Prisma - A Novel PCB Engineering Software

Pascal Simon
DYCONEX AG
Bassersdorf, Switzerland

Abstract

Prisma is a PCB-Engineering software developed by DYCONEX AG, Switzerland (manufacturer of PCBs). Compared to existing solutions on the market it allows for broad standardization of the process flow while not imposing any restrictions on the design. It is a platform to specify the build-up, materials and the complete work instructions for PCBs. Engineers transform the customer data into full manufacturing papers by means of Prisma. The software has been developed for company internal use only and is (currently) not being sold.

One of the key features of Prisma is its freely definable library of process modules. These modules always reflect the current capabilities and process settings. Existing products can be compared to the current state of the module library und be updated in a semi-automatic way. Build-ups and operation plans are presented in an interactive graphical screen that allows the engineer to build the product and incorporate changes in an easy and intuitive way without the need to take care of the detailed process specifications. In addition to formatted easy readable work instructions, Prisma returns schedule- and cost relevant operation times for each process allowing a quick and precise cost estimate for quotations.

The software includes an automatic revision management complying with the high traceability requirements of customers working in the medical and military sector. Access to data is restricted by user login. The software is based on SQL Server and .NET technology and includes an interface to the ERP-systems (Enterprise Resource Planning) Abacus and Microsoft Dynamics AX. Live access to the material, product and customer database kept in the ERP-system guarantee always current data. Production planning and costing are accomplished in the ERP-system based on data provided by Prisma.

Introduction

Printed Circuit Boards are manufactured in a long chain of processes, each of which can have several parameter settings. A typical operation plan for a PCB consists of 50 to 300 single processes. Most processes are critical, meaning that they can not be omitted without leading to a non functional or lower quality PCB. A certain design does not lead to a unique process chain however. There always exist optional processes or groups of processes as well as alternative process blocks. Which of these alternatives is chosen may influence yield, costs and quality of the product. The requested quality level - e.g. the extents of AOI and visual inspections being planned - is primarily given by the customer (specification, IPC level) and the standards of PCB manufacturer (defining that certain tests are done even if not requested by the customer). Optimization of yield and costs is an essential key in gaining competitive advantage, allowing lower target prices. Raising the yield of a product from 80% to 90% reduces its costs by 1/9. If this can be achieved by simplifying the operation plan, one can easily gain significant cost reduction without implementing new technologies or changing the build-up. Optimization itself has its costs, since it usually involves engineering capacity. Our company manufactures around a hundred different PCBs at a time making it next to impossible to optimize each of these products. The idea here is to automate the optimization process, or better still to start with a near optimum design and apply optimizations of one product on other products. For PCB shops focusing on a certain type of products (like rigid multilayer only, or 2 layer flex only) this optimization needs less engineering capacity per product. Prisma is designed for a manufacturer with a wide range of products (rigid, rigid-flex and flex boards) with a broad range of materials (polyimide, FR-4, LCP, molybdenum etc.) in a high-wage region (Switzerland).

Concept

Modularity

It can be observed that process chains of very different PCB build-ups usually have similar groups of processes. The processes might use different recipes, but their topology is the same. An example is the signal layer etching that usually consists of the following processes:

Measure panel compensation → Plot films → Pretreatment → Apply photo resist → Punch reference holes → Expose → Develop → Etch → Strip → Automated optical inspection (AOI) → AOI Verification

For rigid and flex boards this flow is slightly different (no punching for rigid boards), but there are much less variants in the signal layer process than there in the build-ups. We call these generic process flows ‘process modules’. Once the process modules for all logical manufacturing steps have been identified (via creating, lamination, surface finish etc.) one can start building PCBs using these process modules like Lego bricks or jigsaw pieces as shown in Figure 1.

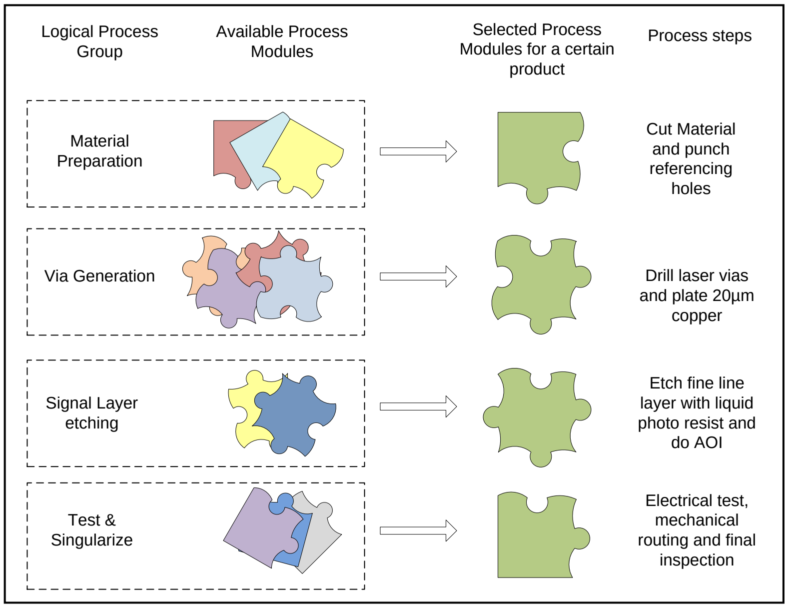

Figure 1: Principle of process modules

For the principle to work it is essential that the process modules are as universal as possible and have as little influence on each other as possible. There are two counteracting tendencies: One prefers larger modules because it leads to a higher degree of standardization and it is advantageous not to have too many modules as to reduce the searching and managing efforts. Large modules tend to be too specialized however to be uniformly used. The top end would be to have one single process module for each PCB. On the other hand, modules could be as small as containing only one process. Both cases actually render the use of modules unnecessary as all advantages vanish. The difficulty is to find the optimum module size that yields a manageable number of modules that can be used for many products while containing as much logic as possible. We found 8 distinct top level categories for process modules:

Material preparation: Includes steps like reference hole punching and initial copper thinning
Via generation: Combines drilling and plating
Signal layer generation: Creation and inspection of signal layers
Contours: Non-plated contours, holes and depth routing
Inspection: All inspections that are not directly coupled to processes, like electrical testing
Surface finish: solder mask, ENIG, silver etc.
Lamination: Includes pretreatment, drying and curing
Auxiliary processes: Short process steps like marking of panels that need not be part of the other modules

Most products need modules of the first 7 categories. Each of these categories possesses a hierarchical sub-tree containing a total of 10-40 process modules.

Up-to-date processes

One major advantage of using process modules is that it greatly simplifies the management of process flows. Typically the number of actually occurring variations of process flows in range of products is reduced simply by the fact that process modules are being used. Reusing an existing module is easier and faster than creating a new module or composing the process flow using single processes. Due to the unique module identification, it is well known for which products a certain process module is used. If one such module is changed, one can decide if the products using this module should be updated as well. Generally this will not be done automatically, because the effect of a change might be different in different products. Even if the update is not done instantaneously, the product still 'knows' that one of its modules is not up to date and offers the user the possibility to update the module at any time (Figure 2).

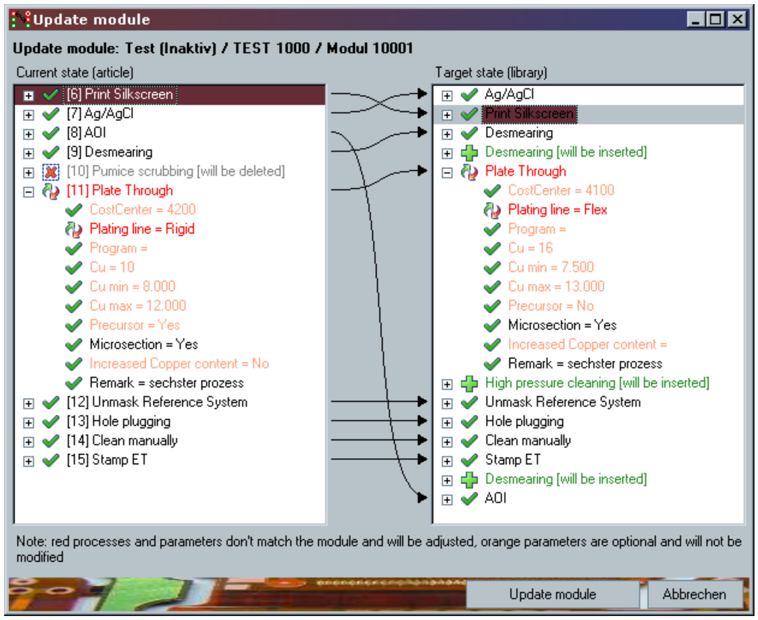

Figure 2: Updating a process module: All processes of the selected module are shown. The icons indicate if the process will be updated (arrow icon) deleted (x-icon) or inserted (plus icon). For each process that is being updated all of its parameters are listed and each parameter is either updated or not, depending on its definition. (Note that this is an example and not a functional process module)

Different levels of process parameters

The process module update feature simply transforms an existing process flow in an operation plan into the reference process flow of the process module. Each process can have several parameters however and it is not desirable to always update these parameters. An example for a parameter that should always be left untouched by the update process is the ‘remark’-property that specifies additional unstructured product specific information. Other parameters like the equipment that must be used to do a certain process are typically ‘hard’ parameters that must not be changed by the user and will be updated.

Prisma defines three types of process parameters

Hard parameters: are fully defined in the process modules and must not be changed by the user (e.g. the equipment to use for exposure)
Soft parameters: are fully defined in the process modules but can be changed if necessary by the user (e.g. the recipe of the plating process, which defines the amount of copper to be plated)
Product specific parameters: These are not defined in the process modules at all. Their value is always product specific (e.g. the product-id of the needle bed adapter for electrical testing)

In real life, a system that handles modularized operation plans must also be able to handle non standard operation plans, consisting of individual processes rather than process modules. This is for two reasons:

The system initially has to cope with an existing, ‘chaotic’ (non-modularized) product portfolio. Modularization takes time, because it inevitably leads to processes changes in existing products. Each change must be checked for yield impacts and must possibly be released by the customer (e.g. for FDA approved customers)
For prototypes it is often necessary to quickly try a new materials and/or processes setting, which later may or may not result in a new process module. At least the first lot can not be fully modularized.

The main challenge for a software supporting the standardization process is to be very flexible for prototype and ‘not-yet-standardized’ products while enforcing the use of modules for all the other products. Prisma is based on the paradigm that the user will choose the fastest of several possible ways to work with the software. That means generally using the process modules and not single processes. In order to further boost the standardization it is possible to limit the use of single processes to sample and prototype products and prohibit it for serial products. This approach allows for full flexibility and creativity in the prototype stage and forces the engineer to establish new technologies as official process modules once the series stage is reached. Other engineers hence automatically profit and can use the new technology in other products.

Revision management

Apart from the standard feature to have several parallel versions of a PCB (only one of which can be marked as active however), Prisma includes an automatic revision management. To support traceability, it is important that any relevant change in the product specification (process or material) is tracked. First one has to define what relevant changes are. The main feature of using a revision number is certainly to be able to compare two documents (either electronically or on paper) for accordance. Equal revision numbers indicate that both documents are identical. Translating this to the software it means, that any operation plans and build-ups that have been printed out or exported to the ERP system must carry a revision number. If the user opens the PCB specification within the software and the revision number is the same as the one on paper, he must be safe to assume that no changes whatsoever were made to the specification since the last export/print out was conducted. This could be achieved by simply increasing the revision number each time the user modifies the product. To prevent the unnecessary increase of the revisions (and the related storing of each changed record in the database) only a modification done directly after an export/print out triggers a revision increase (see Figure 3).

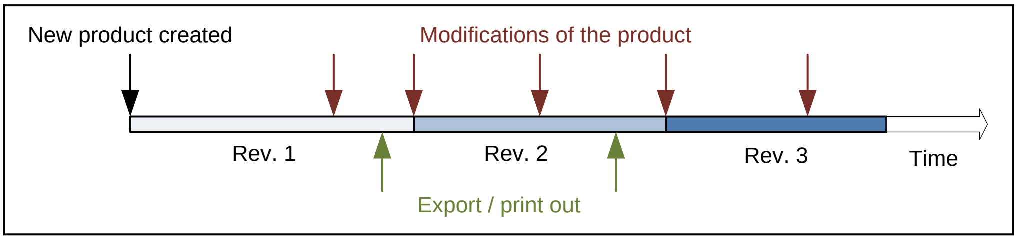

Figure 3: Illustration of the automatic revision change. Each data export or print out freezes the current state and the first change afterwards leads to a revision increment.

Records in the database are generally only modified or deleted if no revision change is pending. Modifications of the product after an export or print out lead to insertion of new records while the original records are left unmodified. The date of each record modification as well as the user-id is stored in the database. This system guarantees full traceability of all changes down the date and user while minimizing the amount of stored data. Only the last revision can be edited, all previous revisions are read only.

Process times and cost calculation

Prisma requires a full description of PCBs on the process level and stores all data in a structured way in the database. This prepares the ground for advanced features such as the calculation of realistic process times and costs based on the processes and the process parameter settings. A formula editor provides the framework to define:

setup times
cycle times (cost relevant)
total process times (relevant for production planning)

The formulas can make use of all technical parameters of the current process that the software knows of, as well as all general parameters of the PCB such as the dimensions, the IPC level or the number of layers. Based on the setup and process times the ERP system is able to calculate a realistic cost expectation that can be used to set the price of the PCB. The total cycle time is an absolute necessity for an accurate production planning (part of the ERP system as well). To illustrate this concept, a sample formula is shown in Figure 4.

```
DECLARE @Size FLOAT
DECLARE @Speed FLOAT
SET @Speed = 1.0*60*1000
IF $PanelWidth$ < 306
       SET @Size = $PanelWidth$
ELSE
       SET @Size = $PanelLength$
SELECT ($StdLot$*(@Size+100) / @Speed)
```

Figure 4: Sample formula to calculate the cycle time of one standard-sized lot for a horizontal processing equipment. Depending on the dimensions, the panels are either processed with the long or short edge in machine direction, yielding different cycle times (speed is constant in this example).

The syntax of the formulas is TSQL and Prisma does not have an own parser but uses the SQL Server to evaluate the results. The sum of setup and cycle time can be multiplied by the cost rate of the process to get a cost estimate. Different calculation schemes are possible, e.g. not using time but technical quantities such as the number of panels processed. The total process time formula can reference to the cycle time. In the above example it could add the total time it takes for the last panel to run through the equipment to the cycle time.

Copper thickness calculations

Copper thickness is often an issue in designing the manufacturing process of a PCB, especially when using a panel plating process. Minimum copper on the surface is desired for signal layers etching while a safe amount of copper plating is needed to guarantee the minimum copper thickness inside the vias. Many cleaning steps reduce the copper thickness (e.g. the treatment before applying photo resist, solder mask, cleaning before lamination etc.). For complex products it can become very time-consuming to manually add up all positive and negative effects on the copper thickness for each layer, always respecting the minimum and the maximum tolerances. Prisma does just that for the user. Each process has a predefined or parameter dependent min/max effect on the copper thickness that is applied to the copper layers the process has been linked to (see also Figure 5, the column 'Cu+Met' shows the average base copper plus plated copper on each layer after final processing). A plating process has a positive effect (adding copper) and cleaning or etching processes have negative effects.

Benefits for the customer

Process excellence

PCB manufacturers sell their process capability to customers. Prisma manages process flows and helps establishing standards. The key attributes customers expect from a good PCB manufacturer apart from low prices are reliability (constant and good quality), predictability (constant yield, no unexpected technical problems) and short lead times.

Prisma helps achieve improvements in all categories. Reliability is enhanced by the fact that elements of a library consisting of tested process modules are used to build new products. This reduces the risk of design defects, neglected process steps and unconscious introduction of new and untested process flows. Since inspections are reflected in process modules, the amount of testing done during the fabrication is standardized as well. Quality is a result of stable, tested processes and an adequate level of inspection.

Predictability is partly guaranteed by the fact that changes to existing products are tightly controlled. Series products can only by changed by modifying existing process modules or introducing new ones. In both cases the procedure must be release by a committee (Prisma only limits such modifications to super users, release procedures are part of business processes and not the software). As a result, sudden yield losses or technical problems leading to supply problems are minimized. Customers can be confident that there will be no surprises when ordering products based on existing technology.

Lead times are reduced by two circumstances. First, the engineering time is cut down because working with blocks of processes is faster than reinventing the same technology again and again. And it is more error prone than copying existing products because each process module must be deliberately chosen and checked. Secondly, a smaller number of variants in the process flows leads to more clarity and less errors during the fabrication.

Traceability

As described in the revision management section, any change in the specification of a PCB such as the material, process, process parameter or even a remark in the operation plan is tracked if a revision increment is pending. Based on this system it is possible to reopen the product in the software for each production lot at any time. The clear work instructions automatically generated by Prisma from the operation plan increase the certainty that each process step is done in the same way each time (in contrast to a system where everyone has the freedom to influence the wording an formatting of the work instructions).

Visualization

Especially for complex PCB build-ups with multiple lamination steps and various interconnection levels a visual representation of a cross section can be helpful. Simplified, a build-up of a PCB can be characterized through the following features:

Materials
Interconnections
Routings
Laminations

Prisma supports a graphical interface that allows to user to quickly sketch a product from scratch using a library of generic materials and processes. The generic material library only defines the category of material (polyimide, FR-4, Adhesive, etc.) and the processes distinguish vias (mechanical, laser and plasma, either plated or non-plated), routings and laminations. Especially in the initial inquiry phase when different technical solutions for the customer's design are being discussed, visual representations help establishing a mutual level of comprehension between customer and supplier. Examples of graphical build-ups are shown in the following section.

Sample PCBs

To illustrate the potential of the presented concepts we show two examples of actual PCBs (built and sold) implemented with Prisma. The first is a fairly simple construction of a fully flexible PCB built with polyimide and acrylic adhesive. Micro vias connect layers 2-3, 1-2 and 3-4 and are drilled in a plasma process. Additionally, layers 1 and 4 are connected by mechanical holes. Solder mask is applied on both side and the final separation is done in a mechanical routing step (Figure 5).

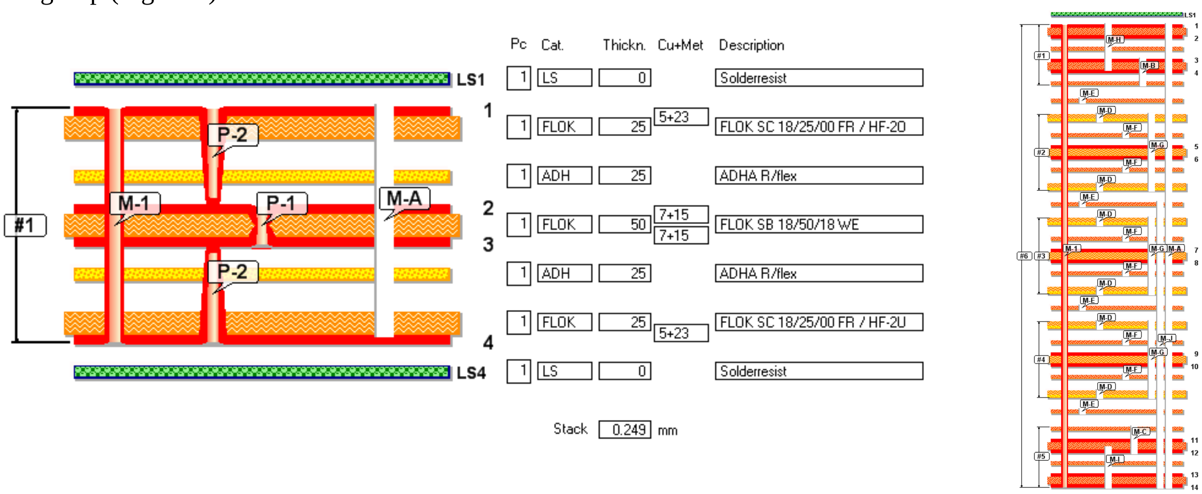

Figure 5: Left side: Build-up of a 4 layer flex board with plasma drilled micro vias. Further information is printed in the table next to the illustration: number of material sheets (Pc), material category (Cat.), base material thickness (Thickn.), copper thickness (Cu+Met) and material name (Description). Right Side: 14 layer rigid flex board (table with details omitted).

This product was assembled using 11 process modules from the standard library yielding a total of 90 processes. The sequence of the process modules is the following:

Prepare material → Drill & plate vias 2-3 → Signal layers 2 & 3 → Laminate → Drill and blind vias and through holes 1-4 → Signal layers 1 & 4 → Apply solder mask → Mechanical routing → Surface finish → Electrical test → Final inspection

It is easy to modify this product, e.g. replace the plasma drilling process by a laser process. In that case the substitution of the two drilling modules would be sufficient. Similarly, the modification of the surface finish could be achieved by replacing only one module and possibly moving it after the electrical testing if necessary (e.g. for surfaces like OSP that could be damaged by the electrical testing).

An extract of the operation plan is shown in Figure 6.

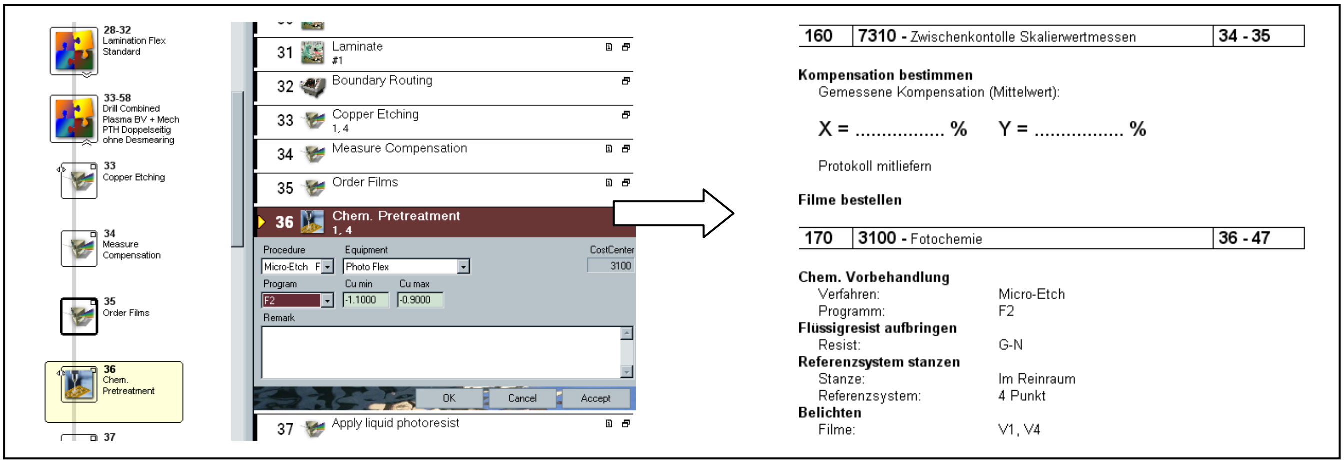

Figure 6: Section showing a few processes of an operation plan. The left side holds a visual representation of the operation plan consisting of processes that are grouped into process modules. Each process may have several parameters that can be modified in the parameter editor. In the right half of the illustration, the conversion of the operation plan in to work instructions can be seen (in German)

In order to illustrate the power of the concept, an example of a 14 layer rigid flex board is also shown in Figure 5. The bendable area consists of 3 double layers flex areas, copper being protected by pre-routed coverlay sheets. Two 4 layer rigid cores made of glass reinforced polyimide provide the stiffness. 105 processes and 25 modules were used to build this product.

Conclusion and Outlook

We have presented a modularization concept for the manufacturing of printed circuit boards. This concept has been implemented in the engineering software Prisma. The power of modularization is its simplicity and ease of use for the engineer. It inherently leads to standardization of the products because the same process modules are used over and over again. Most essentially it reduces the efforts in optimizing processes by allowing updates of modules. The software has additional key features like a full revision management, a graphical build-up editor and process time calculation capabilities.

Not only does it streamline the engineering process on the supplier’s side but it provides advantages for the customers such as process stability, good lead times and a persistent traceability. The graphical cross section is useful for the engineer, the operator and the customer the get a quick overview of the product.

After about one year use of Prisma many ideas exist to further extent the modularization concept and the software in general. One improvement would be a compatibility check that prevents the user from inserting incompatible adjacent modules, or even better an expert system that suggest possible process modules based on the precedent module and the build-up. Such a system would require meta data on the process module level that allows the software to understands its function. Currently only human readable descriptions can be defined. Another approach to promoting modularization could be an automated module recognition / optimization procedure that converts a given operation plan into one with a minimum number of process modules from the current library. This would allow the user to easily update prototype products that were initially built with single processes rather than process modules.

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Pascal Simon
Manager IT
Dyconex AG,
Bassersdorf, Switzerland

Contents

Challenges in PCB manufacturing

Focusing on: High reliability, high complexity, high density market

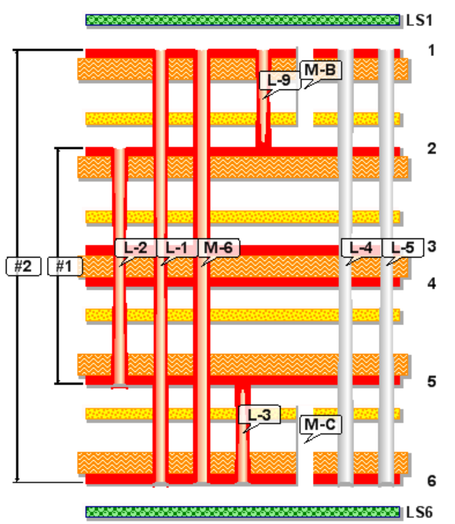
- Manufacturer is confronted with a large variety of products and relatively small lots
- Process variety is hard to manage because resources are limited
- Engineering time for new products is critical, quality is crucial and failure for first order lots is no option
- Streamlining production is difficult, because many customers react very conservatively to process changes

There was no suitable software solution for our company available on the market → We decided to build our own

Key goals of the software

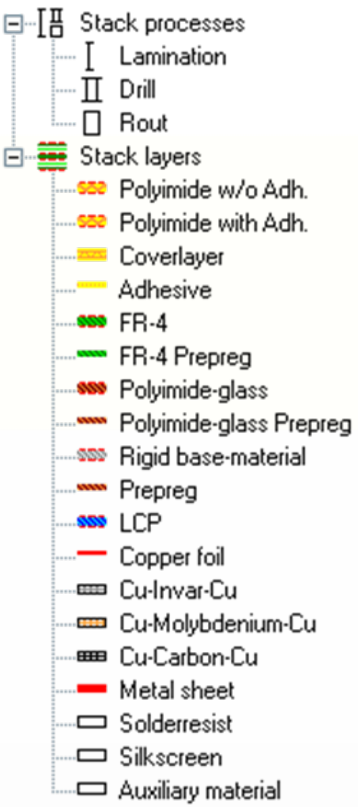
- Guide the engineer in creating build-ups and operation plans (containing 100 - 300 processes and > 300 parameters on average)
- Standardization of operation plans
- Full flexibility in creating an operation plan (not limiting progress in technology)
- Base for cost calculations
- Automated creation of easy readable lot travelers for the manufacturing department
- Possibility to do selective, fast updates of existing products in case of general process changes

Build-up generation



Build-up in Prisma

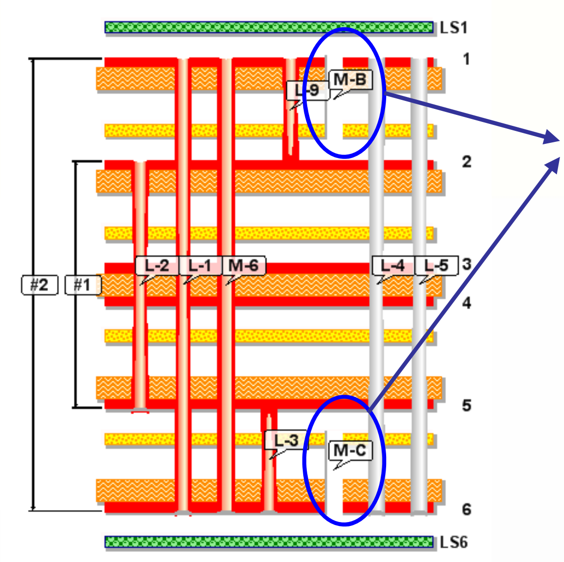
Company ERP System



Prisma Material-class library

From the build-up to the operation plan

- Vision: Automatically create operation plans based on build-up
- Problem: Does not work with the highly complex product portfolio of the company



6 Layer flex board with 4 layer bending zone

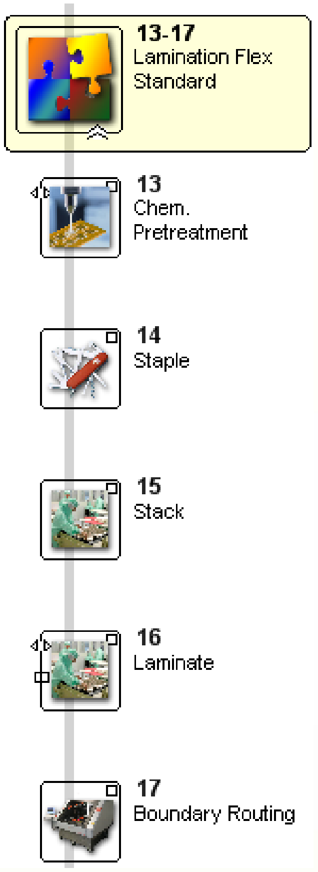
Millings can be created in different ways:

- Pre-rout before lamination
- Rout after lamination with el. contact on layers 2 and 5
- Etch with plasma process

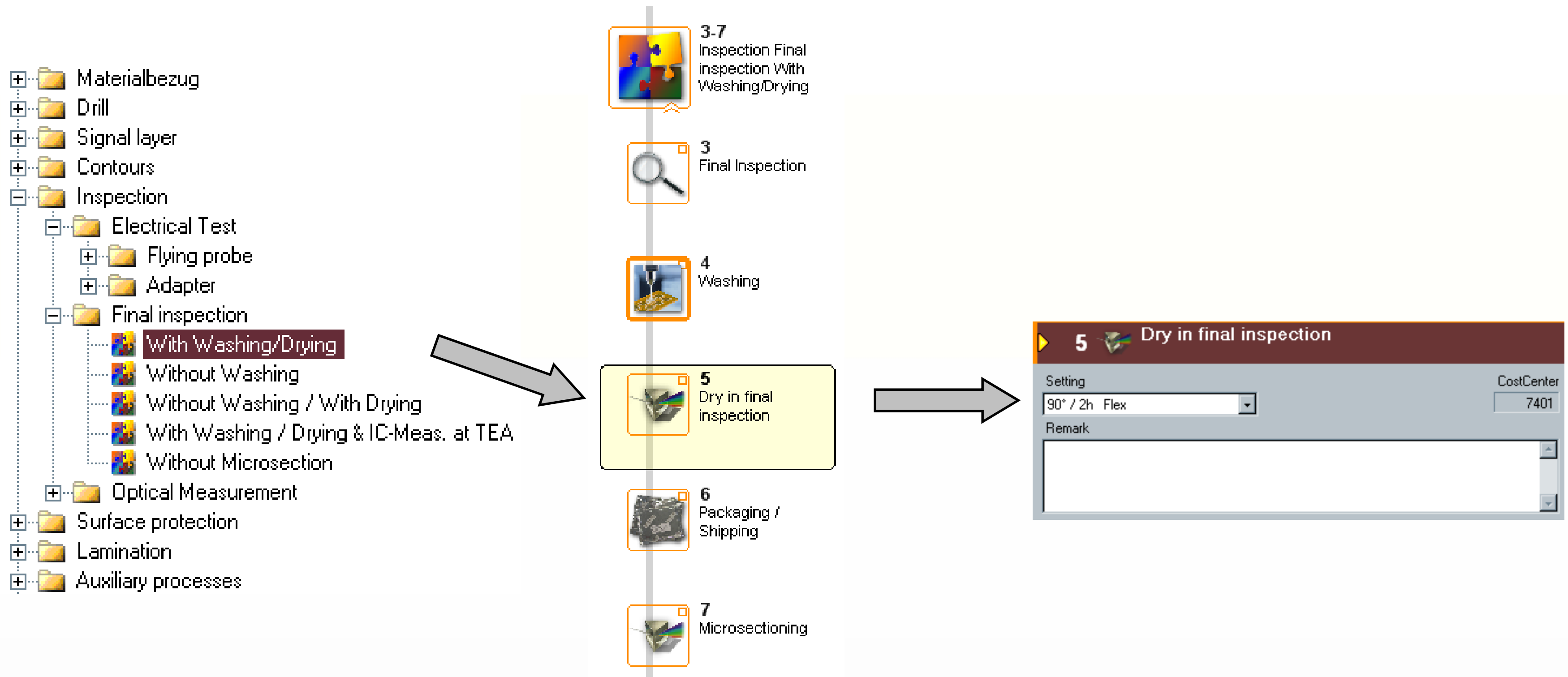
- Solution: Create build-up and operation plan independently and link certain key processes to features in the build-up

The Concept of Process Modules

- Group repeating process flows into rigid compounds
- Simpler than using single processes
- Usage of process modules is traceable to the products
- Updates of process modules is easy and fast
- Use of process modules is optional in order to keep the full flexibility



Module – Process – Parameter



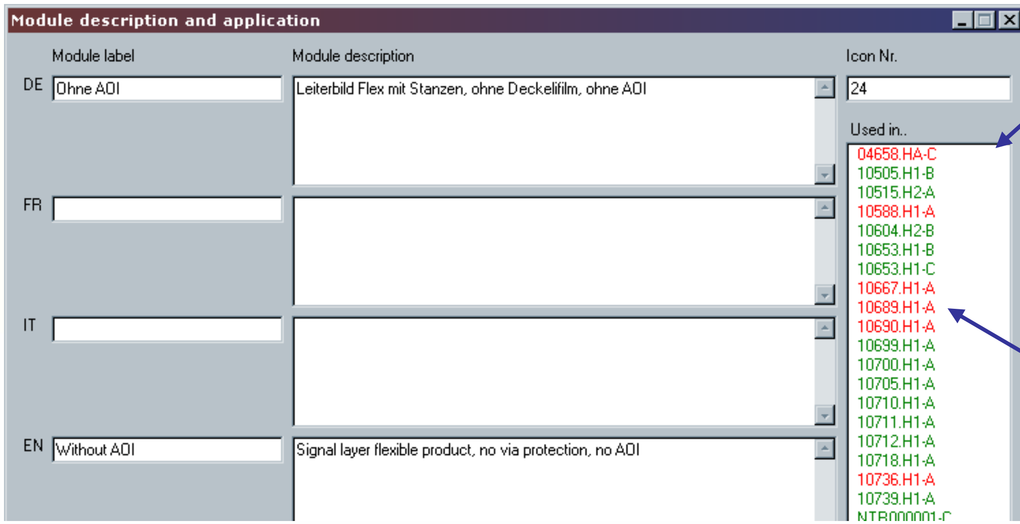
Library of tested and released process modules

Operation plan built with process modules

Settings of a process inside a process module

4

Managing Process Changes



For each process module, a list of all products that use the module is available

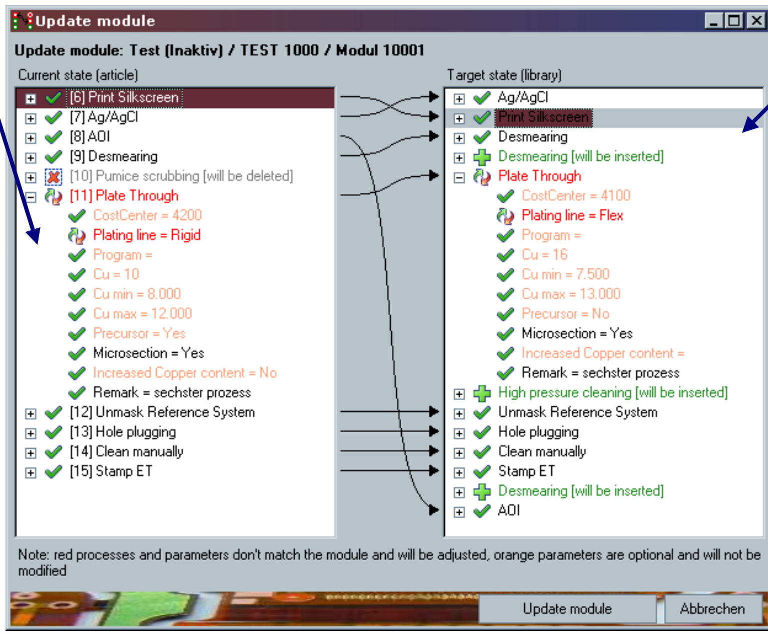
Products that use not up-to-date versions of the module are highlighted in red

4

Updating Process Modules

State of the module used in the product

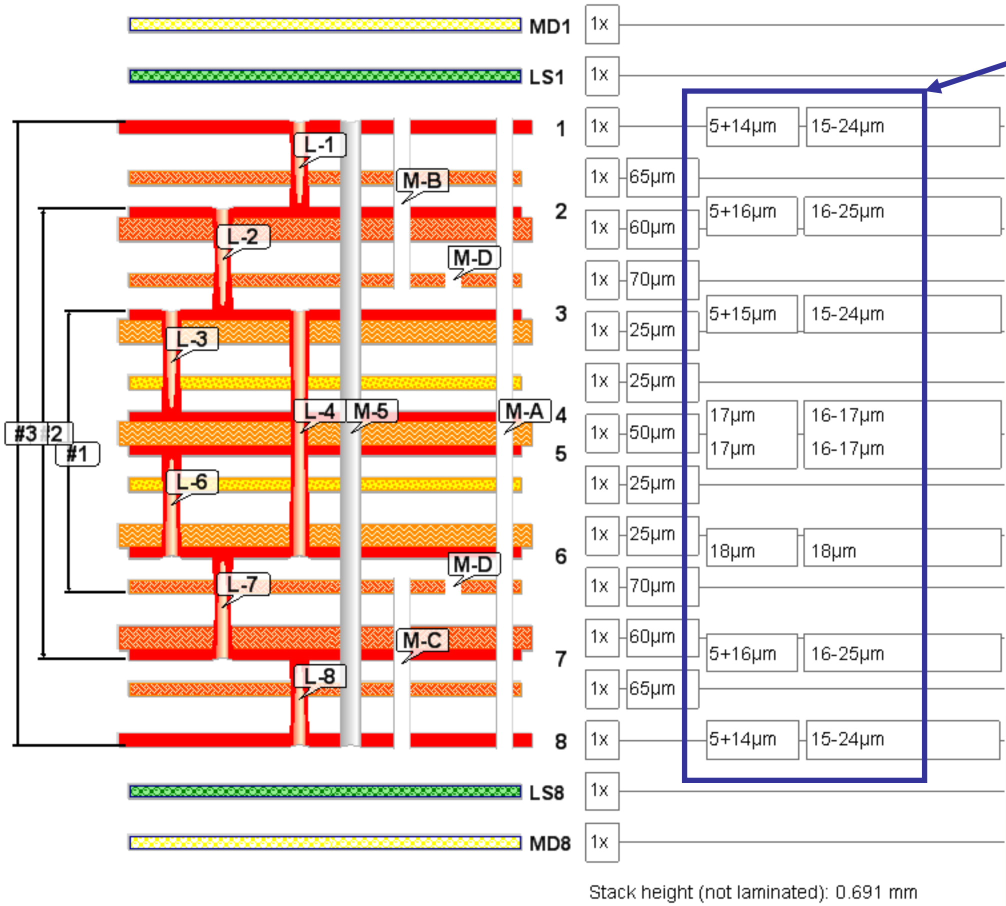
Current state of the module in the library



(Non functional sample module)

- Update of module is a single mouse click
- Processes within the module are moved, deleted or inserted
- Product specific parameters are not updated (e.g. remarks)
- Critical parameters are updated

Benefits for the Engineer



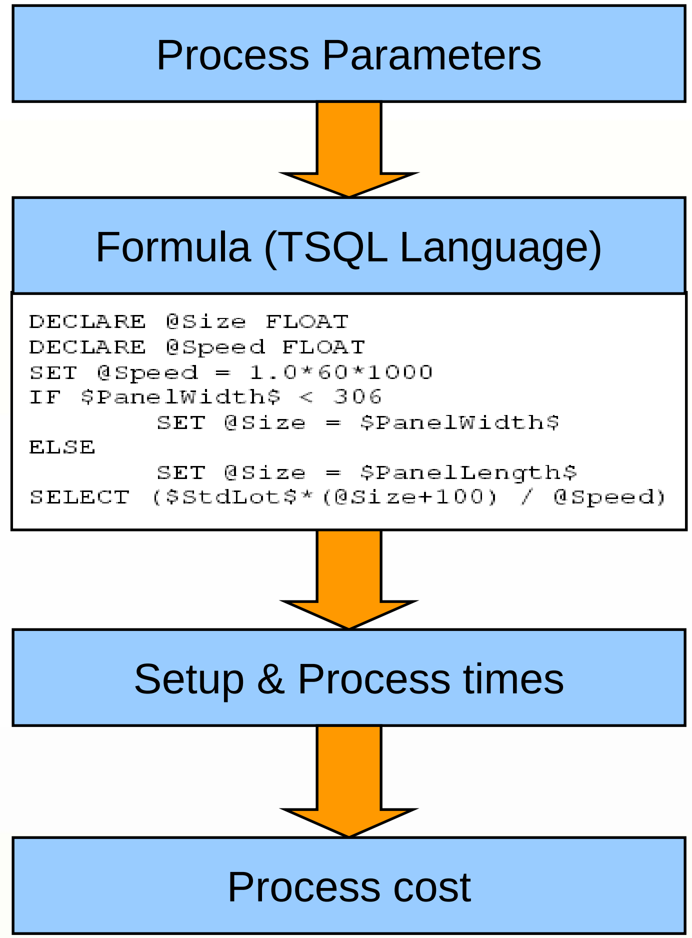
Automated Copper thickness calculations including tolerances

All processes that affect copper thickness are taken into account

Benefits for the Engineer

Automated process time and process cost calculation:

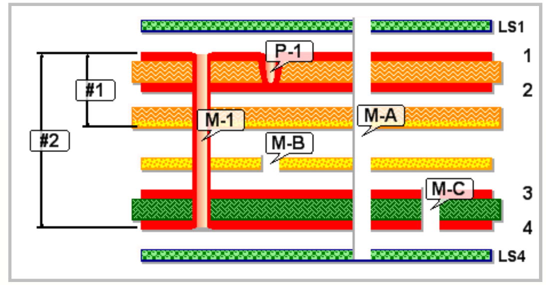
- Formulas for each process have been defined
- The results base on the actual process parameters

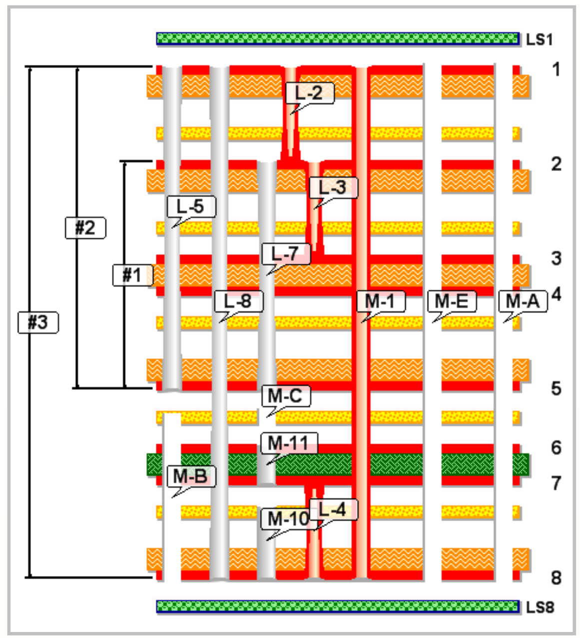


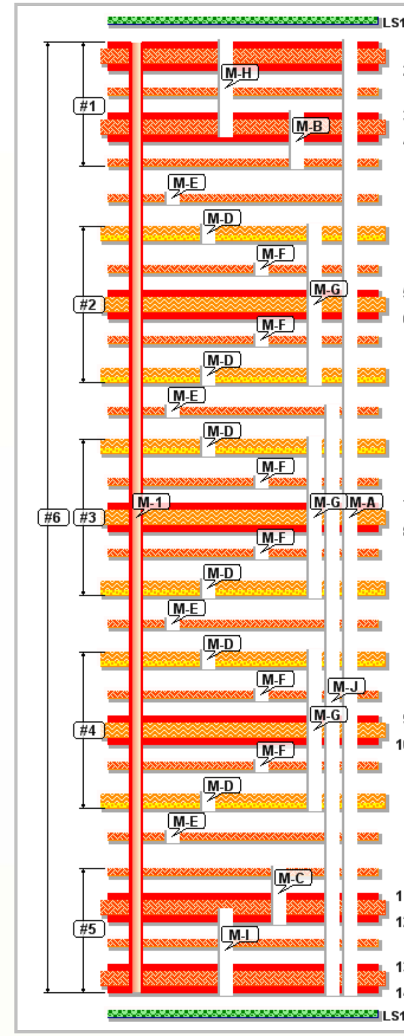
Benefits for the Customer

Visualization of build-ups:

- Materials (color coded)
- Vias (incl. type: plasma / laser / mechanical)
- Millings
- Solder mask and silk screen
- Lamination steps

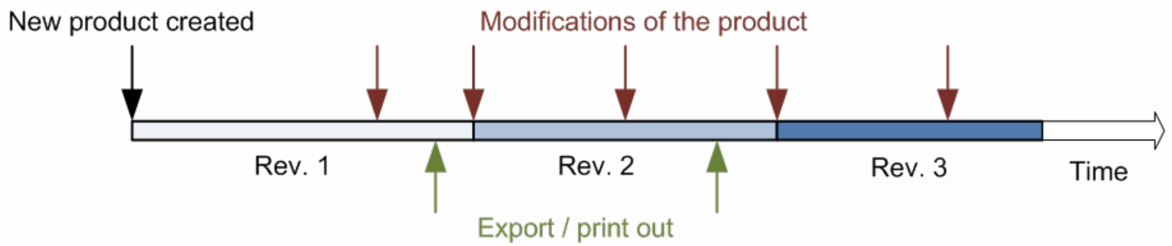






Benefits for the Customer

- Process Excellence: High first pass yields due to usage of established process modules
- Shorter lead times: Process module library reduces engineering efforts
- Traceability: Automated Revision management



Conclusions

- The concept of process modularization has been implemented in the Software and proved to be working in our company
- Flexibility of using single processes rather than tested process modules is necessary to evaluate new technologies
- Cost transparency has been improved
- Plans to extend the functionality of the software exist:
  - Process module compatibility checks
  - Automated clustering of process flows into modules
  - Import of CAD data