SMT DATA PREPARATION, LOAD BALANCING, AND SCHEDULE PERFORMANCE

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Our factories today are picking up steam. As a result, companies are looking for ways to improve performance-to-schedule. The rate of on-time delivery coupled with measurement of actual unit cost compared to planned unit cost, are critical Key Performance Indicators (KPI) for the success and profitability of the manufacturing operation. This paper addresses several critical factors in achieving on time delivery and unit cost targets. It all starts with better planning.

**BETTER PLANNING FOR BETTER PERFORMANCE**

SMT factories face a long list of obstacles for efficient and optimized production planning. The greater the number and different platforms of SMT lines in production, together with an ever increasing number of different products and product variants, the more critical and difficult it is to create a production plan that can balance the load between lines and optimize the adherence to schedule. There are four steps to achieve a successful production plan: 1) product data optimized for manufacturing, 2) preparation flow for development of machine programs and documents, streamlined for speed and accuracy, 3) intelligent production planning based on a variety of product grouping strategies, and 4) automated distribution of production work orders (can be thousands) across all of the lines in the factory. We will look at each of these four steps in more detail.

1. **THE CRUCIAL FIRST STEP IS AN OPTIMIZED PRODUCT MODEL**

There is a critical need for speed and accuracy in data preparation for SMT electronics manufacturing. More and more factories are pressed by competition to shift to a build-to-order strategy to achieve maximum shop floor flexibility and to keep inventories as lean as possible. We see smaller and smaller lot sizes also for the same reason. A slow, engineering-labor intensive preparation flow can have a domino effect that slows everything else down. The data preparation process must quickly create an accurate manufacturing optimized data model of each product. The product data model (PDM) must be neutralized, centralized (for parallel use by all manufacturing and test departments), and enriched for the needs of manufacturing.
Data preparation starts by transforming the PCB design data and bill of materials (BOM) without loss of fidelity to design intent, into the PDM. Native EDA data translators and BOM parsers can easily achieve this. The value added by best-in-class preparation tools today is the immediate validation of the PDM as suitable for the expected assembly and test operations. Before wasting any time on creating perfect process recipes, documents and finely tuned production plans, the PDM must be analyzed for Design for Manufacturability (DfM) and any critical issues found must be resolved in the design, or mitigated in some way by the process team. It is also crucial to know the trade-offs between the use of intelligent data and non-intelligent data in the exchange between design and manufacturing.

INTELLIGENT VS. NON-INTELLIGENT DATA

There are two types of design and manufacturing data: intelligent and non-intelligent. Non-intelligent data are typically in a vector format known as Gerber. For a manufacturer to make sense of Gerber data, it must be “reverse engineered” to reconstruct what the complete PCB looks like. Gerber data, for example, contains no information about the physical component, component pins, component definitions, or the relationship between circuit features, like a pad and the component associated with it. Likewise there is no definition of the net list. A PCB assembly shop must find a way to rebuild all this information and transform Gerber back into something like CAD data. This ability is a fundamental requirement for data preparation tools because some OEM companies or the owners of a PCB design will only send out Gerber data.

Intelligent data coming from the EDA system contains objects such as components, pads, traces, and net names. Open Database, or ODB++, was developed by Valor Computerized Systems (acquired by Mentor Graphics in 2010) as an open database to address the need for an intelligent data set that could be assembled from PCB design data, manufacturing process data, and design rules, then provide the vehicle for DfM analysis. Eventually, PCB design companies, fabricators and contract manufacturers found ODB++ allowed for an easy interchange of data between them, so ODB++ has become an industry standard for data exchange. With ODB++ the manufacturing engineer can proceed with data preparation without reverse engineering, just as if the designer had provided a native CAD format to the manufacturer. ODB++ contains all the specific information (intelligence) required by manufacturing such as the refdes, part number, CAD package, number of pins, XY location, length, width, height, rotation and pin pitch. These data are critical to the manufacturing process and simply not available without manual intervention when using non-intelligent data.

Figure 2: With the intelligent data in ODB++, a full set of data is available, including Refdes, Part Number, CAD Package, Number of Pins, XY location, Length and Width, Height, Rotation and Pin Pitch, Pin Name and Netname are all available, and can be interactively displayed as you click on the features.
THE IMPORTANT ROLE OF DFM IN DATA PREPARATION

Much has been written about DfM and its high value to the SMT factory, both for the bare board and the printed circuit assembly. Both have their own unique set of issues and the omission of either one can be devastating to the factory. Let’s review only a few basic examples from the assembly side of the house as these have a more direct impact on production planning, then move on quickly. The most important thing about DfM is that is must be incorporated EARLY in the process, even at the point of schematic capture during the design phase. An early look at components required by the schematic can have large impact on the outcome of both design and assembly.

Using technology illustrated in Fig 3, a component engineer, or even the buyer, can take the parts list from engineering and quickly determine if there is geometric equivalence with components chosen from the company approved vendor list (AVL). This is a true value-added service that not only helps engineering in their component search, but is also extremely useful in cleaning up the entire AVL. Often physical package equivalencies are taken for granted only to be proved false downstream during production when the stakes are much higher. Geometric equivalence is crucial for true overall interchangeability, but for a given project it is equally important that the correct package intended by the engineering design is used. Here again technology is available to ensure there will be equivalent solder joint performance intended by the designer regardless of which AVL component is selected in the BOM.

Subtle differences can throw us off and lead to disaster because we may not pay them any heed. The precision of the fit between the component lead contact-area (the portion of the surface mount lead that makes contact with the corresponding pad on the PCB) is crucial to the quality and long term reliability of the product. The geometric relation between the pin contact-area of the component in the BOM/AVL and the pad used in the PCB design is a critical factor in the ultimate solder joint reliability. A solder joint formed with too little volume of solder in the heel or the toe (depending on the package) will be less reliable, and put the whole assembly at risk for poor yield or field failures due to weak solder joints than break the circuit during common stress fatigue.

Figure 3: Software automatically compares the dimensional attributes of pin pitch, pin length, pin contact area, and body length-width-height of the AVL parts in the BOM. The analysis shows exactly where package equivalence is true or false according to your acceptable tolerance.
Engineering or component specialists should validate the correct package-to-pad selection for every design. This can be done as soon as the PCB designers have completed the component placement phase of the CAD flow. In parallel with the CAD flow, smart software can simulate actual SMT placement by merging the CAD layout data as is with the BOM and AVL data already chosen. The actual component shapes and pin contact areas from the manufacturer’s part number in the AVL are layered automatically over the CAD design onto the intended pads. Any deviation from set numerical rules for pin-to-pad analysis are instantly found and highlighted. At this point, purchasing can participate in the trade-offs between correcting the AVL to parts that meet the design requirements or engineering changing the pads in the designed footprint. Either way is major cost avoidance because a form-fit mismatch will not be sent to the production floor. Figure 5 shows a typical example of a slight mismatch that will create massive problems if not corrected before production. Many times part height can also be a critical issue for process considerations for reparability, testability or tolerance conflicts in box build assemblies, and therefore must be included in building up the perfect AVL.

There are many examples of DFM for assembly, based on the overlay of an accurate graphical component layer constructed from the BOM, AVL and Valor
Parts Library (VPL). The VPL is a massive library which maps millions of part numbers to their package body. The package data is dimensionally accurate to the vendor data sheet. The data preparation solution creates a link between the parts listed in the BOM and the VPL, so that highly accurate shapes can be used for DFM, machine library generation and clear detailed assembly drawings. The use of the data source is part of the unique ability of Mentor Graphics tools to streamline this entire process. Figure 6 illustrates some common everyday DFM examples.

SMT manufacturing is a BOM driven process where the PCB is considered to be just another component within a hierarchical or multilevel BOM. Also higher levels of assembly such as box build or system assembly must also be supported where the PCB assembly is itself linked into the higher level assemblies. Once the CAD and BOM data are merged, and the resulting product data model is neutralized, validated, and optimized, it must contain all essential engineering information for development of SMT programs, stencil tooling for printing of solder paste, development of test and inspection programs, and all production documents such as work instructions, inspection instructions, and setup guides.

The product data model (PDM) is then ready to be used in a production planning process.

2. STREAMLINED PROCESS PREPARATION

Now that we have a qualified product model, the process preparation flow can be engaged. In this context the “process” is the collection of all engineering data sets, recipes, NC programs, test and inspection programs, and electronic documents. Let’s call it the Manufacturing Process Definition or MPD. The portion of the MPD that is most co-dependent on the development of the production plan is SMT programming, so that is where we will focus.

Mentor Graphics provides a best-in-class SMT programming engine. This engine is unique in the industry because it is completely machine-platform independent and because it has the ability to create machine library data, on-the-fly, it bases programming and optimization models on actual machine simulation, and makes use of valuable time-saving aids such as offline Virtual Sticky Tape. The heart of this programming engine are the detailed individual machine configuration files, line configuration files and a detailed matrix of rules by which any missing parts data from any machine library can be constructed instantly based on the part
shapes connected to each SMT part number in BOM. The project data and programming session data are maintained in a database that is linked to a BOM revision. Therefore, whenever an engineering change notice (ECN) requires a change to a part number, etc., the program and document files associated with that BOM change get updated. This keeps everything current, and in sync. All of these advanced features are necessary for factory-wide production planning because individual machine programs can be created fast enough to support last minute changes. For example, when the need arises to relocate a job from one line to another line or when it becomes necessary to build a new product grouping based on a change to the run-rate of one the products. A new grouping means new programs. Manufacturing in electronics assembly is always dynamic. It is critical that programming tools use automation and smart libraries to support the fast pace of change by minimizing the chaos, and preventing errors from being tossed into the fray.

SHAPE DATA ORIENTATION AND VALIDATION

A frequent cause of production delays is shape data and orientation validation. Shape data must be created to ensure the machine ‘recognizes’ the component and knows which parameters to use when picking and placing that specific component. Shape data validation requires an SMT machine shape-data library managed within the software so that shape data can be visually overlaid onto the design data pad stacks. This graphical overlay of the “as built” program data unto the design data of the PCB is what we call “Virtual Sticky Tape”. This contributes to smooth planning because it does not require line time, like actual sticky tape, and it finds rotation or position errors BEFORE production begins.

The SMT programs and the related shape data (i.e. machine library data) used by the SMT equipment is created in the software work flow. The process engineering software models the actual kinematics of the machines. This is key to the success of optimized recipe generation. These kinematic models allow the software to run complex algorithms to ensure that appropriate feeder capacity, placement capabilities, and available nozzles are considered. When it comes to managing large groups or product families, the programming dependency on accurate feeder capacities for each machine is fundamental. The programming logic must know what types of feeders are allowed on each machine and calculate feeder capacity accurately regardless of the mix of feeder widths needed for the part. Figure 8 illustrates how Mentor Graphics software accomplishes this.
3. INTELLIGENT PRODUCTION PLANNING AND GROUPING

PRODUCTION PLANNING SCENARIO “A”

In this scenario there is high volume and low mix. There may be many different products, but only a few are actually in production at any given time. In this scenario, change-overs on the line from one product to another, or from one product family to another, are less frequent. Therefore, products are often grouped into families well ahead of production and assigned to a specified production line. In this case, the programs are also generated in advance. The programs are verified offline with a Virtual Sticky Tape simulation, and the test and inspection programs are generated, and all corresponding assembly documentation are created. This entire process preparation is set to a work flow, using centralized data and many automated procedures, and all is right with the world, especially if there is enough feeder capacity for one static setup for the group.

There are two main benefits to product grouping with a static setup. The first is the reduction of wasted time in performing setup changes. The second is that the sequence of production in the group is completely open. The order in which you run the products makes no difference. Depending on machine capacity, component counts and the product run rates, how do you even know if a static feeder setup will work for the group? What about running the group on a different line that may have more feeder or less capacity? What about defining a group that WILL fit within the feeder capacity for the line you want to run on? In most cases
running production with groupings that use one static setup is ideal, even if only to give the scheduler flexibility so all he has to consider is what materials are needed and what product deliveries are most important. Without a setup optimization tool that is easy to use, machine driven and very fast, it can take more time to answer the questions that it does to run the product!

THE SYMBIOTIC ROLE OF PROCESS PREPARATION AND PRODUCTION PLANNING

What is meant by machine driven? This is where the symbiotic relationship between machine programming and production scheduling comes into play. A machine driven schedule means that decisions for grouping and line assignments are based on the actual individual machine constraints including placement rate (% de-rated by user), feeder capacities, and feeder availabilities, for each machine in every line that you want to manage. These are the same machine parameters used by the SMT programming engine, so this individual machine configuration data can be passed to the production planning tool. The symbiotic relationship continues. Once the planner has created the optimum plan which defines each group for production and

Figure 9: The Product Sequence charts show the production plan for a given line, show each group assigned to the line and each product/work order in each group. There is a color coded time line at the bottom for a quick hour by hour look at change over time, run time per product. It can also be configured to hide or display “non-working time” based on a calendar input for holidays, scheduled maintenance, etc.
assigns the groups to particular lines, these groupings and assignments are passed to the SMT programming engine for final program output.

PRODUCTION PLANNING SCENARIO “B”
Manufacturing scenario “B” is more complex. This scenario is low to medium volume with high mix or even ultra-high mix. This is where human error is almost unavoidable if you are using conventional or typical planning methods. More and more plants are shifting to low to medium volume with high mix or ultra-high mix as competition drives manufacturers to be more flexible. It is also becoming more common for contract manufacturing companies to shift their strategies to “build to order” to reduce inventories and gain more flexibility. Also, product lifespans are getting shorter and there are more and more product variants and customization requirements in the business today. All of this means smaller lot sizes, higher quantity of production lots, and more line setup changes. In scenario “B”, setup optimization and machine-based production planning are a must to achieve high performance of on time deliver at or below cost.

You know you need factory-wide setup optimization when:

- A considerable proportion of total production time is spent on planning and changing the feeder setups
- Planning the feeder setups is slow, difficult, or even impossible with your current tools
- Knowing how to get the best use out of dual track feeders escapes you
- Production times, material consumption, and feeder setups need to be clearly reported and visualized
- You need to optimize the usage of offline carriages so that as few as possible are needed and the total number of carriage changes is minimized
- You need to find an alternative setup strategy that does not require using offline carriages
- Where work-in-progress (WIP) inventory accumulates on the shop floor
- Your capacity is constantly changing with newer, faster machines, or also with fewer machines.
- Work scheduling and sequencing are not under control

Control means you can easily schedule and sequence your jobs based on machine timing calculations, actual feeder capacity and availability, material availability, non-working time and shift loading. When the planning process is under control you can easily add any number of new jobs to the schedule at any time, and make adjustments to delivery priorities. Planning in control means you can also easily visualize the schedule and the job sequence. Manufacturing scenario “B” is a real challenge in this regard.

The planning flow in scenario “B” starts with creating or importing the work orders (WO). These contain the model number, run quantity, and delivery targets. Since the software knows the current machine capacities and preferences, any reserved static setups presently onboard the machines, all the common parts between the work orders, feeder availability (including offline feeder trollies and dual track feeders), the set-up optimization program can combine thousands of product models into “best fit” groups very quickly. The speed is achieved due to the fact that the heavy lifting of machine programming is done separately with other software. When these groups and assignments are handed off to Mentor Graphics SMT programming engine, the finished MPDs, run ready for right-first-time production, can be ready to go very quickly. The process is fast enough to handle a high frequency of change without slowing down the factory.
STATIC FEEDER SETUP VS DYNAMIC

In many cases the full static feeder setup strategy will not work, simply because of feeder limitations. In these cases the software will help you quickly identify the highest running parts common to the products in the group, and allow you to create a smaller reserved static setup. In this way some product changes may require a smaller number of feeder changes. The point is the planning tool must help define the best use of a reserved static setup. You can visualize the impact and trade off between static settings and dynamic settings very easily.

Since a static set up is mostly a feeder capacity issue, a large grouping of many products may not all fit within the feeder capacity limitation on the machines. So the trade off is between using smaller groups that do not over-reach the feeder capacity, or reserving a small number of feeder slots as for a partial static setup of the highest running common parts within the large family being considered. Then the software creates the largest groups that can “live” within the remaining feeder capacity. Some small amount of change overs may occur between smaller groups.

Exchanging dual track feeder reels in multi-track feeders is a time-consuming operation, therefore unnecessary changes should always be avoided. Best-in-class planning software must help the user to find the components pairs that are used in a largest number of products and can be placed in multi-track feeders.

Other “what if” considerations can also be very useful. Consider how valuable it would be to know if you can cut back from three shifts to two shifts, or relocate capital equipment from one factory to another factory, or bring in new capital equipment, or add a temporary weekend shift for a period of time, and instantly see how these “possible” changes would impact your schedule performance!

Figure 10: The display shows the overall time needed per line and number of groups assigned to each line.
4. MULTILINE LOAD BALANCING

Setup optimization reaches a new level of benefit when it can automatically define the product groups and distribute the WOs across multiple lines in such a way to achieve a best fit and balance the load across the factory. If a balanced load is not your top priority, you can change the settings to emphasize run rate, capacity usage, or quantity of groups.

One of the challenges to creating a multi-line grouped plan has always been the fact that most factories use SMT equipment from different vendors. This requires a planning tool that is truly vendor independent. The other challenge in a whole factory solution like multiline grouping, is the constraints of available inventory. It does not do any good to create a planning masterpiece if the inventory cannot support it.

Mentor Graphics has a unique solution for this complex problem of high mix planning, including multiline load balancing and production plan setup optimization. The product is the Line Executive, or LX. This software works in conjunction with our SMT data preparation solutions for platform-independent machine programming and test engineering. LX can also run stand alone. In multi-line mode, you set your preferences for each line to be considered for WO distribution based on settings to prioritize workload, group count, run time, or capacity usage. Then Multiline mode will generate the groups and distribute work orders across the selected lines based on station configuration constraints and preference chosen.

When the multiline grouping, line assignment, and sequencing is done, we can quickly see if there are any material shortages. This analysis is based on an import from your material control system or ERP system. Once complete, the resulting production plan can be reviewed on a line-by-line basis. If your ERP system is incapable of delivering an accurate inventory count (stock room PLUS extra parts on reels already sent to the line, but will not be needed to compete their assigned production run), you may want to consider a materials management solution that accurate tracks the quantity used on every reel, along with MSD status.

![Figure 11 – Line Executive reports any material shortages and the impact those shortages may have on the production plan.](image)
SUMMARY

This paper has clearly shown how data preparation works together with factory-wide setup optimization to achieve the best possible production plan, even in the most difficult circumstances. The best production plan will balance the load between lines and optimize the schedule performance, and only takes minutes to create. We looked at four steps to achieve a successful production plan: 1) product data optimized for manufacturing, 2) preparation flow for development of machine programs and documents which is streamlined for speed and accuracy, 3) intelligent production planning based on a variety of product grouping strategies, and 4) automated distribution of production work orders (can be thousands) across all of the lines in the factory.

We also looked at several of the benefits to best-in-class data preparation and planning. There are pitfalls to be avoided and tangible improvements can be achieved. Here are few of the many painful problems that can be avoided:

- Accumulation of work in process (i.e. Inventory) that follows constant schedule changes
- Time spent on changeovers wastes a significant proportion of production time
- General chaos where productivity and quality suffer, resulting is missed deliveries and highcost

Some of the tangible improvements to be realized include:

- Reduction in lost time due to setup changes achieved by (a) intelligent product grouping, and (b) smaller changes using partial static setups
- Increased production flexibility because grouped products can be assembled in any order
- Improved quality because with fewer possibilities for human error
- Improved asset utilization and increased manufacturing capacity at a lower unit cost