**OEE for Test Floor Managers, Engineers and Technicians**
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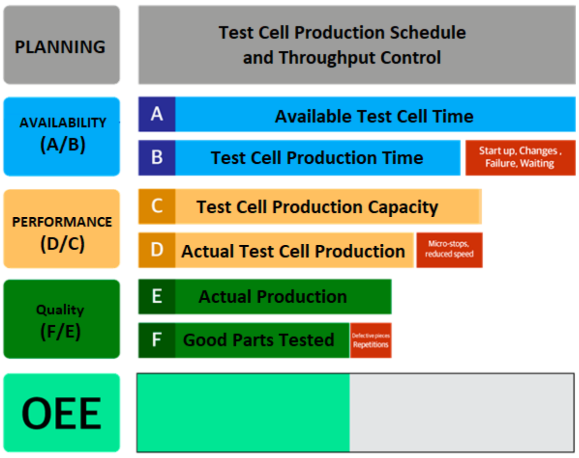
Use of Overall Equipment Effectiveness (OEE) aligns the activities of semiconductor production test to critical measures. While the primary purpose of OEE is to benchmark progress in improving manufacturing productivity. These same measures are used to help ensure the production of good parts that meet or exceed customer expectations.

OEE tools are used to plan and analyze process data. These data will help you gain important insights on how to systematically improve your semiconductor testing processes. It is my opinion that OEE is the single best metric for identifying losses, benchmarking progress, and for improving the productivity of test cell by eliminating waste. Waste as measures include time, scrap, retest, and/or unscheduled test cell repairs and or maintenance. Even when semiconductor demand is down, test system availability means the ability to respond immediately to unexpected increases in test production schedules. With simple OEE measures and calculations, an OEE can be generated for each test cell and each product type being tested.

Production test systems are complex and unique and are designed for different test formats and device package variations. The production test system can be sourced from several equipment suppliers and subsystem suppliers. IDMs and subcontracting test houses spend a significant amount of money to design, integrate, and operate test cells. This is done to provide the best quality in devices tested at the lowest cost. Being a low-cost or controlled cost producer means improving the productivity, reliability – maintainability, and the test cells throughput quality with minimal waste. To do this, we measure for improvements.

The three measures of Overall Equipment Effectiveness are Availability, Performance, and Quality. Considering that we measure to improve, OEE is a benchmark. OEE is a systemic measure of the test cell. The three OEE measures ratios are defined as:




- **Availability ratio:** the quotient of the measured time the test cell is producing tested parts (test cell uptime) and the scheduled or planned test cell uptime for the output of tested parts.
- **Performance ratio:** the quotient of the measured output of the test cell in tested parts and the scheduled or planned number of test cell tested parts output.
- **Quality ratio:** the quotient of the measured number of parts tested to the customer specification as good parts and the number of scheduled and/or planned parts to be tested to the customer specification.

The three OEE Rate variables are expressed as ratios. The ratios are obtained by dividing the actual result by the planned result. At a high level this is shown in the following three formulas.

**Availability Ratio** = Planned Test Cell Uptime ÷ Measured Test Cell Uptime Time

The measured test cell uptime is the measured uptime minus downtime losses measured. Test Uptime and Downtime measures will be explained in some detail later in this paper.

**Performance Ratio** = Measured Test Cell Output ÷ Planned Test Cell Output

The measured test cell output is the measure of units tested, while planned test cell output is the planned number of units to be tested.

**Quality Ratio** = Measured Output of Good Parts ÷ Planned Output of Good Parts.

Test Cell OEE Element Examples:

| **Availability Ratio** | **Hours** | **Ratio** |
|---|---|---|
| Measured Test Cell Run Time | 7 | = 0.875 |
| Planned Test Cell Run Time | 8 | |
| **Availability Ratio** = 7 Hrs ÷ 8hrs = 0.875 | | |
| **Performance Ratio** | **Units** | **Ratio** |
| Measured Test Cell Output | 6000 | = 0.666 |
| Planned Test Cell Output | 9000 | |
| **Performance Ratio** = 6000 ÷ 9000 = 0.666 | | |
| **Quality Ratio (Test Cell Yield)** | **Yield, Parts Tested Good** | **Ratio** |
| Measured Output of Good Parts | 96 | = 0.979 |
| Planned Output of Good Parts | 98 | |
| **Quality Ratio** = 96 ÷ 98 = 0.979 | | |

Analysis of the individual OEE system performance measures will indicate that two out of the three are performing well, with one performance ratio being slightly less than mediocre. However, the test cell is a system, and the overall effectiveness of the system is affected by the individual pieces. OEE Rate is a systemic measure of the overall effectiveness of the pieces that are a complete test cell. OEE rate is expressed as a percentage. The percentage provides a systemic snapshot of the test cells current capability for producing the desired results. The formula for calculating OEE as a percentage is as follows:

**OEE Rate** = Availability Ratio× Performance Ratio × Quality Ratio × 100

OEE Rate Calculation Example:

| ***OEE Rate =*** | ***Availability Ratio*** | × | ***Performance Ratio*** | × | ***Quality Ratio*** | × | ***100*** | = | **57%** |
|---|---|---|---|---|---|---|---|---|---|
| OEE Rate = | **0.875** | × | **0.666** | × | **0.979** | × | **100** | = | **57%** |
| | *Availability Ratio* × *Performance Ratio* × *Quality Ration* × 1( | | | | | | | | |

In the above example, the Overall Equipment Effectiveness Rate of the test cell is 57%. OEE authorities will say that an OEE result of 57% for a test cell is less than satisfactory. As OEE is a main systemic indicator of three system performance measures, the overall goal for each piece and OEE are as follows:

Typical OEE Ratio Goals:

- **Availability ratio:** should be at least 90%.
- **Performance Ratio**: should be at least 95%
- **Quality Ratio**: should be at least 99%

Typical OEE Rate Standards:

- **OEE Rate < 65% is unsatisfactory.** The test cell is severely under performing.
- **OEE Rate 65%-75% is satisfactory.** Work for test cell effectiveness improvement is required.

- **OEE Rate 75%-90% producing favorable results.** Continuous improvement can make it better.
- **OEE Rate 90%-95% is the desired level of OEE.** Continue work to maintain and/or make improvements.

**Measuring and Calculating for the Test Cell OEE Rate:**

As described, the OEE Rate is the product of Availability Ratio× Performance Ratio × Quality Ratio × 100, we must gather the information required to develop the three elements of the OEE Rate formula. Calculating the OEE rate as shown in the following is based on The Total Productivity Maintenance (TPM) OEE rate calculations described by Seiichi Nakajima, Vie Chair of Japan Institute of Plant Maintenance. The formulas and methods are adopted here for calculating the OEE Rate of a test cell.

**Test Cell Availability Rate**

*Total Test Cell Operating Time* is the time a test cell is testing devices,

*Test Cell Down Time* is the time when the test cell is not producing tested parts. Test Cell Down Time can be *scheduled*, for example test cell changeover, test cell setup, scheduled time for contactor cleaning and rebuilding. Test Cell Down time can be *unscheduled*, for example test cell equipment failure. Mathematically, Test Cell Planned Downtime is calculated using the following formula

**Test Cell Downtime** = Scheduled Downtime + Unscheduled Downtime

Mathematically, Test Cell Net Available Time is calculated using the following formula:

In this example, we will assume a 24-hour product test cell run. During this24 hour product test cell run, two-hour test cell production run equal to 24 hours. We also assume a sum of 3 hours of scheduled downtime (preventive maintenance). Added to this is the sum of hours of unscheduled down time (Repeated cleaning of solder buildup on crown tip contact pins 3.5 hours + Worn crown tip contactor rebuild (3 times) 4 hours) + unscheduled stop time (waiting for more parts to test 0.5 hours).

*Test Cell Loading Time* is the time the test cell is planned to operate. Test Cell Loading Time includes: the time when the test cell produces devices tested plus the time for scheduled downtime (test cell changeover, test cell setup, scheduled time for contactor cleaning and rebuilding). Mathematically, Test Cell Loading time is calculated using the following formula

Test Cell Loading Time = Total Time – All Scheduled Downtime

Test Loading Time = 24 Hours – 5 Hours = 19 Hours

*Test Cell Operating Time* equals Test Cell Loading Time minus the sum unscheduled down times and unscheduled test cell stopped time. Mathematically, Test Cell Operating Time is calculated using the following formula

Test Cell Operating Time = Test Cell Loading Time – (Σ Unscheduled Down time + Σ Unscheduled Stop Time)

Test Cell Operating Time = 19 Hours – (7.5 Hours+ 0.5Hours) = 11 Hours

Mathematically, Test Cell Availability Rate is calculated using the following formula:

Test Cell Availability Rate = Test Cell Loading Time – (Σ Unscheduled Down time + Σ Unscheduled Stop Time) ÷ Test Cell Loading Time

Test Cell Availability Rate = (19 Hours – 8 Hours) ÷ 19 Hours = 0.58

**Test Cell Performance Rate**

Test Cell Performance Rate is the rate at which the test cell is running in relation to its full potential for the individual device types being tested and sorted. Performance rate is the speed and/or throughput part of OEE, that is, this is the efficiency element, and therefore is sometimes refereed to as the throughput efficiency and/or performance efficiency. The performance rate is the ideal test program time plus the ideal handler index time multiplied by total devices to be tested.

As a test cell performance rate example, our full device test program executes in 300 milliseconds and our test handler has an index rate of 700 milliseconds. In this case, ideal test program time plus the ideal handler index time equals one second. In this ideal case we can test and sort 60 device per minute or 360 device per hour. Mathematically, Test Cell Performance Rate is calculated using the following formula.

Test Cell Performance Rate = (Ideal Test Cell Cycle Time X Total Devices ÷ 60) ÷ Test Cell Operating Time Hours

In the above formula, we divide Ideal Test Cell Cycle Time X Total Devices by 60 to convert the result to hours as the unit of measure for Test Cell Operating Time is hours.

Test Cell Performance Rate = (0.016 Minutes X 33000 Devices ÷ 60) ÷ 11 Hours = 0.80

In the above formula, we used the ideal Test Cell Cycle time of 0.016 minutes (100 milliseconds). However, the actual test cell cycle time may be different from the ideal. We have the measures required to establish the actual test cell cycle time. There are two ways to calculate the Actual Test Cell Cycle Time. The first formula uses the uses the time the test cell was actual producing test parts divided the number of units tested. In the second formula, the Ideal Test Cell Cycle Time is divided by the Test Cell Performance Rate.

First Actual Test Cell Cycle Time Formula:

Actual Test Cell Cycle Time = Test Cell Operating Time Minutes ÷ Devices Tested

Actual Test Cell Cycle Time = 660 minutes ÷ 33000 = 0.02 Minutes

Second Actual Test Cell Cycle Time Formula:

Actual Test Cell Cycle Time = Ideal Test Cell Cycle Time ÷ Test Cell Performance Rate

Actual Test Cell Cycle Time = 0.016 minutes ÷ 0.80 = 0.020 Minutes

**Test Cell Quality Rate**

The test cell quality rate is most often measured as test cell yield in devices that passed the test, i.e., good devices. There are cases in which parts are graded based on the measured test results. Grading can be based on AC parametric performance, and/or device functional parametric performance, and/or device DC parametric performance. Mathematically, Test Cell Yield or Test Cell Quality Rate is calculated using the following formula.

Test Cell Quality Rate = Good Devices ÷ Devices Tested

Test Cell Quality Rate = 29000 ÷ 33000 = 0.87

The above examples have provided the necessary three elements of the OEE Rate formula. Calculating the OEE rate for the above examples is shown below.

| ***OEE Rate =*** | ***Availability Ratio*** | × | ***Performance Ratio*** | × | ***Quality Ratio*** | × | ***100*** | = | **40%** |
|---|---|---|---|---|---|---|---|---|---|
| OEE Rate = | **0.58** | × | **0.80** | × | **0.87** | × | **100** | = | **40%** |

The result of the example is an OEE rate of 40%. This indicates that the test cell is under performing. This could limit an IDM or Contract Test House in their ability to be a high throughput low cost supplier of semiconductors.

Since machines rarely operate at 100% effectiveness, something slightly less than 60% of the example test cell effectiveness is being wasted. This waste also has a negative impact on the company's return on assets (ROA), as the equipment in the example test cell are assets expected to produce a return. Simply stated, companies buy equipment to produce products to be sold to customers for making money for the company and its investors.

**Lean Waste and OEE Loses:**
Total Productive Maintenance as part of Lean teaches us that when the same problem happens repeatedly, it should be concluded that this is a critical situation, and it may be time to invest in the situation. Taiichi Ohno credited as the father of Lean Production Management described two kinds of *muda*.

- *Non-Value Added.* This is pure waste. For example, all wait times are non-value added, just as rework is a waste retest is a waste, and unused test data and measures are a waste.
- *Non-Value Added, but Required*. Ohno called this "non-value-added work" or, sometimes, incidental work. This includes inspection, maintenance, control systems to check that procedures are being followed, documentation, etc.

In the example we calculated Test Cell Loading time as Test Cell Available Time minus Scheduled Downtime is non-value added but required. Scheduled Downtime is non-value added as it does not provide the product with additional value for the customer. Although Scheduled Downtime is required to get the most return in products tested from the test cell, the amount of scheduled downtime should be squeezed out to reduce unnecessary process steps and time to work the process. In this same example, we see a Quality Ratio of 0.87. This quality ratio in reverse means 13% off all devices tested were scrap, a pure waste. However, some will try to reclaim some of the scrap through retesting of the devices. Retest is a pure waste of test cell availability of the test cell to test parts other than those that have already been tested. The end result of retest is a reduction in test cell throughput and device test center throughput. However, if the rejected parts are not retested, the risk is in scraping good parts another form of pure waste. From an inventory point of view, parts waiting for retest or test are unfinished inventory, and The Theory of Constraints (TOC) and TPM tells us that unfinished inventory is useless inventory. The goal is to increase throughput by reducing required but non-value-added work, and to eliminate pure waste.

For the device-under test contactors we can qualify pure waste loses and required loses and how they are factored into the OEE rate. OEE loses are causes that have a negative impact on the OEE rate. With each of the three OEE Rate elements there are loses. It is beyond the scope of this paper to cover the entire potential of test cell loses. A critical test cell subsystem with the greatest single impact on test cell OEE rate is the interface to the device-under-test (DUT), that is the contactor or sometime called the test socket, and some probable contactor required OEE loses and pure waste loses.

Overall Test Cell Equipment Effectiveness, Loses, and Focused Improvements have been adapted from the Toyota Implementation Formulas: T*he Tiger Volume* (Nikkan Kogyo Service Center), Sekine, Arai, and Yamazaki. The adapted Model is shown below.

**Overall Equipment Effectiveness = Availability Ratio × Performance Ratio × Quality Ratio**

| | Availability Ratio | Performance Ratio | Quality Ratio |
|---|---|---|---|
| | Test Cell Waste From Stoppage | Test Cell Waste due to Poor Performance | Test Cell Waste due to Defects |
| Test Cell OEE Losses | • Test Site Device Jams<br>• Breakdown and Stoppage<br>• Thermal Soak Time Loses<br>• Unscheduled Setup Adjustment | • Slowdown Loses Test Program Wait States<br>• Slowdown Loses Signal Settling Time Wait States<br>• Slowdown Loses Test Ready Wait States<br>• Minor Stoppages | • Yield Loses<br>• False Failures<br>• Bent Device Leads<br>• Crack Packages<br>• Scrap and Retest<br>• Startup Loses |
| Focused Device Under Test Interface Improvement Technology | • Improve Setup Procedure<br>• Reduce Changeover Time<br>• Reduce Setup Time<br>• Reduce Frequency of Contactor Cleaning<br>  ○ MTBF<br>• Reduce Contactor Replacement or Rebuild Frequency<br>  ○ MTBR<br>• Improve Device Centering and Alignment to contactor Control | • Interface Performance Analysis for Ongoing Improvement<br>• Interface Inspection Analysis<br>• Interface Inspection Analysis<br>• Contactor Maintenance and Inspection Procedure Training<br>• Test Algorithm Wait State and Guard Banding Efficiency Analysis<br>• False Failure and Retest Rate Analysis | • Standard Operation Monitoring<br>• Standard Setup Monitoring<br>• Standard Test Cell Interface Configuration Monitoring<br>• Quality Interface Component Management<br>• Interface Mechanical Performance Monitoring<br>• Interface Thermal Performance Monitoring<br>• Interface Electrical Performance Monitoring |
| Increasing Capacity | • Reduced Number of Operator and Technician Assists<br>• Easy Conversions with Correlation between Hand Test and Automated Test<br>• Design For Reliable Operation | • Expand Existing Equipment Capacity<br>• Compress Test Process Time<br>• Increase Test Algorithm Speed<br>• Eliminate Retest<br>• Reduce Process Steps, and Process Execution Time | • Optimum Interface condition set<br>• Continuous Improvement For Almost Error free Change Over and Setup |

**Conclusion:** Improving OEE can happen in a number of ways. As OEE is a pice of TPM, the approach taken in this paper is to connect OEE loses, and TPM waste as a systemic approach for increasing OEE. So far, we have identified 2 types of waste and test cell loses.

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