OML

OPEN MANUFACTURING LANGUAGE

AN INTERNET OF MANUFACTURING SOLUTION FOR PCB ASSEMBLY

BY MICHAEL FORD AND DAN BAILEY

WHITEPAPER

For years, the PCB manufacturing industry has needed a robust real-time, comprehensive shop-floor communication standard that would include detailed bidirectional machine-to-machine communication as well as shop-floor to IT computerization communication. Now, engineers at the Valor Division of Mentor Graphics have introduced a real solution: the Open Manufacturing Language (OML), an open communications standard managed through a community of industry members and designed to support the evolving Internet of Manufacturing. OML makes vendor/platform-independent data accessible across the entire shop-floor, opening up the potential for Industry 4.0 and Smart Factory 1.0 solutions. This paper describes the basics of OML, as well as real-world uses and values to which it can be applied.

WHAT IS THE OPEN MANUFACTURING LANGUAGE?

The driver behind OML has been the strong demand from the industry to provide a standard language on which the Internet of Manufacturing for the PCB assembly industry can be based. Unlike previous standards, OML features bidirectional data flows, supporting shop-floor data collection as well as process control, all through a single standard format, language, and protocol. The specification of the OML standard is available free of charge to OML community members (www.omlcommunity.com).

OML development is based on many years of PCB assembly shop-floor communication experience, where information from production processes has been gathered in real time and applied to real-world manufacturing shop-floor solutions such as finite production planning, Lean material management, quality management, and full materials and production traceability.

As a result, the OML standard represents a high degree of value from the start and can be put to use immediately. Any creator or consumer of OML data will require the development and support of only one standard interface, compared to the pre-OML situation of needing many different interfaces. Development costs and lead-time for PCB assembly shop-floor projects, including advanced manufacturing computerization, can be reduced significantly using OML. This improved efficiency enables manufacturers to evolve to meet their customers' demands. OML will continue to be developed by the community to ensure that it meets expectations in the industry and continues to enable a true Internet of Manufacturing environment.

WHO BENEFITS FROM OML?

OEM MANUFACTURERS

Large manufacturing companies continuously run internal improvement projects that focus on individual aspects of the shop-floor operation. They try to keep a balance between in-house manufacturing and services procured from EMS companies. The key to success for OEM manufacturers is to retain competitiveness within the operation. Internal production offers the advantage of having a vertical management and operational structure from design through manufacturing, so that design can be optimized for the manufacturing capability; however, manufacturing also can be setup and optimized according to the needs of the products to be built. With a common supply-chain and engineering flow, the main variables to consider then become planning around the growing number of products and variants that are made at each site, as well as material flows to support all of the many changeovers required on the SMT machines as lot sizes become smaller.

Three key goals for an OEM manufacturing business are productivity, material turns, and quality management to protect the brand. The management and improvement of each of these metrics are driven by collection of data from the shop-floor. The current production status of completions, as well as measured performance statistics, has to be known so that upcoming production jobs can be planned for, modeled, and scheduled effectively.

The current practice of pushing materials out from the warehouse to the shop-floor as full kits for the series of upcoming work-orders on each line becomes unmanageable in high-mix environments. A pull system based on actual materials consumption and spoilage can reduce the investment in needless bloated stock on the shop-floor and in the warehouse. Accurate visibility of inventory by ERP eliminates internal shortages, which means buffer stocks can be further reduced. Active quality management is driven by the immediate visibility of test performance and repair issues. These three initiatives are all driven by information. Some of this information is used in parallel by common productivity analysis and material management as well as quality control, with data overlapping between these different uses.

Information traditionally has been gathered haphazardly, using different standards, protocols, and methodologies, which causes delays and a significant unwelcome workload for data and production operators. The use of OML provides the opportunity to gather all such data and convert it into a single standard, which can be exchanged between production, engineering, and IT "big data" systems with ease, providing the opportunity for enhanced control and management of the production operation as well as performance enhancement.

EMS MANUFACTURERS

The perspective for electronic manufacturing services (EMS) companies is a little different. Their essential priority is cost-effectiveness, running the production lines for customers' products with as little cost and risk as possible. The focus is online level performance rather than site-level because there are no crossovers between products made for different customers. EMS manufacturers want to avoid needless costs for the single product being produced or for the small and limited number of products that are made on each production line. The productivity and capability of the line's SMT program efficiency, line balance, testing time, and the first-pass yield are all important metrics.

As SMT and related machines have grown more complex over recent years, the time when an operator could just look at a machine or line and see whether there is inefficiency have long since passed. Different elements within machines now work together simultaneously, with different modules, heads, and lanes. Any issue with individual operations can result in a "chaos theory" effect to the rest of the machine or line. Advanced computerized solutions are needed so that inspection machines can be used to assess the performance of the assembly operation, highlighting the need for process adjustment that would improve the reliability of the operation.

The solutions that are important to EMS companies are those that have a significant effect on first-pass yield and raw productivity of the lines. These solutions are often provided by different machines from different suppliers, each with different communication capabilities. Using the OML standard allows all of the machines to share a common communication backbone and language so that advanced computerized solutions can be realized by each line and deployed across the entire factory. OML enables EMS companies to manage and control optimized production lines for their customers, and by so doing, provide a direct measurement of production cost, which in turn helps to improve EMS business strategies.

MACHINE VENDORS

A third perspective is from the machine vendors. For many years, customers aware of the data that could be obtained from automated production processes have been demanding that machine vendors release more ways to make relevant data available. The machines from different vendors have their own platforms, all of which have different specialist technology that has driven different ways of communication. On the information consumer side also, customers of these machines have requested that different kinds of information be provided in different ways. This has put a significant strain on the machine vendors to provide, not only information, but also the first steps toward solutions.

In many cases, the solutions have benefited those vendors who made partnerships, such as between inspection machine vendors and placement machine vendors, that excluded other vendors. The OML standard allows all vendors to produce data and solutions based on a single common data format, bringing the opportunity for customers' requests to be satisfied with the minimum amount of work, cost, and time.

HOW OML FITS INTO A MODERN FACTORY

The OML Internet of Manufacturing standard defines the different types and content of data, and it provides the common backbone infrastructure for communication. The extent to which OML can be applied in a factory spans from even the lowliest of processes on the shop-floor to the largest enterprise IT systems and production support infrastructures. OML simplifies the integration of IT systems with factory equipment and processes, allowing the use of a rich variety of reliable, real-time data. This removes a critical barrier—the expense of development and support to create the multitude of interfaces required for each of the enterprise systems.

A key attribute of OML is the ability not only to collect and exchange data between processes and systems, but also to allow control of processes and even entire lines through commands from computerized systems. OML allows the shop-floor to be automatically controlled and “fine-tuned” to react quickly to sudden changes, while maintaining the highest levels of productivity and quality. Manufacturing data from one site can then be exported through the cloud and combined with data from other sites to provide a continuous health check on global manufacturing.

For the developers of software solutions and system integration, OML provides key advantages, while minimizing risks to the operation. Offline development or simulation of new application code is possible in advance of deployment. Any new production process that creates OML data, or any new consumer of OML data, can be developed and tested against the known standard, so that all issues can be resolved reliably in advance before joining the newly developed module to the main backbone. For example, deployment lead-time and operational downtime would be reduced when new automation is added to the factory.

As well as the addition of simple processes, complex uses of data can be streamlined with the OML standard. Where there are many individual uses of the same manufacturing process data, the use of OML avoids conflicts. For example, certain pieces of information may be normalized in different ways or even be excluded according to the needs of the first application each time a new application or use of the data is added, which potentially affects all existing applications and systems, causing unexpected system issues and failures.

OML provdes a common data language between all systems, avoiding the need for changes and reducing the risk of these post-development integration side effects. It also makes sure that every user of the data sees the exact same view of the data, all normalized in the same way. This enables different areas of production and support operations to work together with a common view of any issues or requirements that may arise, avoiding operational conflict. The OML standard also allows support for the protection of sensitive data, such as customer- or business-specific data elements that should not be openly available.

THE BUILDING BLOCKS OF OML

TECHNOLOGY CHOICES

Many technology and design choices need to be considered when developing modern software systems, including a huge range of programming languages, frameworks, databases, data formats, and communication standards. As we enter the age of the Internet of Things (IoT), there is an increased focus and healthy debate regarding how these choices affect IoT.

It is sometimes natural to make technology or design choices based mainly on recent market trends, company preferences, or other local factors. Although making choices like this may be simpler, it is not always a good long-term approach. Deciding on the initial development choices for OML was difficult, but the process was made easier by using the following five criteria.

Meet Requirements—The technology has to meet the technical requirements. In particular, performance and reliability requirements are paramount, but also factors such as cross-platform support.

***Open Support*—**The technology must be inclusive to individuals or companies with a wide range of backgrounds, across the global manufacturing and software community. The technology needs to have complete support and avoid dependency on specific expert knowledge, environments, or immature libraries. It also avoids favoring specific platforms, companies, or hardware.

Factual Comparisons—All technology, whether new or old, must be compared based on the facts and data available today. A newer technology might clearly provide benefits, but if unproven in real-world conditions, it would add considerable risk.

Domain—The primary domain of OML is the factory shop-floor. The chosen technology must be a good fit for meeting the needs of applications, equipment, and hardware within this domain.

***Flexibility*—**Future improvements for OML cannot be predicted, but technology choices need to generally support the evolution of the standard.

MESSAGE PROTOCOL

OML is message-based. A message is simply a parcel or packet of data exchanged across the network. Some of the benefits of working with messages are:

- Messaging protocols can usually be clearly specified and documented, often visually using diagrams.
- Message content can be translated into other formats if needed by other systems.
- Messages can be validated in the context of sending or receiving.
- Production scenarios can be simulated, tested, or reproduced accurately by running software components with messages.
- Messages can be stored offline for short or long periods, allowing for functionality such as reliability and recovery to be supported.
- A clear version control and compatibility strategy can be implemented.
- Messages can be individually traced though all system components to aid troubleshooting and debugging.
- OML messages are exchanged using a simple protocol. OML supports several communication patterns using the protocol.

OML EVENTS

Applications can subscribe or listen to specific OML events and receive them in real-time from the factory floor. For example, an OML event provides the current production status of equipment.

Events provide for “loosely coupled” system architectures, meaning that one part of the system is not tightly dependant on another part. A loose coupling is generally favored because it allows the whole system to be more flexible to change and easier to maintain.

OML events also provide reliable delivery by using an acknowledgement from applications. If an application does not respond, OML ensures the event is not lost and is either sent again later, or in a worse case, a recovery can be made.

OML REQUEST/RESPONSE

OML request/response messages provide OML applications with real-time control of equipment or processes at the shop-floor. These messages are bidirectional. Control can be initiated by the OML application toward an OML process on the shop-floor. For example, specific equipment or lines can be stopped. Control can also be initiated from the OML shop-floor process toward an OML application. For example, the shop-floor process can check if a specific PCB is allowed to enter specific equipment every time a PCB enters the process.

DATA FORMATS

OML uses the JavaScript Object Notation (JSON) standard to represent each message. The use of JSON in the software industry has rapidly increased year on year, with the format now widely used in most web-based technology and across the Internet generally. JSON can represent the same data, using significantly less space than XML, which means performance gains. However, like XML, JSON is still human-readable and is able to represent complex data. JSON is easily compressed to reduce size for further efficiency. JSON is a fully open standard, with mature future support in most major programming languages and platforms.

Simple JSON example of OML:


```
{
  "$type" : "ItemStartedEvent",
  "header" : {
    "uuid" : "4f6dfc5a-c5c0-4d72-921f-861166854541",
    "dateTime" : "2016-01-22T14:42:02.453+0000",
    "senderAddress" : "192.168.2.1:80",
    "processId" : "ProcessId",
    "version" : "1.0.0b",
    "requestId" : "4f6dfc5a-c5c0-4d72-921f-861166854541"
  },
  "dateTime" : "2016-01-22T14:42:02.453+0000",
  "itemId" : "123",
  "barcodeId" : "Barcode123",
  "laneId" : "1",
  "recipeId" : "A"
}
```


COMMUNICATION PROTOCOL

A huge variety of technology and standards is available to allow different applications to communicate or exchange data. Some standards are designed for specific applications, such as financial systems, social media, chat, or voice and video transmission. Higher level standards sometimes favor or enforce the use of particular programming languages or operating systems. A lot of this technology is powerful and widely used, and hence they were researched and trialed as potential technologies for OML. However, some popular technologies were unable to meet all of the criteria, such as having enough open support available for different platforms.

The protocol chosen to exchange OML messages is the Transmission Control Protocol (TCP). OML messages are exchanged with standard network sockets. TCP is the underlying protocol of many Internet applications. TCP is a mature, open standard with support for creating the communication sockets available across all major programming languages and platforms. TCP also meets the low-level performance and reliability requirements of OML.

SOFTWARE DEVELOPMENT KITS

A software development kit (SDK) enables a software developer to work more effectively with specific platforms and development environments. SDKs are already available for OML. For example, using the .NET platform from Microsoft, a developer using the popular Visual Studio IDE can simply reference an OML .NET assembly, and within a few lines of programming code, immediately start to communicate with any other OML-based applications in the factory. SDKs are also available that support the popular Maven build system for Java. These SDKs typically provide real working sample application code and OML simulator environments. A good SDK will allow software developers to focus their time on building the value-added logic for their application, safe in the knowledge that the SDK is managing the OML communication layer.

THE INS AND OUTS OF OML SOLUTIONS

OML represents a low barrier to entry for applications that require the use of real-time data acquired from both automated machines and manual processes. Existing solutions can be enhanced and new solutions created, for which the return on investment can be compelling. The following are some simple examples that illustrate the scope of the usage of the OML standard.

KPI DASHBOARDS

The role of a dashboard is to bring a continuous summary of key points about the operation into a single simple display that can alert even the casual observer to issues that require attention. The measurement of effectiveness of a dashboard is to have accurate and timely information. Accuracy of data has historically been a huge challenge, at least when pushed beyond the most simple of parameters. For example, a count of the number of PCBs passing through each process may be an easy parameter to measure across the whole shop-floor through the use of sensors and then report using a dashboard. However, without OML, it is exceptionally difficult for the real use of data from each of the various machines and processes to include such things as peak and average production rate, minimum cycle time, stop events with reason and duration, production modes such as changeovers, pass and fails, top 10 defect list, production WIP bottlenecks, first-pass yield, repair cycle counts by PCB, etc., with like-for-like comparison of data in different formats and protocols.

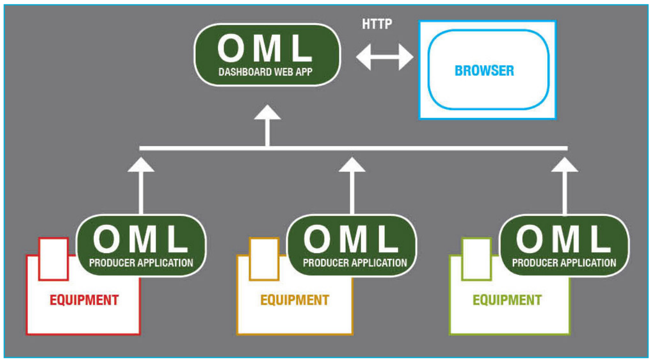

Figure 1: Data collection with OML to create a KPI dashboard.

At each production process location, standard OML is typically provided by a dedicated producer application. This makes the data available continuously to any OML application that requires it (Figure 1). Development of the web app is simple because it only needs to work with one language, OML. The scope for the content and analysis is huge because data can be coming from literally any production process to be capable of supporting many useful KPIs. OML producer applications can be developed for each type of process location using the specifications of OML. The data most often used for dashboards is a record of events so that whenever anything happens on a machine or process, it is communicated to the OML dashboard app, from which current status and historical trends can then be reported.

POKA-YOKE CONTROL

The principle of poka-yoke control is to ensure that processes are not allowed to operate where it is known that the operation is likely to result in a defective or incomplete product (Figure 2). The reason for the OML stop controller to prevent the process from operating can come from several triggers, such as the needed materials were not set up and verified, the machine program was not confirmed, or a trend analysis of data from quality-focused dashboards identified a high risk of an issue.

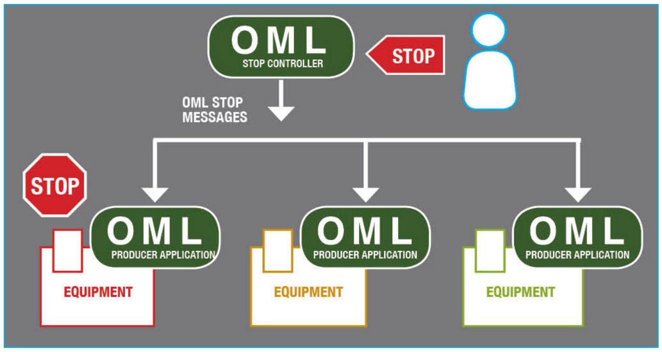

Figure 2: Poka-yoke execution using the bidirectional OML standard.

OML data can be used to enforce compliance of management practices, as well as be a part of process setup and active quality management systems.

SUPPLY CHAIN

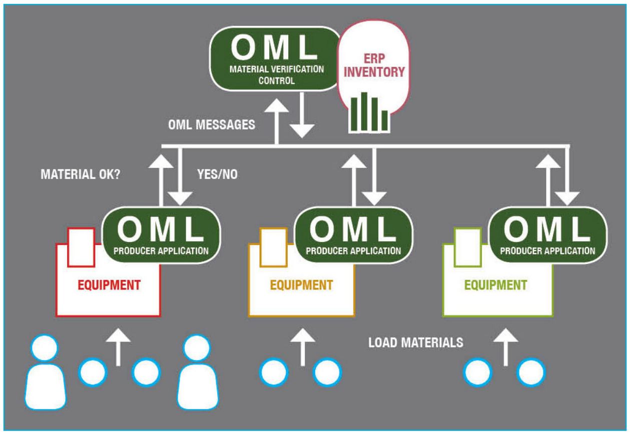

Figure 3: Material verification and inventory management-based on OML.

Looking at the process setup stage in more detail, OML can be used to record the events associated with the setup of materials. The assignment of materials to unique feeder IDs, as well as the staging of the feeders on to the SMT machines in the positions designated by the machine program, can all be recorded by the OML material verification controller by collecting all of the appropriate OML events. After the completion of the material setup, information about the consumption of materials and any spoilage can be read from the machine, then fed to ERP.

This information can be used by a factory-wide computerization system to supply materials to the various machines and processes when needed, rather than pushing all materials out in advance. The reduction in the need for advance materials is possible through the visibility of the actual material consumption and spoilage for each reel, automatically ensuring the accurate inventory record of physical stock against the ERP database and eliminating unexpected internal shortages.

MATERIAL TRACEABILITY

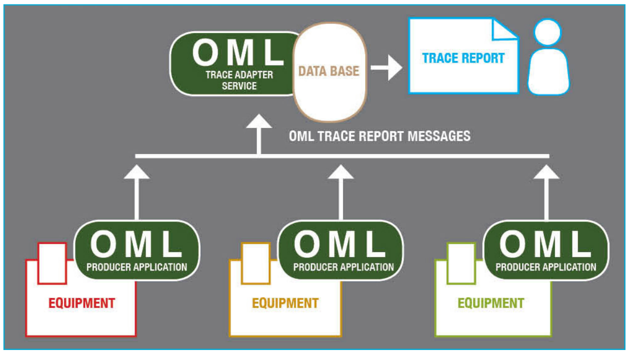

Figure 4: OML-based material traceability.

As an extension to the previous example, the setup confirmation of materials, plus the gathering of material consumption data from the machines, provides the opportunity for materials traceability. An OML trace adapter service can collect information into a database to create a clear record of material allocation that has been used, on a lot, job, or work-order basis.

Adding the reading of a unique serial number from each PCB as it enters each process, the information can be refined to provide more exact traceability for each PCB. The OML trace adaptor service can easily put together event records for each PCB as it passes through each of the shop-floor production processes to create a complete product build record of materials used.

ROUTING CONTROL

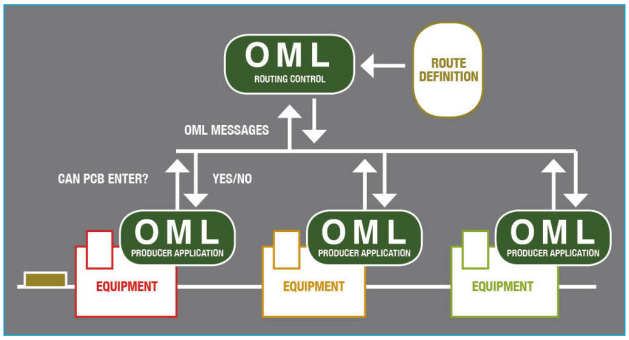

Figure 5: Bidirectional control for routing enforcement.

The use of a unique PCB-ID when read at each process can also be used by another OML control for routing. A primary function is to confirm that, as each PCB arrives at each process, the process has been correctly set up and the process is the correct next process for the operation of that PCB. This prevents the omission of a process or even the duplication of processes. The routing control can also be used to manage repair loops so that any PCBs that have failed a test process cannot pass to the next planned operation until they have been inspected, repaired, and retested. Routing control can use the same bidirectional capabilities as poka-yoke to enforce the routing decisions.

In addition to the control of the routing itself, OML routing can be used to monitor and report the number of PCBs between processes, as well as record the times for which each PCB has been in any process or has been between processes. Analysis can be perfomed on the shop-floor product flow to expose any bottlenecks, which can be a key indicator on the OML dashboard.

CLOSED-LOOP LINE CONTROL

A final example of the many more applications for which OML can be used is closed-loop control on a production line. Information can be taken using OML from an automated inspection process and can then be analyzed by an OML closed-loop analysis solution. For example, if an inspection was made on each PCB by an automated visual inspection (AOI) machine, the drift of placements made as measured by their *x* and *y* position, as well as rotation, can be calculated as a trend, and processed through a 6-Sigma algorithm to identify at what point the trend is out of control such that a defect might soon be made.

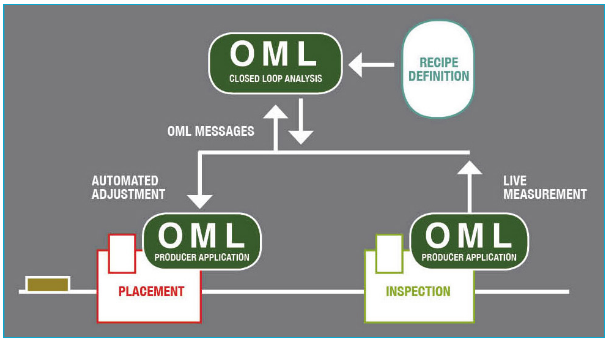

Figure 6: Closed-loop line control using OML.

The result of the analysis could be a message on the OML dashboard to say that attention is needed. Or, the OML interface can again be used to communicate back to the SMT machine that has been identified as being the cause of the drift to automatically modify program parameters and compensate for the trend, which allows production to continue without risk of defect.

CONCLUSION

These examples are merely a handful of applications of OML seen already on the PCB assembly shop-floor. Until the public introduction of OML, they have been available only to those with a specific set of machines or a significant installation of third-party software that provides custom machine-interface connections. OML now offers the opportunity for any operation with a competent software development team to create computerization systems such as those suggested by Industry 4.0 and Smart Factory 1.0. OML is the standard behind the Internet of Manufacturing for PCB assembly production.

GET YOUR OML NOW!

The specification of the OML standard is available to anyone free of charge when registering on the OML community website at www.omlcommunity.com. End customers, machine vendors, and anyone with an interest are encouraged to register as a member of the community, which, as it grows, will create more OML resources, experiences, and ideas for the community to share.