CHAPTER 11

CONCLUSIONS AND SCOPE FOR FURTHER RESEARCH

11.1 CONCLUSIONS

This research work has substantiated the fact that the efficiency and performance level of the sand casting process has been improved by applying a Six Sigma approach.

DMAIC based Six Sigma approach is implemented to reduce the defects rejection percentage of a flywheel by optimizing parameters with help of Taguchi, RSM and validated by PWA based on TRIZ. Empirical study of employee job satisfaction upon Six Sigma implementation has been evaluated. Optimal base stock level for on-time delivery and OEE with performance indicators also have been analyzed and determined. From this work the following observations are made by the Six Sigma improvement group.

- The tangible results are achieved and defects rejection percentage level is reduced from 20.65 % to 14.78% with an equivalent improvement from $3.32\sigma$ to $3.47\sigma$. Higher sigma levels indicate less likelihood of producing defects and hence better performance.

- The different salaried workers (Rs.3000-5000 and Rs.5000-10000) are satisfied with their jobs, and they did not differ significantly in terms of overall job satisfactions. But there is very small significant difference in factors of salary and benefits, working conditions, training for adapting Six Sigma,
policies and procedures; it indirectly affected the overall job satisfaction when it has longer difference in the mean and standard deviation.

- None of the relations between job satisfaction and its factors are statistically significant. In most of the cases, low level salaried workers recorded lower job satisfaction scores than highly salaried workers. Both the cases are neither satisfied nor dissatisfied. This level of satisfaction significantly varied as employees stayed with company up to a year. Satisfaction level then began to increase.

- These results might indicate that the job satisfaction level falls within the tabulated value even though they experienced low job satisfaction level. Correlation coefficients are calculated to describe the relationship between job satisfaction and factors and they ranged from 0.98–0.99 (±0.85 to ± 1.00), indicating relationships of negligible to moderate magnitude.

- It is also believed that the workers need a more in-depth understanding of the relationships with one another. Awareness or sensitivity training also is arranged according to the nature of requirement of the employees.

Casting defects in sand casting process is analyzed by Taguchi method. From the results of the study, it is found that the application of Taguchi’s method to the green sand casting process has the following contributions:

- Improves the productivity of the castings produced.
• Increases stability of the casting process. Before the application of Taguchi’s method, the parameters of the casting process are more arbitrary and difficult to control and hence the product quality suffered instability problems. Taguchi’s method yielded optimized control factors, resulting in superior product quality and stability.

• A higher product yield is possible because, prior to the application of the Taguchi method, the casting defects of the casting process were 7.703%, and after the application of Taguchi’s method, the casting defects of the casting process declined to 7.32%. It shows the reduction in average percentage of rejection rate of sand casting process by 0.38% and process sigma level of the company increased from 3.47 to 3.68. From this analysis, it is concluded that, the quality can be improved by Taguchi’s method of parameter design at the lowest possible cost. It is also possible to identify the optimum levels of signal factors at which the noise factors are least affected on the response parameters. The outcome of this work is Taguchi’s method to optimize the process parameters of the green sand castings process which lead to minimized casting defects. Also, the experiments give a clear picture of every factor’s contribution to the variation in the green sand casting process, and the quality can be improved without additional investment.

Using the RSM to complement the results obtained by the Taguchi approach, a significant reduction in percentage of casting defects is obtained and hence the product quality is improved.

Based on the experimental and analytical results, the following conclusions are made.
The effect of significant casting parameters (F value > tabulated value) of moisture content, permeability, volatile content and mold pressure are analyzed by using the RSM and optimal casting parameter conditions are determined to minimize the percentage of defects.

A second-order response surface model for defects is developed from the observed data. The predicted and measured values are fairly close, which indicates that the developed model is effectively used to predict the defects on the casting of Cast Iron flywheel, with 95% confidence intervals. Using such a model, one can obtain remarkable savings in time and cost.

In this work, with the Taguchi and RSM, the average percentage defects came down from 7.32 to 6.44 and the average error percentage decreased from 11.8 to 6.64. Thus the overall casting rejection percentage declined from 14.78 to 6.44. The application of Six Sigma methodology brought up the sigma level from 3.47 to 3.8 and this yields a financial benefit.

The results revealed that minimal casting rejection percentage could be arrived significantly for casting operations. Verification test results revealed that the determined optimal combination of casting parameters satisfied the real requirements of casting operation. The DMAIC methodology of Six Sigma resulted in a quantum improvement in the sigma value of the casting process.

This procedure has been shown to be efficient and effective for achieving the optimum set of operating parameters for a particular product quality characteristic. A number of experiments carried out to validate the
results indicate that the cost of the experimentation will be more than the payback achieved by the increased efficiency and quality of the process. Hence, PWA, a suitable tool for quickly evaluating the quality and robustness of the process setup is implemented. It is also used to validate the optimization process more quickly and precisely with least resource. Based on the experimental and analytical results, the following conclusions are made.

- **TRIZ based PWA** is an innovative validation and optimization method for casting process parameters. In the PWA, all the individual parameters are interacted with each other to optimize parameter level to identify the impact of parameters on casting defects. It can also be applied for various other process parameters optimization.

- Under a different parameter combination, the TRIZ tool can acquire different innovative principles and provide an improvement in optimization and concept to avoid much unnecessary trial and error work. Verification test results revealed that the determined PWA optimal combination of casting parameters satisfied the real requirements of casting operation. The predicted and measured values are fairly close, which indicates that the developed model is effectively used to predict the defects on the casting of Cast Iron flywheel. This is the robust process parameter set up to produce less percentage of casting defects confirmed by PWA.

- In terms of PWA, conflict problems (technical) encountered in the process is provided by the alternative thinking principles of TRIZ. Thus, innovation replaces conventional compromise to avoid reduction of process quality and waste of substance.
In the TRIZ method, designer thinking is not limited by a single professional experience and the solution is equipped with innovation and diversification. Through the PWA, this article effectively combines TRIZ to validate a sand casting process optimization that can remarkably reduce the reliance on professional technical personnel in the future optimization validation process. Using such a model, one can obtain remarkable savings in time and cost.

The implementation effect and efficiency of the Six Sigma program is also improved by determining the base stock inventory system. This is applied to improve on-time delivery and meeting the customer demands in a stochastic nature. From this study the following observations are made.

- This study shows that the most noticeable measurements of effectiveness of Six Sigma program by determining base stock system are plant productivity, product quality measures, and variation in inventory costs, on-time delivery and profit.

- Based on the recommendation of the Six Sigma improvement group, the company maintained the minimum inventory or base stock of units per day and it could meet the real demand for this given input and is confirmed by exponential smoothing method. It also improves the satisfaction level of customers, in the process profit and goodwill of the company.

- This work extends the customer-satisfaction concept from manufacturing vertically to the user and customer. This performance system provides three flexible weights to linearly combine performance parameters that help management formulate the most suitable measurements for several kinds of
manufacturing projects/teams to attain accuracy effectiveness, different weight combinations (r1, r2, r3,) calculated in this work.

- Based on the calculation of performance measures, the equipment effectiveness of the system is also increased 23% and this model can assist firms in selecting and rewarding the best manufacturing process and integrating their capabilities in developing an appropriate profit improvement program for meeting and exceeding specific customer requirements.

The effectiveness and difficulties encountered in the Six Sigma based casting company is studied and measured with help of OEE and also the major success factors that contribute to the success of TPM are determined.

- A pilot study of the implementation of TPM through measuring of OEE and its various performance indicators are determined with the help of the maintenance activities performed by an improvement team.

- In the TRIZ method, designer thinking is not limited by a single professional experience and the solution is equipped with innovation and diversification. This improvement enhanced the equipment in both effectiveness and quality in product produced and on-time delivery of products also improved.

In conclusion, the following changes are observed:

- Empowering the workforce caused a development of a bright, cheerful and relaxed workplace for production people. Growth of work habits, technical skill development and promotion of
cross-functional team created an enthusiastic workforce to enhance the company in both competitive power and image. The workers work happily after the introduction of the new and people participatory system, Six Sigma.

- This relatively simple application of OEE, using a structured DMAIC technique, should allow for increased use of the methodology for tackling many maintenance issues. Likewise, the results can also provide the stimulus for the wider application of the technique to create process improvements at relatively lower costs.

- The OEE approach developed a culture towards continuous improvement and the systematic implementation of the system throughout the organization. The application of the OEE approach allowed the company to develop advanced systems mapping and analysis techniques and to become generally more ‘technical’ in their approach to problem solving.

- The Pareto chart helped to locate the causes of poor quality or extent of the reject rate due to production scraps and breakdowns. The causes of rejection had been investigated and followed by troubleshooting with workers participation. The Six Sigma initiative had been introduced in the company as a recommended guideline to reduce the reject rate as low as possible or to improve the quality of the customer products.

- The efficiency of the finishing line is always better than the casting line. This happened because there is no serious equipment problem in the finishing line but the jolting and pouring equipment in the casting line is frequently causing the
Stoppage of production and delayed the production directly. Introduction of newer technology helped to reduce that bottleneck.

- The OEE measures only applied to the casting line through its skilled operators. Its OEE value has shown a significant value and OEE has been increased gradually towards the world class standard (OEE > 0.84) set. The operators should be trained and empowered to record the loss data and take adequate measures in all production lines.

- For successful implementation of a new system of Six Sigma with OEE, organizational structural, along with employee’s ability enhancement through training, is a vital issue. In this study, it is observed that the workers are not exposed to adequate training courses, especially for the workers involved in the casting line. They are not provided training (external) on modern casting methods but could only learn the casting technique from the experienced workers on-the-job. They are willing to work harder to increase the productivity and improve quality of the process and products and training could have helped them.

- Overall, the performance of the company could be considered good and growth trend is obvious from the time of introduction of the new system. Under the Six Sigma approach, the unit recorded marked success towards productivity improvement. Over the time, upon companywide ‘total’ implementation of OEE, the performance measures in terms sigma is improved from 3.32 to 3.84 and it shows the road to success. There is definitely room for further improvement.
Finally,

- Prepared the employees for a full time, committed focus on the Six Sigma initiative
- Used Six Sigma tools to isolate and improve factors affecting firm’s quality and performance
- Sustain Six Sigma, and created a ripple effect throughout the entire organization.

Overall, the objectives of this work is achieved and fulfilled. This experience can be applied to other manufacturing process industries.

11.2 SCOPE FOR FURTHER RESEARCH

The work completed so far in the present system offers many interesting extensions to it. This procedure has been shown to be an efficient and effective for implementing and achieving Six Sigma. More research in this area is necessary to contribute to the science and practice of implementation of Six Sigma model to reduce waste and create value.

- Based on the successes and limitations found in the company, the additional performance indicators, financial performance indicators, “first line” maintenance approach and sufficient technical training should be required. The applicable strategic actions to promote the willingness and capabilities of the management and manufacturing teams could be considered as a direction for future research, including profit sharing, internal promotion programs, and organizational expansion projects and so on that may be critical for performance’s improvement and sustaining.
• The training (Yellow, Green, Black and master black belt) should be given to the employees of the concern about the Six Sigma implementation model from the bottom line of the Six Sigma by the improvement.

• In this work, workers job satisfaction is enhanced before implementing Six Sigma program. Six Sigma becomes successful only when workers are involved for which motivation and empowerment are essential. The company by doing the “people survey,” made every employee feels important. Hence enhancing of job satisfaction is to be done at the particular interval to know the impact of workers if needed.

• In this study, it is the authors’ experience from process development that it is difficult to get the authority to implement major changes in an organization if it cannot provide an estimate of the payback on the investment and this could be considered as a future work.

• The optimization of process, delivery of the product based on production, overall equipment efficiency and workers satisfaction level are determined. The other Six Sigma process management initiative and cost effective analysis can be carried out.

• More number of casting critical parameters can be taken and multi objective optimization can be applied for further improving process performance. Optimal inventory system can be applied for all type of production, and cost analysis can also be done for the Six Sigma implementation.
APPENDIX 1

QUESTIONNAIRE

ENHANCING JOB SATISFACTION UPON IMPLEMENTING SIX SIGMA

Name: ............................ Department: ............................

I) Designation:
   a) Permanent employee  b) Contract employee  c) Casual employee

II) Sex:
   a) Male  b) Female

III) Salary in Rs.
   a) Below 3000  b) 3000 – 5000  c) 5000 -10000  d) Above 10000

IV) Education Qualification:
   Technical:
   a) ITI  b) Diploma  c) UG  d) PG

V) How long you are with this company
   a. Less than one year  b. 1-3 year’s  c. 4-6 years  d. more than 6 years

VI) How many hours (on average) do you work per week?

____________________

For the questions given below please tick mark your options in the box provided.
<table>
<thead>
<tr>
<th>S. No</th>
<th>Questions</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neither Agree Nor Disagree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I feel that am happy with company policies.</td>
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<td>2</td>
<td>I never thought of changing the organization</td>
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<td>3</td>
<td>I had a good idea of what this position involved before I began.</td>
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<td>4</td>
<td>I feel that I am valued by this agency.</td>
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<td>5</td>
<td>I receive adequate training to do my job well.</td>
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<td>6</td>
<td>I feel overwhelmed by my responsibilities at work.</td>
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<td>7</td>
<td>My work activities are personally meaningful to me.</td>
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<td>8</td>
<td>Other people view my job as a valuable profession.</td>
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<td>9</td>
<td>The orientation I received prepared me well for this work.</td>
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<td>10</td>
<td>I am confident of my abilities to succeed at my work.</td>
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<td>11</td>
<td>I am satisfied with the way that this company is managed.</td>
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<td>12</td>
<td>I believe that my position at work is a professional position.</td>
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<td>13</td>
<td>I am satisfied with my income.</td>
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<tr>
<td>S. No</td>
<td>Questions</td>
<td>Strongly Agree</td>
<td>Agree</td>
<td>Neither Agree Nor Disagree</td>
<td>Disagree</td>
<td>Strongly Disagree</td>
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<tr>
<td>14</td>
<td>I have mastered the skills necessary to perform my work.</td>
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<tr>
<td>15</td>
<td>For the work I do, the pay is good.</td>
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<td>16</td>
<td>Prior to accepting this position, I understood my job.</td>
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<td>17</td>
<td>I make a difference in the lives of other people.</td>
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<tr>
<td>18</td>
<td>I have ample opportunities for advancement in this profession.</td>
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<tr>
<td>19</td>
<td>This job demands too much (Physically, emotionally, mentally).</td>
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<tr>
<td>20</td>
<td>I believe that my supervisors Care deeply for me and for our clients.</td>
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<tr>
<td>21</td>
<td>The work I do is interesting.</td>
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<tr>
<td>22</td>
<td>This job adds significant pressure and anxiety to my life.</td>
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<tr>
<td>23</td>
<td>I am satisfied with the benefits offered to me through this job.</td>
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<td>24</td>
<td>I receive adequate support from my supervisors.</td>
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<td>25</td>
<td>I am involved in decision making that will not affects my job.</td>
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<tr>
<td>S. No</td>
<td>Questions</td>
<td>Strongly Agree</td>
<td>Agree</td>
<td>Neither Agree Nor Disagree</td>
<td>Disagree</td>
<td>Strongly Disagree</td>
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<tr>
<td>26</td>
<td>I am encouraged to develop new and more efficient ways to do my work.</td>
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<tr>
<td>27</td>
<td>Employees work well together to solve problems and get the job done.</td>
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<tr>
<td>28</td>
<td>Management is flexible and understands the importance of balancing my work and personal life.</td>
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<td>29</td>
<td>I would recommend others to work for this company.</td>
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<tr>
<td>30</td>
<td>I feel happy with the available benefits.</td>
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<td>31</td>
<td>I am satisfied with the working conditions.</td>
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<tr>
<td>32</td>
<td>I receive recognition for a job well done.</td>
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<tr>
<td>33</td>
<td>I feel close to the people at work.</td>
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<tr>
<td>34</td>
<td>I feel secure about my job.</td>
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<tr>
<td>35</td>
<td>I believe management concerned about me.</td>
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<tr>
<td>36</td>
<td>All my talents and skills are used at work.</td>
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<tr>
<td>37</td>
<td>I feel good about my job.</td>
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</table>

Lastly, think about your overall satisfaction with your job. This includes all the different components of your work life, from your pay rate and benefits, to your management and the organization of your company, to
relationships with coworkers and supervisors, to your particular responsibilities. Circle the number on the scale from 1-10 where it best represents your overall degree of job satisfaction.

(Yours)

______________________________________________________________

No Job
Greatest Satisfaction
Satisfaction
Possible Job
Satisfaction
APPENDIX 2

DESIGN OF EXPERIMENTS

A2.1  TAGUCHI METHOD

Dr. Genichi Taguchi of Japan developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,

Step-1:  identify the main function, side effects, and failure mode
Step-2:  identify the noise factors, testing conditions, and quality characteristics
Step-3:  identify the objective function to be optimized
Step-4:  identify the control factors and their levels
Step-5:  select the orthogonal array matrix experiment
Step-6:  conduct the matrix experiment
Step-7:  analyze the data
Step-8:  predict the optimum levels and performance
A2.2 FACTORIAL DESIGN METHODOLOGY

The accuracy and effectiveness of an experimental program depends on careful planning and execution. The steps involved in the research work for the optimizing sand casting process include the following.

1. Identifying the important process control variables.
2. Fixing the upper and lower bounds of the control variables,
3. Conducting the experiments as per the full factorial design matrix
4. Recording the responses.
5. The development of mathematical models.
6. Calculating the coefficients of the polynomials
7. Checking the adequacy of the models developed
8. Optimization of parameters
10. Studying the influence of variables on responses.

A2.3 RESPONSE SURFACE METHODOLOGY

RSM is the procedure for determining the relationship between various parameters and with the various machining criteria and exploring the effect of these process parameters on the coupled responses. RSM is a technique for determining and representing the cause-and-effect relationship between true mean responses and input control variables influencing the responses as a two or three-dimensional hyper surface. The accuracy and effectiveness of an experimental program depends on careful planning and execution. The steps involved in the research work for the experimental investigation include the following

1. Identifying the important process control variables.
2. Finding the upper and lower limits of the control variables.
3. Developing of the design matrix using box-behnken design and conducting the experiments as per the design matrix.
4. Recording the responses.
5. The development of mathematical models.
6. Calculating the coefficients of the second order polynomials.
7. Checking the adequacy of the models developed.
8. Presenting the main effects and the significant interaction effects of the process parameters on the responses in two and three dimensional (3D surface, interaction and contour plots) graphical forms.

A2.4  BOX- BEHNKEN DESIGN

Box-Behnken designs are experimental designs for response surface methodology, devised by George E. P. Box and Donald Behnken in 1960, to achieve the following goals:

- Each factor, or independent variable, is placed at one of three equally spaced values.
- The design should be sufficient to fit a quadratic model, that is, one containing squared terms and products of two factors.
- The ratio of the number of experimental points to the number of coefficients in the quadratic model should be reasonable

The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In
this design the treatment combinations are at the midpoints of edges of the process space and at the center. These designs are rotatable (or near rotatable) and require 3 levels of each factor. Box-Behnken designs are geared to fit second-order response surfaces for four factors at three levels.

A2.5 ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. The initial techniques of the analysis of variance were developed by the statistician and geneticist R. A. Fisher in the 1920s and 1930s, and are sometimes known as Fisher's ANOVA or Fisher's analysis of variance, due to the use of Fisher's F-distribution as part of the test of statistical. Degrees of freedom are used to describe the number of values in the final calculation of a statistic that are free to vary. Estimates of statistical parameters were based on different amounts of information or data. The number of independent pieces of information that go into the estimate of a parameter is called the degrees of freedom. In general, the degrees of freedom of an estimate is equal to the number of independent scores that go into the estimate minus the number of parameters estimated as intermediate steps in the estimation of the parameter itself. The error is the amount by which the estimator differs from the quantity to be estimated. The difference occurs because of randomness or because the estimator doesn't account for information that could produce a more accurate estimate. Mathematically, degrees of freedom are the dimension of the domain of a random vector, or essentially the number of 'free' components: how many components need to be known before the vector is fully determined. This design consisted of nine factors at three levels for Taguchi design and four factors at three levels for RSM design.
APPENDIX 3

SAND CASTING PROCESS

The term "green sand" is known principally because of the moisture content within the sand. The sand undergoes a "mulling" process in which various clay and chemical additives that act as binders are blended with the sand, which results in a compound which is suitable for the sand molding process. This prepared sand mixture is then compressed around the pattern at specific pressures and temperatures, to ensure it will maintain its shape throughout the remainder of the casting process. The blended sand and binders are compacted around the pattern, taking on the shape of the desired casting. Sometimes the design of the casting entails internal passageways being formed into the mold. This is done by using sand cores which are made of a similar sand mixture. The cores are strategically placed to form the necessary passageways in the casting. The two halves of the mold are subsequently closed and metal is poured into the cavity and left to solidify. Green Sand Casting gives enough Green Strength to get dimensional stability, provide excellent surface finish and better collapsibility during the knockout. The casting process has a large number of parameters that may affect the quality of castings. Some parameters are controllable but some are uncontrollable. The purpose of the process development is to improve the performance of the process related to customer needs and expectations. The process development can be achieved through experimentation and the aim is to reduce and control variation of a process.
SAND CASTING PROCESS – OPERATIONS - PHOTOS
APPENDIX 4

HYPOTHESIS TEST

Check the selected distribution- Exponential Distribution ((Jerry Banks (1996) Table):

**Hypothesis is exponential distribution**

<table>
<thead>
<tr>
<th>Ri</th>
<th>0.04</th>
<th>0.08</th>
<th>0.18</th>
<th>0.3</th>
<th>0.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/N</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>i/N-R(i)</td>
<td>0.16</td>
<td>0.32</td>
<td>0.42</td>
<td>0.5</td>
<td>0.61</td>
</tr>
<tr>
<td>R(i) – (i-1)/N</td>
<td>0/04</td>
<td>----</td>
<td>-----</td>
<td>---</td>
<td>----</td>
</tr>
</tbody>
</table>

1. $D^+=0.61 \quad D^-=0.04$
2. $D^- = 0.61$
3. Critical value $D_a : ( a = 0.01 ) : D_{0.01} = 0.669$
4. $D \leq D_a : 0.61 \leq 0.669 \quad$ (Jerry Banks (1996) Table) Hypothesis is Accepted.

**Hypothesis is Gamma Distribution**

<table>
<thead>
<tr>
<th>Ri</th>
<th>0.16</th>
<th>0.46</th>
<th>0.51</th>
<th>0.53</th>
<th>0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>i/N</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>i/N-R(i)</td>
<td>0.04</td>
<td>----</td>
<td>0.09</td>
<td>0.27</td>
<td>0.4</td>
</tr>
<tr>
<td>R(i) – (i-1)/N</td>
<td>0.16</td>
<td>0.26</td>
<td>0.11</td>
<td>----</td>
<td>---</td>
</tr>
</tbody>
</table>

1. $D^+ = 0.27 \quad D^- = 0.26$
2. $D^- = 0.27$
3. Critical value $D_a : ( a = 0.01 ) : D_{0.01} = 0.669$
4. $D \leq D_a : 0.27 \leq 0.669 \quad$ Hypothesis is Accepted.

where, $R(i)$ is the value of variable parameters, $N$ is the number of occurrences and $D$ is the critical value.
APPENDIX 5

OEE CALCULATIONS

1. OEE calculations after Six Sigma Implementation

Planned Production Time = [Shift Length - Breaks] = [480 - 60] = 420 minutes

Operating Time = [Planned Production Time - Down Time] = [420 - 70] = 350 minutes

Good Pieces = [Total Pieces - Reject Pieces] = [230 - 28] = 202 pieces

OEE factor

1. Availability = operating time / planned production time
   = 350/420 = 0.8333 = 83.33 %

2. Performance = (total pieces / operating time) / ideal run rate
   = (230/350) / 0.76 = 0.864 = 86.4%

3. Quality = good pieces / total pieces = 202/230 = 0.8783 = 87.83 %

4. Overall OEE = availability x performance x quality = 63.3 %

Under ideal conditions with suitable TPM techniques applied the OEE can be raised up to 85%. Traditional yield= good pieces / total pieces = 87.83 %. Rolled throughput yield (RTY) = Process (1): 54 parts passed through this process and 47 “good” parts left this process (scrapped 7) = 0.8703.

Process (2): With some WIP laying around 79 parts passed through this process with 69 “good” parts passing (10 scrapped) = 0.8734.
Process (3): With even more WIP laying around this process they managed to produce 97 parts with 86 parts passing (11 scrapped) = 0.8865.
RTY = 0.833 \times 0.848 \times 0.845 = 67.4% 

**OEE calculations before Six Sigma Implementation**

Planned Production Time = [480 - 60] = 420 minutes
Operating Time = [420 - 82] = 338 minutes
Good Pieces = [220 - 32] = 188 pieces

**OEE factor**

1. Availability = 338/420 = 0.804 = 80.4 %
2. Performance = (220/338) / 0.76 = 0.856 = 85.6%
3. Quality = 188/220 = 0.8545 = 85.45 %
4. Overall OEE = availability x performance x quality = 58.9 %

Under ideal conditions with suitable TPM techniques applied the OEE can be raised up to 85%.

Traditional yield= good pieces / total pieces = 85.45 %

Rolled throughput yield (RTY)

- Process 1: 64 parts passed through this process and 55 “good” parts left this process (scrapped 9) = 0.8593
- Process 2: With some WIP laying around 72 parts passed through this process with 61 “good” parts passing (11 scrapped) = 0.8472
- Process 3: With even more WIP laying around this process they managed to produce 84 parts with 72 parts passing (12 scrapped) = 0.8571

RTY = 0.8593 \times 0.8472 \times 0.8571 = 62.4%