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Applying Automation to the NPI Process

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Abstract
With the increase in outsourcing activity throughout the electronics industry, OEM's are turning to Electronic Manufacturing Services (EMS) to provide quality quick turn prototypes and fast New Product Introduction (NPI). The differentiator between success and failure in the EMS marketplace is the data and the automation that can be done to streamline data entry and eliminate duplicate data sources and data entry errors. This difference is usually in the data; whether OEM or EMS the requirement for accurate and complete data has become the standard. Data and Process Transparency can help transform Front-end engineering NPI from an emphasis on quick-turn prototyping into a gateway to volume production, but there will need to be a change in perception with regards to how data and process information are treated and handled.

Data Transparency

Clearly understanding who owns the data – the data source, data management (which may not be performed by the owner), consistency of data, a good data interface and defined data granularity are all a must to guarantee a smooth transfer.

Who owns the data is usually straightforward; however, any group that may or may not have an interest in data integrity, accessibility or even security could perform management of the data. Information integrity will require ontology (principle of creation) and taxonomies (systems of classification) that clearly support standardized rule sets, shared / common databases and increased data entry speed. This in turn will drive simplification and automation. Once consistency in the method of data handling is achieved, data interfaces can be created. These interfaces should look and behave the same way regardless of site or user, whether internal or external. Finally, agreed upon data granularity is a must. (See Figure 1)

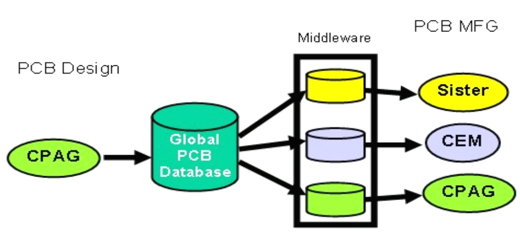

Figure 1 - Data Transparency

The OEM Perspective

As OEM's, we are now faced with several challenges. Rapid prototyping, Design for Manufacturability (DFM), process and cost modeling for best fit manufacturing site (OEM or EMS) and quick ramp to production are all factors; complicating the situation is that the various groups may not be using systems that can communicate with each other.

In the case of a typical OEM with multiple internal sites supporting different business units, one can and does build the prototypes at multiple sites. Since the shift to partial outsourcing at the Rockwell Automation - Mequon facility, the focus has been to produce prototypes and pilots and then shift the work to another site for full production and quick ramp for market introduction. This makes the NPI work all the more important because of the differences in facilities and machines. Seamless integration of data into these different information systems is difficult at best given that most of the systems in place grew up with the businesses that they support.

In order to solve this problem, a proprietary file format called an "ETF" (electronic transfer file) was created. The file format was shared across division lines and is the basis for data sharing. However, as with anything, revisions were inevitable. Controlling version skew (different facilities/groups having different versions installed) and implementing changes in the file structure can sometime become contentious, due to requirements that one facility might have but others may not. These issues have at times the appearance of creating make-work at facilities that did not require these changes. Maintenance of this type is a drag on resources that can be better used elsewhere, especially given that so much work has been done in this area by standardizing bodies and CAM software providers. After the last revision change to the ETF specification, it was decided that an off-the-shelf software package that would produce machine programs and line documentation was required. We now use the native CAD files to produce the required files for production; we still use our EFT formatter to support work that was done in the past with the ETF file.

Automating the Data Stream

As a provider of quick turn prototype/pilots it becomes increasingly important to provide our partners with accurate data sets. This meant that the data had to be controlled and come from the same place. We have invested time and effort into making certain that the data is clean and ready for use.

Native CAD files are loaded to the CBT (Circuit Board Technology) web site and vaulted into an internal OEM PDM system. The CAD layout groups load these files into these systems. Once loaded into the site the job is placed into an auto-created directory folder made specifically for that unique assembly. Emails are sent out to notify the appropriate people that the files are available to work on and in what directory this information resides. Technicians or Engineers then assign work-cells (machines). Work-cell assignment is a blend of rules, based on both the part and engineering knowledge and is done through a web front end. Component parts already in the database have been assigned and the work-cell defaults to that assignment unless there is intervention from a technician or engineer. If there is intervention the technician or engineer can either chose to assign a part as a one-time occurrence to a different work-cell for that particular assembly or do a wholesale change. An example of a wholesale change would be a change in equipment, say one fine pitch placer for a different fine pitch placer. This assignment is done inside the CBT database.

Once work-cell assignment is done a routing is auto generated (Figure 2) based on work-cell assignments. Intervention is required only if a process sequence is out of order (i.e. test before de-panel). If there is nothing out of the ordinary, there would be nothing more to add than the routing notes (i.e. .0125" lead clearance acceptable).

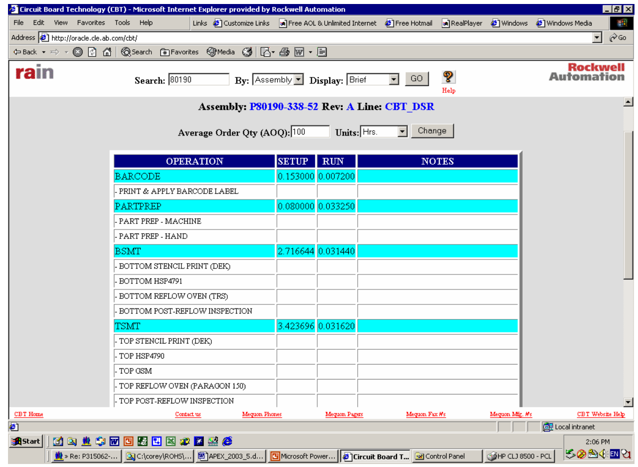

Figure 2 - Routing Information

Part Prep

Part prep can significantly impact time and ability to ramp quickly. During work-cell assignment, some parts will be identified as manual placement. These parts are flagged and when the part prep application is started they appear for disposition; some parts have nothing done to them and are placed as is, while others will require parts prep. Significant effort was spent developing this application. (See Figure 3)

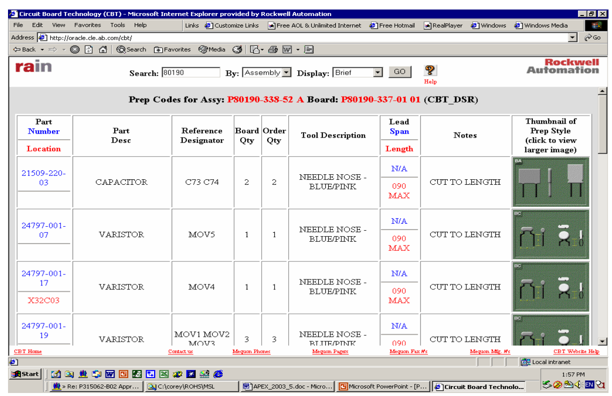

Figure 3 - Parts Prep Instructions

There were several reasons for this effort. First, we needed to reduce our internal time to create this documentation; re-creating this documentation at out sister divisions or EMS partners was taking as much as 3 days. Another important point is that these documents can be printed directly from the web interface and are known to be good and revision controlled. Finally, communicating specific parts preparation requirements eliminated finding the same parts defects every time a new production site was used.

Machine Programs and Line Documentation

The Manufacturing Execution System (MES) software sits as a layer on top of the CBT database described above. A standard off the shelf MES program and documentation tool is opened after work-cell assignment is completed and typically in less than 10 minutes documentation and machines programs are produced. As was mentioned earlier, an email is sent out with a notification and directory location of the new files that were received into the CBT database. The technician or engineer will cut the directory information from the email that was received and open the MES. Once opened they will paste the directory information into the browse portion of the "Open File" command in the MES and open the MES. Once that is done a script is started that automatically steps through the program and documentation creation. The scripting language that was provided by the MES is not fully functional so there are two places where the user is required to provide key clicks to continue the script. We expect that this will be fully automated once the MES vendor provides us a complete scripting package with full functionality. This system automation has allowed production of over 300 prototype/pilot in an average turn around time of 3.62 days

Data would included the following: Assembly Photo, Bom, Centroid Data, Firmware, Machine Counts, Packaging details, Parts Prep, Routing, Work-cell information, and Build Reports.

One item in the above list that is an end result of the data but which cannot be derived from it is the build report. The build report document serves as the vehicle that describes the process and problems that occurred in a particular assembly. This is our way of documenting the process and changes to the process that are required to make the boards as robust as possible. Each step of the build process is listed. Each process step is broken down further into Design Concern, Process Concern, Board and Component Concern. Process information, such as preheat temperatures, conveyor speed, pot setting, etc. is noted along the way. Our next step is to develop this documentation into processes that can be shown on line through the current web page. This will include machine metrics, process profiles both reflow and wave, current SPC, etc. It is our hope that if we manage the data and provide enough information about the process regardless who builds the product it will turn out correctly assuming manufacturing fit is maximized.

Another item that will affect an OEM's ability to transfer designs especially as they become more complex is Design for Manufacturability (DFM) analysis. Currently we use a spreadsheet / checklist that has rank values for each violation against our design guidelines. This does cause some differences in ranking because of the subjectivity of the evaluation rather than having a rules set that can be checked by computer such as a Design Rule Check like CAD programs run today.

Solid tools and tight cooperation between partners that leave no questions about a design's viability will be required for success. Very clear defined rule sets will be required if OEM's are going to be able to pass designs along to EMS and expect the same or better results with short ramps to production and first pass yields that met or exceed the originating organization. This will be discussed in more depth later in the EMS example.

With good data we can manufacture product wherever our best fit scenario models show. The web front-end allows instant access to all authorized personnel without the duplication required in the past for revision control. The challenge now is to integrate this into our business models and implement this same thinking into process transparency.

The EMS Perspective

As has been mentioned earlier in this paper, OEMs are requesting shorter NPI cycles so as to support faster time-to-market. In order to accomplish this without increasing headcount (and therefore cost), MSL has chosen to rely on automation to aid in the NPI process.

Although it may appear at first glance to be a trivial issue, the correct interchange of data between the OEM and the EMS can set the pace for the remainder of the NPI process. If the proper set of information, both product and process specific, is not transferred in a mutually understood format, then the efficiency of the NPI implementation will be compromised. (See Figure 4)

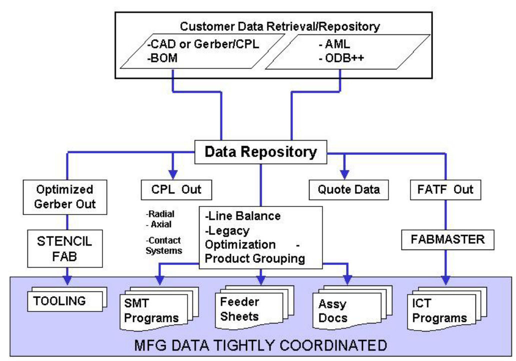

Figure 4 - Information Flow

The initial point of contact is typically a request for quotation from the customer. This is also the point at which the product-specific data set begins its growth. It is also at this point that the investment that the customer has made in their data becomes apparent.

A minimal data set, while acceptable, will not generate the most accurate quote. The greater the granularity of assembly information that can be provided, the closer the quote will come to the final production number. The quote model is very specific, looking at details of not only number of parts, but types of components, pitch, and packaging[1]. Advance identification of non-populated components can greatly change the way the board is processed in the facility, and therefore the amount of the quote. By automating the parsing of information supplied by the customer, the speed with which quotes can be processed and the accuracy of the results both improve.

DFM Engagement
In order to allow for this amount of data manipulation, there must be a great deal of trust in the accuracy of the assembly and board data. This can best be obtained by subjecting the board to the scrutiny of a Design for Manufacturability (DFM) analysis. However, a DFM performed in the traditional manner of an engineer visually surveying the design data is a very subjective inspection; what one engineer considers manufacturable another may not.

Again the solution lies in automating the method. By utilizing software that contains all of the DFM rules that have been developed by the EMS provider, a rapid, accurate, estimate of the manufacturability of the design can be obtained.

The DFM rule set comprises both equipment and process capability information. The rules should exactly follow the abilities of the actual assembly lines. In this era of growth by acquisition, EMS providers are often left with many different equipment platforms across their sites; the rule set for the provider as a whole should represent the lowest common denominator common to all sites. This will guarantee that the customer's product (as analyzed by the DFM) can be built at any of the facilities; those facilities with better than normal capabilities should be noted in the event that demanding challenges are presented.

The results of the DFM analysis fall into two categories, dependent on the severity with which the DFM guidelines are violated. (See Figure 5)

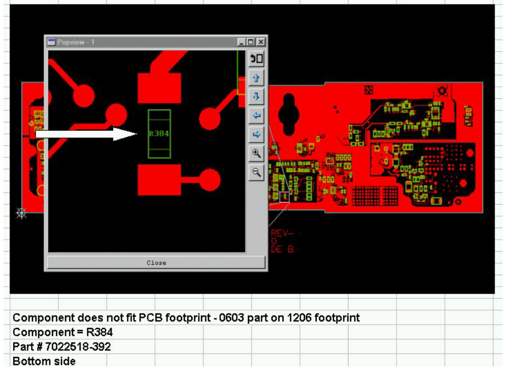

Figure 5 - Example of DFM Finding

Major violations are those that preclude effective assembly of the PCBA. These include issues such as component interference, incorrect footprints, missing board information, and incomplete solder patterns. These are issues that must be resolved with the customer prior to the build.

The minor violations are generally concerned with process tolerance considerations. Here are found questions regarding component spacings, process tolerances, and other details that will not preclude assembly, but may cause complications. These issues need not be communicated to the customer, but must be discussed with the customer and process engineers so that risk can be obviated.

The ideal model is one where the customer has communicated the issues that they observed during internal pilot builds, as per the Rockwell model. Transferal of this level of process knowledge from the OEM to the EMS increases the EMS' confidence that major issues will not have gone undiscovered during the pilot builds. As the two reach a closer partnership, the individual process requirements of the companies come closer into alignment, gradually reducing over time the number of issues found in DFM analyses. At the same time, the assembly information is provided early in the design cycle to allow for DFM inputs to be incorporated. The DFM analysis must be performed in an expeditious manner, so as to allow feedback to the customer early enough to effect the design.

However, there will always be minute differences between the assembly techniques, or in some instances there are aspects that affect the EMS in volume production (as NPI is generally a proving ground for later volume builds) that are not considered by every OEM, or need to be tailored to the particular EMS. The most common one of these is board panelization.

Pre-Build Processes
The data set transferred from the customer will typically contain a great deal of board related information beyond the basic layer pattern data– materials, layer stack-up, testing required, and final board finish. However, the final panel requirements are usually left to the EMS to decide in conjunction with the PCB fabricator, as these requirements will be strongly affected by the EMS' specific process and equipment related parameters.

Unfortunately, the generation of panel information has regularly been left solely to the PCB house. In doing so, the EMS has given up a level of control over detailed board parameters that will affect how well the PCB will run through the factory. Beyond specifying the "number up" and depanel requirements, panel details are not specified. There are two reasons given for this: the time and resources it takes to add panel drawings are not always found in an EMS, and fabrication specific requirements vary between PCB suppliers.

Again, automation and forethought hold the solution. As with the DFM rule set, the fabrication panelization requirements from the PCB houses with whom the EMS works can be combined to form a common data set. From this, it is possible to automate the placement of the board data into a standard fabrication panel, optimizing the board utilization for best-cost efficiency. At the same time, test coupons and fiducials may be added to satisfy both assembly and customer requirements. Automation eliminates the need for a board designer to spend several hours or days panelizing the board.

When the project has reached the stage where solder stencils need to be ordered, automation begins to show promise of significant timesavings. Whereas almost every stencil supplier can guarantee a 24-hour delivery, this does not mean that a stencil will appear on the doorstep one day after the order is placed.

The scenario typically proceeds as follows: an order is placed, and Gerber data supplied to the stencil manufacturer. The stencil house modifies the plots per an agreed-upon set of rules, and faxes/e-mails back a check print within one day. The Process Engineer spends one day verifying the correctness of the check print, and communicates acceptance. Then, one day later, the completed stencil arrives. Thus a one-day process stretches to three days.

The solution is to apply the optimization rules to the data *before* it is supplied to the stencil house. In this way, the cycle of check and approval is avoided. To take this one step further, sending cutter-ready data to the supplier will save additional time. Of course, this will require close, proven ties between EMS and vendor. (See Figure 6)

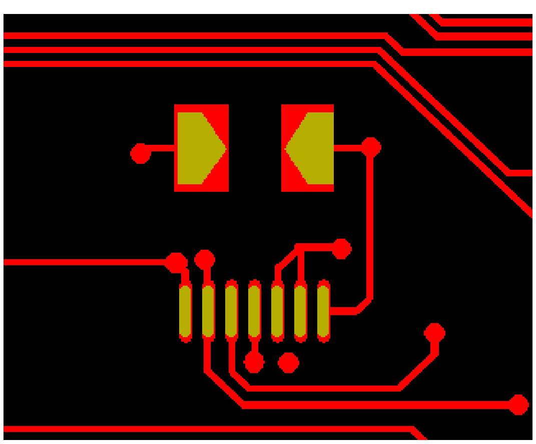
Figure 6 - Optimized Stencil Pattern

Generation of production machine programs is another area that benefits from automation. The general strategy employed with programming is that it is the purview of the process engineers, and as such happens offline to the remainder of the NPI effort. Relying on machine-vendor supplied tools, the process engineers must struggle with gathering the data required for shape and program generation (part shapes, board data, BOMs, etc.) in addition to the actual program production.

If we refer back to the central data set that was started at the initial contact with the customer, much of the information required for programming already exists, but has not been handled in a manner that allows for accessibility by the process engineer. Using an offline programming tool that links to the central data repository will allow the engineer to avoid having to repeat the data gathering stage.

One of the newer MES toolsets that are commercially available was chosen to implement to assist in the offline machine programming and documentation tasks. The advantages of such software packages are well understood, providing interfaces to the production line equipment, program optimization, and template-based documentation. For the scope of this paper, we will focus solely on how the data into and out of the MES package is integrated into the rest of the flow.

The programming effort can be looked upon as two concurrent efforts. First, there is the generation of the programs themselves, which must take into account not only the parts being placed but also the machines used to place them. Secondly, the placement machines must be taught to recognize the parts; this is what is referred to as shape creation.

There are several efforts underway to automate the shape creation process. These involve automatically pulling the appropriate information (outline, pin configurations, centroid, nozzle and lighting information, etc.) from pre-existing databases. These efforts are being driven by the major MES providers; once complete, they will automate one of the more tedious and time-consuming processes within the NPI cycle. However, these are not yet available.

Automation of the programming effort itself is more of an iterative process and is dependent upon the degree to which machine shapes exist for the parts to be placed during the NPI build. It begins with definition of the machine configurations within the MES program. Once the machines and lines have been defined, rules for assigning the parts to the machines can be determined. These rules can be based on part size pitch, package style, pin count, lead configuration, or many other parameters. The rules will be used to automatically assign the parts to be placed to the machine best suited to place them.

The iteration occurs when not all of the parts have shapes defined. The programming flow must be interrupted at this point while the process engineer steps through all of the parts that require shape definition. As the library of parts for a particular customer grows, the frequency of this occurrence diminishes. Once the shapes are defined, the programming effort can be completed. (See Figure 7)

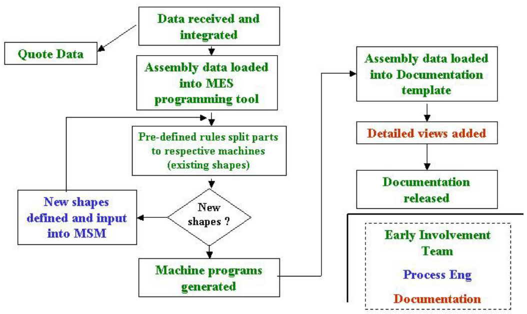

Figure 7 - Programming/Documentation Flow

Application of a more automated approach to programming has allowed MSL to lower its time for program generation from several hours to several minutes (exclusive of part shape creation).

The same level of automation can continue through to creation of work instructions and other documentation. Now that the MES package "knows" what parts are placed at which step it is a simple matter to use a pre-defined template of the assembly process to generate the entire set of work instructions and inspection templates. The documentation personnel then need to add some of the detailed mechanical assembly views not handled by the software to create the completed package

The impact of automation upon the documentation process is quite impressive. During initial evaluation, a test case was used that included over 2000 placements, including significant hand and post-reflow mechanical assembly. The time to produce the work instructions for the 19 process steps in the line was reduced to less than three hours, including the time to generate detailed mechanical views and hand-wiring diagrams.

The additional benefit to centralizing the programming process is that the programs fall under the same configuration control as the rest of the data set. This ensures that the correct version of the program is synchronized with the remainder of the build data.

During and Post Build

Once all of the preparatory work has been completed, the actual task of building the assemblies can begin. At this point, we have a comprehensive set of data that began back with the customer information, proceeded through DFM analysis, programming and documentation, and ending with line-support information. Since all of these reside within the same database coordination of the correct revision levels is assured.

Now that actual product is flowing down the production line, there are several metrics that need to be collected. The first is work-in-process (WIP) tracking. Without belaboring the obvious, it is impossible to control and schedule line activity without knowing the location and cycle time of product moving through the assembly process. The ability to produce accurate time studies of each step within the assembly line permits not only rapid identification of bottlenecks, but more refined input into the quote model, allowing for tighter cost controls.

We have chosen to deploy an in-house developed factory management system called FMS. This system permits not only tracking of where material is within the production line, but allows for collection of quality data. The designated inspection steps allow for inspector input of pass/fail information and identification of failure modes. There is an automatic interface between FMS and the in-circuit test (ICT) equipment that permits direct capture of test failures. Consequently, it is possible to obtain both yield and failure pareto information for products moving through the factory.

The data collected during the build is utilized in the generation of post-build summaries (PBS), a feedback mechanism to both the customer and the internal engineering community about what went right or wrong with the build. The PBS also provides another means by which we can make recommendations to the customer about changes to the product/process to improve yield and reduce cost, based on observations made during the construction.

As a final check, the PBS results are compared with the initial DFM analysis output to determine if the issues that were identified during the DFM analysis were actually observed during the build. Closure of this loop allows for refinement of the DFM process. Issues seen during the build that were not identified during the pre-build analysis will trigger an examination of the DFM rule set, in order to determine why the escape was allowed. Conversely, any issue noted during the analysis that did not adversely affect production will be examined to see if a lessening of its potential effect is warranted.

Bridging the OEM-EMS Space

As can be seen from the preceding sections, both partners have invested a great deal of effort in automated processing of NPI information. Up until now, we have treated the two approaches as separate entities; in this section, we will discuss the bridge between the two information approaches that fulfill the promise of job portability.

In an ideal world, the two systems would be completely compatible and information transfer would be seamless and instantaneous. However, an EMS needs the flexibility to deal with the data schemas of many different customers; consequently, the exact, customized set of interfaces needed for fully automated transfer of all of the Rockwell information cannot be readily implemented without sacrificing the ability to interact with other customers' data transfer formats.

That being said, our data transfer model does fulfill its original intent as an automated data stream. The OEM internal Circuit Board Technology website does provide a comprehensive, coherent, and controlled set of data for a particular job. Please remember that one of the greatest impediments to rapid NPI implementation at an EMS is incomplete and/or conflicting information received from the customer. Pulling the information from a data repository such as the CBT guarantees that all of the information will be available when needed.

With the level of automation applied, as described here, to the NPI process, there is even more information that can be pulled from the CBT structure. Although the EMS partner has their own preferred documentation structure (which is consistent across the customer base), the information included in the OEM process documents and parts preparation instructions are useable. The process for producing work instructions is begun by automatically populating a template with board information, but the next step is providing detailed views of specific part lead preparation, mechanical assemblies, and packaging related information. All of these areas are covered in the OEM information; the photos and detail drawings included in the website are easily transferred to the EMS documentation. Reusing the customer-supplied information not only reduces the time investment, but also ensures that the assembly will be produced in exactly the way the customer desired. As the template model reduced the overall time for creation of documentation, so retrieving and applying the customer details to replace the re-drawing of the same views will further reduce the NPI cycle.

Also included in the OEM transferred data are the machine programs for pick and place equipment. Thus the EMS partner has the capability of using this input in two ways, dependent upon schedule. First and fastest, we can take the supplied programs and translate them to our machine lineups. If the lot size is large, it is beneficial for both sides if the EMS partner imports the machine programs completely into the MES programs and re-balances them. This process takes slightly longer, but results in a set of programs that are better optimized to the actual line upon which the assembly will be built. Either method avoids the usual expenditure of 0.5-1.5 days that can be spent regenerating programs.

The payback for the OEM side's investment in organizing and controlling the project data in a unified and readily accessible manner is that the +EMS partner is able to access and use the information supplied without having to recreate it from scratch, shortening the time required to begin and complete the NPI build.

Conclusions

The rapidity of an NPI build is directly tied to the quality of the data received from the OEM, and the efficiency with which the EMS can process it. Given the globalization of the manufacturing effort, it is no longer possible for direct verbal contact between the designers and the assembly house to ensure that all aspects related to the build are transferred.

The OEM must have an effective, automated means of guaranteeing the completeness and accuracy of the data set provided to the EMS. On their part, the EMS must have efficient, automated processes in place to handle the data received from the customer. Time-to-market is also time-to-money; any delay in meeting an NPI schedule will adversely affect production implementation, and may impact resultant market share for the product.

The interface between the OEM and EMS must be configured in such a way that the flow of information transfers smoothly between the two. The links to transport data between the two must be robust enough to ensure that the necessary information (and correct revision) are communicated, while permitting the EMS the flexibility to interact with its other customers.

Without automated processes, the NPI cycle slows to that of manual data handling, with all of the delays, redundancies, inaccuracies, and lack of repeatability that are inherent in non-automated processes. In the EMS industry, great effort has been made to automate the assembly process to avoid these problems; the same needs to continue to be applied to information handling.

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2. Lee, D., "Automating the DFX Process: Leveraging Today's Technology Tools", Proceedings of APEX 2001.