INDUSTRIAL INTELLIGENCE

Introduction to:

Overall Equipment Effectiveness (OEE)
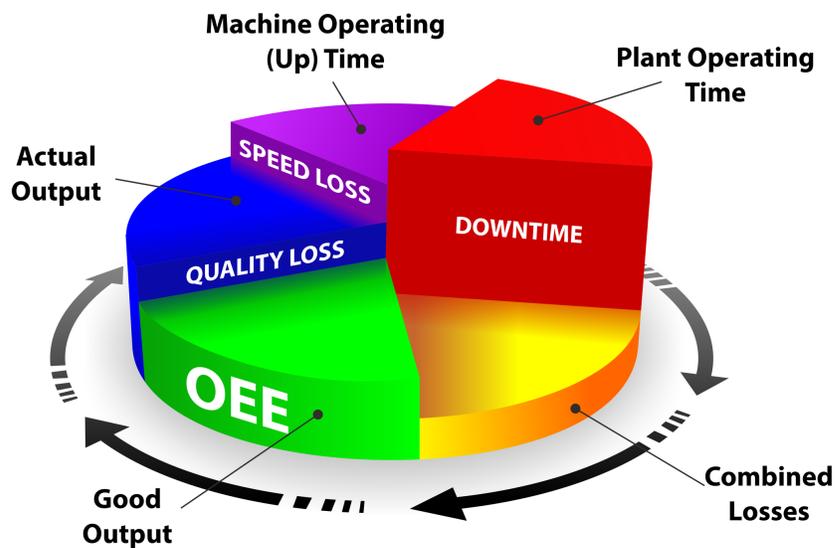
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What is OEE?

The Overall Equipment Effectiveness (OEE) of a machine or set of equipment is a Key Performance Indicator (KPI) that indicates the equipment's overall operational performance. In essence, OEE is a measure of the actual output that was produced with a machine, compared with the maximum output that could be expected from the machine over the same period of time. OEE takes into consideration the cumulative impact of three factors: the equipment's availability (percent of scheduled production time in which units are actually produced, also called the Machine Operating Time), its performance rate (percent of material produced compared to standard), and the quality of its output (percent of good material produced compared to all material produced during the Machine Operating Time). In equation form, OEE is the multiplication of these three factors: OEE = % Availability x % Performance x % Quality.

Availability:	$30.1\% =$	$\dfrac{\text{289 Minutes Machine Operating Time}}{\text{960 Minutes Plant Operating Time}}$
Performance:	$44.1\% =$	$\dfrac{\text{88 Average Speed fpm}}{\text{200 Maximum Speed fpm}}$
Quality: 🖊	$98.0\% =$	$\dfrac{\text{24,974 Good Material}}{\text{25,484 Total Material}}$
OEE:	$13.0\% = \mathbf{30.1\% \times 44.1\% \times 98.0\%}$	

Example of OEE Calculations

Many manufacturers are already using OEE, both as a KPI and as a catalyst for change. OEE is a standard metric used to evaluate manufacturing performance by taking a broad view of all aspects of production. By using its three factors, OEE provides a manufacturer with the best measure of machine utilization and helps them focus on improvements that most directly impact their profits. As part of the lean manufacturing tool kit, OEE does this by identifying and driving all elements of waste out of manufacturing processes.

What is the benefits of using OEE to improve operational performance?

Continuously and visibly monitoring and reporting OEE provides the basis for achieving optimum operational efficiency. When implemented on key manufacturing equipment, all levels of the manufacturing organization will be able to take greater control of the daily management, and improve the utilization of those plant assets. In short, this will save the company money while increasing production output. In addition, utilizing automated data collection and OEE measuring systems that are highly visible and easy to use, such as OEM Partner's Remote Monitoring solutions, saves enormous effort and delivers highly visible, real-time intelligence on the overall equipment effectiveness of a machine, a work cell, or a plant. This allows operators and supervisors to proactively track, monitor and respond to operational issues as well as measure and justify ongoing improvement efforts.

Typically, manufacturers are able to achieve rapid improvements upon the initial implementation of such systems, and when done well, small improvements can result in a big impact to the bottom line:

- An increase in OEE of around 10-15% can often be realized in the first year; this can translate to a 50% improvement in Return on Assets (ROA). [R. Hansen, OEE for Operators]

- OEE initiatives are generally ten times more cost-effective than purchasing additional equipment capacity, and over time can reduce major capital expenditures by 50%.

- In many major industries, an improvement of 1% in reduced downtime of a high value asset can translate to over $1 million in annual savings.

- As machine OEE increases, total energy consumption per unit produced is reduced. The manufacturer's carbon footprint is reduced, while they enjoy lower costs.

How does OEE build and support a culture of Lean Manufacturing?

The OEE metric provides for several critical elements of the most successful Lean Manufacturing initiatives. In these cases, OEE is used by lean practitioners on the shop floor to identify and eliminate the sources of losses in all areas of the operation. Everyone in the organization from upper management down to the shop floor is actively and highly visibly engaged in supporting the teams and giving them the resources needed to be successful. In the most successful companies, measurements become consistent, accessible, widely understood and accepted. To achieve this, they use clearly communicated standards and automated systems for collecting and interpreting data, as well as for reporting and distribution. In some cases, additional incentives are created in compensation systems that incorporate an element of OEE improvements.

When used properly, OEE is used to educate and train the workforce, to gain a common sense of purpose; it provides an accepted system of measurement that drives a common understanding for team problem-solving. Further, with the completion of each project, visible OEE improvements provide a source of motivation for the workforce by clearly showing the benefits of their efforts.

In particular, OEE dashboards and reports provide a platform for organizations to:

- Increase output by quickly identifying and responding to the highest priority sources of losses, thereby producing more in the same amount of time with the same equipment, with less energy consumed;

- Empower shop floor personnel by providing clear and visible measures of their performance compared to goals; and

- Support continuous improvement.

How is OEE used?

OEE can be evaluated for a single piece of equipment or machine, or for multiple pieces of equipment, over a discrete period of time, or for a particular job or product. Like many standardized metrics, OEE has a set of basic rules to follow in its implementation, and the application of these rules can vary. The most important consideration to follow in an implementation of OEE metrics is to be consistent in the application of its rules, so that comparison and trending analysis from machine to machine and in tracking improvement efforts provides valid results.

The most important aspect, which is universally recognized, is that the practitioner should know how their particular organization's interpretations and definitions are applied so that they can effectively use them to obtain improvements. Then, within a consistent framework and terminology that is accepted across the company, OEE is used to identify losses associated with each of its components: Availability, Performance, and Quality. Analysis of the respective losses is performed to prioritize improvement projects and determine root causes, and then the improvements are tracked for verification and further actions as needed. For smaller projects, formal process improvement tools and techniques may be used, such as FMEA, DOE, 8D, DMAIC, and Plan-Do-Check-Act. More substantial opportunities would benefit from more systemic, business process improvement tools such as Value Stream Mapping and Kaizen, and sometimes from department- or company-level initiatives such as modified work schedules or supply chain changes.

Our platform is flexible enough to provide for different interpretations, and robust enough to properly implement those differences consistently and accurately in both how it calculates OEE components and how it displays the results. For example, some companies differ in how they interpret what constitutes planned or unplanned down times in the measurement of their machines' Availability or Performance. More advanced users of the application can tailor and automate them to fit such local customs and interpretations from within the Downtime Tracking module, with its assignment of individual downtime codes to different categories of downtime.

From where and when did OEE originate?

The concept of OEE was developed as a metric and tool to be used for improving operating efficiency of manufacturing plants. Its origins come from the framework of Total Production Maintenance (TPM), introduced by Seiichi Nakajima's *Introduction to Total Productive Maintenance* in 1988. Since then, OEE has become widely known as the best metric from which to gain control, and then optimize the overall operational performance, and financial return on high value manufacturing assets.

What are the benefits of an automated data collection?

If done properly, manually executed OEE systems will identify losses and opportunities for improvement. However, collecting and interpreting data for evaluating OEE this way is a time-intensive process that is wrought with risk of error and inconsistency. The time and effort spent doing it this way would be much more efficiently used to work on actual improvement projects. In addition, at higher levels of OEE, it becomes more difficult to obtain further gains, which makes the time and effort in manual systems seem less worthwhile. In some cases, this is because the losses are occurring at very high rates but also in very small amounts, and these are extremely difficult to capture with any manual data collection process.

Inevitably, most manufacturing continuous improvement projects and facilities using a manual collection method will quickly discover the value of automated systems. There are many benefits of automated OEE systems. They are powerful tools used to provide automated data collection, analysis and reporting of accurate and consistent, data-based OEE evaluation summaries and details. The following table provides a comparison of these two methods, and shows the powerful and cost-effective benefits of using the OEE productivity tools in OEM Partner's Remote Monitoring platform.

OEE Using Manual Spreadsheet	Remote Monitoring System
Proper data collection and reporting can take up to 20 man-hours per month, per work cell or line, and information accuracy and detail is limited	Data is captured automatically, reports are user-defined and generated on demand, or automatically generated based on schedules set by any user
Visual alert system on shop floor when machine goes down slows communication to responsible support staff and extends time to resolution	Automatic email/SMS alerting for machine down or exceeded threshold of any machine or process parameter chosen by platform user, provides for fast response
Difficult, complex analytical methods to consistently apply, and then manually map results to sources of OEE shortfalls for subsequent analysis	Pareto analysis tools automatically provide top reasons for downtime losses, and the detailed data needed to identify and resolve the root causes
Errors can come from operator influence, data collection and reporting, missed stoppages, memory of events, and estimations; impact to OEE subject to interpretation and inconsistencies	Every production stop and performance loss is captured, validated and analyzed; down time reason codes can be assigned automatically by the machine and updated by authorized operator or engineer; OEE impact consistently applied per facility guidelines and industry standards
Timeliness and accuracy of data and level of detail is dependent on individuals involved, and organizational, political, and cultural influences	Data is analyzed in real time, and delivered with valuable information tailored to the requestor, whether operators, maintenance, engineers, or management
Spreadsheets must be analyzed, transcribed to reports and distributed manually; no control over subsequent editing unless access is limited	Unlimited, multi-user read-only access to a user-friendly system with standardized information, distributed on-demand or on a user defined schedule
Data storage and retrieval, and data integrity risks, due to above issues	Secure, backed up database with user access controlled by customer's platform administrator

How is the OEE Model implemented?

The platform uses a cross-industry standardized model for OEE productivity data. It provides a visual illustration for each component of OEE (Availability, Performance, and Quality) and the component's respective value, in a horizontal bar format. The model is designed to visually represent the calculated value of OEE as the amount of Good Material produced as its appropriate equivalent proportion of total calendar time. To accomplish this, the maximum values of the components Performance and Quality are graphically aligned with respect to their respective parent component. For example, the theoretical maximum speed of the machine for the amount of material produced is graphically aligned with the Machine Operating Time. This is intuitively logical as well because Performance is measured only over the period of time the machine is considered to be producing actual production material. Each of the three components itself is then divided by the proportional percentages of its respective elements, e.g. Good Material is shown graphically as the respective percentage of the Total Material produced.
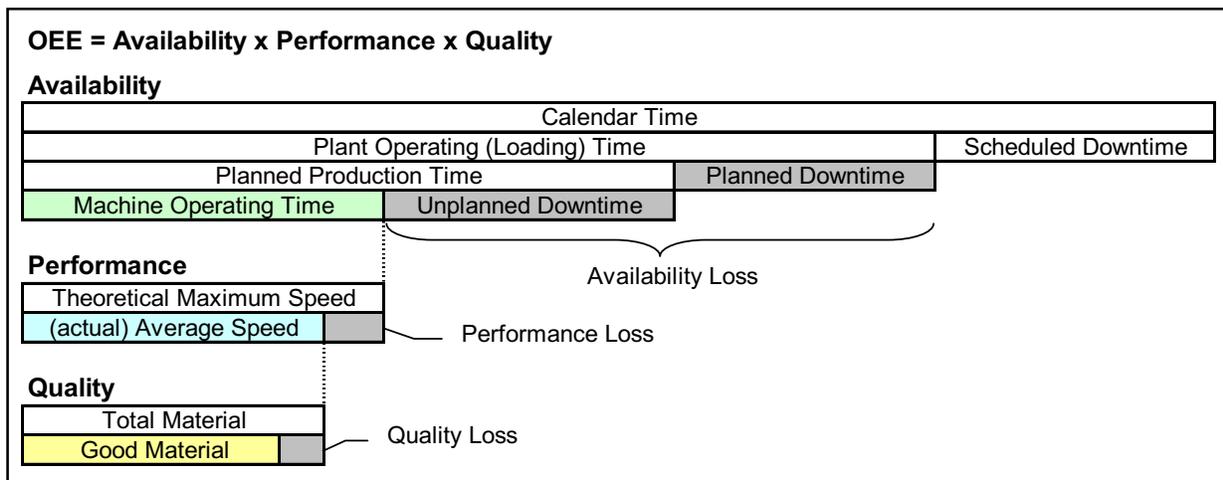

Figure 1: Cross-Industry Standardized OEE Model

Using this model, reporting of OEE productivity data in the remote monitoring platform is provided in two levels. The top level is an executive summary view, using an aggregate, simplified horizontal bar chart as shown in Figure 2. This is provided any time that a platform user requests a summary of OEE data for a discrete, i.e. non-trending, time period. The calculated value of OEE is provided in bold font at the top of the chart, with the equation of its components appended for reference. Then only one bar is provided to illustrate a summary of each of the OEE components of Availability, Performance, and Quality, with each of the components' associated value labeled above it. The top bar

represents the full calendar time period for which the Availability of the machine is evaluated. It is divided proportionately by color for each of the standard types of downtime, with planned and unplanned downtime combined into one color (grey) for simplicity. Each additional component of OEE is then graphically aligned with its parent component as described in the model above, and is similarly divided proportionately by its respective elements. A more detailed description of this format is provided below.
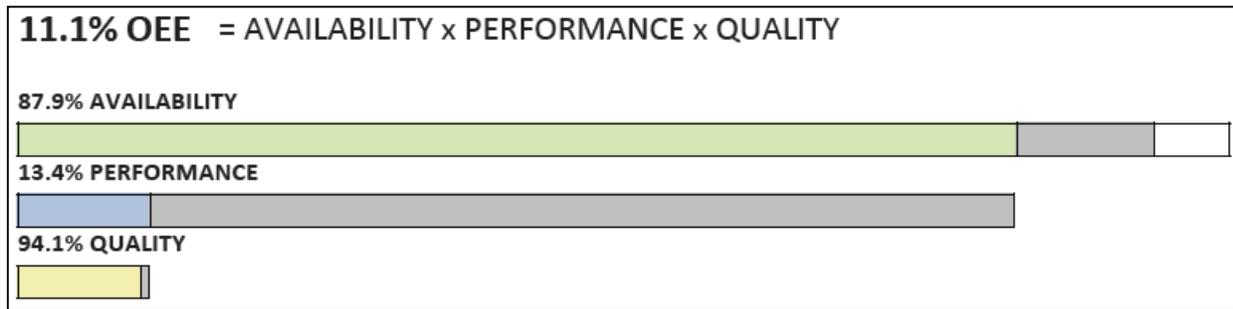

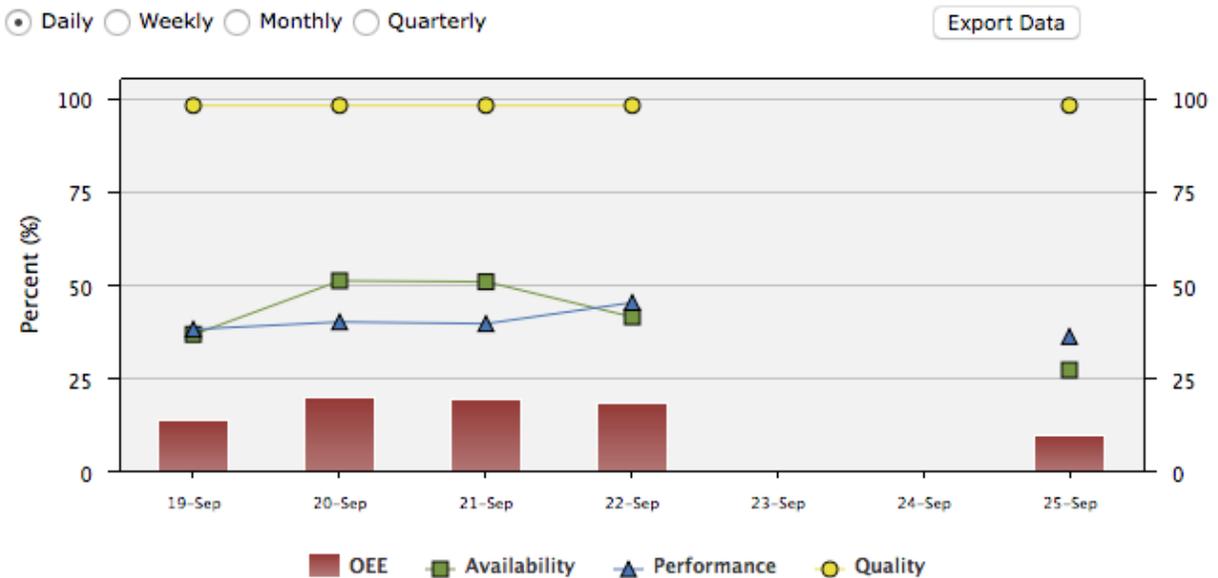*Figure 2: Example of executive view format for summary of OEE*

Figure 3: Example of view format for summary of OEE Trends

The second level of OEE reporting provided by the remote monitoring system is a detailed breakdown of OEE component elements with their respective values. This format, shown here in Figure 3, provides the equivalent detailed summary data, numerically by component, and is color coded to match the top level bar chart. This is provided for the lean manufacturing practitioner to drill down into the details for further analysis toward the design and execution of actionable improvement plans.

		Productivity Details		
AVAILABILITY	87.9% =	$\dfrac{\text{19 hours 46 minutes Machine Operating Time}}{\text{22 hours 30 minutes Plant Operating Time}}$	Scheduled Downtime:	1 hours 30 minutes
			Planned Downtime:	2 minutes
			+ Unplanned Downtime:	2 hours 42 minutes
			= Availability Loss:	2 hours 44 minutes
PERFORMANCE	13.4% =	$\dfrac{\text{33.4 Average Speed Cycles/Hr}}{\text{250.0 Maximum Speed Cycles/Hr}}$	Performance Downtime:	1 hours 47 minutes
			+ Reduced Speed:	14 hours 20 minutes
			= Performance Loss:	16 hours 7 minutes
QUALITY	94.1% =	$\dfrac{\text{622 Good Material Parts}}{\text{661 Total Material Parts}}$	Waste:	39 Parts
			Quality Loss:	1 hours 10 minutes

Figure 4: Example of format for OEE component details

The top level summary of data shown in Figure 2 provides the value of calculated OEE for the selected time period at the top of the chart, above the component bars. Each component bar is defined and formatted as follows:

Availability:

The numerical value of Availability is a measure of the time a machine has been up and running and making any production material. This metric is dependent upon the time that the machine has been scheduled for production. Data acquired directly from the machine is used to compute the downtime called the Availability Loss, as the amount of time that the machine has not been creating production material during the Plant Operating Time. The Plant Operating Time is defined by the operating shift schedule for the machine, and does not include Scheduled Downtime. Availability Loss may be further sectioned into Planned and Unplanned Downtime. This is accomplished either automatically or manually by the practitioner, through the use of downtime codes that are acquired either directly from the machine or through manual assignment using the platform. Planned Downtime such as operator breaks or planned maintenance during normal operating hours are included in Availability Loss because this is fully burdened time that is available to operate the machine. For example, in cellular work flow designs, special arrangements can be made to rotate break periods and operators so planned bottlenecks don't stop running during breaks, and maintenance can be planned during scheduled plant shutdown periods.

The Machine Operating Time is shown in a light green color, with the remaining time portion of the Plant Operating Time shown in grey. All loss in Available time, whether planned or unplanned downtime, is shown in this grey portion. Time that the machine or plant is not scheduled to operate, if there is any such time in the selected calendar time period, is shown in white (no color) on the right side of the bar. The total length of the bar represents the calendar time period selected for the report.

Performance:

The performance portion of the OEE Metric represents the average speed at which the machine was operated during the Machine Operating Time of the calendar time period chosen, as a percentage of the theoretical maximum speed that the machine can operate. It is a measure of the quantity of units actually produced as a percentage of the quantity of units that would have been produced in that same time period if the machine were running at maximum speed. This method is equivalent to an evaluation in which a machine's performance is represented by the ideal, or minimum time it should take to produce a unit of material as a proportion of the average time it actually took to produce a unit of material during the Machine Operating Time of the selected calendar time period.

The maximum speed can be defined by the machine "nameplate" speed, which is the maximum design speed of the machine. This is the default method of evaluating OEE, which can be used for benchmarking productivity analyses across work cells or plants. Alternately, OEE can be evaluated for specific jobs, products or materials being produced on the machine. In this case, the maximum speed can be defined as the "standard" or ideal speed for a particular job, product or material being produced as determined by the manufacturing or process engineer who developed the process for the machine. This product- or job-based method of evaluating OEE can also be informally called the "Rated OEE", to reflect that the evaluation was rated to a specific product or job, and to differentiate from the default, machine nameplate speed based OEE evaluation. In the platform, the Rated OEE is administered using the Job Management tools.

The total quantity of units produced during the Machine Operating Time is represented as the entire bar (light blue + grey), with the portion shown in light blue representing the ideal time it would have taken to produce the same quantity of units at the theoretical maximum machine speed. The type of units of production are defined by the particular machine and its available control parameters, and set up by the platform administrator.

Quality:

The numerical value of Quality is the quantity of Good Material produced as a percentage of the Total Material produced during the Machine Operating Time of the time period chosen. This is commonly referred to as First Pass Yield. More sophisticated monitoring systems will take into account relevant, on-machine quality assurance or inspection steps, to better represent the Quality performance of the machine operation. In some cases
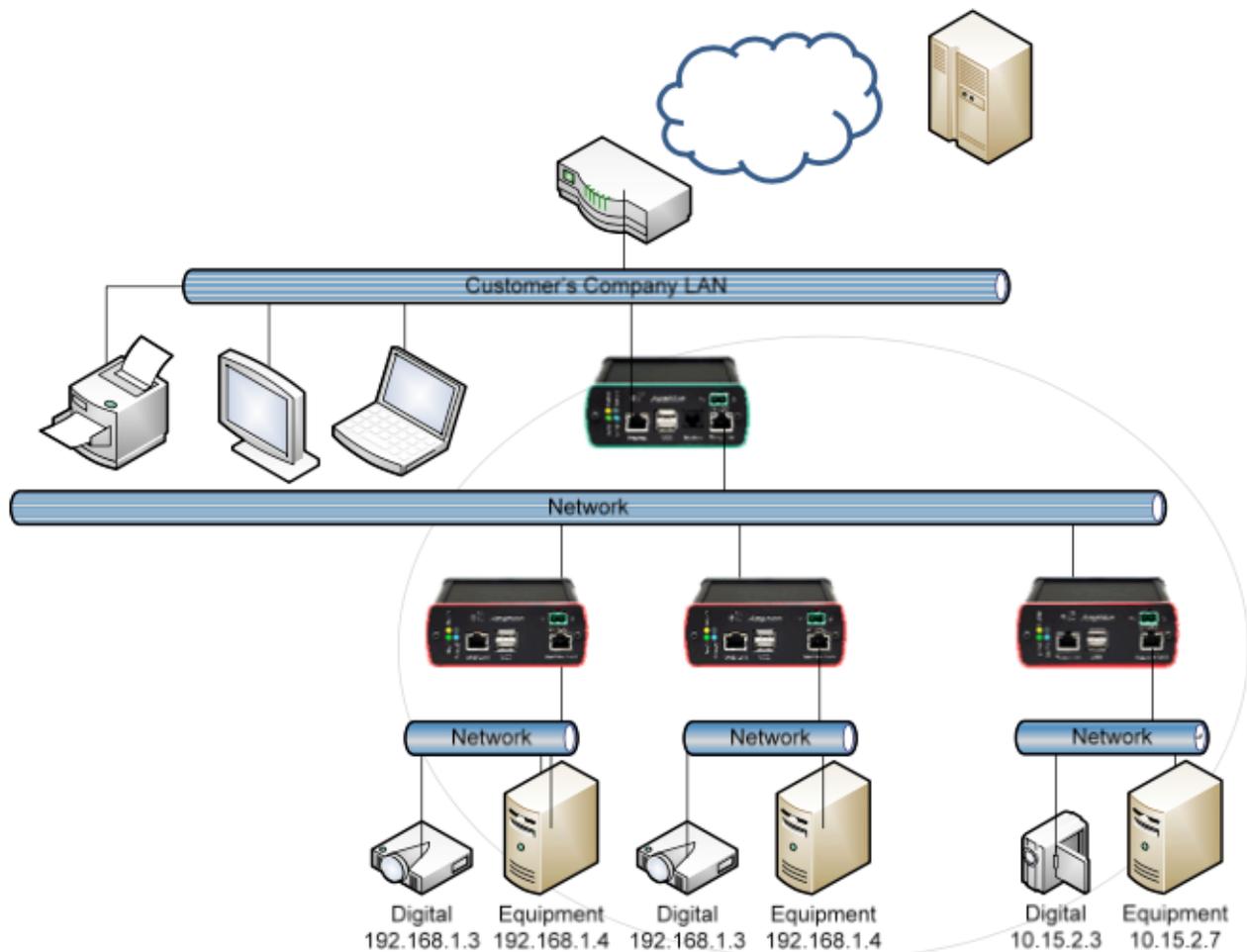
downstream inspection devices can be monitored and directly related to production on the machine. Once the material being produced is off the machine, however, care must be taken to consider only the quality aspects of the particular machine operation being measured.

The total quantity of units produced during the Machine Operating Time is shown as the entire bar (yellow + grey), with the portion shown in yellow representing the quantity of units produced that meet specification (good units).

Connecting to Devices & Security

Below is the architecture of the Network and Amphion (hardware) equipment delivered to each customer site to enable secure remote monitoring and remote service to machines.

The architecture is designed to allow secure remote service and remote monitoring while isolating each machine and the Customer's network from each other for the security of both.

Methodology

The isolation is accomplished by using a pair of small, but powerful, purpose built Ei3 Amphion devices running embedded software based on hardened Linux according to a design by Ei3's network security team. Each machine, e.g. an extruder, has its own Amphion Machine Router Firewall Device, "MRFD" or "red box", attached. All MRFDs for a customer location communicate to an Ei3 Amphion Remote Service Support Device, "RSSD" or "green box" for secure communication to the Ei3 VPN Server located within the Ei3 Datacenters. If a factory location has multiple machines receiving Remote Support or Remote Monitoring, then each machine will be equipped with its own MRFD. The MRFD is normally enclosed in the machine's PLC control cabinet, and is usually installed as a part of the machine control system by the machine builder.

Each machine can have many IP enabled devices included in to control the many machine operations, collectively called a "Control System". For the integrity of the machine operation and for increased security, the devices in the machine Control System do not need visibility to or direct connections to the factory LAN. The architecture of the Ei3 network is designed to completely isolate the machine from the factory network and vice-versa, thereby protecting factory IT resources from the machine Control System and the machine Control System from factory IT resources. The MRFD unit provides this function by acting as a NAT-ing router and firewall. The MRFD only allows communications of precisely defined traffic required for Remote Support between the RSSD and the Machine devices.

Methodology - RSSD

The RSSD is a VPN endpoint device, firewall, and NAT-ing router in one box. Its purpose is to provide a secure connection for remote monitoring and remote access to equipment within a customer facility. The remote service function permits access only to authorized service technicians who connect in usually for the purpose of making diagnostic sessions and Control System adjustments.

The RSSD makes an SSL VPN using Transport Layer Security. The RSSD makes the VPN by connecting to a Ei3 VPN server located in a secure co-location facility, for example in the United States Ei3 has equipment within an AT&T owned data center. There are thousands of machine connected from all over the world using this connection methodology. The RSSD can be placed on your internal LAN and make its VPN connection outbound through a firewall, which is the most common application. Alternatively it can be placed directly on the Public Internet. Since the RSSD is a strong firewall, it is safe to do so. The choice is yours. The SSL VPN produced by the RSSD can also be placed inside an Inter-corporate Ipsec VPN and connected that way.

The normal configuration of the RSSD is as follows. It provides the VPN and Network Address Translation of the IP addresses on the machinery into private addresses within Ei3's remote network IP space in a manner that creates unique addresses for the Control System on the machinery and prevents any overlap with IP addresses for any other machine or customer. The RSSD communicates with another firewall device, the MRFD one of which is installed on each machine. The communication between the RSSD and each MRFD (one per machine) is done over a separate network which we call the Shop Floor LAN. This SF LAN can be whatever you desire it to be for your plant. It can be a physical LAN separate from the rest of your company LANs, it can be a tagged VLAN within your corporate infrastructure, or it can be simply a logical LAN carried over your existing LAN media. The choice is yours.

We don't need you to add any routing within your network. We just need you to allow the RSSD to make its VPN to its server, and we need you to allow the RSSD and the MRFD(s) to communicate with each other on a mutually agreeable subnet of 254 usable addresses, a /24 network that supports up to seven machines. The default configuration of the SF LAN is 192.168.100.0/24. But this can be changed to suit your needs.
The addressing on the SF LAN is fixed. It does not require any DHCP servers. It works according to an allocation scheme where each of the seven possible machines uses a fixed subnet of size /27 abstracted from the /24 net.

Traffic on the Shop Floor LAN is unencrypted as a convenience to the customers. It is available for inspection should you choose to inspect it.

For your information, the IP scheme of the machines is such that all addresses of devices on the machine are in the RFC 1918 subnet 172.16.0.0/12. These addresses will never be visible on your network.

If the factory requires LAN access to these devices, that is possible and the factory needs to work with the machine builder to agree upon certain details. Ei3 can help mediate and create this access. If this is a requirement the access would be to the address for each device as represented by a Mapped IP for the device on the Shop Floor LAN, and the access is only allowed if it meets certain criteria. Since the MRFD is a firewall, it only will allow defined traffic through it, and this traffic is to destination ports on the devices required to control them. Specific examples of traffic that is not allowed across the MRFD are those used for Remote Procedure Call, SMB, and Microsoft DS, ports 135-139, 445, and so forth.

The RSSD is configured so that it only routes traffic from the virtual tunnel interface to the private IP addresses in the Ei3 IP space that correspond to the devices on your machines'

Control System. It is not possible for traffic to be routed through the RSSD to any other equipment that is not on the "Shop Floor LAN". There is one exception to this rule.

Occasionally, factories choose to place a computer, (e.g. a data collection system) on the SF LAN, between the RSSD and the MRFD. If the customer desires that a service provider have remote access to this computer we can allow it. But that computer is not on your LAN.

The RSSD and MRFD are proprietary products of Ei3 Corporation. They are built on a customized version of linux which has been hardened by us and is maintained by us. Updates to the device's firmware are scheduled and applied by us remotely on an as needed basis. The base firewall rules which control forwarding across the interfaces cannot be changed by any third party, nor can the NAT scheme. It is a minimal system running few services and only those needed to have it perform its intended function.

Applicability with IPSec VPNs

The combination of these two devices has been approved for use across many companies. Very few have chosen to connect these devices in alternative ways. We require that the NAT function provided by the RSSD and the MRFD be used in all cases. If you chose, we can connect the RSSD VPN to its VPN server through a corporate to corporate IPSEC VPN, and we can discuss with you some recommended methods to do so. We find that IPSEC VPNs provide an excellent way to convey and control the traffic from the individual RSSDs in a geographically diverse organization without the need for local "exceptions" to corporate policy.

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