tbody>
<tr>
<td>Gunasekaran, and Cecille</td>
<td>1998</td>
<td>wiper systems for the automotive industry</td>
<td>1) JIT 2) Kanban 3) Kaisen</td>
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<td>Edis, Kahraman, Araz, Özfirat</td>
<td>2011</td>
<td>Marbel factory</td>
<td>Simulation based investigation on facility layout change</td>
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<td>Norani, Suhadak, Johari, Kassim</td>
<td>2012</td>
<td>Food manufacturing company</td>
<td>Simulation based investigation on facility layout change</td>
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<td>Alkaya, Demirer</td>
<td>2014</td>
<td>surface coating</td>
<td>Lean manufacturing, green manufacturing</td>
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Framework development

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Year</th>
<th>Approach</th>
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<tr>
<td>Khan, Bali, Wickramasinghe</td>
<td>2007</td>
<td>Mainly applicability of Kaizen in SME</td>
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<tr>
<td>Dassisti</td>
<td>2009</td>
<td>business process re-engineering, continuous performance improvement,</td>
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<td>continuous quality improvement</td>
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<tr>
<td>Bautista, Ortega, Zubieta, Macías</td>
<td>2010</td>
<td>Business process re-engineering, continuous improvement</td>
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<td>Pecas, Jorge, Morgado, Hemiques, Cernadas</td>
<td>2012</td>
<td>Continuous Improvement, Lean Manufacturing, Benchmarking</td>
</tr>
<tr>
<td>Ham and Park</td>
<td>2014</td>
<td>Continuous Improvement, time and motion study, Line balancing</td>
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</table>
Discussion and research gap

• Single approach is not holistic enough to deal with the incumbent challenges

• Most of the approaches utilizes continuous improvement, which is a long term approach and requires highly educated and competent team within the industry itself

• No provision for economic based analysis (considering they are already manufacturing the required quantity by overtime)
Framework
Data Collection
Initial data collection: Time and motion study

- Identification of major parts manufactured in house
- Processes involved in manufacturing those parts
- Time and motion study to measure flow of processes and time
Analysis
Initial Simulation Modelling

• The data collected and processes selected important for study in the first step will be used for making the initial simulation model for the manufacturing system.

• The model should depict the plant properly. The simulation run should also validate the plants productivity properly.

• The simulation modelling can be done by using any standard simulation software e.g. ARENA, SLAM, AweSim, Technometrics etc.
Search for Bottleneck

• Bottleneck can be defined as the processes that limits the performance of a production system.
• Identification of bottlenecks are utmost important for further proceeding in this framework.
• There are several methods for detecting the bottleneck.
• An easy and effective method to find out the bottleneck is by searching for highest utilization factor (Law and Kelton, 2000).
Stopping criteria

• If the productivity of the system reaches to the targeted productivity with the proposed strategy in the comparison step, the iteration of the framework stops. Else, the iteration repeats from bottleneck identification.
Action
Process Activity Mapping

• Process activity mapping is one of the seven lean management tools as described by Hines and Rich (1997).

• This tool aims in identifying the possibility of improvement of a process within itself without any additional resource.

• The tool consists of four major work:
  • Analyse processes.
  • Identify and eliminate non value added tasks/works/processes.
  • Study for rearranging of activities or processes.
  • Relocation of activities or processes.
• This tool should first be applied to the bottlenecking process itself in order to identify any possibility of performing the operations in a better way within the process.

• Once it is applied within the process and the productivity do not reach to the required productivity, or no improvement is possible within the process, then this tool should also be applied within the entire manufacturing system in a way described in the next figure.
Flowchart for process activity mapping steps under various material transfer strategies
Human Resource Modification: Sensitivity Test

• Sensitivity analysis means investigation of changes in the output by modification in the resources.

• If productivity improvement of a bottlenecking process is not possible with the previous method, then the process can further be analysed if there has a possibility of modification of human resource for the process.

• In some process, increment of human resource may reduce the operation time. This step identify these possibilities within a bottlenecking process.

• However, before adding those resources in simulation model, the possibility of the addition must also be justified with the real situation to avoid any unrealistic solution.
Process Benchmarking

• Process benchmarking means comparing one industry's process with the industry's best practice from other companies.

• The steps involved in benchmarking are:
  • Identify other industries that have similar processes
  • Identify organizations that are leaders in these areas
  • Survey companies for measures and practices
  • Visit the "best practice" companies to identify leading edge practices
  • Estimate the time changes and update the simulation model
Parallel processing

• If all the above methodologies cannot be applied or do not make considerable improvement in productivity, a parallel process can be added to improve the productivity of the process.

• However, the possibility of addition of a parallel process depends on the availability of required space in the layout.
Validation
Validation

• If any methodology would found suitable for the modification of a process, then the modified process measurements should be estimated properly and simulation model should be updated accordingly.

• The simulation model should again be run by keeping all the other process characteristics similar.

• If significant improvement in system productivity is not possible with the proposed changes in the processes, then the next available methodology, as shown in the framework, should be explored for improvement.

• If the productivity of the system improved with the modified process, then cost comparison should be performed as discussed in the next section.
Cost comparison
Cost comparison

• This part of the framework mainly identifies whether the process modification is beneficial or the overtime production for the same quantity is beneficial.

• The overtime cost for the same process is estimated for the modified quantity after implementation of a process.

• The process modification cost is also estimated.

• These two costs are compared to determine the process have the lower cost of production.
Case study
Case

• In order to demonstrate the real world implementation of the framework, a local three wheeler manufacturing SME in India is considered. The plant works under make-to-stock environment. The plant faces a problem of daily overtime expenses. Their productivity per day within the normal eight hour working shift is 16-20 autos depending upon the mixture of models they produce. On a random requirement check, it is found that, the company is scheduled to produce 710 different types of auto within 30 days. This implies, they require 23.667 auto productivity per day to match the demand. The organization fulfils the demand by using overtime production strategy.
Initial Data Collection: Time and Motion Study

- The firm mainly manufactures five models of three wheelers (auto)
- Similar sequence of manufacturing steps are involved in making all these models
- The model variation is mainly based on the size of the auto and engine (diesel based or compressed natural gas (CNG) based)
- Several subparts are manufactured altogether before they reach to the main assembly area where all the subparts are joined to make the auto
- Among them, two major parts having significant process flow and manufactured daily are
  - Chassis, and
  - Front Show
- All the other parts are very small and does not have very much significant process flow lines and also manufactured per month or per week basis
- The firm has total eight main departments/shops in their manufacturing plant viz. – 1) cutting shop, 2) machining Shop, 3) press shop, 4) sheering shop, 5) front show shop, 6) welding shop, 7) painting shop, 8) assembly shop
- The plant manufactures total 5 verities of model viz: model1-model5
- Each model again have sub classification of diesel and CNG (based on the fuel used in the engine)
- The manufacturing process flow is more or less similar in all the cases with very minor difference
Time study

• Based on the time taken in each process and similarity in their manufacturing, the auto models are now onward classified into 5 categories:
  • Auto1: model5
  • Auto2: model3 (diesel)
  • Auto3: model4 (both diesel and CNG)
  • Auto4: model3(CNG)
  • Auto5: model1 and model2 (both diesel and CNG)

• The manufacturing percentage combinations of the five types of autos in a financial year is approximately 4.2%, 6.34%, 23.98%, 9.15%, and 56.33% respectively.

• The processing time of various processes are shown in the next table
<table>
<thead>
<tr>
<th>Process</th>
<th>Min time</th>
<th>Max time</th>
<th>No. of resource</th>
<th>Name of the resource</th>
<th>Top show levelling (taper type)</th>
<th>1 min</th>
<th>1.5 min</th>
<th>2</th>
<th>Other auto MIG welding</th>
<th>10 min</th>
<th>12 min</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting (rectangular tube)</td>
<td>45 sec</td>
<td>50 sec</td>
<td>1</td>
<td>Cutting Machine</td>
<td>Top Show levelling</td>
<td>3 min</td>
<td>3.2 min</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press (rectangular tube)</td>
<td>2.5 hr/40</td>
<td>3 hr/40</td>
<td>1</td>
<td>Press_rectangular</td>
<td>Bottom show levelling</td>
<td>7 min</td>
<td>8 min</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drill (rectangular tube)</td>
<td>20 sec/hole</td>
<td>30 sec/hole</td>
<td>1</td>
<td>Drill</td>
<td>Dashboard levelling</td>
<td>20 min/25pieces</td>
<td>25 min/25pieces</td>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>Mill (1270)</td>
<td>2 min</td>
<td>2.25 min</td>
<td>1</td>
<td>Mill</td>
<td>Dashboard levelling 2</td>
<td>25 min/25pieces</td>
<td>30 min/25pieces</td>
<td>2</td>
<td></td>
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<tr>
<td>Mill (1660)</td>
<td>3.1 min</td>
<td>3.25 min</td>
<td>1</td>
<td>Mill</td>
<td>Top Show (press)</td>
<td>2 hr/25 pieces</td>
<td>2.5 hr/25 pieces</td>
<td>2</td>
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<tr>
<td>Initial welding</td>
<td>10 min</td>
<td>12 min</td>
<td>1</td>
<td>Welder</td>
<td>Top show denting</td>
<td>5 min</td>
<td>7 min</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cutting (steering tube 70)</td>
<td>2 min</td>
<td>2.3 min</td>
<td>1</td>
<td>Hexacutter</td>
<td>Dashboard denting-filing</td>
<td>4 min</td>
<td>5 min</td>
<td>2</td>
<td></td>
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<tr>
<td>Cutting (steering tube 76)</td>
<td>2.25 min</td>
<td>2.6 min</td>
<td>1</td>
<td>Taper cutter</td>
<td>Front show denting</td>
<td>8 min</td>
<td>10 min</td>
<td>2</td>
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<tr>
<td>Tapper cut (steering tube 70)</td>
<td>2.85 min</td>
<td>3 min</td>
<td>1</td>
<td>Taper cut</td>
<td>Re enforcement of auto5</td>
<td>2 min</td>
<td>2.5 min</td>
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<td>Tapper cut (steering tube 76)</td>
<td>2.85 min</td>
<td>3 min</td>
<td>1</td>
<td>Taper cut</td>
<td>Dashboard reinforcement</td>
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<td>3 min</td>
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<tr>
<td>Residual cut (steering tube 70)</td>
<td>2 min</td>
<td>2.3 min</td>
<td>1</td>
<td>Bending mc</td>
<td>Dashboard marking</td>
<td>3 min/25pieces</td>
<td>4 min/25pieces</td>
<td>1</td>
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<tr>
<td>Residual cut (steering tube 76)</td>
<td>2.25 min</td>
<td>2.6 min</td>
<td>1</td>
<td>Bending mc</td>
<td>Dashboard hand cut</td>
<td>20 min/25pieces</td>
<td>25 min/25pieces</td>
<td>1</td>
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</tr>
<tr>
<td>Bending (steering tube 70)</td>
<td>8 min/10 tubes</td>
<td>10 min/10 pipes</td>
<td>1</td>
<td>Bending mc</td>
<td>Dashboard collar bending</td>
<td>20 min/25pieces</td>
<td>25 min/25pieces</td>
<td>1</td>
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<tr>
<td>Bending (steering tube 76)</td>
<td>8 min/10 tubes</td>
<td>10 min/10 pipes</td>
<td>1</td>
<td>Bending mc</td>
<td>Dashboard marking 2</td>
<td>3 min/25pieces</td>
<td>5 min/25pieces</td>
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<tr>
<td>Pressing (steering tube 70)</td>
<td>2 hr/10 tubes</td>
<td>2.5 hr/10 tubes</td>
<td>1</td>
<td>tube_press</td>
<td>Dashboard press</td>
<td>2 hr/25pieces</td>
<td>2.5 hr/25pieces</td>
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<td>Notching (drill) (steering tube 70)</td>
<td>15 min</td>
<td>18 min</td>
<td>1</td>
<td>notch_drill</td>
<td>Dashboard drilling</td>
<td>1 min</td>
<td>1.5 min</td>
<td>1</td>
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<td>Notching (lathe) (steering tube 76)</td>
<td>18 min</td>
<td>20 min</td>
<td>1</td>
<td>Leathe</td>
<td>Auto5 top-bottom show join</td>
<td>4 min</td>
<td>5 min</td>
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<td>Trekking (chassis1)</td>
<td>35 min</td>
<td>40 min</td>
<td>1</td>
<td>trekking_welder</td>
<td>Other auto bottom - dashboard join</td>
<td>2 min</td>
<td>2.5 min</td>
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<td>Trekking (chassis2)</td>
<td>24 min</td>
<td>28 min</td>
<td>1</td>
<td>trekking_welder</td>
<td>Other auto bottom - dashboard join</td>
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<td>2.5 min</td>
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<td>Trekking (chassis3)</td>
<td>25 min</td>
<td>30 min</td>
<td>1</td>
<td>trekking_welder</td>
<td>Auto5 Dashboard Join</td>
<td>4 min</td>
<td>5 min</td>
<td>1</td>
<td></td>
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<tr>
<td>Trekking (chassis4)</td>
<td>24 min</td>
<td>28 min</td>
<td>1</td>
<td>trekking_welder</td>
<td>Other auto top - bottom join</td>
<td>8 min</td>
<td>10 min</td>
<td>1</td>
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<td>Trekking (chassis5)</td>
<td>22 min</td>
<td>26 min</td>
<td>1</td>
<td>trekking_welder</td>
<td>Other auto bottom - dashboard join</td>
<td>2 min</td>
<td>2.5 min</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Final (chassis 1)</td>
<td>25 min</td>
<td>30 min</td>
<td>1</td>
<td>final_welder</td>
<td>Auto5 Dashboard Join</td>
<td>4 min</td>
<td>5 min</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final (chassis 2)</td>
<td>18 min</td>
<td>20 min</td>
<td>1</td>
<td>final_welder</td>
<td>Other auto top - bottom join</td>
<td>8 min</td>
<td>10 min</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Final (chassis 3)</td>
<td>20 min</td>
<td>24 min</td>
<td>1</td>
<td>final_welder</td>
<td>Other auto top - bottom join</td>
<td>8 min</td>
<td>10 min</td>
<td>1</td>
<td></td>
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<td></td>
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<tr>
<td>Final (chassis 4)</td>
<td>20 min</td>
<td>24 min</td>
<td>1</td>
<td>final_welder</td>
<td>Other auto top - bottom join</td>
<td>8 min</td>
<td>10 min</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final (chassis 5)</td>
<td>18 min</td>
<td>20 min</td>
<td>1</td>
<td>final_welder</td>
<td>Other auto top - bottom join</td>
<td>8 min</td>
<td>10 min</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chipping and grinding</td>
<td>10 min</td>
<td>12 min</td>
<td>1</td>
<td>Chipper</td>
<td>Other auto MIG welding</td>
<td>10 min</td>
<td>12 min</td>
<td>1</td>
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</tbody>
</table>
Initial Simulation Model Generation

• The simulation model that captures all such aspects is developed using ARENA simulation software (Kelton et.al, 2004). The entity creation criteria at each create node that are associated with different processes is as follows:
  • Rectangular tube: 60/day
  • Steering tube: 5/day
  • Top show: 25/day
  • Bottom show: 25/day
  • Dash board: 25/day

• The simulation model is then run for a year considering 300 working days with 8 working hours per day. Types of auto manufactured after simulation run are:
  • Auto1: 225
  • Auto2: 330
  • Auto3: 1343
  • Auto4: 458
  • Auto5: 3204

• The obtained average productivity of the plant per day is 18.533. The plants actual productivity per day varies between 16 and 20 depending upon the auto mix they produce. This can be concluded with the result that the obtained average productivity is within limits of actual productivity per day.
From the figure it is quite evident that the highest utilized resource is the Trekking welder (0.9961), followed by rectangular pipe press (0.9925) and Painter (0.9617). All the other resources exhibit utilizations below 90%, suggesting that the above three processes are the bottlenecks.
Present cost to the company for the additional production

The company requires to manufacture 23.667 autos on average per day to meet the required productivity. The simulation result shows, they can produce 18.533 autos per day with the present set up and also it is known that presently the company fulfils the requirement by overtime production only. Hence,

- Overtime production every year: $5.134 \times 300 = 1540.2$
- Number of skilled labour require to work for the overtime (press, paint, and welding): 6
- Number of helper required for overtime: 4
- Total hour required to produce this number of auto: $1540.2 / 2.3166 = 664.76$
- Total effective man hour requirement (considering each hour in over time is equivalent to 1.5 hour of work in normal shift): $664.76 \times 1.5 = 997.14$
- Cost of skilled labour (@INR250 per 8 hour shift): INR 186963.75
- Cost of unskilled labour or helper (@INR 170 per 8 hour shift): INR 84756.9
- Total overtime expenditure in a year for the organization with present working condition: INR 271720.65
Process activity mapping

The bottlenecking processes will be considered sequentially in this step. We will start discussing with the bottlenecking process having highest utilization factor i.e. the trekking welding process.

• The processing time here can be divided in two part viz. 1) the operation (welding) time, and 2) the material transfer time from the other departments. The operation trekking is basically joining of all the rectangular pipes to form a chassis. Not much significant possibility of rearranging, relocating, or eliminating of activity is found in this operation after detailed study of the process activities.

• The process uses “pull” strategy for material transfer and is fed by five predecessor processes (pipe cutting, drilling, milling, press, steering tube residual cut). Hence, all the predecessor processes are to be considered for re-organization and non-value added task elimination possibilities and all the processes are to be considered for facility layout optimization.

• Following table summarizes pertinent observations and decisions on various predecessor processes of the process trekking.
<table>
<thead>
<tr>
<th>Observation</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The transfer of material times for the process is about 10-12 minutes for each auto type.</td>
<td>By reducing this movement; loading-unloading times of the process can be reduced.</td>
</tr>
<tr>
<td>The workers visit four workstations, viz., (i) cutting shop to collect 155/100/205mm pipes, (ii) machine shop to collect 1600/1660mm milled pipes and 988/930mm drilled pipes, (iii) press shop to collect 988/930 mm press holed pipes, and (iv) tube cutting shop to collect steering tube.</td>
<td></td>
</tr>
<tr>
<td>The diameters of holes are same for the drill and the press.</td>
<td>Drilling machine can easily make all holes; but, the press cannot make all holes.</td>
</tr>
<tr>
<td>Upon discussion with the plant manager, it was found that previously only drilling machine was used to make the holes, which was shared by many small processes. This resulted in heavy work load on the drill and its worker. To reduce some work load, making of two holes were assigned to the press shop.</td>
<td></td>
</tr>
<tr>
<td>However, press machine cannot make all the holes due to criticality of the part. Hence, the edge holes are made by the press, after which the raw material is brought back to the drill for drilling other holes.</td>
<td></td>
</tr>
<tr>
<td>There has another drill with same capacity, which is used for other operations for the small parts along with notching operation in the 70 mm steering tube</td>
<td>As both the drilling machine are of same capacity, the drilling and notching can easily be transferred to one drill and other drill can easily be dedicated for machining other small parts.</td>
</tr>
<tr>
<td>The cutting machines (in the cutting shop), the milling machine, the lathe used in notching the 76mm dia. steering tube, the hexa-cutter at the auxiliary cutting shop, and the bending machine, all are special purpose machines dedicated to a specific process.</td>
<td>All these machines can be combined into a small work cell.</td>
</tr>
</tbody>
</table>

Observations and decisions regarding the process concerning Trekking
Based on the observations and decisions discussed in Table 1, the following changes are suggested:

• A manufacturing cell can be developed by combining one cutting machine, two hexa-cutting machines, one mill, and one drill from the two available drills for drilling holes and notching 70 mm dia. steering tube, one lathe, and the bending machine.

• This separation of drill is possible because the utilization factor of one drill which is used for notching operation is 0.58 whereas the utilization for the drilling operation in other drill is 0.14. Although the utilization factor for drilling operation is 0.14, the operator is basically ideal for some time because once one batch of drilling is made, he has to wait till the next batch of work piece come. Which eventually decreases the overall efficiency. With the cell like formation, this problem of pulling of work piece will be eliminated as well.

• The process of making hole by press is eliminated.

• The process flow will remain largely the same with minimal modifications like eliminating the press operation, and reducing the trekking worker movement to five workstations to one workstation.

• No change in the work force is required. Only work station and worker re-adjustment is required.
Facility Layout optimization of the plant

• In the current layout, workers travel 5770 meters per day for an eight hour shift. After applying process re-organization; cutting area, and steering tube cutting/bending shop are eliminated. The machine shop cannot be eliminated as it performs other operations. Under this scenario, the facility layout problem was solved to minimize the interdepartmental material movement.

• Quadratic Assignment Problem (QAP) (Koopmans and Beckman, 1957) approach was used to optimize the facility layout of the plant with the modified process flow.

• Artificial Bee Colony algorithm (ABC) is used to solve the problem

• The results show subsequent reduction in the interdepartmental material movement. The optimal material movement was only 3080 meters per day (as found by ABC algorithm) to maintain same throughput. This amounted to a reduction of approximately 46.6% in material movement.
Facility layout of the plant
<table>
<thead>
<tr>
<th>Location no</th>
<th>Present department</th>
<th>Proposed department</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Painting shop</td>
<td>Painting shop</td>
</tr>
<tr>
<td>2</td>
<td>Sheering section</td>
<td>Front show shop1</td>
</tr>
<tr>
<td>3</td>
<td>Cutting shop</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Machine shop</td>
<td>Shaping shop</td>
</tr>
<tr>
<td>5</td>
<td>Steering tube cutting and bending</td>
<td>Front show shop2</td>
</tr>
<tr>
<td>6</td>
<td>Front show shop1</td>
<td>Generator room</td>
</tr>
<tr>
<td>7</td>
<td>Front show shop2</td>
<td>Sheering section</td>
</tr>
<tr>
<td>8</td>
<td>Shaping shop</td>
<td>Rectangular pipe and steering tube making cell</td>
</tr>
<tr>
<td>9</td>
<td>Generator room</td>
<td>Machine shop</td>
</tr>
<tr>
<td>10</td>
<td>Assembly shop</td>
<td>Assembly shop</td>
</tr>
<tr>
<td>11</td>
<td>Welding Shop</td>
<td>Welding Shop</td>
</tr>
<tr>
<td>12</td>
<td>Press Shop</td>
<td>Press Shop</td>
</tr>
</tbody>
</table>

present and proposed location of various work stations
• The second highest bottlenecking process i.e. press operation in the rectangular pipe is eliminated and the discussion remains open for the painting.

• In this process two helpers bring the chassis to the painting area from final welding; painting is done by the painter, and the painted chassis is put into the heating chamber for drying.

• Although the material transfer and operation are not in parallel, due to fixed position of the painting and final welding, the possibility of relocating these processes are eliminated.

• No significant un-necessary activity found in the painting process, neither any activity can be re-arranged. Hence as per the framework described, the next possible method is tried to improve the productivity of the process.
As discussed in the earlier section, the painting process seems to be critical but cannot be improved with the previous step hence the possibility of adding one human resource for the process is checked. It is found that mainly spray painting is used for painting all the parts under consideration.
Simulation model modification and results

In order to numerically evaluate the effect of manufacturing process re-engineering; the initial Arena simulation model was modified as follows:

• The press operation was eliminated for making holes.
• The drilling times were changed as follows:
  • For the pipes that were holed by the press initially, a replacement drilling operation of U (40, 60) seconds to drill two holes.
  • The replacement drilling time was added to the original drilling times as all the holes are now made on the drilling machine.
• Material movement from one shop to another was done in pre-defined batches. However, with the proposed manufacturing cell layout; such batching is eliminated as all machines are in the same cell.
• The drilling machine will be also used for notching of the 70mm dia. Steering tube.
• With the proposed layout, distance travelled by the trekking worker got reduced to approximately 10 meters from the earlier 110 meters. We estimated that this saves around 4 minutes of time, in reduced travel, loading-unloading, collection, and chatting times. The present time requirements and estimated time requirements are given in the next table.
<table>
<thead>
<tr>
<th>Loading Unloading steps</th>
<th>Time (seconds) (minimum required)</th>
<th>Loading Unloading steps</th>
<th>Estimated Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving chassis from trekking jig</td>
<td>90</td>
<td>Moving chassis from trekking jig</td>
<td>90</td>
</tr>
<tr>
<td>Worker movement from welding shop to cutting shop (position 3 to position 11 in Figure 5)</td>
<td>30</td>
<td>Worker movement from welding shop to new rectangular pipe and steering tube making cell (8 to 11 in Figure 5)</td>
<td>10</td>
</tr>
<tr>
<td>Loading material at cutting shop</td>
<td>40</td>
<td>Loading material at the cell</td>
<td>60</td>
</tr>
<tr>
<td>Returning back to welding shop from cutting shop</td>
<td>50</td>
<td>Returning back to welding shop from the cell</td>
<td>30</td>
</tr>
<tr>
<td>Worker movement from welding shop to machine shop (4 to 11 in Figure 5)</td>
<td>20</td>
<td>Fixing all parts into the trekking jig</td>
<td>140</td>
</tr>
<tr>
<td>Loading material at machine shop</td>
<td>40</td>
<td>Flexibility</td>
<td>30</td>
</tr>
<tr>
<td>Returning back to welding shop from machine shop</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worker movement from welding shop to Steering tube cutting/ bending shop (11 to 5 in Figure 5)</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading material at to Steering tube cutting/ bending shop</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Returning back to welding shop from Steering tube cutting/ bending shop</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worker movement from welding shop to press shop (11 to 12 in Figure 5)</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading material at press shop</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Returning back to welding shop from press shop</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixing all the parts into the trekking jig</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>600</td>
<td>Total</td>
<td>360</td>
</tr>
</tbody>
</table>

Present and proposed loading-unloading steps and corresponding times for trekking
The simulation run time and other inputs were kept the same as the initial model. The major results are:

- Total autos manufactured: 6720
- Type wise output:
  - Auto1: 276
  - Auto2: 423
  - Auto3: 1593
  - Auto4: 607
  - Auto5: 3821

- Average output per day: 22.4
Modification cost, overtime cost, comparison

• Per day avg. improvement in productivity = 3.86
• Increase in total output in a year: 6720-5560 = 1160
• Percentage improvement: 20.86%
• Number of additional human resource required for this improvement: 1
• Total extra cost to the company for this employment: 1 X 250 X 300 = INR 75000
• Other handling expenditure (Approximate): INR 50000
• Total cost of modification: INR 125000
• Overtime cost of producing 1160 auto: INR 204539.88

The required productivity of the plant is 23.667 autos per day. The modification described above can reach the productivity up to 22.4 autos per day. Hence the iteration will not stop here and again begin with the “search for bottleneck” section.
Search for Bottleneck

Utilization of various factors after first modification
From figure, it is clear that the trekking process remains bottleneck again with utilization factor of 0.99. The final welding process has a utilization factor of 0.94. Although the assembly process is at the utilization factor 0.91, understanding that with the previous modification, the plant requires only to improve its daily productivity by 1.267, this process is exempted from considering a potential upcoming bottleneck under present requirement.
Parallel Process

• As the material transfer time of the process trekking is already considered and not possible to improve further with the present system, now we will consider the feasibility of increment of human resource to the process to improve the productivity.

• For the process trekking, two welders and two helpers work simultaneously along the four sides of a special jig.

• Addition of one more welder is not possible because of the place restrictions.

• Addition of helper for working is not feasible because the two helpers are sufficient to help the process.

• Considering the fact that after trekking process, these two workers only moves to bring the parts for the next process, addition of one more worker who will bring the parts in the intermediate time is also thought of.

• But the idea is not applicable because of unavailability of place for storing the parts for next operation circle. Hence addition of human resource is not possible for this case.

• The welding process solely cannot be changed because there does not have any replacement for such welding. Hence only addition a parallel process remains only option for the present scenario.
Simulation model modification and results

- After adding one more resource to the trekking and final welding process, the simulation model is run with the same input parameters. The following analysis can be made with the results:

- Total no. of output: 7350 with various types of auto as:
  - Auto1: 291
  - Auto 2: 427
  - Auto 3: 1712
  - Auto 4: 613
  - Auto 5: 4307

- Productivity: 24.5 autos per day

- The bottleneck is now shifted to assembly process with an utilization factor of 0.99, followed by mig welding 2 (where the enforcement of front show is joined) with utilization factor of 0.95; Drilling process is at 0.94; heating furnace 1 (where painted chassis is dried) and show shop grinder is at 0.91; colour bending process (front show) is at 0.92; denting process is at 0.9 utilization factor. The utilization of various processes are shown in the next figure.

- With the latest increment of resource, the plant can be able to produce its present requirement productivity of 23.667 per day.
Utilization of various processes after second modification
Modification cost, overtime cost, comparison

• The total cost to reach the required productivity with adding additional parallel process for the trekking and final:
  • Number of worker requirement: 7 (4 skilled and 3 unskilled)
  • Total labour cost: $3\times300\times170+4\times300\times250=\text{INR} \ 453000$
  • Other expenditures (Approximate): $10000$
  • Total cost : INR $463000$ (1)

• The total cost to the organization to reach the required productivity with overtime and after first modification:
  • Average overtime production requirement per day: $(23.667-22.4) = 1.267$
  • Total overtime production requirement in a year: $380.1$
  • Total overtime expenditure in a year: INR $40215.9375$ (2)

• Comparing (1) and (2), it can be concluded that, inclusion of another trekking and final welding parallel process is not beneficial for the present required productivity. The plant should be rearranged according to the way discussed in the previous sessions and then the remaining $1.267$ autos on an average per day should be manufactured with overtime production.

• The total cost of production with the advised process modification and overtime production (2 and 4) = INR $161907.03125$. Which reduces the present production cost by INR $106504.7125$. Which approximately $39.2\%$ less comparing to the strategy of doing all the required additional amount of production in overtime.
Conclusions
This paper presents a framework which consists of five interactive levels (data collection, analysis, action, validation, cost comparison) for the iteration based improvement of productivity of a SME. At each iteration, the bottlenecks are to be found out and modified according to the methodologies provided in the framework.

- The application sequence of methodologies are also arranged logically in the ascending order of their modification cost.
- The modification done by any methodology is then validated with the simulation run to identify improvement quantity.
- The cost of modification is calculated and compared with overtime production cost or with other methodology cost as shown in the framework.
- The minimum cost strategy is suggested.

A case of Indian three wheeler manufacturer is considered to illustrate the applicability of the framework. The result shows the additional production cost can easily be reduced by 39.2% from their present cost by improving the productivity of the plant by 20.86% with the suggested changes.

- In conclusion, it can be said that the framework not only improves the productivity but also compares the cost of improvement with the overtime production cost.
- This ensures the managers of the firm to select the most economic strategy for the additional production.
- However, the applicability of this framework may be limited to the flow shop kind of environment. Development of similar framework for job shop or other environment remains the future scope of this work. 
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