Will The "Internet of Manufacturing" Really Impact Business?

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Abstract
With technology these days, we often find solutions without a problem, rather than the other way around. The concept of the "Internet of Manufacturing" (IoM), combined with the evolution toward automated and computerized factories, is an exciting subject for engineers. However, managers who are responsible for the business side of manufacturing, need a solid business case for change that is driven either by need from the customer or by a compelling internal performance enhancement. The decision to purchase new equipment today is a catch-22—with requirements to be "future-proof" just in case the factory will become a computerized operation as put forward by the proponents of Industry 4.0, but without really knowing the full implication of what that might be.

Let us take a look at these two potential business cases. First, we will look at the likely reasons that would compel customers to change their demands and requirements from factories, whether OEM or EMS. Second, we will look at what is the "state of the art" today for automated factories that have a controlling layer of computerization, understand the challenges and potential costs, as well as direct operational benefits. We will see if we can find the balance point between the two.

Lastly, we will look forward at what needs to be done to provide a practical and economical way to address the various challenges to implementing an Internet of Manufacturing, with solutions and benefits for both manufacturers and customers. If these areas are addressed, the adoption of computerization and the creation of more automated factories could then become mainstream.

Demand Patterns Are Changing
The real pressure that a factory feels comes from its customers, whether a vertical organization that supplies a world-wide customer-base or an EMS operation that supplies products according to the changing needs of multiple customers. The line of distribution of products between the factory and the customer, from consumer goods to business-to-business assemblies, has always been a major cost to the electronics business. In the "old world," economic theory stipulated that products needed to be physically present in retailers' stores to be sold because a good salesmen would not let the customer leave the store empty-handed. If the desired product was not available, an alternative would be offered, and the sales opportunity for the customer's original choice would be lost. In retail especially, the distribution chain has ensured that any product could be on the shelf at every store in every city, in every region, in every country in the world.

The amount of products across the globe in this distribution chain, whether in transit stored in warehouses and hub locations, or in the storeroom of every retailer, adds up to a significant investment, which, like the raw manufacturing cost, becomes part of the final product cost. This distribution chain also significantly increases the risk of depreciation, as the value of products often reduces over time when they gradually become end-of-life or, more abruptly, when a new competitive product is introduced by another company. A competitive product reduces sales of existing products, and introduces the costs of promotions and discounts.

These distribution costs have been a key issue for consumer goods for more than 20 years, but they are now having significant influence in other areas of manufacturing. For the automotive industry, the amount of electronics used in vehicles has increased rapidly in recent years, which means that the cost in the supply chain has also grown and automotive OEMs are seeking to reduce it. As technology for communications has evolved, the cost and quantity of manufacturing telephone, broadband, and wireless infrastructure network products has also increased. Almost all areas of electronics manufacturing are now feeling the effects of supply or distribution costs, depending on the company's point of view, more than they were expecting to when manufacturing started to move in the 1990s to locations such as Eastern Europe, Asia, and China to reduce their labor costs. What has made the supply and distribution costs more significant is the increase in the amount of products and their variations.

Seen as a way to be more competitive, companies have now made the features, functions, and even aesthetics such as color, in many electronic products configurable for the customer, as well as creating products compatible with various service providers that have different software versions.

As a result of all this variation, few sectors in the industry now support the investment of a long and complex distribution chain. We are experiencing the age of electronic ordering, where physical shops are being replaced with on-line shops, and where the long distribution chain of products has been shortened or replaced with direct shipping from a central hub for the region or the entire country. Although the incremental logistics cost of each end-customer delivery may increase with these practices, the overall cost of distribution is reduced.

The logical extension of this trend is to move the entire business closer to the factory to save on distribution costs and to speed delivery; however, this can only work if the factory is based near the market. Conducting business this way can be more difficult for factories located in more remote locations. An exception to this is mobile phones, which have enough value and risk of depreciation to justify air-shipment while the demand in developing countries is growing. However, the majority of other products have to make do with surface or sea-shipping. In China and other low-cost manufacturing areas, flexibility and agility is difficult to achieve when the shipping time is a more significant problem in their distribution chain. As factories based closer to their market evolve, the potential for more business cases where local manufacturing is effectively cheaper overall than in China increases when considering the costs of the distribution chain. Factories that can react quickly to make what the customer needs remove an element in the overall product cost that exceeds many times over the cost difference of manufacturing near market locations compared to remote manufacturing locations.

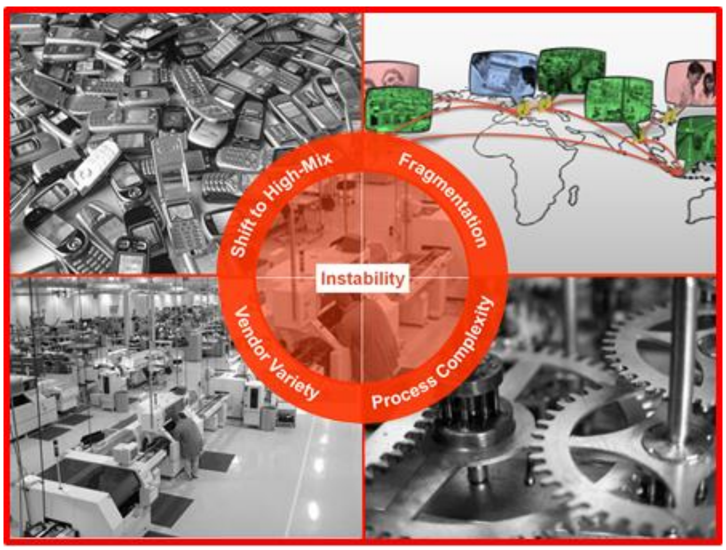


Figure 1: Demanding Flexibility Is a Challenge For High-Mix SMT Production

For SMT-based assembly manufacturing, however, flexibility comes at a price. Although SMT machines are responsible for the majority of materials placement during assembly, labor is an important fixed cost because of the complexity of back-end processes. Therefore, companies have significant incentive to increase the use of automation, usually focused on the replacement of manual assembly, test, and inspection processes, all of which require complex solutions with many different kinds of processes supporting potentially many diverse products. As the need for flexibility increases, the efficiency of machines and processes decreases, as well as the productivity of the whole operation, because of changeover times and complexity of production sequencing. A simple unexpected delay in one process, caused by a damaged or missing material for example, can have complex and far-reaching consequences, resembling a kind of chaos theory, where reactionary inter-dependent processes can be affected by increasing amounts, unless it is stopped and recovered by a management action.

The effects of unexpected delays and consequences of changes however can be complex to calculate and get right because of the many issues that have to be taken into account, such as delivery demands, equipment changeovers, material and resource availability, and process dependencies. The greater the amount of visibility and the intelligence of the live operation, including accuracy and timeliness, the greater the opportunity for improvement.

If there was a way to have every possible piece of information available in a standard and automated way, with computerization able to take that data and continuously tune the production activity and flow, the SMT-based assembly factory could become extremely flexible and able to fulfill complex delivery needs as is required when working with a short or almost non-existent distribution chain. The effect of this increase in flexibility without loss of performance could reverse the trend of moving manufacturing off-shore.

“State of the Art” Computerization Today

The adoption of computerization on the SMT-based shop-floor is in a poor state. Without an established standard for communication, equipment vendors have been free to develop and implement whatever they like. Originally, SMT machine communication was based on the need for measuring and fine-tuning machine performance. Because machines from different vendors can have fundamentally different operational mechanisms, the parameters, format, and protocols for communication have all started with different paths.

As customers wanted to replace their original manual methods of production data collection with automated data capture, they requested different information in various ways from machine vendors. And, for key customers, especially where working with third-party software vendors, the machine vendors would expose or create protocols and formats that would in some way meet the customers’ needs. The largest machine vendors, created their own proprietary broader format that could cover many of their latest machines to reduce the number of individual requests they had to support, which initially reduced their costs, and then went on to create for them an additional revenue stream.

Other machine vendors’ efforts were more limited in scope, embracing some of the many attempts at machine-communications standards, the most significant of which are CAM-X and GEM-SECS. The GEM-SECS standard has been successfully applied to semiconductor manufacturing, focusing on architecture and protocol definitions, through which individual processes declare their operations and capabilities and enabling services that can automatically execute them. The weakness of the SECS-GEM standard when applied to SMT production is that data is not managed or defined. In the case of the relatively simple semiconductor processes, this has not been a major issue, but it has little scope to address the complex needs of SMT.

Alternatively, the CAM-X standard, an XML-based format, also defines a method of architecture and protocol. It also includes a rudimentary definition of data exchange format specifically orientated for SMT. Effectiveness of the standard was short-lived, however, as evolving machine complexities and increasing functionality expectations rapidly led to extensive need and use of customization. This increased the verbosity of the protocol so that it could never be used without modification in anything but the simplest applications, such as run-rate dashboards. CAM-X has enjoyed a better success than GEM- SECS within SMT, although neither standards has been widely adopted.

The incentive to resolve these kinds of issues through the introduction of new standards or the enhancements of existing standards is not strongly supported by the key SMT machine vendors because revenue streams from sales of their proprietary software tools are now seen as important to their business. So it has been left to third-party software vendors to provide support for the countless interfaces that are unique to specific machine models or platforms which neutralize, transfer, and combine data. This support involves considerable difficulty and expense because, while SMT machine vendors continue to adapt, customize, and create protocols and formats, they leave behind a significant legacy of machines with “special needs” for reliable communication with accurate data interpretation.

A successful Internet of Manufacturing standard has to be able to model even the most diverse and complex SMT and related process so that the data obtained will satisfy any need to which it is applied. The application of computerization in PCB assembly currently has to exist on top of these platforms, where only the best third-party providers can provide data and information across all processes on the shop-floor in a way that is reliable enough to trust automated decision-making based on the data, such as Lean delivery of materials and finite production planning.

For most of the industry who are not taking advantage of such tools, the default position is computerization done by humans. Dashboards for many KPIs related to performance, quality, and materials are almost mandatory today in PCB assembly manufacturing. Engineers, operators, and managers continuously assess the likely accuracy of what they are seeing and the need to take action. For most SMT production floors building a high mix of products, though the machines do not appear to be working most of the time, and there are excuses and reasons why this is necessary. In this situation, figuring out how to take effective action is often beyond the scope of human analysis given the variability of the data and the time available.

New Technology Needed to Support the Internet of Manufacturing

The word "Internet" implies an access of information by a person who is looking for some information seemingly randomly. For an Internet of Manufacturing, each production machine and process has to include what is effectively a web server that provides clients with whatever information they may need using something analogous to a standard browser. A built-in standard communications engine at each SMT-related process is actually a requirement today already, because many different messages can come from the machine that represents a single event of significance, and they all need to be collected in real-time to then be interpreted together to create the knowledge of the event.

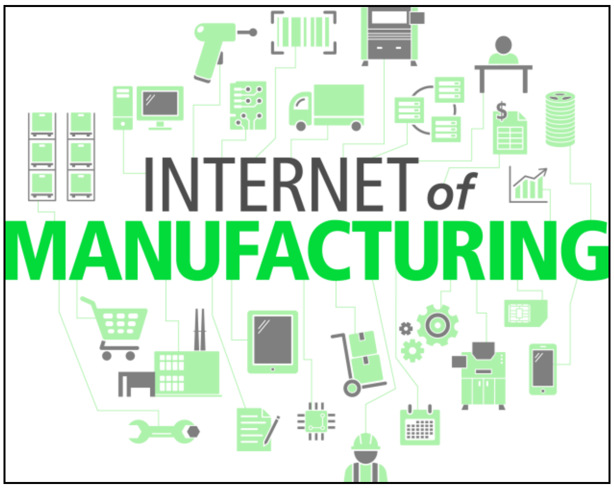


Figure 2: Internet of Manufacturing Technology for PCB Assembly Could Soon Be With Us

In the traditional approach of sending all messages to a central server for interpretation quickly, the server and the intermediate network become a critical bottleneck. A dedicated data neutralization device at each process, however, could take and interpret whatever machine or process language is required and store the normalized events locally to be queried through a standard IoM interface. Data could then be collected as immediately as necessary, or in a more relaxed way, by any number of people and machines. For example, such an IoM device at each process could store up to three days of events to preserve data integrity even where host systems are unavailable or issues exist within the network infrastructure. Operation can continue even when power is removed for some time because loss of power to the machine is an event in itself.

Information about each event can then be accessed through ad-hoc requests by someone who may need to know certain key information that helps resolve an issue. However, most of the information would be used for higher level computerization on the shop-floor. The ability to access information in the same neutralized format irrespective of the type or model of a machine, or whether the process is an automated placement machine, tester, or even a manual process such as inspection or repair, can greatly simplify the communication interface requirement for any MES or related system. Using one protocol and format standard enables clear visibility, and analysis of data by "big data" and business intelligence tools would be relatively easy to implement. Such a technology also would lead to the reliable adoption of computerization to replace the human interaction that is needed for both technical and operational management issues within production.

In the future, we expect that the best machines and automated processes will have the capability to support the Internet of Manufacturing through the standard protocol and devices built into their machines. However, a critical issue today is the support of the thousands of different machines that are in use throughout the industry. Modification of legacy machine hardware and software is not likely to be commercially viable for the machine vendors without a revenue stream associated with the upgrade. A dedicated external Internet of Manufacturing device would be necessary to implement IoM standards, protocols, and computerization for the whole shop-floor, without having to replace every machine. This is a critical factor for the adoption and success of the Internet of Manufacturing within SMT and associated PCB assembly.

Functions and Benefits Associated With the Internet of Manufacturing

Adopting an Internet of Manufacturing enables a quantum leap increase of performance when considering the demands for flexibility now being asked, as well as a world-class level of quality. The actual scope of such benefits is already expansive, and the ideas are increasing as more people become aware of what can be possible.

At the base level, the availability of accurate and timely data improves the scope and the effectiveness of dashboards, reporting, and issue resolution. However, the more significant values come where the IoM data opens up areas of computerization that previously could only be done in a limited, proprietary, or restricted way or where the complexity made implementation appear to be difficult. Some of the major areas that IoM could include:

- ***Technical (Line) Solutions***

  A self-governing feedback loop can be used to automatically monitor and improve the performance of processes on a production line. Variation in processes that become significant enough to risk a defect being created can be controlled and corrected by automated adjustment. An example is linking data between automated optical inspection (AOI) machines and data from SMT machines. The data needed from the AOI machine is a list of measured component positions, described as *x* and *y* coordinates and the rotation *r*. Data is collected for each PCB that is inspected. The placement positions of each successive PCB are then compared to the designated positional data contained in the SMT machine programs.

  While the normal AOI function is to create a defect notification if any of the placements are outside of a certain threshold, the analysis of any deviations and drift of positions within error limitations over time can yield trends that would eventually lead to defects occurring. Computerization based on the data collected may find that placements in certain areas of the PCB start to drift, which could indicate a potential PCB position problem. It could also be that only certain placements are affected, indicating a problem on a certain machine, a certain head, or a certain nozzle. Real-time data from the SMT placement machines can match up any drift patterns to specific items such as the wear on a nozzle.

  The second step of the computerization is to make minor adjustments and corrections to the relevant SMT machine operations that will prevent the trend from continuing to the extent in which a risk of a defect would be created. This increases first-pass yield (FPY) and quality overall. There are many examples of these kinds of feedback loops, which require detailed information from many processes simultaneously, including a mechanism to apply adjustments to machines on the fly without the need for the machine to stop or be reset. The benefits from these types of solutions include productivity improvements of approximately 1%, as well as the reduction of line engineering analysis time.

- ***Planning Solutions***

  Solutions that affect the operation of the entire factory can yield much more significant benefit than line solutions. Knowing the exact progress of every process in the factory can provide opportunity for planning changes to avoid bottlenecks and starved processes. This knowledge can even provide the ability to change the factory plan at short notice if the delivery demand from the customer changes suddenly. The data available through the Internet of Manufacturing shows the exact status and progress of each process. Computerization can then be applied that would take this information, with the delivery demand, product, and process modeling information to provide a finite plan for the whole factory.

  Unlike other planning methods, finite planning means that key activities and dependencies are calculated, including execution rate, changeover time, and actual material and resource availability. The best finite planning software for SMT also includes the reduction of changeover times through the automated commonization of feeders across sequentially running products that are grouped according to priority of customer delivery. In this way, the productivity of SMT processes and lines can increase by 30 to 50% in high-mix production. The lost time caused by poor planning is rarely addressed by regular production metrics that compare performance to the plan. However, in many cases, it is the plan that is the cause of most of the operational loss time.

- ***Supply Chain Solutions***

  A key barrier to the actual realization of flexibility is the physical management of materials. The SMT shop-floor is usually home to an extreme amount of unmanaged raw material inventory that accumulates as SMT machines perform changeovers. It takes time and effort to count and return materials into the warehouse; and, with some ERP systems, it is not even possible. Instead the materials stay on the shop-floor in unmanaged locations. At times, where unexpected materials shortages happen that stop the line operation, it would be convenient to be able to find the needed materials locally so that production can restart more quickly.

  However, it is the unmanaged material on the shop-floor that ERP does not have visibility over that creates the internal shortages in the first place. When the Internet of Manufacturing can be used to account for every material consumption or spoilage, material inventory accuracy is ensured. The use of the IoM materials information can be translated into material pull signals so that needed replenishments and materials for changeover can be automatically ordered and Just-in-Time (JIT) delivery managed through automated logistics. Not only is the inventory accuracy preserved, but as much as 95% of the material accumulation on the shop-floor can easily be avoided, which reduces the physical constraint on executing planning changes, reduces investment cost, and doubles inventory turns. The accuracy and timeliness of the IoM data means that the entire shop-floor material logistics can be fully automated.

- ***Quality Solutions***

  In addition to the closed-loop line feedback solutions, IoM can be used to augment quality performance through automated collection of traceability data. This data includes:

  - *Material Traceability:* The use of specific materials used on specific PCBs, for example, from SMT, pin-through-hole machines, manual assembly stations, repair stations, and system builds.
  - *WIP Traceability:* The routing confirmation and enforcement of PCBs through all production processes.
  - *Process Traceability:* The collection of key data from processes, especially those that provide test results and/or defect symptom information, including manual operations.
  - *Engineering Traceability*: The assurance that the setup execution of the operation of each process was in line engineering specifications, including program names, document names, versions, and revision control.

  Both traceability and the enforcement of correct machine operation, where done manually, has been a significant burden to the industry for many years, mostly in safety-critical sectors such as the automotive, medical, and aerospace industries. With expectations of cost reduction now affecting every part of the operation, the gathering of traceability data going forward needs to be done without representing a net cost to the operation.

  Having the fully detailed and complete product build record in the form of traceability data, deep analysis can be made to find the root causes of even one-off defects found during the assembly or test processes or in the market. The scope of any issues found can also be determined accurately, for example, the use of a specific material or a specific process in a certain condition at a certain time. These benefits with the low cost of automated data capture can greatly help to reduce the cost of poor quality and provide brand image protection by ensuring that traceability data is available and visible in any situation.

Yes, the "Internet of Manufacturing" Really Can Impact Business!

The principles of IoM as we have discussed here include the ability to get data from any process in manufacturing analogous to a browser and website service at each process. The effect on manufacturing starts with the ability to capture data, retain memory, and distribute at each process step to qualify and normalize information ready for use. A standard IoM protocol would be able to provide access to the information on demand for better reporting and to be used by big-data applications.

IoM data also could create technical engineering solutions that allow line equipment to “adjust itself” to increase productivity and quality. Across the whole production floor, the automated collection of traceability data can eliminate the burden imposed by manual data collection for conformance, compliance, and quality. The IoM data can be used to actually optimize and manage the live production schedule, which includes the flow of materials and products so that operational performance can remain at nearly the same levels when executing high-mix production as it is with high-volume production.

This ability to manage and optimize a live production schedule is the biggest impact on business, not just for the incremental cost savings, but by redefining manufacturing itself. Rather than accepting the assumption that, for the past 20 years, manufacturing is only financially viable when done in lower cost geographies, the whole business, including product distribution, can now be conducted at a lower cost when manufacturing closer to the market.

Supporting legacy, new, and future automated processes, as well as the vast number of manual processes in use today, is the key to being able to successfully introduce the Internet of Manufacturing into SMT production. The electronics industry is coming of age with the Internet of Manufacturing technology, and we now have the opportunity to escape from the shackles of data compatibility and reliability problems. The SMT manufacturing world is on the brink of revolution.

IPC-1782 Standard for Traceability

Supporting Counterfeit Components

Michael Ford Mentor Graphics

Counterfeit Is Not Funny…

- Safety concerns
- Brand image / company reputation
- Cost of market issues including recalls
- A barrier to technology adoption

APEX EXPO IPC 2016

The Reality of Counterfeit Ingress

Opportunity:

- Many touch-points
- Raw materials
- Sub-assemblies
- Finished Products

Cleverness:

- Labels can be copied
- IDs are not hard to forge

Today, There Can Be No Guarantees

FORWARD THINKING FOR TOMORROW'S TECHNOLOGY

APEX EXPO IPC 2016

Counterfeit: Risk versus Reward

Today:

- “Lost” in the crowd
- Buried in the detail
- Plausible deniability

With Traceability:

- Detection = prosecution
- Precise track-back of which, when, where, and who

With Real Traceability, Counterfeit Does Not Pay

FORWARD THINKING
FOR TOMORROW'S TECHNOLOGY

Traceability Today

What is It?

- Different in each case
- Negotiated
- Resented

A Burden:

- Additional cost
- Additional work
- Will it actually be effective?

Key for success: Can we turn the burden into a value?

APEX EXPO IPC 2016

"A Single Traceability Standard For The Whole Industry"

IPC-1782

FORWARD THINKING FOR TOMORROW'S TECHNOLOGY

IPC-1782 Concept & Background

Compelling Event

- Due to a recent industry wide memory issue, a huge resource and cost was needed to find and remove impacted products

- IPC was approached and approved the development of a comprehensive tiered component traceability standard

- The working group is starting with SMT components to develop a template for other parts

- Draft completed in record time

IPC-1782 Core Values

Making Traceability Practical

- Reasonable to implement with “off-the-shelf” technologies
- Economically viable / good return-on-investment
- Appropriate level of detail can be selected based on risk
- Importance of automated data capture
- Ultimate goal is to provide coherency
- Efficient approach of data storage

IPC-1782 Concept & Background

Removing The Burden

Insurance

- Scope of recall
- Show me the data
- Proof of Operation

Assurance

- Conformance
- Do it “right the first time”
- Counterfeit track-back

Quality

- Yield
- “One-off” analysis
- Lower returns
- Process defined maintenance

Safety

- Pro-active management
- Appropriately focussed intelligent response

Reliability

- More refined reliability models

IPC-1782 Traceability Values

Historical Barriers & New Opportunities

Bringing Traceability Up To Date

- ❑ Traceability has been applied uniformly independent of risk
- ❑ Automated data capture and "Big Data" tools are now more widely available
- ❑ IPC-1782 brings the whole principle of traceability coherently up to date
- ❑ Easy to articulate in a contract
- ❑ Traceability, as defined by IPC-1782 represents the most effective quality tool

Risk Analysis Determines Traceability Need

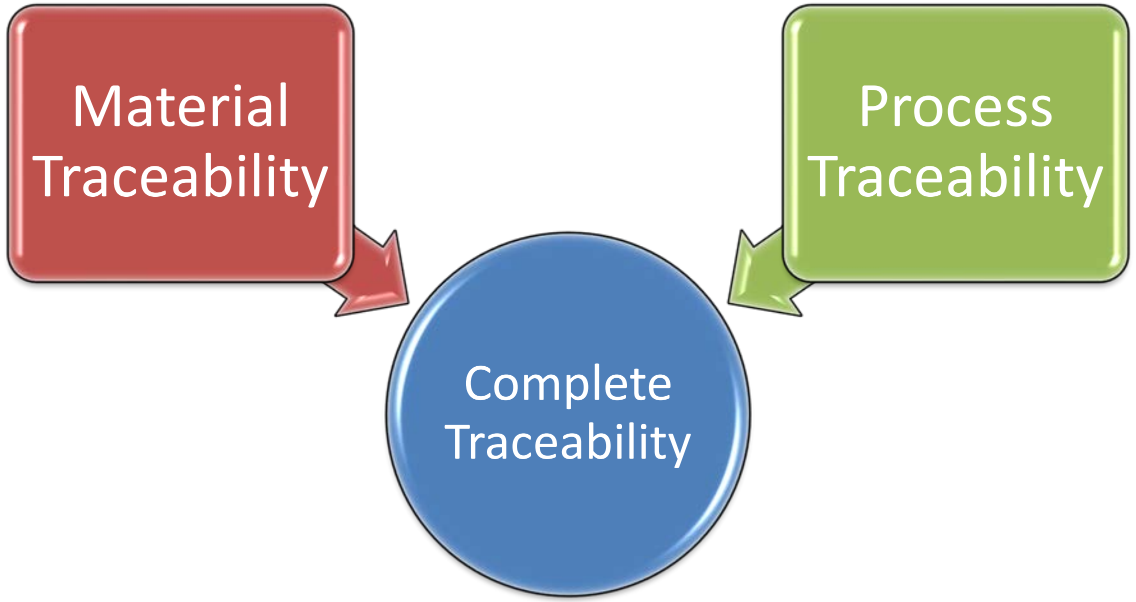
Risk Assessment Example

Risk Assessment Matrix from MIL-STD-882-E

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Content of Traceability

Practical Adoption Of A Single Standard



- The complete scope of traceability data collection includes many elements
- Details can be divided into Materials and Process
- Different levels of details of each are relevant in different situations
- The appropriate combination can be VOLUNTARILY agreed between parties

Traceability Levels

Quick Reference Table

	Level 1 "Basic"	Level 2 "Standard"	Level 3 "Advanced"	Level 4 "Best"
Material Traceability	**M1:** Listed to work-order by part number and incoming order	**M2:** Listed to work-order by unique material ID	**M3:** Listed as loaded, by PCB, by unique material ID	**M4:** Exact materials used on each PCB
Process Traceability	**P1:** Significant process exceptions against batch record/traveler	**P2:** Capture common key process characteristics, exceptions and test and inspection records to serialized PCB	**P3:** Capture all key process characteristics, exceptions and test and inspection records to serialized PCB	**P4:** Capture all available metrics: complete test results and process data
Data Integrity (in the range of)	3 Sigma	4 Sigma	6 Sigma	9 Sigma
Data Collection / Storage Automation	90% Manual	70% Automation	>90% Automation	Fully Automated
Reporting Lead Time	48 hours	24 hours	1 shift	Live Access
Data Retention Time	Life of Product plus 1 year	Life of Product plus 3 years	Life of Product plus 5 years	Life of Product plus 7 years

Importance Of Automated Data Capture

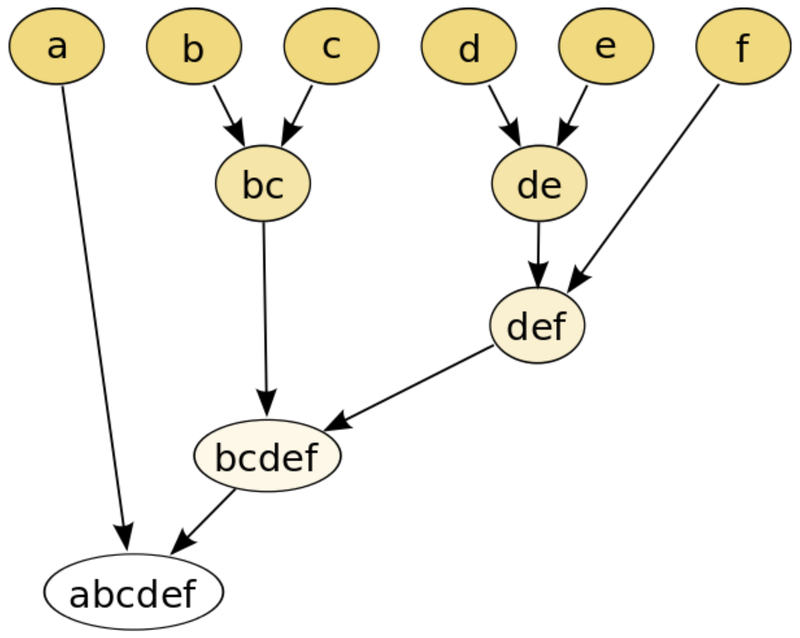
Reliability, Timeliness, Accuracy

- Costs of data collection and analysis are minimized
- High data accuracy
- Immediate access to critical information
- Higher levels of efficiency with data-driven decisions
- Root cause analysis can be reached with greater expedience

Cellular Approach To Traceability Data

Organization Of Traceability Data In An Efficient Way

- The traceability data of one product can be very significant in itself
- Multiplying that be the number of the units made is incomprehensible
- A method was found to eliminate duplication, and inconsistency
- A single structure to represent all levels
- Make it possible to easily add information or links to other information



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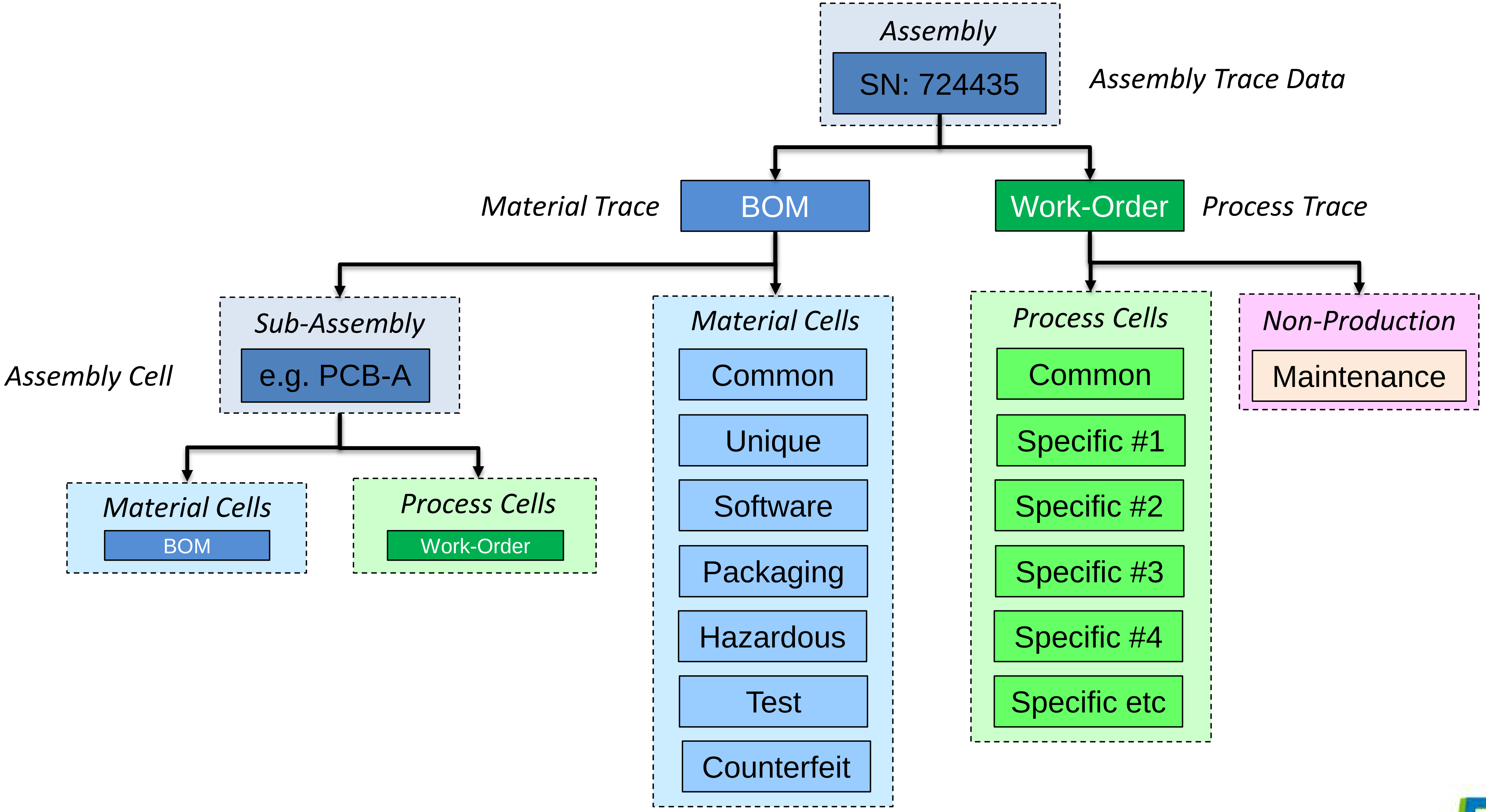

Thank you!

We Look Forward To Your Questions And Comments