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Breaking The Information Bottleneck in Printed Circuit Board Engineering Teams: The Promise of New Software Innovation

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Abstract
This paper addresses the challenges of pre-production engineering, why the engineering department is viewed as a bottleneck in many PCB companies, and how a dedicated software system breaks the information bottleneck and permits true collaborative engineering. There is now software technology that integrates and automates standard and customized engineering processes to streamline workflow and collaboration, improve quality, reduce errors, and reduce pre-production costs. With it, the productivity of an engineering department can increase dramatically, reducing time-to-production and increasing customer order fulfillment rates. The need for rules, an extensible data structure, and an open architecture in an intelligent, collaborative system is explained. The key characteristics of the features and functionality are outlined. The benefits of such a system are described and how value is added to the engineering function, the company, and customers.

Introduction

The printed circuit board (PCB) has played a vital role in the success of the electronics industry. Key trends such as miniaturization have been due in part to advances in PCB manufacturing. Paralleling advancements in component technology, PCBs have become denser, traces have become finer, drills have become smaller, the layer counts have increased, and specialized needs like controlled impedance, blind vias, and buried vias have become common.

The engineering department, which has coordinated these developments, ironically has not seen similar advances. As a result, the engineering department is viewed as a bottleneck in many PCB companies. Lack of integrated information makes engineering a board a highly manual and cumbersome process – inefficient, time and labor intensive, and often error prone.

The Limitations of Traditional Engineering Systems

The engineering department must deliver the production information to the shop floor while it is still working on a job, which is not an easy task when data is fragmented across multiple systems, needs to be consolidated, and even gathered from sheets of paper. In reality, production has already started while the job is still in engineering.

PCBs are still engineered as they were decades ago. As they became increasingly complex, so did the data. Along with computer-aided manufacturing (CAM), tooling, test, and enterprise resource planning (ERP) data, engineers are handling drawings, impedance modeling data, specifications, and engineering changes in different data formats. This has had the effect of turning the engineering department into a data processing center. The data output from engineering drives most of the critical processes in production, which has improvised its own data systems.

Traditional engineering uses paper-intensive, manual processes. Each job produces thick paper files from disparate applications, which are cumbersome to manage. The problem is compounded when a job is run in more than one plant. Paper-based revisions cannot easily be synchronized and it is a burden to file, archive, and retrieve them quickly and easily. In fact, reliance on paper has been one of the major obstacles to collaborative engineering.

Engineering decisions became increasingly subjective as they rely on an engineer's knowledge of processes and checklists. There was no one source of engineering information so individual engineers used different parameters and developed ad hoc practices that were usually from trial and error. The loss or absence of a key engineer had negative consequences in terms of resource utilization, customer satisfaction, and business opportunity. With knowledge walking out the door each day, few companies achieved a satisfactory and cohesive approach to systematizing the collection and use of engineering information.

Traditionally, the two big system players in engineering have been ERP and CAM. Considerable time and resources were spent on these two systems as they emerged and took their place in the engineering department. Critical engineering and production information resides in both of these systems, but there has always been a data chasm between them. In addition, engineers quickly found that data from one system could enhance processing in the other if they could communicate. Both CAM and ERP have failed to deliver a practical solution to support the overall engineering process, so engineers have been forced to develop internal solutions that are now a combination of software and paperwork.

Some CAM and ERP suppliers contend that they offer the capability to customize their systems, but the task is usually left in the hands of overburdened engineering and IT staff. As a result, few PCB companies have attempted to create a dedicated engineering system and even fewer have been successful. The ultimate challenge is trying to adapt existing systems that were not originally designed to handle these requirements. Meanwhile, suppliers are too busy keeping up with new challenges in their specific fields to seriously focus on a set of requirements that really call for a new approach.

These limitations can be summarized as follows:

- CAM and ERP systems are not designed to provide functionality for the overall engineering process.
- The engineering functions that do exist in ERP and CAM systems are inadequate, inflexible, and not positioned for future requirements.
- Critical data is scattered across multiple systems, which are often unintegrated.
- Internally developed solutions have proven costly to maintain, difficult to upgrade, and complicated to integrate with other systems.
- Engineering departments rely heavily on paperwork for key information, instructions, and procedure checks.

The Pitfalls of Customized Solutions

The engineering systems that are typically developed by PCB companies are neither integrated nor collaborative and have their own set of problems.

Lack of Integration

The purpose of customized, internal solutions has been to tackle both missing functionality in CAM and ERP and the inadequacies of existing ones. The most glaring example of this is the 'Stack-up/Lay-up and BOM Generator.' While all ERP systems have some mechanism to generate the stack-up and BOM, they have proven to be cumbersome and lack flexibility and adequate automation, particularly with today's high layer counts and sequential lamination requirements.

CAM solutions suffer the same limitations and lack the connection to material inventory where specific purchased parts are selected and checked for on-hand quantity and standard cost. Engineering is also looking to reserve on-hand material, particularly in quick-turn, or to generate a purchase requisition when required material is not in stock. Thus engineers are forced to keep all key information on paper because there is no logical place to store all of it.

These internally developed solutions exist alongside CAM and ERP and help the process by providing limited functionality. However, they add to the problem at the enterprise level because of lack of integration and high cost of maintenance in terms of people, time, and money.

The integration issue is highlighted again when you consider specialist tools. Impedance requirements have been around for years and are increasingly being incorporated into board designs. PCB manufacturers use one or more impedance modeling programs developed by specialized software companies or material suppliers and their use is now increasing.

Lack of Collaboration

Engineering has always been an inherently collaborative effort conducted in a 'multi-tasking' environment and requiring the ability to work closely with sales, CAM, and plant staff. Even as the engineer is reviewing the part requirements, quotation, customer specification and calculating the stack-up needs, a pre-CAM operation is taking place where CAM files are loaded for an initial view and assessment of the data. As inner layers are processed by CAM, numerical control (NC) tool files are generated for buried-via sub-assemblies, manufacturing process requirements are determined for the outer layers, and a traveler is generated for production planning and scheduling. Trying to achieve this using the traditional 'linear' traveler, which has a pre-defined sequence of steps, doesn't work efficiently in engineering. The traveler and 'engineering route' concept were inherited from ERP's production traveler, which were designed to sequence the manufacturing steps of a PCB.

Intelligent collaboration is already streamlining procurement processes, inventory control, sales and marketing functions, manufacturing planning and scheduling, transportation and logistics, and customer relationship management. The same collaborative technologies, if designed specifically for pre-production engineers and intelligently deployed, would deliver enormous value to engineers, PCB manufacturers, and their customers by streamlining workflow and ramping up productivity to reduce time-to-production and increase customer fulfillment rates.

The Need for a Dedicated Engineering System

These limitations and pitfalls point to one solution: engineers need a dedicated engineering system, which would act as an umbrella over the entire engineering process and provide a comprehensive, collaborative approach integrating engineering, shop floor, and business systems processes.

The dedicated engineering system would provide engineers with intelligent tools to lighten the workload and be open and flexible enough to accommodate a wide range of data sources. The system would also accommodate the concept of Product Data Management, i.e., having all the relevant information in one location in order to act upon it, make smarter decisions, learn from historical information, utilize shop-floor process statistics, and apply that knowledge to today's problems.

Rules: A Requirement for a Dedicated Engineering System

A dedicated engineering system requires a number of key elements to be successful. One element – Rules - has already been deployed, although in a limited capacity, in the more advanced systems available today.

How did the requirement for rules come about? Not so long ago, when almost everything was done by hand, travelers, drill tapes, revision tracking, artwork measurement, step and repeat, travelers, and route-cards were pre-printed and listed the process operations in their logical sequence. Pre-production engineers selected which operations were required and wrote down the sequence number next to it. This worked satisfactorily for the most part until new processes and process sequences were implemented in production.

The pre-printed travelers were, of course, templates that could be modified to suit a particular need. This was the initial model adapted by early ERP systems to create routes and travelers. The route library allowed users to define templates that could be copied to a part and modified if needed. Whether this worked depended largely upon implementation.

One approach is to create a 'master' route containing all or most of the operations required. Users may then delete the ones not required. This is easy and quick to implement, but requires a lot of editing at the part level and therefore is time-consuming and error prone. Another approach is to define specific route templates for a broad range of product types. This minimizes editing at the part level, but is longer to implement and requires maintenance and supporting documentation. Rules-based route generation finally provided a good solution.

A very simple logical statement as shown in Figure 1 can handle most of the decisions made during route generation as shown in Figure 2:

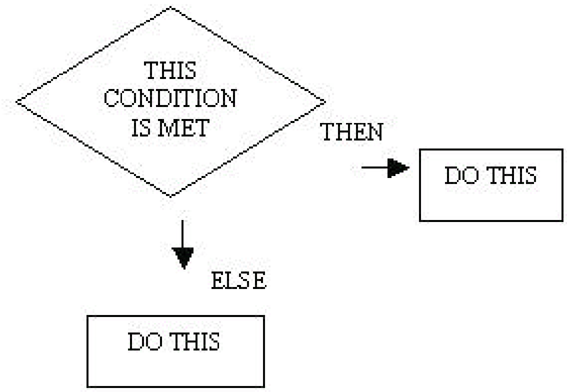

Figure 1 – Logic Statement

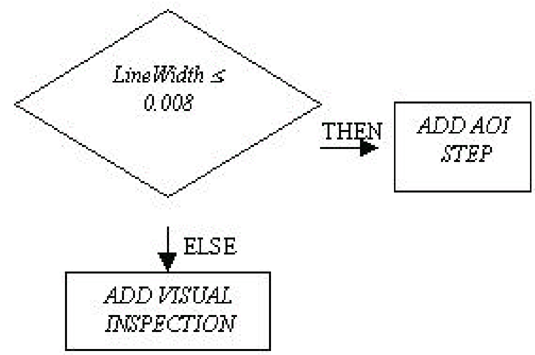

Figure 2 – Route Generation

Defining the rules for traveler and BOM generation is a process of interpreting the process flow of production and the details at each step. This will result in possibly hundreds of conditions, decisions and calculations, especially when you add in material, costing, capacity requirements planning (CRP), and statistical process control (SPC). Once formalized in the rules system, however, the rules application will quickly process the data and provide an accurate and consistent result. Companies have reaped dramatic benefits from rules-based applications, such as reducing direct engineering staff by 50% in some cases and ensuring that everyone gets accurate, consistent, and repeatable traveler data. A lot of knowledge is captured in the rules, which will allow companies to transfer their engineering knowledge from the minds of individual engineers into the system, decrease reliance on the chief engineer, and allow engineers to spend more time applying their skills on core issues instead of working on repetitive tasks.

If the scope of rules application is expanded to include importing and processing of CAM data, customer specifications, plant capabilities, quotations, stack-up generation, impedance modeling data, external files, and legacy systems, and if the rules system is flexible and powerful enough to create customized applications and user screens, and provide flow control through the engineering process, then the benefits could prove to be quite substantial.

Extensible Data Structure: A Requirement for a Dedicated Engineering System

To support such a system, another key element is a flexible, extensible data structure. Many existing systems have a structure where the number of information placeholders or fields is pre-defined. Often, there is no home for a data element that an engineer wishes to add and the system is not flexible enough to accommodate it. For example, ask yourself this: "Does my engineering system easily handle embedded passive components or fiber-optic lines?" Some systems offer user-defined fields, i.e., placeholders in traditional tables set aside for such occurrences, but these are always a limited number. Expanding them requires the supplier to modify the database, which generally means the user has to wait for the next product release if, in fact, the enhancement is accepted. This problem is inherent in any system using a traditional relational-table database.

One solution that exists is a 'tree-structure' as shown in Figure 3.

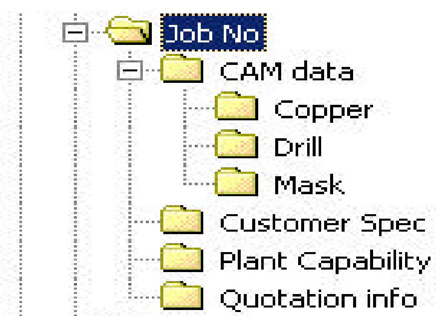

Figure 3 – Tree-Structure

Instead of files in these folders, the engineer would see items or attributes for each main folder. The CAM folder would contain a sub-folder for each layer, and the attributes for each layer would lie in the layer folder. As data is generated, new folders are created to, say, contain the route. It would have a sub-folder for each step with the relevant instructions and parameters, and each step could have a sub-folder for additional data such as costing, SPC and CRP. The engineer would have full control on defining as many or as few elements as is necessary.

This idea is not new and some CAM system suppliers have used similar models. However, instead of using a database, they have used the same tree structure, as is, to store physical data in the system. This has proven to be very cumbersome and inefficient to handle because without a database, it is difficult for engineers to extract information, generate reports or carry out changes on selective jobs.. The solution is to compress the tree structure and store it in a relational table. So, the tree structure needs to be supported by a shadow-relational model where selective data, determined by the user, can be stored for reporting purposes.

Open Architecture: A Requirement for a Dedicated Engineering System

Another key element is open architecture that would allow the system to perform effectively as an enterprise-wide data integration solution. It would tie existing systems into a functioning company-wide system, whether the enterprise operates within the four walls of a single site or across multiple global sites. The collaborative engineering system would have to be built on open architecture with XML support in order to provide platform independence and fast, easy data import and export. As mentioned previously, the system should be rules-based to provide standardized job automation, yet must be flexible enough to meet a wide variety of standard and customized pre-production engineering needs, and fully extensible to handle even the most complex PCBs.

Features and Functionality of a Dedicated Engineering System

A powerful rules-based system, coupled with an appropriate data structure and open architecture, provides a solid platform for adding specific applications and functionality to provide the intelligent collaborative solution that PCB pre-comprehensive dedicated production engineering needs today. A engineering system should be multifaceted and address Engineering Processes, Communication, Engineering Controls, and System Functions. Key characteristics of the features and functionality are below:

- *Automated Production Routing and Traveler Generator* would provide manufacturing with optimized process and machine tool utilization and travelers for every job. These instructions might include plant floor information, such as the process steps and process specifications, parameters and instructions, as well as SPC parameters and key costing data on materials, processes and labor.
- *Automated Stack-up Generator* would provide all data relevant to material selection, material properties for manufacturing processing requirements, and impedance requirements. This generator would automatically perform the complex calculations needed to produce an accurate BOM.

- *Revision Control* would allow changing an internal version of a job running in a plant, e.g., a change in drill size or mask opening clearance should be identified differently. This is critical when multiple batches are running in the plant while changes are being made.
- *Integration with Third-Party Tools* would allow existing systems to talk with each other so that they are functioning as a coherent enterprise-wide system. Apart from facilitating the import of data from tools such as impedance modelers and CAM, this synergistic integration helps a company get much more out of its existing systems.
- *Full Suite of Engineering Applications* would be capable of handling practical, day-to-day tasks such as tool generation and NC tool editing, attribute editing, data import/export, job-to-specification and job-to-quote comparisons, and CAM data analysis.
- *Web Interface Tool* would provide access and deployment of information through a shared environment in which multi-level security access may be granted on a limited or unlimited basis. This Web-based application would effectively enable paperless engineering collaboration across multiple sites as well as provide a secure portal for deployment and sharing of customized job data reports, design drawings, images, and other key information across the enterprise.
- *Engineering Group Collaboration Checklist,* a checklist of steps, sub-steps, key events and data, would keep jobs on track by allowing all participants to plan and track job progress from start to finish to ensure that all requirements have been met. This should provide information about not only if a step is completed, but also when and by whom.
- *Engineering Job Journal,* a comprehensive reporting tool for individuals or engineering teams, would eliminate confusing paper trails while providing a complete job history and central location for maintaining and updating all job-related activities. This would provide easy access to job-related details.
- *Engineering Change Order (ECO) System* would provide version control and revision tracking to speed up and streamline collaborative and concurrent engineering, corporate and site-level changes, and approval routing for project and part changes. It should be possible to initiate an ECO from the shop floor.
- *System Support Applications* would enable the system to be customized by users to specific needs, for example, configuring and modifying the checklist and specifications as customer or engineering requirements change. Users should also have the ability to define and apply rules to the engineering- and production-related 'static data' to be stored within the system.
- *Built-In Report Writer* would enable creation of a variety of standard and custom reports and documents, including travelers, drill/route sheets, stack-up, and other reports. It should have the ability to generate reports in different formats, including but not limited to HTML and PDF. Reports would be stored in the database for easy access, and could also be displayed on the secure-access Web portal.
- *Management of Multisite Engineering Teams* would be possible when all customer specifications and part details are stored digitally for global access. With globalization, a company's prototype shop may be on one continent and its production shop on another. Nevertheless, the engineering department of each facility must have access to current information. The system would provide secure access to authorized users regardless of location. One engineering team could easily pass its work onto another team on the other side of the world for around the clock collaboration. Thus engineering talent would be shared virtually. With all the data in one location and accessible remotely, it would now be easy to manage all of the jobs and to create reports for different sites.

Evaluation and Selection Criteria for a Dedicated Engineering System

When evaluating and selecting a dedicated engineering system, the following criteria should be a consideration:

- A powerful, scalable database and user-definable data structure capable of providing a robust and reliable platform for the collection and deployment of information through a single seamless and secure site.
- Full integration with widely used CAM systems, as well as enterprise business systems such as ERP, MES and APS, and shop floor data collection systems.
- Interface with legacy systems to ensure that both static and dynamic data can be imported from these systems as required.
- Support industry standard formats like ODBC, XML, and ASCII for future connectivity.
- Easy to implement and configure over the course of a few weeks or months without disrupting existing operations and workflow.

Summary

Intelligent, collaborative engineering is rapidly moving from vision to reality. As the technology is developed and enhanced, it will transform the perception of pre-production engineering as a time-consuming bottleneck to a corporate asset conferring distinct competitive advantage and add value for engineers, the enterprise, and customers.

The many tangible cost savings and intangible business benefits would be:

- **At the enterprise level**: The dedicated engineering system would transform a company's engineering expertise from a 'production cost' to a strategic asset by formalizing engineering expertise into a decision support system. The system would enhance a company's competitive position by reducing time to production and improving customer service and satisfaction through more accurate quotes, faster turnaround and improved order fulfillment times. The cost savings could be substantial.
- **At the operational level:** The dedicated engineering system would help contain costs and increase profit margins by minimizing errors and rework, improving product quality, and making more efficient use of available production resources.
- **At the engineering level:** The dedicated engineering system would reduce time and costs of engineering orders, thereby maximizing productivity and throughput. With its end-to-end integration of fragmented data sources, users could collaborate efficiently for faster throughput and slash time-to-production.

The PCB industry is hungry for innovation and advancement. Breaking the information bottleneck in engineering teams with a dedicated engineering system is a step in the right direction.

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