Using Model Simulations to Teach Overall Equipment Effectiveness

by

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Abstract: Overall Equipment Effectiveness (OEE) is a calculation including three variables; availability, rate, and quality. OEE is a tool used to test manufacturing from multiple points of the process. This manuscript reviews current literature on the topic and introduces a model simulation activity that can be used to teach overall equipment effectiveness to operators. Enrichment worksheets and an assessment tool are included for use after the activity.

1. Introduction

Overall Equipment Effectiveness (OEE) is a calculation including three variables; availability, rate, and quality (Clark, 2005). Clark (2005) states, "There is no better statistical tool to use when evaluating the all-around efficiency of a production process than overall equipment effectiveness" (p.13). OEE began to be recognized in the manufacturing industry as a mathematical tool in the late 1980's and the early 1990's (Hansen, 2002).

Manufacturing industries have been struggling since the 1960s for a variety of reasons such as global competition, increased labor costs, and the high costs of benefits paid to current and retired employees (Morley, 2006). A study in October 2005 showed that less than 10% of jobs were manufacturing related. According to Morley (2006), this percentage may be less than half of the estimated figure this is due to the job titles an individual has for example Morley states that half of the manufacturing jobs actually provide a true service. The ever increasing need to improve manufacturing processes and costs is very evident when large amounts of job losses are occurring, for example November 21, 2005; General Motors announced (2005) that 30,000 jobs will be cut and nine plants closed (Associated Press, p. 1). In another instance of job loss in the manufacturing industry, specifically the automotive industry, Ford motor company announces that it plans on closing 14 manufacturing plants in North America and will cut between 25,000 and 30,000 jobs by 2012 (Isldore, 2006), further increasing the downward trend of manufacturing jobs as stated by Morley.

In an effort to increase manufacturing effectiveness, OEE is a tool used to test manufacturing process from multiple points of the processes. As Anderson (2004) states, "What we're trying to measure here is agility, How well have you been able to produce what you wanted and at what level of quality?" (p.38). This notion if furthered by the Modern Machine Shop (2005) stating "Manufacturers need a metric that lets them see the big picture, and measure it" (p. 2) Manufacturing has been able to produce calculations in any specific department; however OEE brings the calculations together. According to Modern Machine Shop (2005), "what manufacturers do not know is the real effect of any one variable on the process as a whole" (p. 1).

Availability is one variable of the calculation. Availability is defined as actual uptime compared with scheduled runtime (Clark, 2005). To further describe availability, it is unplanned downtime including any and all events that entail stopped planned production for an unknown length of time usually several minutes. Other time losses could be included such as setup time, equipment failures, or even production scheduling (Allman, 2004). Allman (2004) states:

> In the roll forming industry coil changes and profile changeovers are a natural part of the roll forming process, even though the processes are naturally a part of the time allotment, these small time losses still count against your availability calculation, to counter act some of these small time losses (p. 4-5).
>
> The operators should be evaluated on how well he or she is able to do the work within the constraints of the equipment. The equipment is the driver and the operators should work within the needs and schedules of the machine. As availability requires numerous ways to track information (p.4-5).

Another multiplier of the OEE calculation is quality. Quality is defined as, "Percentage of good, sellable parts out of the total parts produced per time frame" (Anderson, 2004). Quality is defined differently in each industry, for example, in the electronics industry a quality control item could include the devices ability to monitor current production or read and draw current levels of user-defined bandwidths (Grosshart, 2000). Whereas in another manufacturing industry quality is defined as limiting and reducing the variability of sigma, this is tracked through statistical process control (SPC) methods defined by each individual company within the SPC tracking, as data is collected parts become un-sellable when data points fall outside the defined control limits (Montgomery, 2005). Quality is not only a visual or easily measurable. Quality rejections could include the use of many non-destructive quality tests such as atomic force microscopy, fourier transform infrared spectroscopy, and high performance liquid chromatography (Battjes, 2005). Even though the non-destructive testing methods sound sophisticated, they still define whether a product meets quality standards by defining upper and lower process control limits (Montgomery, 2005).

The last multiplier of the OEE calculation is rate, possible rated performance of the operation or process. The term rate is synonymous with performance efficiency (Clark, 2005). Rate of a process on a production line fluctuates greater compared to quality and availability, "Too little attention is paid to the operating performance of the plant, which often offers even greater potential for reducing production losses" (Colvin, 2002). In another sense, Colvin is placing greater emphasis on the rate of production which will in turn increase overall OEE based simply on the numerical values.

For instance, in high speed machining optimizing the metal removal rate is a constant battle. The process may have a great deal of tool chatter which may break or destroy material, or the machine may simply be underutilized causing the rate to decrease significantly (Woody & Smith, 2006). In order to increase the rate of the machines capability in the high speed machining process, two North Carolina professors have developed a few simple check points to increase the rate of the machines. Cutting parameters should be identified with cutting tests or a stability lobe diagram. Relieved tooling should be used. Machining in layers should take place at the top of the piece. Both sides of the piece should be rough and finished on each layer prior to moving deeper. (Woody & Smith, 2006). By using these simple procedural checks, it has enabled and increased the rate at which material can be removed on a daily basis. Not only can the rate be increased in the machining process but automation is also a means to increase production rate. Daimler Chrysler has turned to using robots that can change or switch specific tools every 42 seconds. This allows different models of cars to be created at a faster speed (Green, 2005). In many cases however, the increase of rate comes at a heavy price in Daimler Chryslers case they have invested over 5 billion dollars to upgrade the North American assembly plants (Green, 2005).

The best way to understand or represent OEE is in example calculations. For example, a hypothetical situation of a manufacturing plant which creates widgets 24 hours a day with three eight hour shifts will be used.

Table 1 Example Availability Calculations

Total Time Available	Available Time Planned	Actual Production Time
480 min	435 min	320 min
8 hr. shift	Work time per shift	

Table 2

Down Time Reasons	
Setup Time (Unplanned)	82 min
Part Development (Unplanned)	19 min
Sensor Error (Unplanned)	14 min
Lunch Break (Planned)	30 min
Mid Morning Break (Planned)	7.5 min
Afternoon Break (Planned)	7.5 min
Total Unplanned Loss	115 min

Production Time (320 min) + Unplanned Loss (115 min) = Available Work Time (435 min)

Table 3 Example Availability Calculation Conclusion

Actual Time	320 Min	x 100	= 73.56%
Available Time	435 Min		

The hypothetical availability calculation results in 73.56%; therefore, the 73.56% is the proportion of time that allows for equipment capable of performing functions as specified. (Paraszczak, 2005). Availability plays a major role in industry. More and more globalization is taking place and direct customers and also business to business customers expect a higher level of service, to meet this demand a data processing center has vowed to increase their availability for the data processing centers to work 24 hours a day and 7 days a week continuously. This would increase the OEE of the particular data processing center to 100% if put in place and tracked correctly (Cotton, 2006).

Using the same hypothetical situation of the widgets manufacturing plant the quality sector must be addressed. Quality carries many different definitions. “Quality has gone through many stages and has produced many solutions depending upon the assumptions made concerning production” (Papadakis, 2007, p. 4). This essentially states that quality is defined to the needs of the production function. In tracking OEE quality is defined as a part or production unit which is no long sellable due to any quality issue (Mckellen, 2005).

Table 4 Example Quality Calculations

Total Parts	Sellable Parts	Number of Rejections
10,000	9,850	150

Table 5 Example Quality Calculations Conclusion

Sellable Parts	9,850	x 100	= 98.50%
Total Parts Produced	10,000		

The values for this calculation are used only for the purpose of the example in industry the actual results may vary significantly. If a company is utilizing a six sigma process and is successful, their production process would yield only 3.4 parts per million defective parts (Montgomery, 2005). The six sigma process then would yield 99.99967% of the parts as sellable product. With a greater value for the quality sector of the OEE, calculations with would increase the value for a total OEE.

The final multiplier of the OEE equation is rate. The widget manufacturer will be used as an example. The run rate is “the speed of the equipment” (Loughlin, 2004). An ideal rate must be defined for widget manufacturing we will use a hypothetical run rate of 31 widgets per minute. The calculation is the total number of output divided by the potential rate of output in a set time period (Paraszczak, 2005).

Table 6

Run at Rate	Projected quantity at 435 minutes available	Actual quantity produced in the set time period (435min)
31 per minute	13,485	10,000

$$\frac{\text{Actual Output} \quad 10{,}000}{\text{Projected} \quad 13{,}485} \times 100 = 74.16\%$$

The 74.16% is nominal value to define the effectiveness of how many parts are produced compared to the projected amount or the machines limits. The percentage is intended to calculate the rate of production as it is running (Vorne, 2005).

After all three segments of the OEE calculation have been defined; it is now time to put all three segments together to calculate total OEE. The full OEE calculation is Availability x Rate x Quality. Utilizing the widget manufacturing example all three segments will be calculated as an example.

Table 7 OEE Calculation

Availability	x	Rate	x	Quality	x	100	=	OEE

Table 8 Example OEE Calculation

73.56%	x	74.16%	x	98.50%	x	100	=	53.73%

A process that produces a consistent 85 percent OEE is classified as world class. This constitutes an average of 95 percent in each category (Clark, 2005). However, the spread in each category is up for debate. Each category should model after the following (Vorne, 2005).

Table 9 World Class Manufacturing OEE Model

Availability	90.0%
Performance Rate	95.0%
Quality	99.9%
Total OEE	85.0%

The numbers initially are deceiving at a glance; one could assume the overall OEE would be at least higher than the lowest of the categories. This is clearly not the case. Even with the example of the widget manufacturer with the two lowest scores of availability and performance in the low 70 percentile and quality nearly 100%, the overall OEE is only 50%.

2. Purpose of the Activity

The purpose of this activity is to give participants the opportunity to use and gain knowledge of the OEE calculation and its uses. To complete this activity, the participants will complete activities guided by the learning objectives. Participants will later utilize the knowledge from these activities in their jobs daily.

3. Activity Challenge

Complete a bench top activity which encompasses; rate, availability and quality. The bench top activity is a model of a real world manufacturing process. In this case it is a model of a turn style robotic welder. The turn style robotic welder helped to increase OEE at Duffy Tool & Stamping L.L.C., in Muncie, Indiana. See Figure 1.

Figure 1: Turn Style Robot Welder used at Duffy Tool & Stamping L.L. C.

To simulate welding, angle braces are secured with carriage bolts, washers, and nuts. After all segments have been completed, a quiz will be issued and an 80% or greater must be awarded to effectively comprehend the OEE calculation. After completing the activities and quiz with an acceptable score, the participants will use their knowledge to track, and raise their machine OEE by 5% in 6 months.

3.1 Learning Objectives:

Upon the completion of the activity :

1. The participants will identify and track OEE and design a plan to increase OEE by 5% within 6 months.
2. The participants will be able to complete OEE calculations and answer a ten question quiz scoring 80% or greater.
3. The participants will use and understand the scale model example for rate, and have the ability to apply their knowledge to their machines.
4. The participants will complete the activity involving quality and know how and when to track quality on a machine.
5. The participants will complete the worksheet for availability. The participants will understand how and when to track availability.

3.2 Activity Limitations & Requirements

This activity has the following limitations or requirements:

1. The three activities are to be completed with prior knowledge and experience in a manufacturing setting.
2. This activity must have two people to a group.
3. All three segments of the activity must be completed to fully understand OEE.
4. The participants must score an 80% or greater on the final quiz, in order to have the training added to the operators training log.
5. The application of the knowledge of the training must be able to be applied to the manufacturing process in order to meet the learning objectives.
6. The individual presenting the activity will need to produce a model welding table, in the case of this activity a device with fixtures to hold angle braces, to teach with is used. See Figures 2 and 3.

Figure 2 Model Welding Table Side View

3.3 Activity Resources

The following is an Internet website where information about OEE can be found.
http://www.oee.com/
The following is a website where operators can use an online calculator to calculate OEE.
http://www.downtimecentral.com/OEE_TEEP.htm
The following is a website where the importance of OEE is explained.
http://www.oeeimpact.com/What_is_OEE.htm
The following is an OEE community website where individuals can post information pertaining to OEE.
http://www.oeetoolkit.nl/community/OEEAlgemeen/what_is_oee.htm

3.4 Activity Material / Equipment List

1. (1)11" Diameter wood block ½" thick
2. (1)6x6 wood block ½" thick
3. (1) ½" x 4" steel pipe (gas line)
4. (1) 4"x11" Plexi-glass 1/8" thick
5. (10) 1/8"x 1" machine screw
6. (4) 2 ½" x 5/8" Corner Braces (with screws to attach)
7. (4) 1" x 1/4" Corner Braces (with screws to attach)
8. (1) 5" x 3/8" Carriage bolt

9. (5) 3/8” Carriage bolt nut
10. (1) 3/8” Carriage bolt washer
11. Jig Saw
12. Drill
13. Drill Bits
14. Wrench
15. Marker
16. Ruler

3.5 Activity Procedures

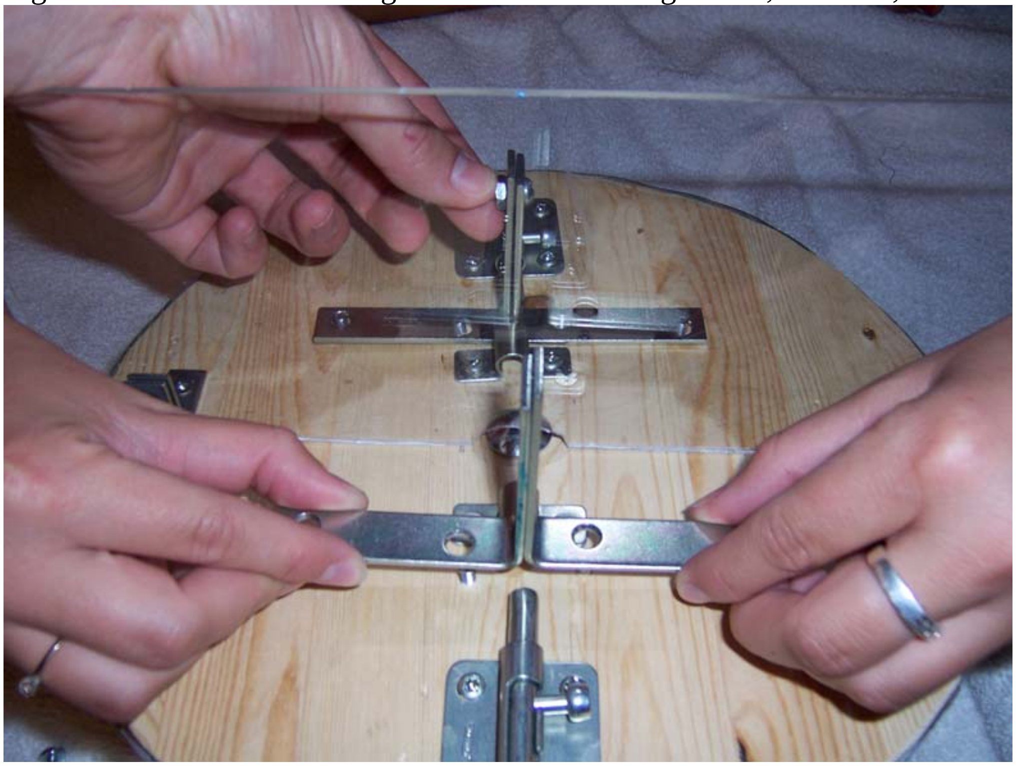
1. Begin by reading all of the introduction OEE information.
2. Present all of the OEE introduction information to participants.
3. In the case of the model represented in this activity, hereinafter “welding table”, carriage bolts along with nuts and washers are used to simulate a weld to secure two corner braces together. See Figure 3.

Figure 3: Model Welding Table Top View

4. Complete time trials using one half of the resources, in this instance utilize only one side of the sample welding table. Participants will place two corner braces on the locator pins, lock the clamp in place, and secure the corner braces with carriage bolts, washers, and nuts.
5. Participants will write down the information and use the time trials and pieces per minute as standard rate.
6. To increase OEE, participants will utilize the other half of the recourses. In the example of this activity, the other half of the sample welding table.
7. A participant will stand on both sides of the welding table. One participant will place two corner braces on the locator pins and rotate the table. The second

participant on the other side of the table will secure the two corner braces using carriage bolts, washers, and nuts. See Figure 4.

Figure 4: Corner Braces Being Secured with Carriage Bolts, Washers, and Nuts



8. The second participant will remove the finished product consisting of two corner braces fastened together with carriage bolts, washers, and nuts. See Figure 5.

Figure 5: Finished Product

9. Complete steps 4-5 various times and record the data. Complete steps 6-8 various times and record the data. Evaluate the rate difference between the two different procedures.
10. The instructor should apply random quality ratios to a given runs as well as random availability ratios to each run.
11. Work example problems as a group until all participants have a grasp of the OEE calculation.
12. Have the participants complete the worksheets. Appendix A, B, and C.
13. Answer any questions that arise.
14. Give the assessment (quiz). Appendix D
15. Ensure all participants have scored 80% if not, answer questions participants have and discuss errors with the participants and clarify any misconceptions.
16. Reissue the quiz if necessary.

4. Conclusions

OEE is a calculation used in production settings where a measure taken to test the agility and performance overall of a specified manufacturing facility (Anderson, 2004). In an ideal setting each of the three categories would have 100% for each of the following; quality, availability and rate (McKellen, 2005). However, ideal situations will not show in true industry. It has been stated that a world class facility OEE would be 85% (Clark, 2005). Industries will continue to track their OEE and pinpoint problem areas to increase their overall OEE (Colvin, 2002). OEE can be taught in any classroom with the use of a simple instructional tool such as the model welding machine used in the aforementioned activity.

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Appendix A

Overall Equipment Effectiveness

Availability

Use the time tables below to answer the questions

DAY	A.	B.	C.	
8am	Running	Running	Running	
9am	Running	15 minute Shutdown. Tool Change	Running	
10am	Running	Running	Random machine failures 20 minutes total.	
11am	Running	Running	Random machine failures 13 minutes total.	
12am	Running	Running	Random machine failures 24 minutes total.	
1pm	Out of service 1 hr unknown problem	Running	Random machine failures 4 minutes total.	
2pm	Out of service 1 hr unknown problem	15 minute Shutdown. Tool Change	Random machine failures 9 minutes total.	
3pm	Running	Running	Random machine failures 4 minutes total.	
4pm	Running	Running	Random machine failures 5 minutes total.	
Total Down Time				Down Time Grand Total
Total Run Time				Run Time Grand Total
				Grand Total

Appendix B

Overall Equipment Effectiveness

Quality

1) Using one side of the welding table assume a rejection rate of 15%. If 15 parts were produced what is the quality ratio?

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2) Using both sides of the welding table assume a rejection rate of 5%. If 15 parts were produced what is the quality ratio?

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3) If the standard ratio is 5% fallout. What is the quality percentage with using one side of the welding table in comparison?

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4) How much if any did your quality ratio increase using two sides of the table?

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5) List three items where you could increase the quality an electronics processing assembly line?

a.____

b.____

c.____

6) If a machine produced 922 pieces and 3 parts were scrapped. What is the quality ratio?

____

Appendix C

Overall Equipment Effectiveness

Rate

1) Using one side of the welding table. How quickly can you and your partner assemble 5 finished parts?

____ min

2) Using both sides of the welding table. How quickly can you and your partner assemble 5 finished parts?

____ min

3) If the standard rate is 4 parts per minute. What is the rate percentage with using one side of the welding table?

____

4) How much if any did your machine rate increase?

____

5) List three items where you could increase the rate of a plastic molding injector?

a.________________________________

b.________________________________

c.________________________________

6) If the standard of a machine is 1,800 pieces per hour what would the ratio be if a machine produced 1,432 per hour.

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Appendix D

Overall Equipment Effectiveness Quiz

1) If the standard rate is 100 parts per min. What is the rate ratio if 94 parts were produced?

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2) If a company claims to have 200 parts per million defects what is the quality ratio?

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3) If there are 485 minutes available to one machine and the machine runs for 400 minutes what is the availability ratio.

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4) If a stamping press normally runs at 1,800 pieces per hour and in that hour the machine shuts down twice totaling 15 minutes of down time yet produces 1,688 pieces with 7 bad parts. What is the OEE?

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5) True or False- OEE stands for Operation Equipment Effectiveness

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6) If the standard of a machine is 1,950 pieces per hour what would the ratio be if a machine produced 1,432 per hour?

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7) What is the OEE value for a "World Class" facility

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8) What are the three variables necessary to calculate OEE?

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9) A motorcycle shop has a robotic welder and the standard rate of 100 motorcycle parts welded per day. Actual produced for Wednesday was 97. Three of the motorcycle parts needed to be reworked, and the machine was shut down for 45 of the 500 available minutes. What is the OEE of the welder?

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10) Do lunch breaks count against the machine OEE?

Score ___ /___
Satisfactory_______ Needs Additional Review and Practice_______