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A Simulation Model for Overall Equipment Effectiveness of a Generic Production Line

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Abstract: *Overall equipment effectiveness (OEE) is one of the performance evaluation methods most common in manufacturing industries. It plays a vital role in improving the efficiency of a manufacturing process which in turn ensures quality, consistency and productivity. In this paper, the authors have designed and implemented a simulation model for OEE computation. The input data needed by the model is derived from XML files generated by the cost optimized production line based on multiple criteria such as (Work In Progress) WIP inventory minimization, idle time minimization and application of Theory of Constraints. Both the crisp model and the fuzzy model based on Mamdani inference system with triangular membership functions are implemented and compared. In the current model fuzzy input variables corresponding to machine down time and machine setup time and the fuzzy output variable corresponding to the availability parameter of OEE are considered. The rule set consists of nine different rules. The front end of the application model is implemented in VB and the simulation model is presented in MS-Excel. It is observed that the fuzzy model deviates from the crisp model as the overlap of the member functions is increased.*
***Keywords**: Availability, Fuzzy model, Performance, Quality, Rule Set, Triangular Membership Functions, XML.*

I. Introduction

While managing change, organizations can deploy change management tools like total productive maintenance and six sigma to remove redundancies and elimination of rework. The objective of Total Productive Maintenance (TPM) is to manage equipment/machine to deliver the most it can by completely eliminating machine down time in all forms. The benefits flow both directly and tangentially, for instance the quality pay offs in terms of fewer defects and rejections mean lower cost and implementation of TPM can play a pivotal role in cost rationalization, resulting in direct cost advantage from reduction in man power, stocks, inventories and repairs. The basic approach is loss analysis, continuous improvement and maintenance of equipment to prevent downtime. This is a participatory management technique which significantly contributes in enhancing productivity and quality, reducing cost, improving adherence to delivery schedules, bettering safety conditions and increasing employee morale. Like all transformation imperatives TPM begins by understanding what is wrong and why it is so by applying rules like kaizen and employee involvement to maintenance. Overall Equipment Effectiveness can be attained with a focus on zero loss, zero break downs, zero defects and zero accidents. TPM is the ideal integrator and the extent of the change and impact on the cost can be huge one. The best approach to combat shop floor cost is through higher machine uptimes and better process capabilities. The measures are overall equipment efficiency, production cost efficiency and production lead time efficiency. Equipment availability is calculated on several fronts including break down, changeover, fixture change and startup time.

OEE is one of the performance evaluation methods that is most common in manufacturing industries. OEE is a mechanism to continuously monitor and improve the efficiency of a manufacturing process. The three prime measuring metrics for OEE are Availability, Performance and Quality which help gauge manufacturing process's efficiency and effectiveness. Further they enable categorization of key productivity losses that occur within the manufacturing process. As such OEE aims towards improving manufacturing processes and in turn ensures quality, consistency, and productivity. By definition, OEE is the multiplication of Availability, Performance, and Quality.

The formula to calculate Overall Equipment Effectiveness is as follows [1]:

OEE = Availability x Performance x Quality

The formula to calculate the three parameters are given below:

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Production Time}}$$

$$\text{Performance} = \frac{\text{Ideal Cycle Time}}{\text{Total Pieces}}$$
$$= \frac{\text{Total Pieces /Operating Time}}{\text{Ideal Runtime}}$$

$$\text{Quality} = \frac{\text{Good Pieces}}{\text{Total Pieces}}$$

Figure1. depicts six major losses to equipment effectiveness.

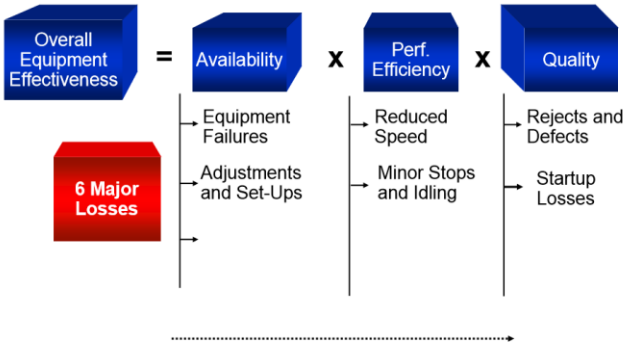


Figure 1. Six Major Losses to Equipment Effectiveness

The six major losses, which fall under three OEE loss categories along are depicted in Table 1. along with possible causes of losses.

Six Major Loss Category	OEE Loss Category	Reason
Breakdowns	Availability	1. Equipment failure 2. Major component failure 3. Unplanned maintenance
Set up and adjustments	Availability	1. Equipment setup 2. Raw material shortage 3. Operator shortage
Minor stops	Performance or, Availability	1. Equipment failure <5mins 2. Fallen product 3. Obstruction blockages
Speed loss	Performance	1. Running lower than rated speed 2. Untrained operator not able to run at nominal speed 3. Machine idling
Production rejects	Quality	1. Scrap 2. Rework 3. In process damage
Rejects on start up	Quality	1. Scrap 2. Rework 3. In process damage

Table 1 . OEE Loss Categories for Six Major Losses

Figure 2. shows improvement goals for major losses affecting OEE.

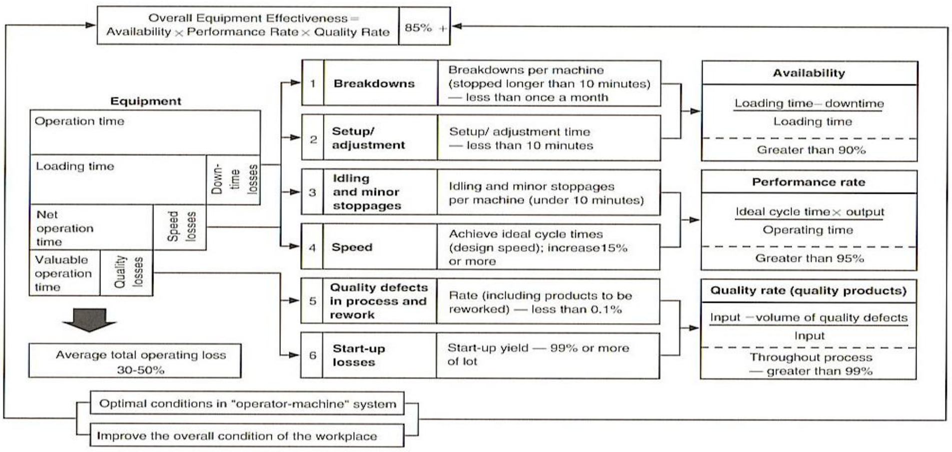


Figure 2. Improvement Goals for Major Losses Affecting OEE.

World class OEE

World class standard for OEE parameters is shown in Table 2 .

OEE Factor	World Class
Availability	90.0%
Performance	95.0%
Quality	99.9%
OEE	85%

Table 2. World Class Standard for OEE

Availability Matrices

The availability data for production line of a manufacturing organization is shown in Table 3.

Serial No.	Production Data	Value
01	Shift Length (8 Hours)	60x8 = 480 min
02	Short Breaks (2@15)	2x15=30 min
03	Meal Break (1@30)	1x30=30 min
04	Down Time	47 min

Table 3. Availability data

Performance Matrices

The performance data for production line of a manufacturing organization is shown in Table 4.

Serial No.	Production Data	Value
01	Ideal Runtime	60 pieces per min
02	Total Pieces	19,271

Table 4. Performance data

Quality Matrices

The quality data for production line of a manufacturing organization is shown in Table 5.

Serial No.	Production Data	Value
01	Total Pieces	19,271
02	Rejection and Rework	423

Table 5. Quality data

II. Literature Review

The outcome of TPM implementation is measured using OEE, serves as an indicator of process improvement activities within the manufacturing environment [2]. The three elements of OEE measure the equipment and production losses experienced. Nakajima grouped and defined these losses into what is termed as production's six big losses. The six major losses are equipment breakdown losses, setup and adjustment losses, minor stoppage losses, speed reduction losses, defective losses and start up losses. Equipment and setup losses are considered as time lost which are used for equipment availability calculation. The minor stoppages and speed reduction losses are used to determine equipment process performance efficiency. On the other hand, defective and start up losses are categorized as quality yield losses [3]. In order to be classified as 'world class manufacturing', the company must achieve equipment availability that is greater than 90%, process performance efficiency that is more than 95%, achieve a quality yield that is greater than 99% and obtained overall equipment effectiveness (OEE) that is greater than 85%"[4]. Total Productive Maintenance (TPM) is a world class manufacturing strategy which aims at manufacturing near to ideal condition with zero downtime, zero defect, lean production, just in time (JIT) production leading to competitive advantage. The most common metric utilized by management to gauge the effectiveness and the successful implementation of TPM is OEE. In their paper, authors have employed DMAIC approach to systematically define, measure, analyze, improve and control the equipment performance. In their paper the authors have highlighted the use of six sigma methodology to mitigate the bottleneck processes which focuses on OEE performance in a semiconductor firm [5]. In literature there exist number of papers focusing on state of TMP implementation in SMIs and interrelationship of TMP with TQM and JIT [6-9]. The authors of paper provide a brief study on the literature related to the application of TPM in the manufacturing industry. The study focuses on the main role of TPM in supporting the established quality improvement initiative such as lean production. Effort was made to discuss the published research related to TPM and lean production. This literature review-based research revealed an important research gap, i.e. the need of a comprehensive integration between these two methodologies. The significance role of TPM as an important complementary to lean production is observed has not been well addressed in the available literature. Most of the researches available investigate these initiatives separately, rather than addressing on the significant role of TPM as one of the main thrust. The beneficial outcome from

TPM methodology is quite hindered and unexposed in some literatures related to lean production. The outcomes from this review is hope justify the needs of further research in the area of TPM integration with lean production, aimed at strengthening its philosophy towards more realistic applications [10].The literature review demonstrates that the implementation of TPM is one of the business philosophies which is basically used to improve the technological base by enhancing equipment efficiency and improving the morale of employees [12]. TPM implementation brings both production and maintenance functions together after initiating good working practices, team working and continuous improvement [13]. The goal of TPM is to continually maintain, improve and maximize the condition and effectiveness of equipment through complete involvement of every employee from top management to shop floor workers [14].

III. Application Architecture

The authors have designed and developed various tools for the selection of manufacturing method based on single organizational objective/multi objective and/or single/multi organizational function. The tools are based on crisp and fuzzy expert systems which can be queried in a human language parsed used Natural Language Processing (NLP) and Deterministic Finite Automata (DFA) parsers. The authors have designed and implemented their own query language name as manufacturing query Language (MQL) for this purpose. A production line is redesigned for total cost optimization based on multiple criteria such as WIP minimization, machine idle time minimization and application of theory of constraints using Genetic Algorithm. There is a trade off between machine idle time and WIP and the objective is total cost minimization. Finally, the line efficiency is analyzed using OEE Analysis Tool designed and developed by us and the results are compared with world class standard. Figure 3. depicts the overall application architecture for the setting up of production line, redesigning and analyzing line efficiency using OEE tool.

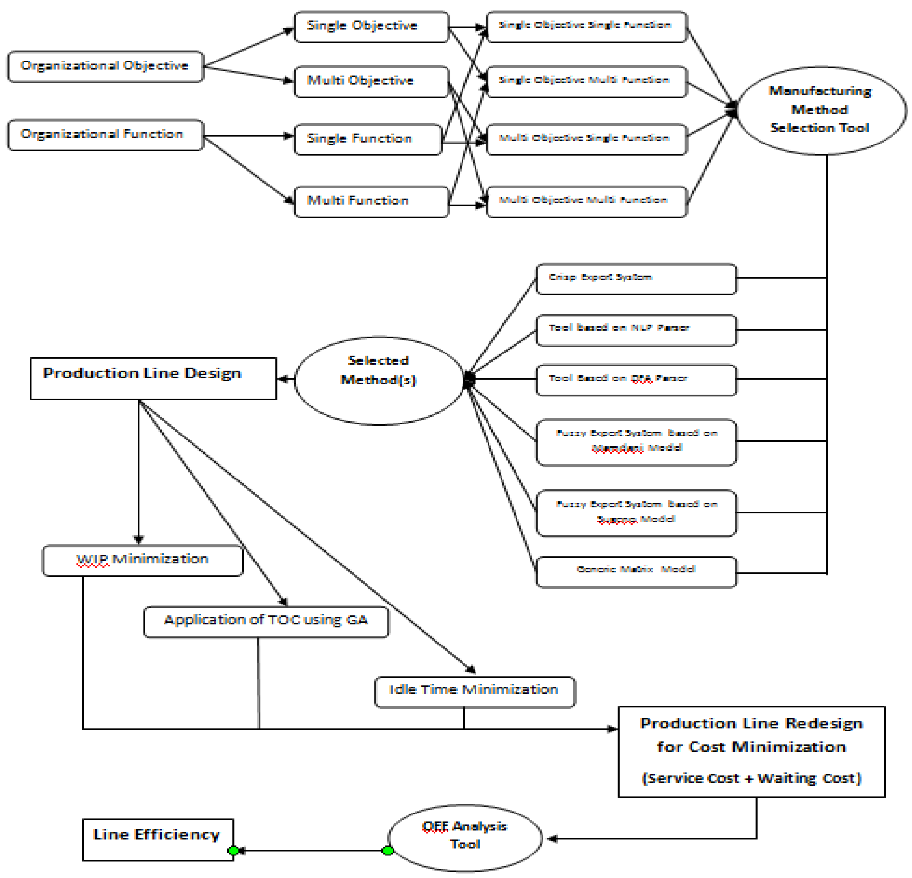


Figure 3. Application Architecture for Production Line Setup, Redesign and Analysis

The output of single channel multiphase optimization model of a production line based on multiple criteria is routed to several XML files which are input to OEE analysis tool for analyzing line efficiency. A simulation model is developed and the input parameters are fine tuned for achieving the world class standard for OEE parameters. The corresponding layered architecture based on service-oriented model is shown in Figure 4. As seen from the figure, each layer except the first derives its input from the previous layer and generates output to the next layer.

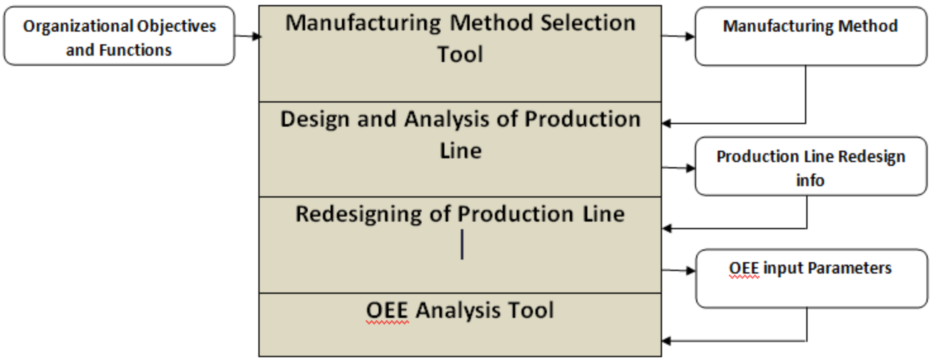


Figure 4. Layered Architecture based on Service Oriented Model.

IV. Results and Discussions

The OEE part of the model discussed above is implemented in VB and Excel for the data presented above. The input data is derived from the XML files generated by the cost optimized production line. The structure of the XML files are shown in Table 6.

availability.xml

```
<config>
 <shiftLength>8</shiftLength>
 <shortBreak>
  <count>2</count>
  <duration>15</duration>
  <min>10</min>
 </shortBreak>
 <mealBreak>
  <count>1</count>
  <duration>30</duration>
  <min>25</min>
 </mealBreak>
 <machine>
  <breakdownTime>32</breakdownTime>
  <setupTime>15</setupTime>
  <minSetupTime>10</minSetupTime>
  <minBreakDownTime>25</minBreakDownTime>
 </machine>
</config>
```

efficiency.xml

```
<config>
 <idealRuntime>60</idealRuntime>
 <totalPieces>19271</totalPieces>
</config>
```

quality.xml

```
<config>
 <rejectedPieces>423</rejectedPieces>
</config>
```

worldclass.xml

```
<config>
 <availability>90</availability>
 <efficiency>95</efficiency>
 <quality>99.9</quality>
 <oee>85</oee>
</config>
```

Table 6. Structure pf XML files generated by the cost optimized production line

The code for parsing of XML files using Microsoft's XML parser is given in Appendix A.

Figure 5- 7 depict the simulation results for machine availability, performance and quality. All the three parameters can be fine tuned based on the priority levels set. As a visual aid, the corresponding world class standard is highlighted.

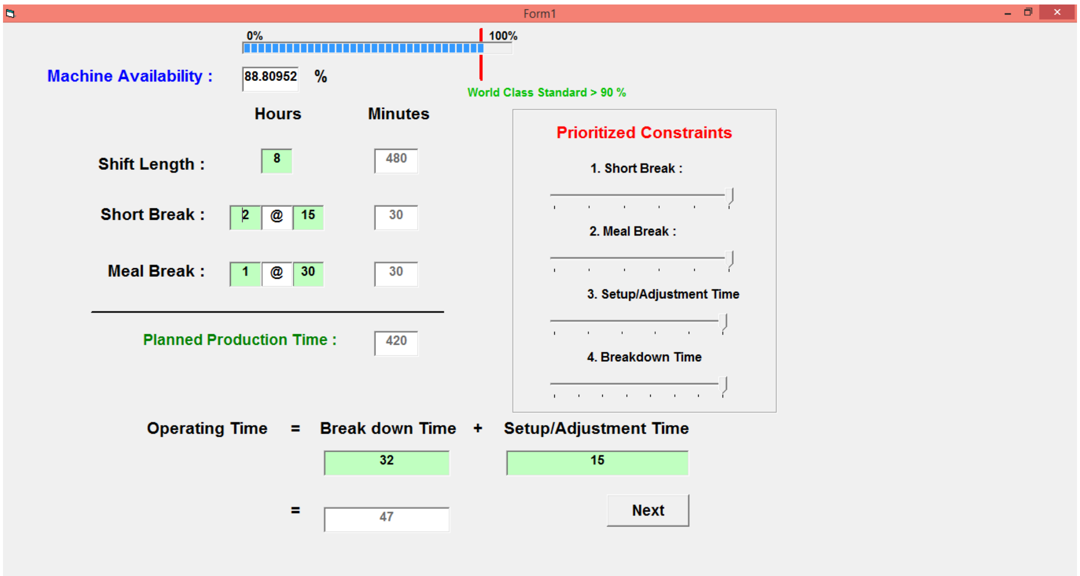


Figure 5. Simulation result for Machine Availability

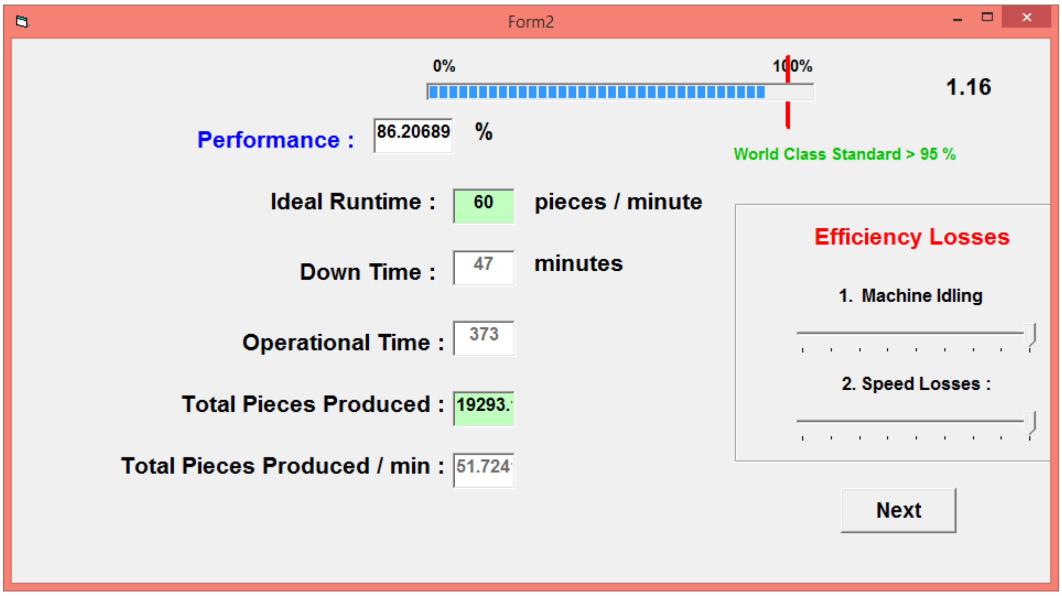
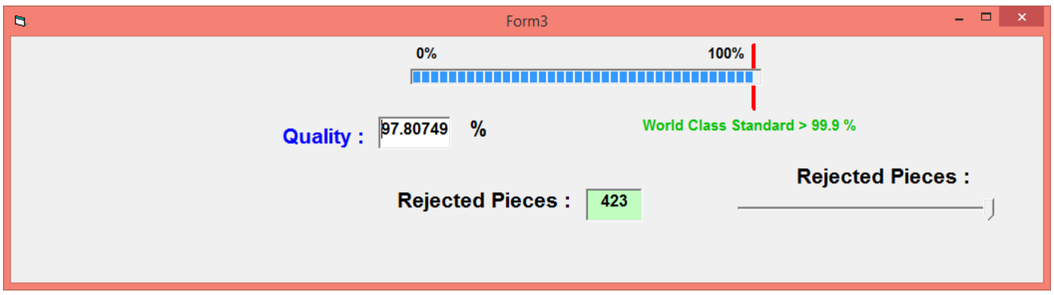


Figure 6. Simulation result for Machine Performance



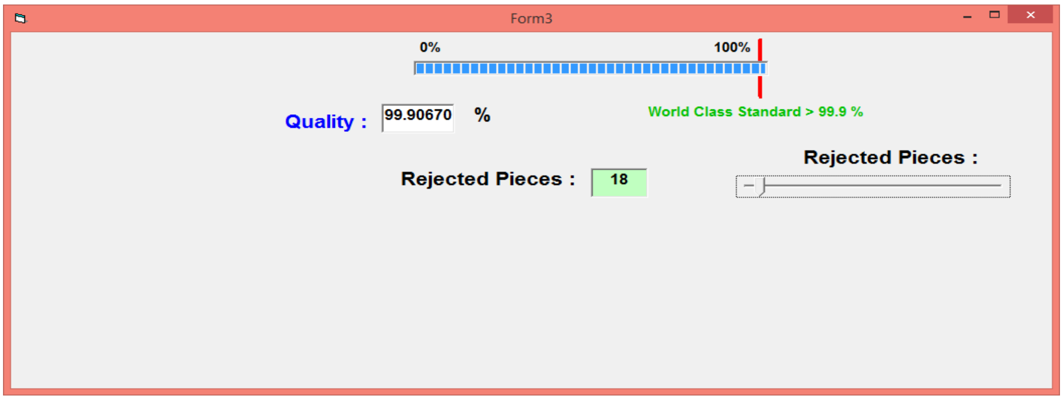


Figure 7. Simulation result for Machine Quality

Figures 8(a) - 8 (b) show the corresponding simulation model results implemented in MS-Excel.

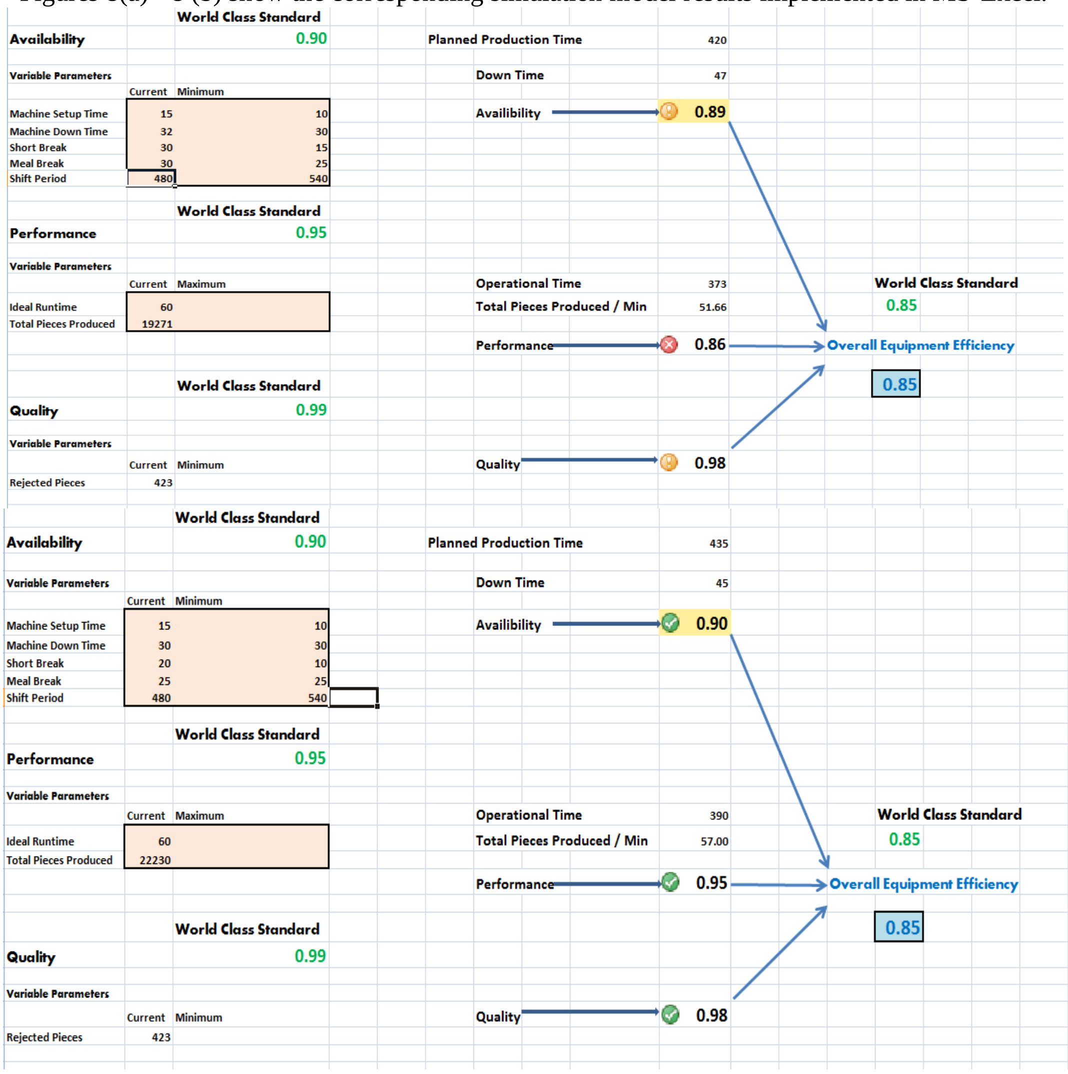


Figure 8 (a)- 8 (b). Simulation Model Results in MS-Excel

Goal seek is employed for determining the changes in the input parameters desirable to attain the world class standard by changing one parameter at a time. Scenario manager is used for storing different scenarios corresponding to the goal for attaining world class standard as shown in Figures 9 (a)- 9 (b) and Figures 10 (a)- 10 (c), respectively.

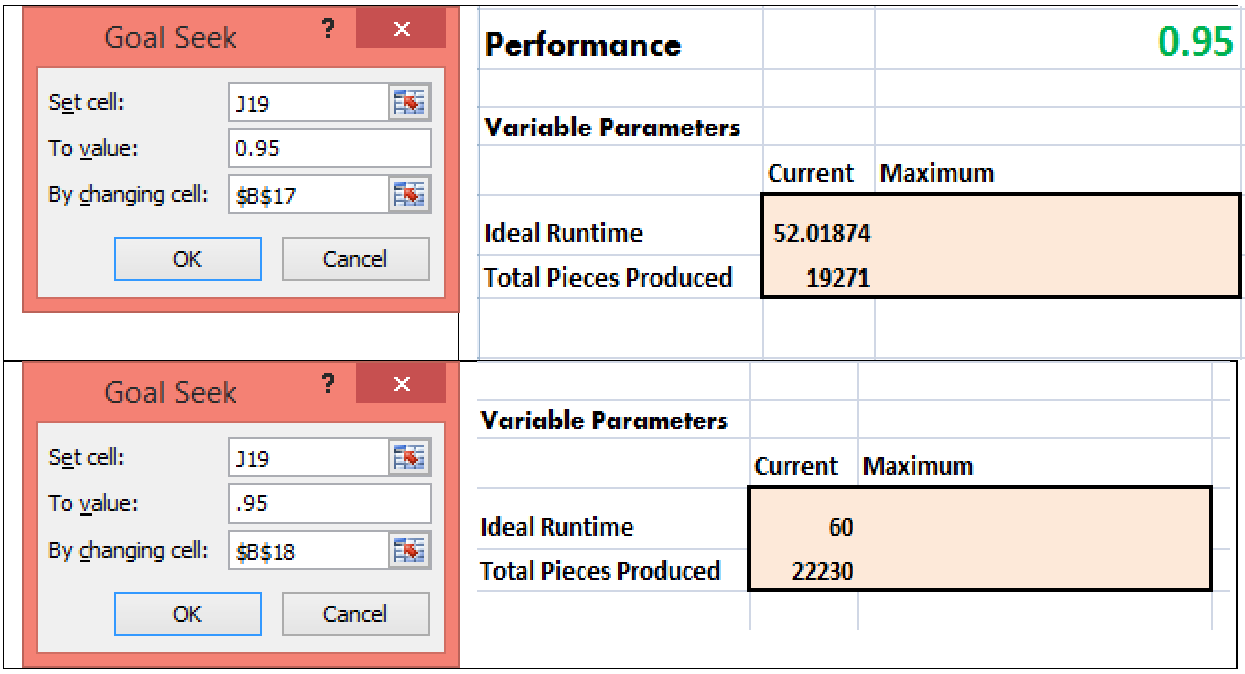
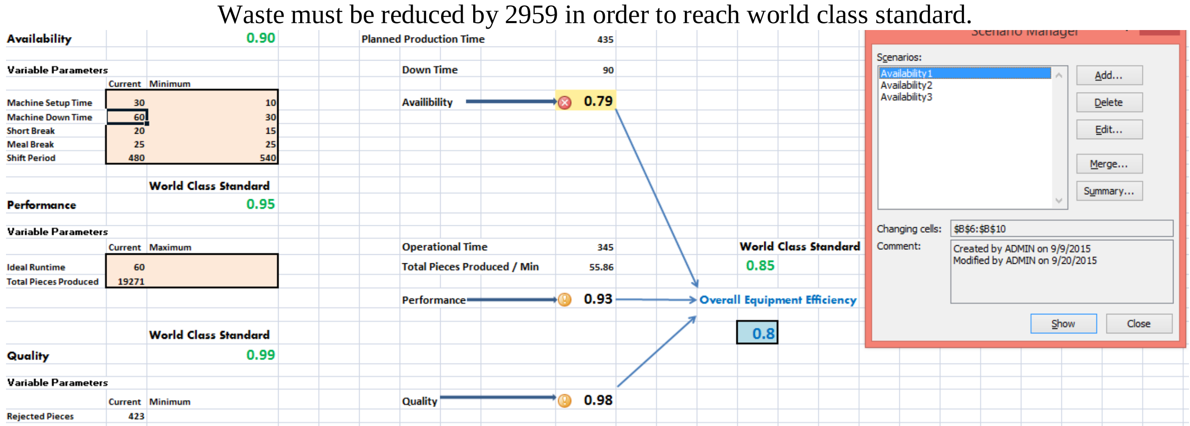
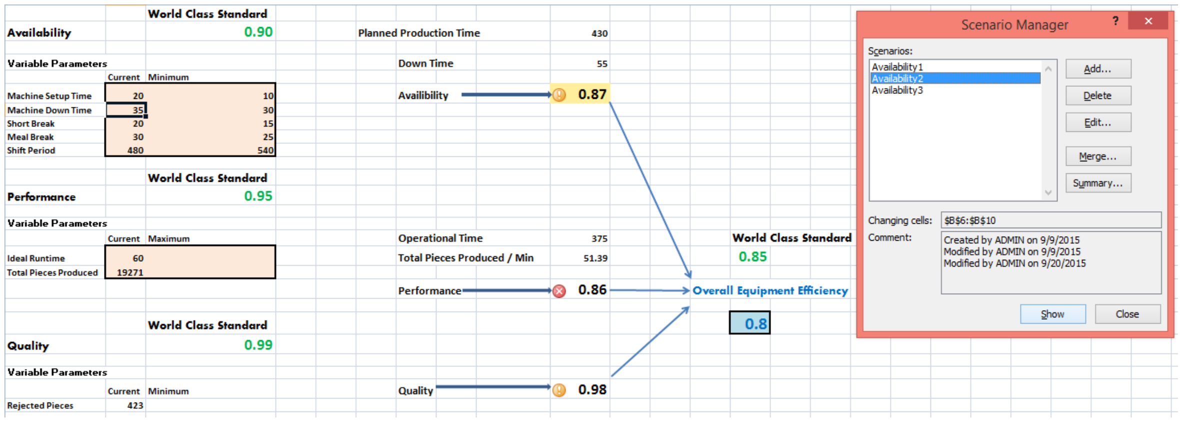


Figure 9 (a)- 9 (b) - Goal Seek Tool for reaching World Class Standard for Availability Parameter

Waste must be reduced by 2959 in order to reach world class standard.





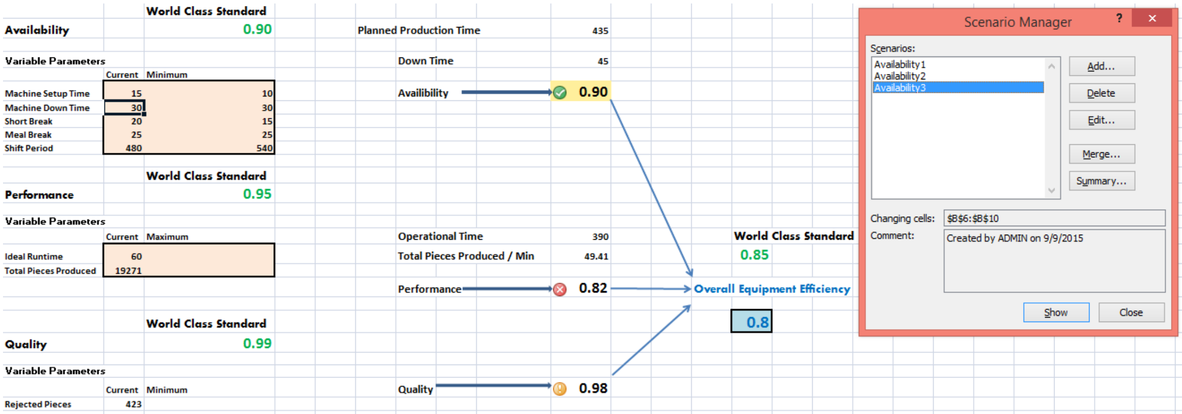


Figure 10 (a)- 10 (c) - Scenario Manager for Storing World Class Standard for Availability Parameter

The relative comparison of OEE parameters between the actual value and the world class values is shown in two Figure 11.

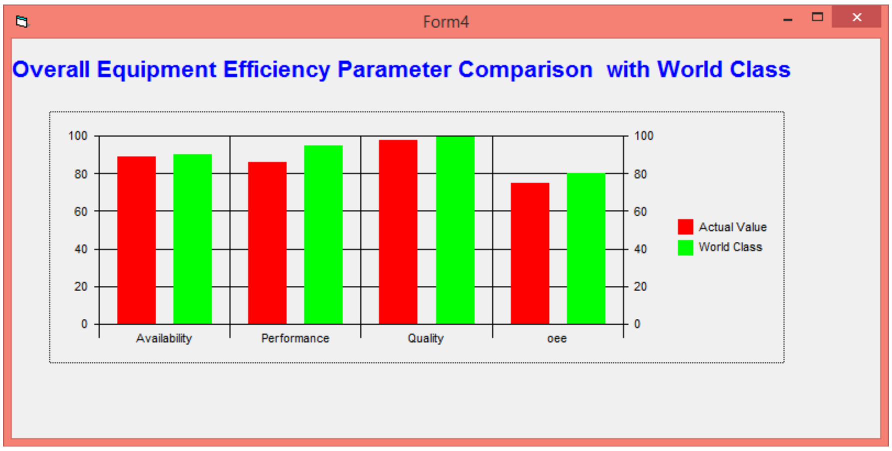


Figure 11. Relative comparison of OEE parameters between the actual value and the world class values
Fuzzy Simulation Model for OEE.

Figure 12. depicts the fuzzy model for availability parameter of OEE using the Mamdani inference system for two fuzzy input parameters, machine down time and machine setup time and fuzzy output parameter OEE availability.

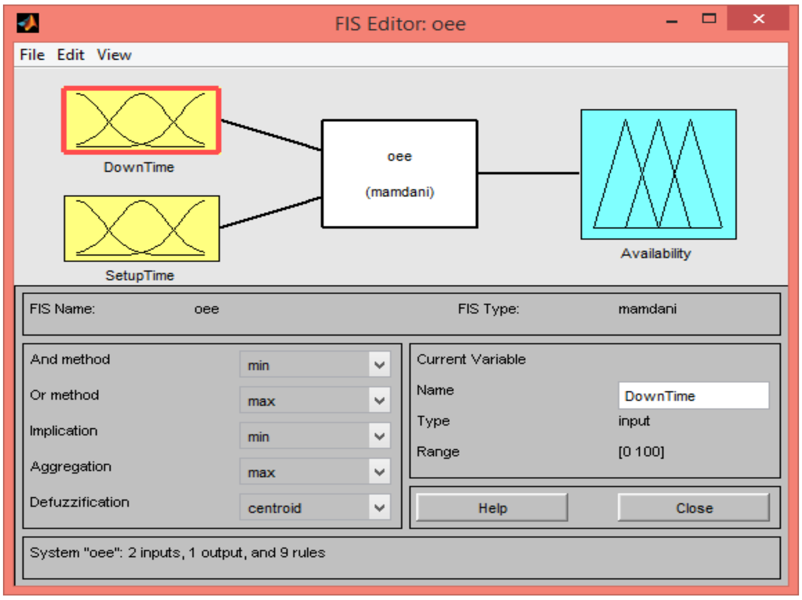


Figure 12. Fuzzy Model for Availability Parameter of OEE using the Mamdani Inference System

Figure 13 shows the rules generated for different combinations of linguistic variables and their impact on the output variable.

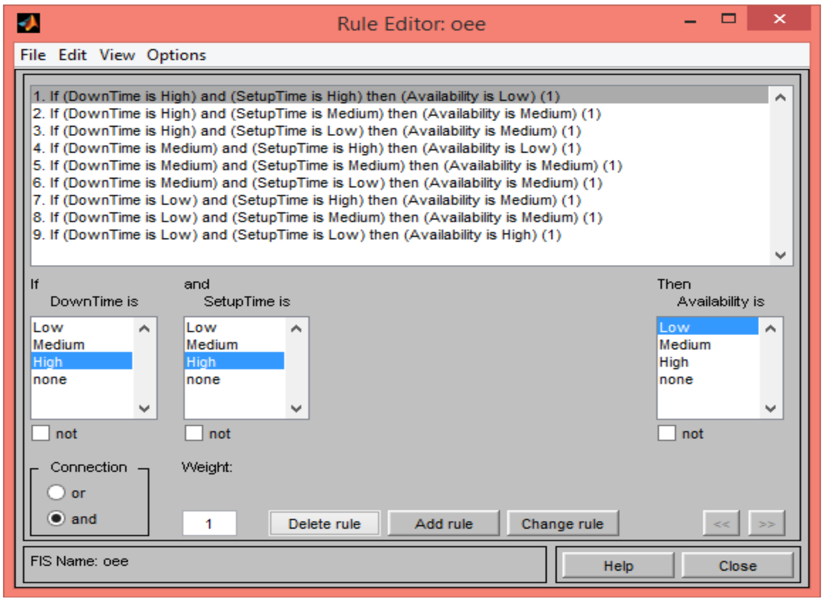


Figure 13. Fuzzy Rules Generated for Model

The triangular membership functions for input and output variables are shown in Figures 14 (a) - 14 (b) and Figure 15, respectively.

Triangular Membership Function for input variable, Machine Down Time

$$\mu_{Low}(x) = (10-x)/10 \qquad x <= 10$$

$$\mu_{Medium}(x) = \begin{cases} (x-5)/30 & 5 < x < 35 \\ 1 & x=35 \\ (x-35)/30 & 35 < x < 65 \end{cases}$$

$$\mu_{High}(x) = \begin{cases} (x-60)/25 & 60 < x < 85 \\ 1 & x > 85 \end{cases}$$

Triangular Membership Function for input variable, Machine Setup Time

$$\mu_{Low}(x) = (10-x)/10 \qquad x <= 10$$

$$\mu_{Medium}(x) = \begin{cases} (x-7.5)/12.5 & 7.5 < x < 20 \\ 1 & x=20 \\ (x-35)/30 & 35 < x < 65 \end{cases}$$

$$\mu_{High}(x) = \begin{cases} (x-30)/10 & 30 < x < 40 \\ 1 & x > 40 \end{cases}$$

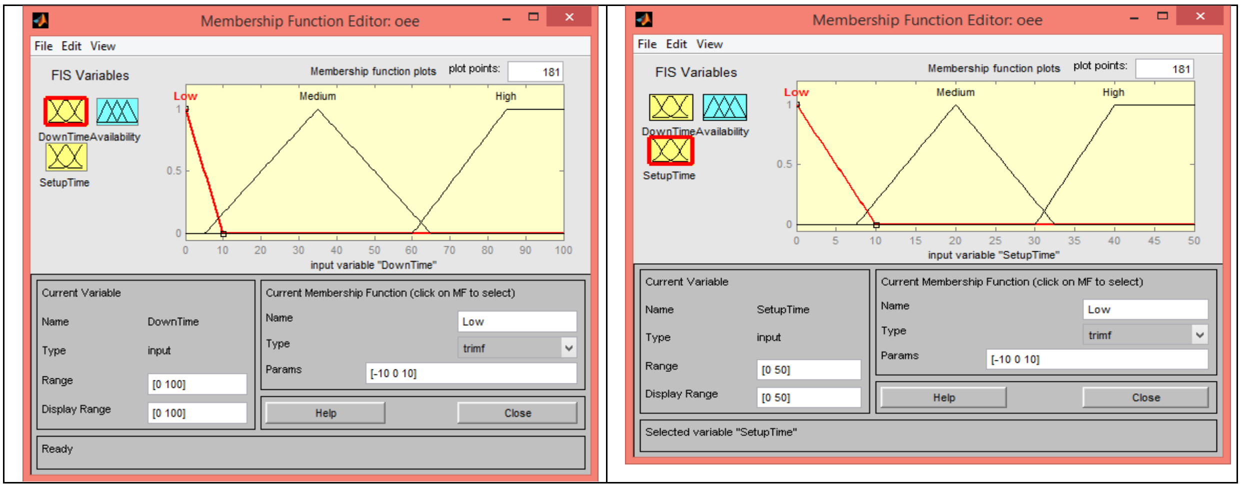


Figure 14 (a) - 14 (b). Triangular membership functions for Input Variables.

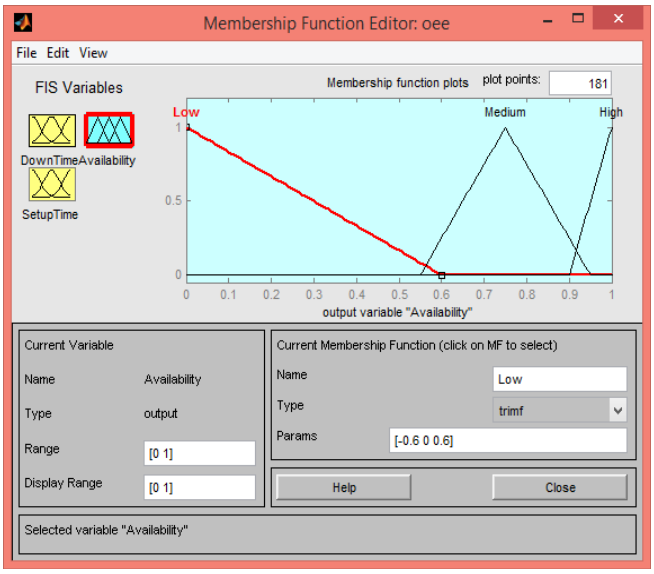


Figure 15. Triangular membership function for Output Variable.

Figure 16 shows the simulated model for availability parameter of OEE based on machine down time and machine setup time.

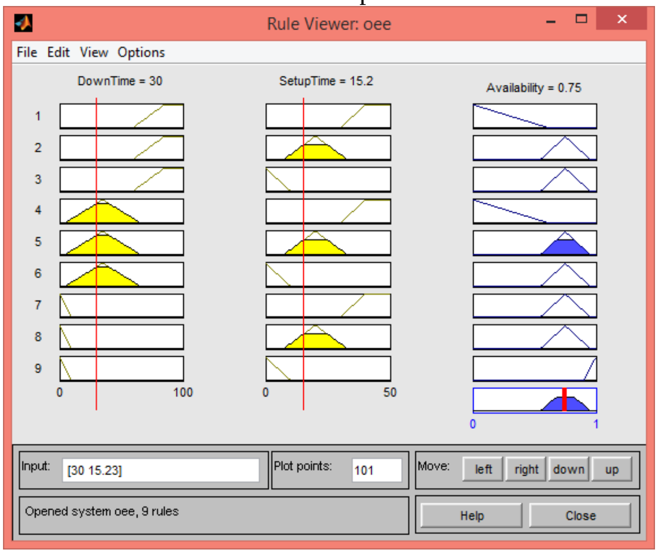


Figure 16. Fuzzy Simulation Model for Availability Parameter Conclusion and Future Work

V. Conclusions and Future Work

In the current work authors have designed and implemented a simulation model for OEE computation.

OEE computation module is the smaller part of the application framework designed by the authors for a production line which analyzes the line efficiency before and after re-design of production line and compares the same with world class standards. The GUI is developed as a visual aid which clearly signifies the gap between the current line efficiency parameters and those needed by the world class standards. The input data needed by the model is derived from XML files generated by the cost optimized production line based on multiple criteria such as (Work In Progress) WIP inventory minimization, idle time minimization and application of Theory of Constraints. Both the crisp model and the fuzzy model based on Mamdani inference system with triangular membership functions are implemented and compared. In the current model fuzzy input variables corresponding to machine down time and machine setup time and the fuzzy output variable corresponding to the availability parameter of OEE are considered. The rule set consists of nine different rules. The front end of the application model is implemented in VB and the simulation model is presented in MS-Excel. It is observed that the fuzzy model deviates from the crisp model as the overlap of the member functions is increased. Our future work focuses on development of fuzzy simulation model incorporating hybrid soft computing technologies such as artificial neural networks and fuzzy logic.

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