Dealing with the Top Five Factory Floor Productivity Killers in the PCB Industry

A Valor White Paper

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valor

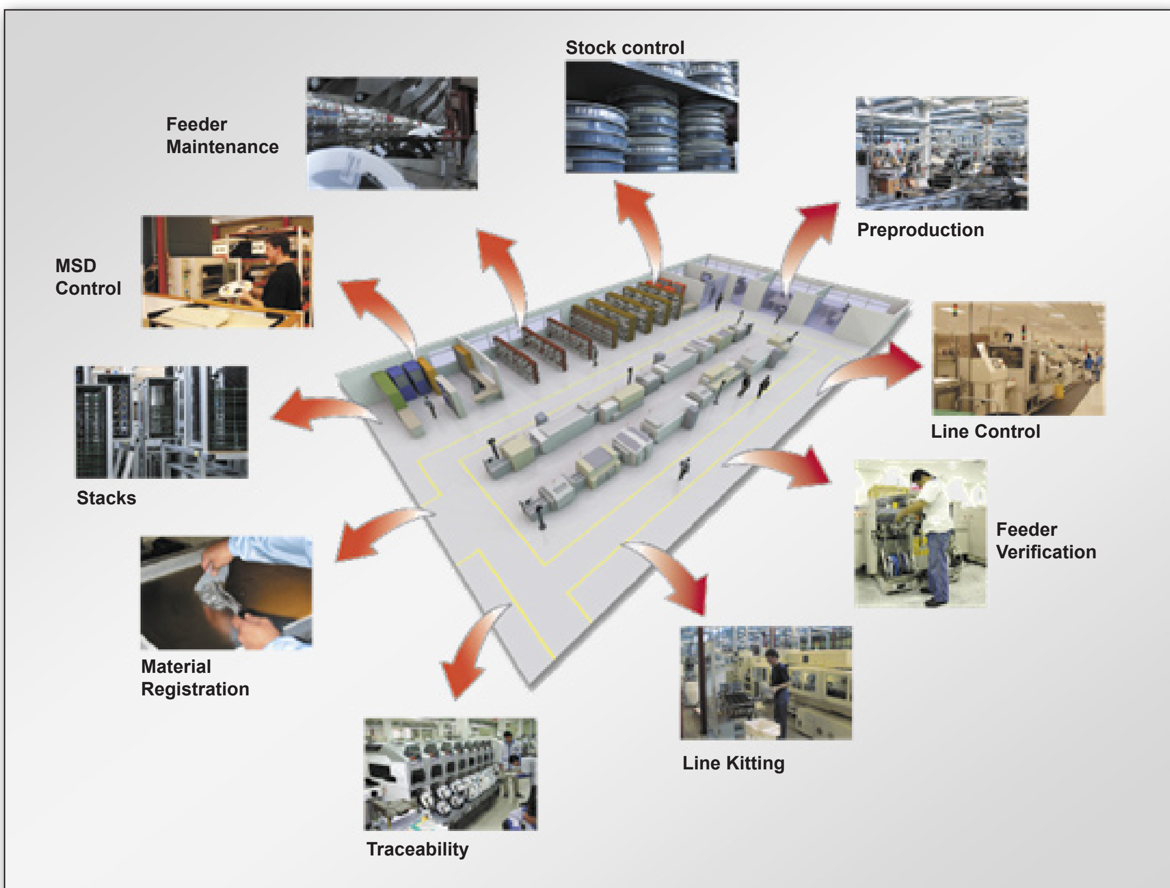
Introduction

The worldwide electronics industry has sales of $750 billion, two thirds of which is accounted for by PCB assembly. PCB manufacturing is characterised by an obsessive drive for increased productivity in the context of three significant industry drivers:

Shorter product lifecycles – The pressure is on to develop better products and bring them to market before the competition does, at lower cost, while simultaneously developing the next generation product. Only five years ago, product lifecycles were measured in years; now they are measured in months, putting pressure on designers and manufacturers to accelerate the process of moving from prototype stage to high-volume manufacture.

More complexity – Manufacturers are producing more complex, higher density designs with increased miniaturization and more sophisticated boards. A typical bill of materials (BOM) for a PCB assembly can now have thousands of parts in total, made up from hundreds of unique line items. The "bought-in" items - capacitors, resistors, diodes and so on - will each have one or more "alternative parts" to enable minimum BOM cost and maximum parts availability. More complex bills of materials (BOM) put a premium on increased component quality and better traceability.

Outsourcing is growing fast – Shorter product lifecycles and increased complexity have forced OEMs to embrace outsourcing, now the fastest growing segment of the PCB industry. Electronics Manufacturing Service (EMS) companies accounted for 21% of the market in 2004, but their share will reach about 30% by 2008. The market overall will grow just 16% in that time. EMS providers offer lower prices, accelerated speed-to-market and better order-fulfilment



Factory Floor

performance because they leverage massive aggregated purchasing power derived from serving hundreds of different customers, and by consolidating their manufacturing assets and managing them to achieve minimum unit cost. EMS providers focus on their core competency of manufacturing and component procurement; OEMs are free to focus on the design and marketing of new products.

These industry trends are well understood and have contributed to making PCB assembly one of the most competitive industries in the world. With pressure to cut costs, while simultaneously improving yields and speed to market, the search is on for those changes to factory floor operations that can improve competitiveness.

Typically, 60-70% of invested fixed-asset capital in PCB assembly operations is locked up in the machines in the assembly lines. SMT assembly is especially capital intensive, for example, with single lines costing more than $1 million and the price is increasing. Hard pressed manufacturing plant managers are asking themselves how they can ensure that their invested capital delivers maximum productivity and competitiveness. The answer lies not only at the level of the individual machines, but also at the level of the complete line or factory-floor.

PCB assemblers use many measurements of manufacturing performance from the product-by-product specifics of cycle-time, line beat-rate and first-pass yield, to higher-level benchmarks such as “BOM conversion cost” and return on capital employed. Whatever Key Performance Indicators (KPIs) are used, the goal is to generate the maximum output of acceptable-quality product from the available assembly lines, materials, fixtures and human resources available.

This white paper examines the five key factory floor challenges that must be overcome by manufacturers who want to become productivity champions in the SMT assembly business:

- Parts chaos
- Inefficient line set up
- Slower than optimal beat rates
- Low machine peak performance
- PCB/process combination is sub-optimal

1. Parts Chaos

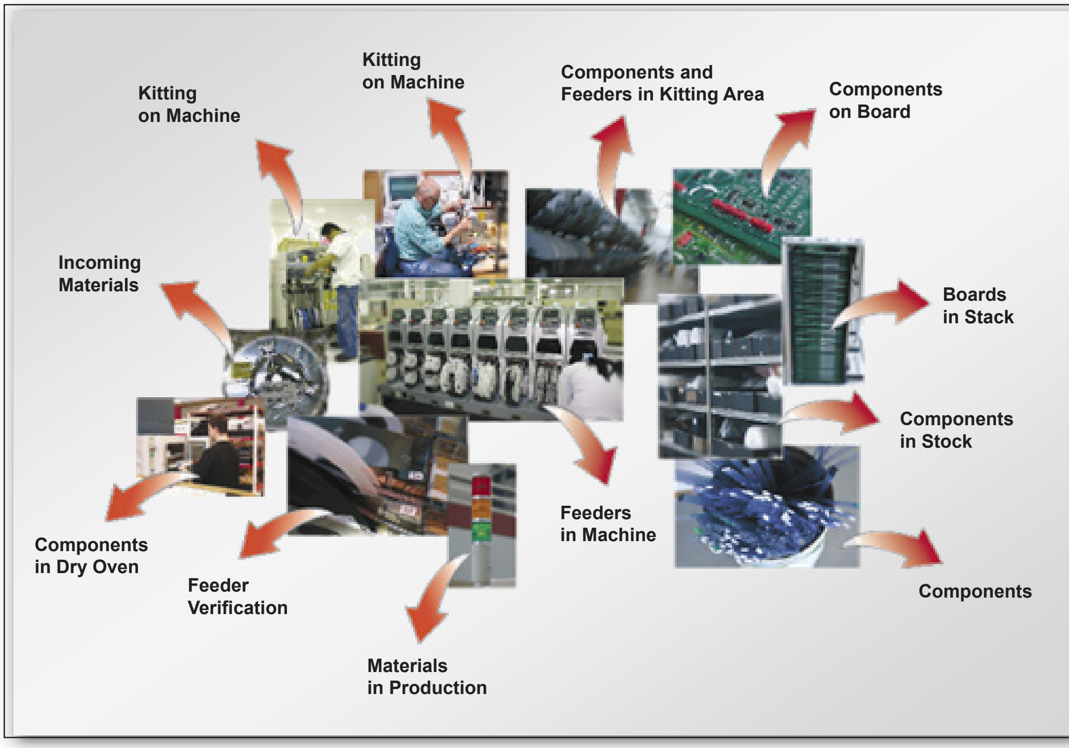
The first issue affecting productivity is that materials are not in the right place at the right time, ready for use on the assembly lines.

Many believe that having complete coverage in the ERP or master stock control system of all BOMs to be assembled is enough. But the critical factor is to have the correct quantities of parts and materials available and installed on the machines at the exact time when needed. Verification of availability of component part numbers en masse does not prevent failure to manufacture due to non-availability of parts on the factory floor because:

i. Parts already committed to other set-ups - Components for assembly onto PCBs are typically handled in bulk - either in reels holding thousands of parts or in stacks of trays holding hundreds. If the same parts are needed simultaneously for two production orders, neither line can be set-up correctly.

Multiplying the impact of this problem across the hundreds of component reels or trays present on a typical PCB factory floor, magnifies the risk of being unable to deliver the right quantities of parts to the lines for every production order, despite the fact that, in aggregate, the required total quantities of parts for the production orders matches the total quantities of parts in the master stock control system.

ii. Available parts cannot be found – Often, in large factories, the ERP systems do not track materials very accurately once they are released to the manufacturing floor. Key data - concerning the line the parts are allocated to, whether the set-ups they are committed to are still in production, and the exact quantity of parts that have been tied up in those set-ups - is frequently missing. While the available data shows the parts are available to start manufacturing, they frequently cannot be located. Unnecessary delays result at the start of a production run while “expediters” are frantically searching for missing material. Equally, and due to the same lack of visibility of which parts are where, often parts can be delivered unnecessarily to a line, to support set-up, when actually a sufficient supply of those parts is already loaded on the line, left over from a previous production order. These tracking inaccuracies result in unnecessary increases in factory floor inventory cost.



Parts Chaos

iii. Parts in quarantine - Another factor affecting parts availability at the pick-and-place machine is the sensitivity of some categories of components to exposure to normal atmospheric conditions on the factory floor. Sometimes components are affected by atmospheric humidity after unpacking from sealed containers and, after just a few hours, they must be baked in an oven to remove moisture from the component bodies. Discontinuities brought about by oven-baking cycles mean that certain parts go through cycles of being "available" and "not-available" for assembly, even though they are "in stock" all the time.

iv. Inaccurate stock control – Parts stock availability held in the ERP system is frequently inaccurate as a result of unrecorded wastage. When components are returned to the warehouse following use on the factory floor, gathering an accurate picture of how many parts remain on the reel is problematic.

Should production managers simply take the starting quantity and deduct the number of placements defined on the BOM? Probably not, because it ignores the parts lost by the machine due to miss-picks or nozzle failure before placement. By and large, this forces PCB manufacturers towards overestimating stock levels, leading to unexpected stock-outs on the factory floor in subsequent production orders. Expensive (and unplanned) production shutdowns like these create the need to purge the materials from the lines for subsequent orders and urgent parts purchasing to correct shortfalls. Inaccurate stock control also forces the time consuming and costly practise of site-wide inventory audits, when manufacturing is essentially put on hold while records in the ERP system are manually synchronized with the reality of the manufacturing floor.

v. The point machine problem - Few PCB assembly factories enjoy standardization of machine types across their lines and a variety of machine-specific component feeder types are in use, few of which are interchangeable. This, combined with the widespread policy of storing reels of components in feeders as a combined reel/feeder pair to minimize set-up time, means that it is often necessary to remove a reel from one feeder and fit it into another before the material can be made available to a specific assembly line and production order.

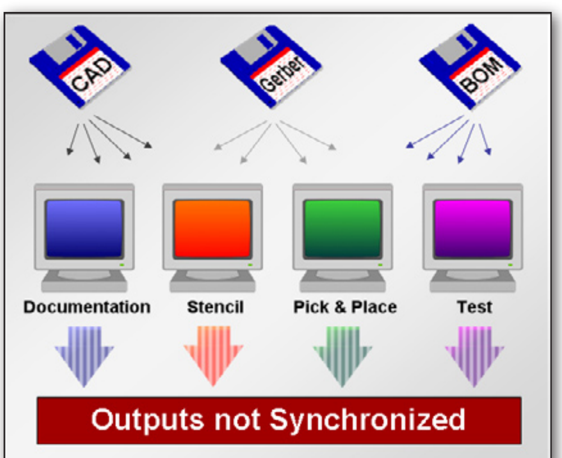
2. Inefficient line set up

An efficient SMT assembly line depends on the ability to coordinate hundreds of set-up variables simultaneously. If any aspect of the line set up is incorrect, poor quality output is the result. There are several common reasons for slow line set-up and debug:

i. Set-up instructions do not match machine programs - In many cases, the engineering data arriving on the lines comes from multiple, disconnected data flows.

The kitting list for each machine is driven from the BOM in the ERP system, yet it does not take into account the BOM-splitting and balancing decisions taken by the machine programmers. CAM systems used for generating machine programs are often working from a different database than the CAM system used to generate the factory-floor traveller. And CAM systems used to program AOI machines are different to systems used to program the pick and place machines.

The fragmentation of data flows can be extensive; each point of disconnect between engineering databases offers another opportunity to generate unsynchronized data or instructions for different parts of the assembly lines. All set-up errors have to be either eliminated at source, by design, or discovered at the "first-off" stage and eliminated by editing set-up instructions while the line is down and unproductive.



Unsynchronized output due to fragmentation of data flow

ii. Parts-data on the machines is missing or incorrect - Every SMT pick and place machine, AOI machine and in-circuit tester needs a library of data to describe key characteristics of every component to be assembled, inspected or tested. Only when the component library of the machine is filled with data describing the components for the production order can the machine do its job. Every new part loaded onto the factory floor means that the library data for that part must be entered into the machines and verified. Once created, the data must also be managed properly as any changes that are made can potentially result in unnecessary down time if not performed by a qualified operator. Without a controlled and centralised solution to manage the machine-level component data, the data must be painstakingly entered into multiple machines, causing unnecessary downtime and a high risk of data nconsistencies between multiple machines.

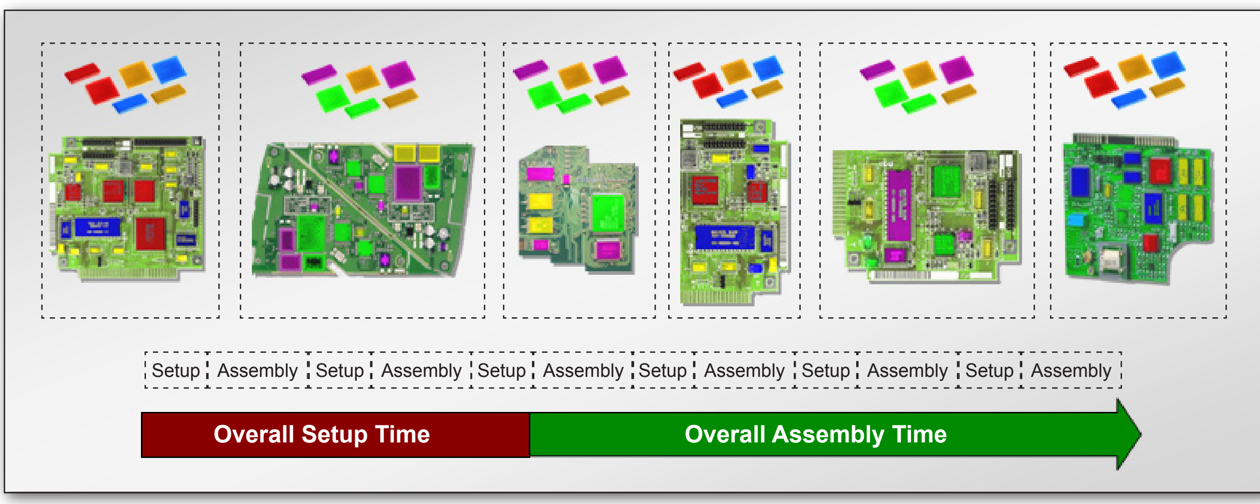
More Libraries = Higher Risk

iii. Full off-line set up is not achieved - Many manufacturers are incapable of offline component loading and set up verification. This forces line strip-down and set up to be undertaken before manufacturing can begin, leading to wasteful downtime. No doubt total feeder inventory cost can be minimized by performing set-up on-line, but a high price is paid in terms of lost line output and machine utilization.

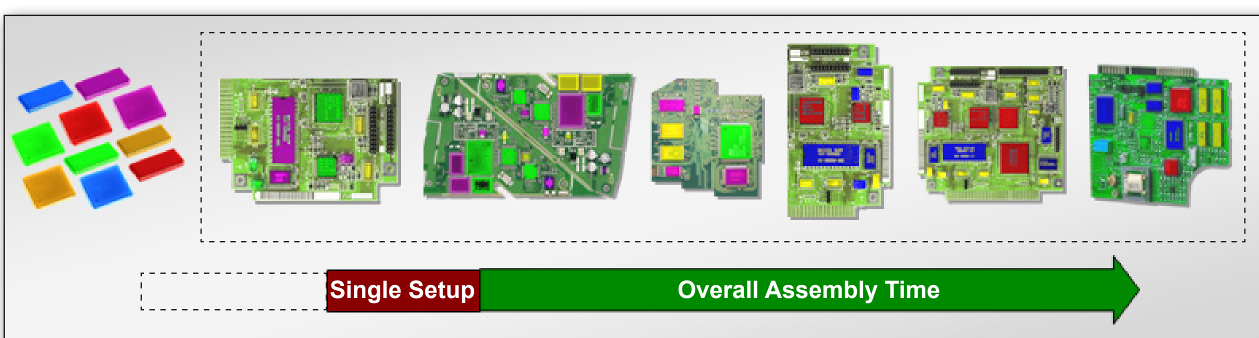
iv. Set-up is incorrect at first-off stage – If overall line set up is not verified in parallel with inventory checking at the outset, errors must be detected at the time of producing the first-off. This is the most expensive way to find and eliminate a set up error, since the elapsed time between creating the error and detecting is maximized. Multiply the error/detect/fix opportunities according to the number of feeders, machines, programs, and the opportunity for escalating set-up debug time becomes clear, as compared to verifying every aspect of the set up as it is carried out.

Once the first off stage is complete and the line is in full production, it is also vital that errors are avoided when new parts are put on a machine to replenish an exhausted feeder. Worst-case, incorrectly placed parts will be detected after assembly of the full batch, at the inspection or test stage. Such repairs have maximum cost and impact on the overall productivity of the plant.

v. Failure to exploit existing machine set-ups – The best way to minimize set up downtime is to eliminate the need to strip lines down and set them up again between production orders. Because of the complexity of managing the huge variety of components, feeders, feeder positions, component quantities, and the factors which affect an optimized set-up for minimum cycle time, most manufacturers strip all the feeders and components from the lines between production orders. This maintains control, but dramatically reduces productivity. By analysing production orders in advance and identifying product groups that can share the same set-up (or majority of the set up) on an assembly line without sacrificing beat rate to an unacceptable degree, massive savings in downtime can be achieved. Using product-grouping techniques delivers significant productivity improvements in High Mix/Low-to-Medium Volume operations where changeovers are one of the major contributors to line downtime.

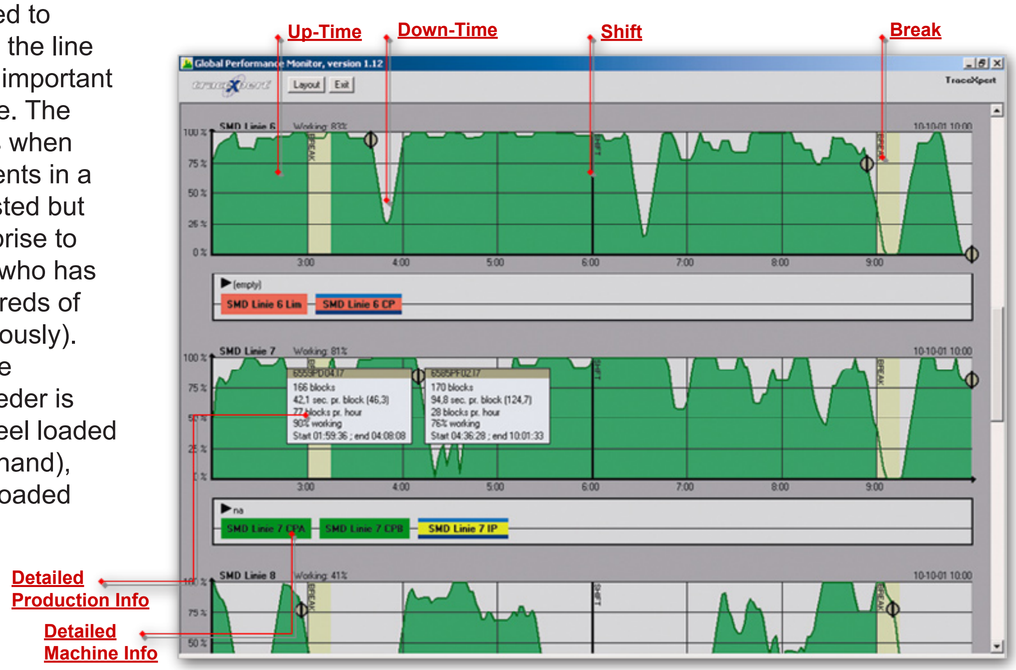


Setup and Assembly time without Grouping



Setup and Assembly time with Grouping

vi. Failure to anticipate parts replenishment requirements - In high-volume, low-mix manufacturing environments, lack of advance visibility of the need to replenish parts on the line is the single most important cause of downtime. The worst case occurs when all of the components in a feeder are exhausted but it comes as a surprise to the line operator (who has to supervise hundreds of feeders simultaneously). This forces the line down while the feeder is removed, a new reel loaded (assuming it is at hand), and the feeder reloaded onto the machine.



Various reasons for machine downtime

3. Slower than optimal beat rates

Once the lines have been set up, production settles into its repeatable rhythm, with assembled PCBs coming off the line at a fixed frequency determined by the line balance, machine capabilities, and the level of optimization embedded in the product-specific machine programs themselves. At this point, productivity is affected in an expensive yet invisible way, if lines are not programmed to run at the maximum possible beat-rate. This can happen for several reasons:

i. Simulation, BOM splitting/balancing, and machine programming are not performed at the <u>full line</u> level - Individual machines can be programmed to an optimal level, but if a full-line approach is not taken to the programming task, based on a complete kinematic simulation of all the machines that make up the line, overall performance suffers, primarily caused by machine workload imbalances. The cycle time, or beat rate, of the line is determined by the slowest machine in the line, emphasizing the need for an accurate simulation-based approach to programming the line as a whole.

ii. Machine programming is not based on full kinematic simulation - If the line-level simulation and programming (balancing) is separated from the machine programming, there will be conflict between the two; the balancing depends on accurate information about individual cycle times, and the machine programming may generate a different machine cycle time to that assumed by the line balancing function. The key is very accurate simulation of every machine's configuration (feeders, nozzles, …) and its motion kinematics. Without accuracy in machine cycle time simulation, not only will individual machine performance suffer, but also the line overall will not be balanced for optimum overall output.

iii. Machine-level parts data is not programmed for optimum handling performance - The parts-data used by each machine defines how to handle the components: at what speed, with which nozzle, how long should the various dwell times be, what offsets should apply to the pickup point and so on. Completing the first-off is enough to verify that the product is assembled correctly, but this does not expose any low assembly speed effects due to sub-optimal handling instructions embedded into the parts data library of the machine. An operator will sometimes choose to reduce the placement speed of a component to ensure assembly, often masking maintenance issues that should be addressed while greatly reducing the overall productivity of the line. As with the optimization of the machine programs themselves, without access to detailed performance data it is virtually impossible for humans to identify these effects; and without detection they cannot be corrected.

Low Machine Performance Indicators

4. Low machine peak performance

With investments in lines running to millions of dollars, clearly machines should be maintained to perform at maximum productivity for the maximum time. However, there are many aspects of machine condition that have an insidious effect on pulling down overall performance.

i. Nozzle vacuum pressure - If this is out of spec., it causes components to be dropped in transit between the pick-up point and their position on the PCB.

ii. Sticky nozzle vacuum switching – If the vacuum switch is sticky it leads to nozzle skips. To pick the components from the feeder without error requires positive and fast switching of the vacuum supply to the nozzles. The same applies to the placement; slow or imprecise switching of the vacuum causes imprecise pick-up or placement.

iii. Worn feeders - This leads to high miss-pick rates. Component feeders are mechanical indexing devices which wear over time. As the mechanism wears with normal use, the accuracy of presenting the component for pickup declines, leading to failure to pick correctly, which wastes components and cycle time.

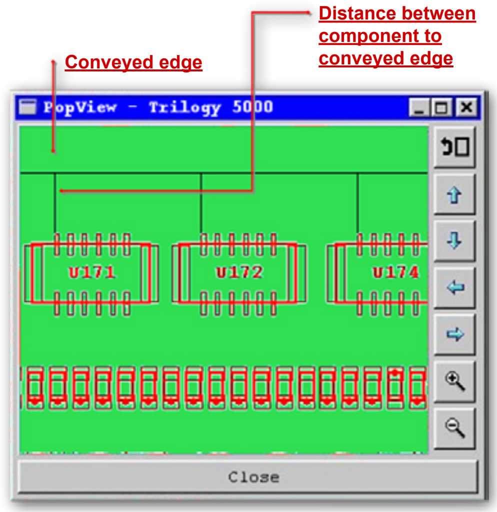
iv. Poor maintenance instructions - SMT lines place components at rates of tens or hundreds of thousands of parts per hour. This lightning machine speed makes it difficult to observe declining performance. Miss-picks happen too quickly to be seen, but a delay of a few milliseconds on a repeating function leads to detuned performance. Without accurate and timely notification of where the performance drop-offs are, line operators and maintenance personnel have little chance of taking the right action to raise performance.

v. Servo, actuator speeds detuned – This can happen for many reasons. Surprisingly often, the performance of two machines of the same type is not identical. Servos can be detuned to minimize the risk of breakdowns during the night shift when maintenance services are not available, and then not be brought back to specification. It is possible that component handling dwell times have been extended in order to compensate for poorly-maintained pneumatics. Without tools that reliably report on these factors and support investigation and rectification, the chances are that machines will drift off-spec. and remain there without it being obvious.

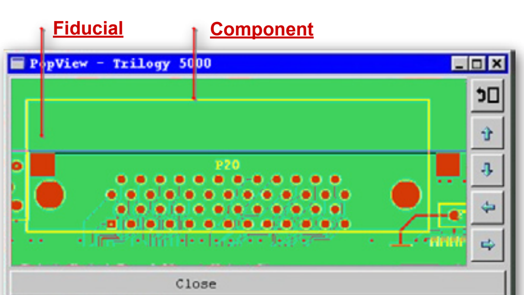
5. PCB/process combination is sub-optimal

PCBs can be designed to be assembly-process friendly or process-hostile. Most PCBs can ultimately be assembled, but higher costs than necessary due to sub-optimal design, rework levels and line efficiencies vary as a result of design features such as:

i. The PCB is not machine- or line-friendly - The fiducials are hidden, components conflict with conveyors, assembly-panel design is not optimization-friendly. Design constraints such as component distribution on the board, or variety on the BOM, is such that one type of machine cannot achieve a low placement cost and this does not become visible until running the product on the line.

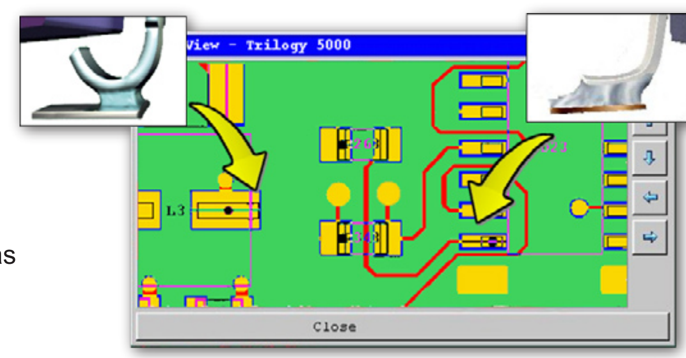


Component too close to conveyed edge

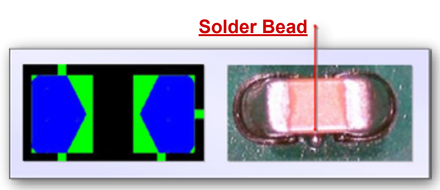


Fiducial covered by component

ii. Solder-stencil design leads to sub-optimal solder joints – This results in high rework. The primary objective of assembly is to create reliable solder-joints. Apart from good control on the soldering process, the combination of component pin, pad-pattern and solder-stencil aperture must be optimized to give the process the best chance of achieving joints that are within acceptable tolerances (typically measured in tens of poor joints, per million manufactured).

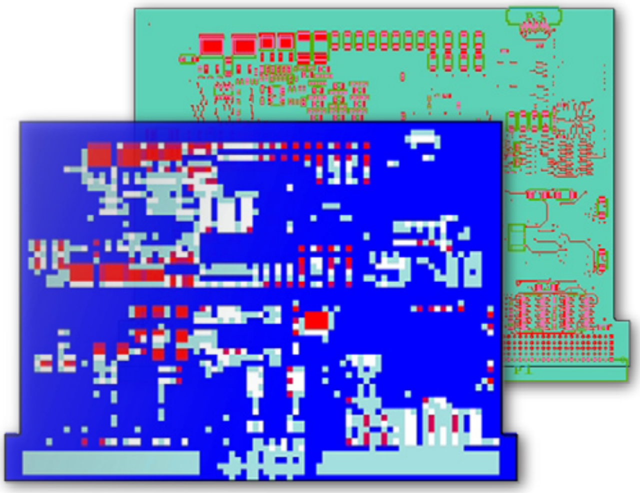


Insufficient toe (left) and heel (right) fillet clearance



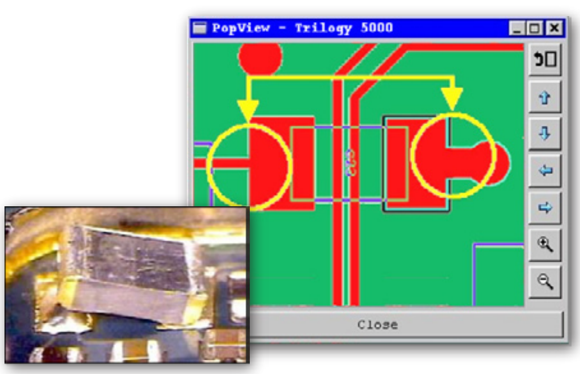
Customized apertures designed to prevent problems such as solder beading

iii. PCB design layout encourages bow and twist - The panels of PCBs loaded onto the line for assembly should be perfectly flat, so as to avoid conveyor "hang-ups" and processing errors in the machines. By designing the PCB with an even distribution of copper in all axes, the tendency of the PCB to bow and twist during processing will be minimized.



Copper distribution map (blue) of a board (green). Colors indicate the percentage of copper in each area.

iv. Pad/track patterns encourage tombstoning during reflow - With the trend towards smaller passive chip-components, such as the 0201 packages now being handled in volume, the design of pad and track patterns to allow equal heat sinking effects on either side of the component is of increasing importance. As the components get lighter, the effect of surface tension effects during reflow become more important; if one side reflows before the other, surface tension can cause the dry side of the joint to lift, causing the "tombstone" effect.



Tombstoning effect caused by unbalanced heatsinking across the component

Some solutions

The route to maximizing factory floor productivity lies in a top-down approach that addresses the detailed operational points in the previous sections. Steps need to be taken in the following areas:

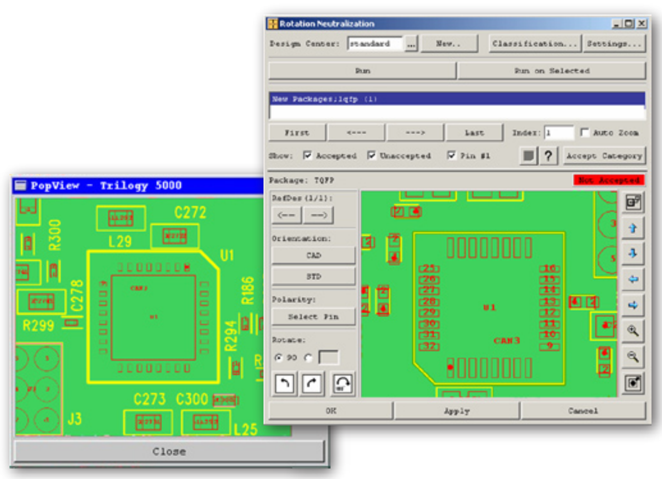
- **Data preparation**
- **Manufacturing process simulation**
- **Manufacturing process preparation**
- **Manufacturing execution systems**

Technical solutions are needed for all of these challenges. And, crucially, reporting systems must be in place for engineers, line operators and manufacturing managers that identify the specific actions that need to be taken to improve performance. Moreover, the information must be timely enough to enable improvements to be made before the opportunity is lost and fresh problems appear elsewhere.

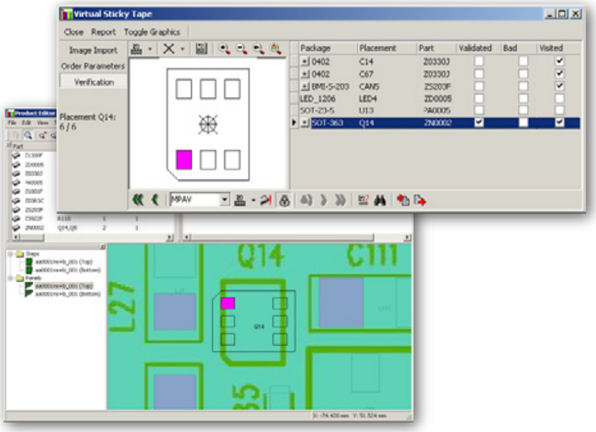
Data preparation
Attention to data preparation for both component model input and design data input is a mandatory first step:

Component modelling - Manufacturers need to put in place accurate physical modelling of all the parts they plan to use on the line, including pin-contacts for solder joints, integrated with the CAD data. This should comprise:

- Consistent, CAD-library neutral, modelling of the parts to enable standardised DFM and process preparation functions downstream.
- Normalized component off-set, rotations and polarity statements to a standard.



Rotation neutralization

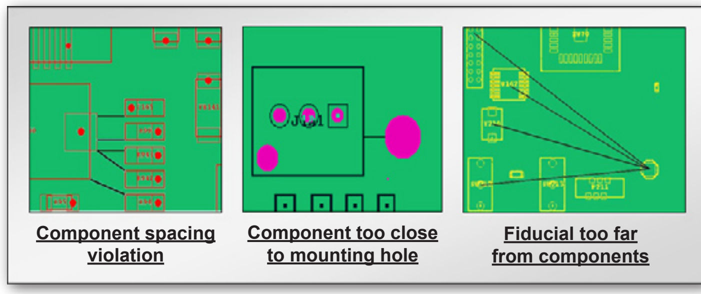


Verifying component rotation through Virtual Sticky-Tape simulation

Manufacturing Process Simulation

This encompasses DFx and assembly line simulation. The first step is DFM analysis and optimization based on the company's manufacturing process constraints and rules, including:

- The identification and elimination of designed-in process risks such as "tombstoning" and bow/twist.
- The design of an assembly panel for optimum handling reliability and assembly cycle time.

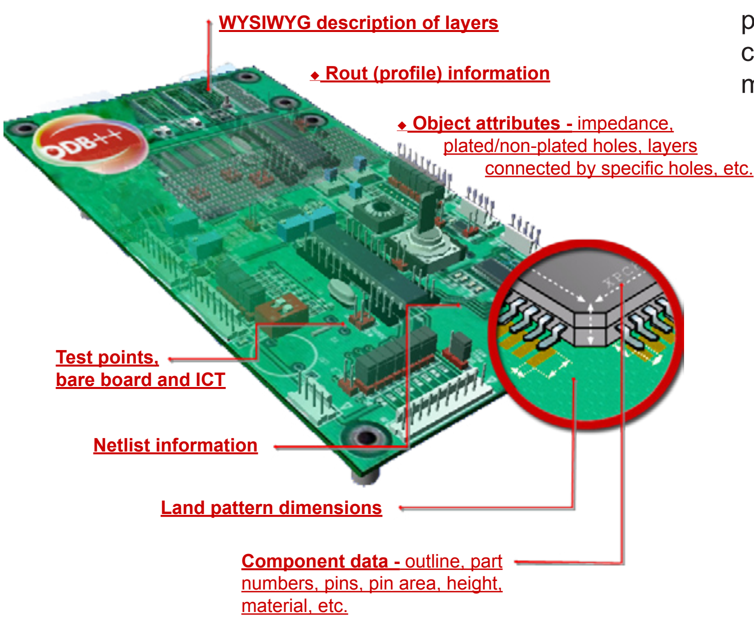


Sample DFM Errors

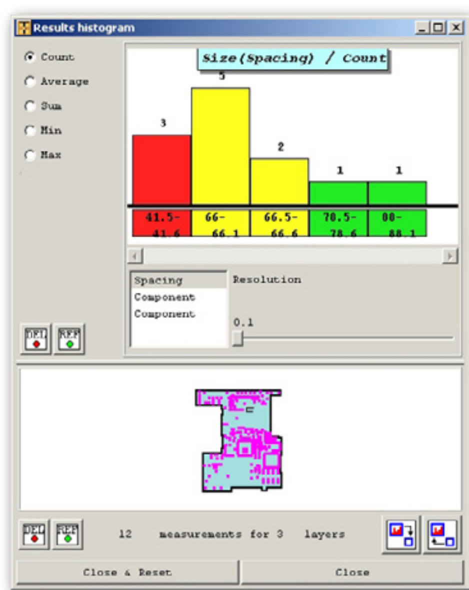
Design data – Production managers must be certain to be able to read all mainstream CAD database formats into a single physical and functional model of the PCB sufficient to support fabrication, assembly and test.

The goal is to establish a "golden reference" model of the product to be manufactured capable of driving all manufacturing operations.

In addition, PCB manufacturers must simulate assembly line cycle times for each new product, either to target the product at specific lines so as to optimize the match between product characteristics and machine/line constraints, or to drive design changes for minimization of assembly cost.



Flexible, comprehensive data model



Result histogram of PCB assembly analysis

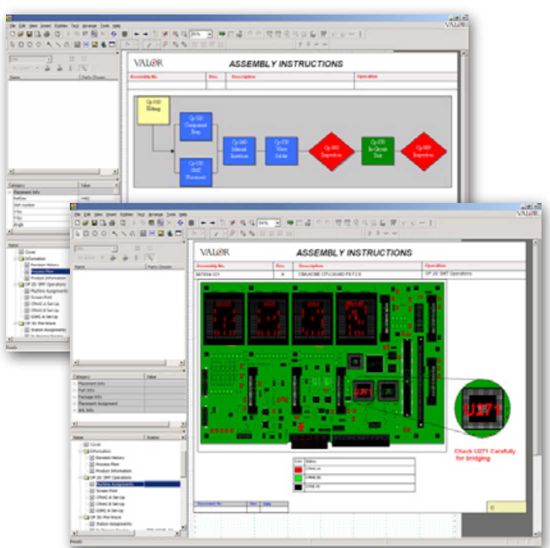
Manufacturing process preparation
This encompasses document creation/tooling design and machine program/library generation and machine optimization and line balancing.

PCB factories should generate all manufacturing documentation and tooling designs from the database-of-record to provide:

- Optimized solder-stencil designs, based on accurate physical modelling of component pins and pad that meet process constraints (lead-free, not lead-free).

Optimized solder stencil designs

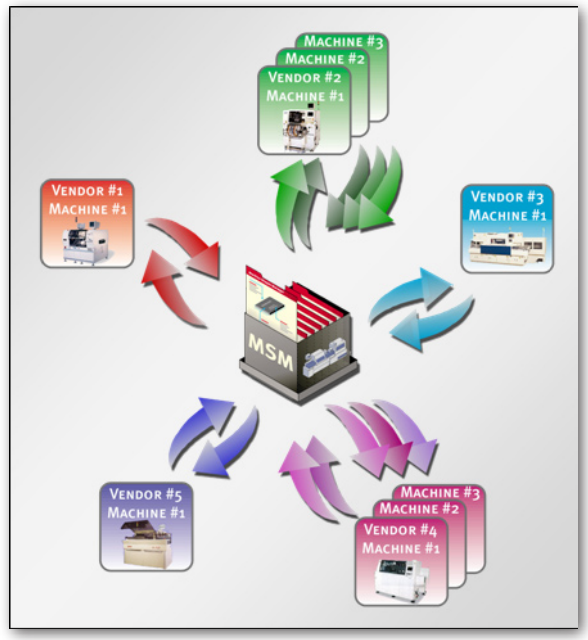
- Output test fixture files and inspection templates.
- The factory-floor traveller, drawings, manual assembly instructions.



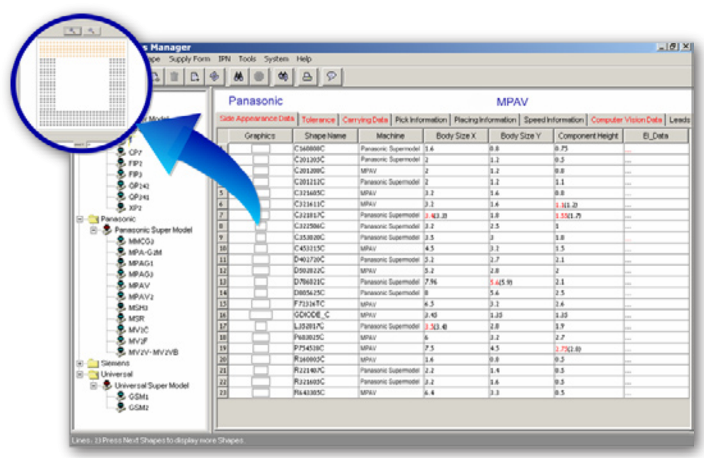
Assembly documentation

In addition, factories must perform full line-level programming that is:

- Simulation-based, for all machines on the line, even from different machine-vendors, so as to achieve optimum overall beat-rate.
- Able to manage and deliver optimized parts data from a central source (factory level), in synchronization with optimized assembly programs.
- Capable of creating groups of products that share a single feeder setup on a line, to drastically reduce line down time due to unnecessary feeder changes.



Efficient centralized shapes-management from one central source



Machine shapes manager

Manufacturing execution systems
Work here encompasses process control, production monitoring and materials tracking and traceability.

Process control - Line-level control of the manufacturing process including:

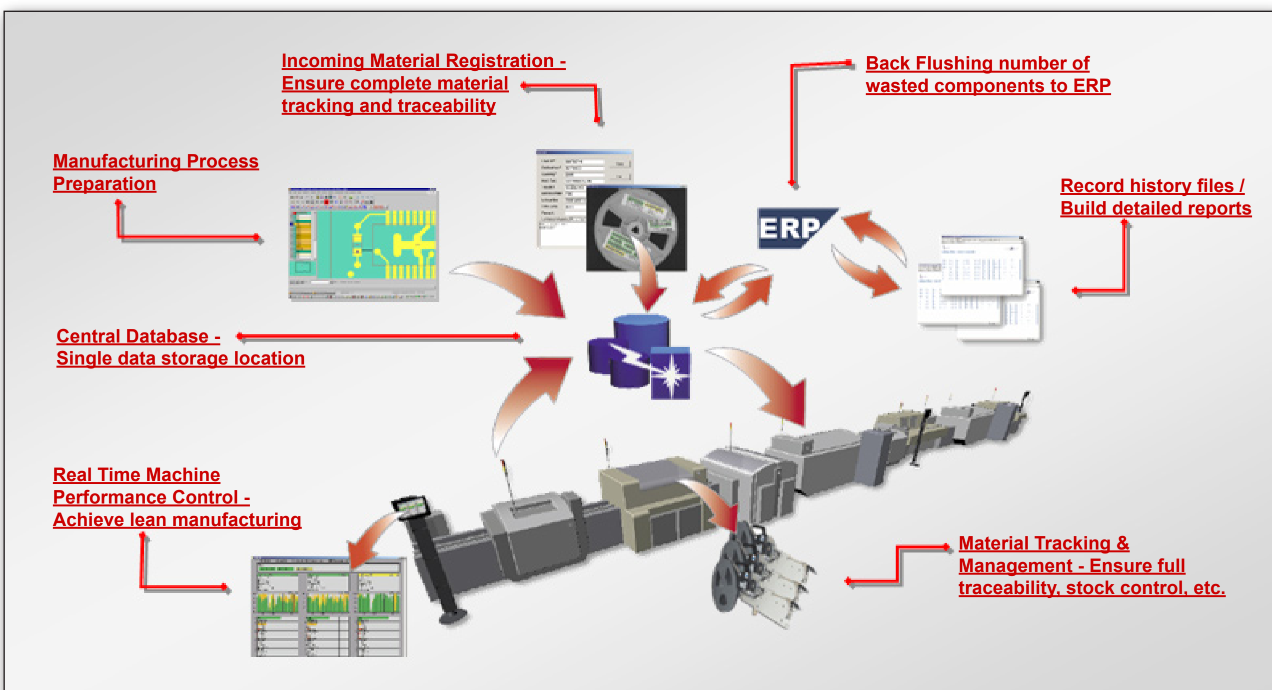
- Closed loop control on program loading, synchronized with the machine set-up and verification of PCBs loaded onto the line.
- Continuous closed-loop verification of line set-up, feeder positions and loaded components, during machine cycles.

Production Monitoring comprises:

- Tracking and verification of every component placement, to verify correct assembly and create a placement-level build-record for the PCB assembly.
- Recording of every miss-pick, nozzle skip,…, to identify reasons for performance deterioration.
- Tracking of machine status (including: “In Production”, “Waiting for Board”, “Machine Down”), and generation of reports on productivity and options to improve.
- Tracking overall line performance with reporting on performance variation between actual and planned. Identification of bottlenecks and reasons for low performance.
- Scheduling of feeder maintenance, based on actual work done (number of placements since last maintenance).
- Advance-scheduling of parts replenishment on the line, for minimum down-time.
- Feedback to the programming, scheduling and kitting functions of actual feeder/ component combinations on the factory floor, for efficient use in up-coming production orders.

Materials Tracking and Traceability comprises:

- Factory-floor management of component inventory, feeders, fixtures, materials
- Integration with ERP inventory records
- Back-flushing of actual materials consumption, per production order
- Management of “availability for execution” for every component, machine, fixture, material, feeder.
- Tracking the build of every PCB assembly (Recording the following information for every reference-designator placement on every PCB: reel number, manufacturer’s lot number, machine, nozzle used, feeder used, feeder position, date & time, operator).
- Generation of full build-record history file for every PCB assembly, by serial number.



Low Machine Performance Indicators

About Valor

Valor Computerized Systems is the leader in integrated software solutions throughout the design-through-manufacturing electronics supply chain. The company is a public company listed on the Prime Standard of the Frankfurt Stock Exchange.

ODB++

The company's powerful software tools are based on ODB++, the most intelligent CAD/CAM data transfer format available today, capturing all CAD/EDA, assembly and PCB fabrication knowledge in one single, unified database. Originally developed by Valor for use in its own solutions, ODB++ has already become widely accepted as the de facto industry standard, providing unprecedented power to PCB design, fabrication and assembly, with the flexibility to expand as required. In parallel, ODB++ is providing most of the technological basis for the new IPC2581 standard for data transfer in the PCB fabrication and assembly industry.

Other Valor solutions include:

Enterprise 3000 DFM system for first-time, zero-defect manufacturing.

vPlan a comprehensive CAD-to-manufacturing solution based on one intelligent database covering NPI, assembly preparation and optimization, test and factory floor documentation.

vManage for real-time assembly execution, material management and exact traceability down to the component level.

Valor Parts Library (VPL) - The unique on-line data service covering over 35 million accurate component geometries.

All are utilized by designers and engineers globally to deliver enhanced productivity, higher yields, shorter cycle times and increased product quality.

More information about the company can be found at www.valor.com.

About the Author:

Dr. Henry Jurgens is responsible for all product management activities for manufacturing solutions. Before joining Valor, Dr. Jurgens led Celestica's Corporate Engineering Systems organization, responsible for all information systems that aided Celestica's engineering community in the introduction of new products into manufacturing. He received both a B.A.Sc in Engineering Science and a Ph.D. in Aerospace Engineering from the University of Toronto. Dr. Jurgens is also a licensed professional engineer.