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ON THE ROUTINIZATION OF ANALYSIS FOR PHYSICAL DESIGN

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ABSTRACT

While it is generally agreed physical designers would like to benefit more from analysis, methodologies are lacking for identifying appropriate analysis models and transforming them into readily usable tools. This paper identifies physical designer needs with respect to analysis, and introduces the term "routinization" to describe the process of creating routine analysis modules - automated analysis models that can be regularly used in product design.

A routinization methodology is presented with electronic packaging examples. Based on the multi-representation architecture (MRA), a design-analysis integration strategy, this methodology creates catalogs of product model-based analysis models (PBAMs) - analysis modules that associate design data with specific analysis models to obtain results in a highly automated manner.

The methodology is illustrated using a simple PBAM for PWB warpage analysis. Applications to solder joint fatigue and plated through hole deformation are also highlighted, with solution methods ranging from encoded formulae to multi-vendor 3D finite element analysis. Observations are given, including how routinization aides both electronic packaging researchers and physical designers. While it enables researchers to more readily benefit designers, it also acts as a catalyst for identifying needed research extensions.

1 INTRODUCTION

Due to a variety of pressures, physical designers typically do not perform as much engineering analysis as they would like [Liker, et al., 1992]. This section identifies some of these analysis needs and introduces a methodology to address them in the light of previous design-analysis integration (DAI) work.

1.1 Routine Analysis in Physical Design

During the physical design process for products like PWAs (Figure 1), a variety of checks would ideally be performed to ensure performance, reliability, and manufacturability [Peak, et al., 1993a]. For a given type of product, the same types of analyses typically need to be executed for each new product instance at several stages during the design process.

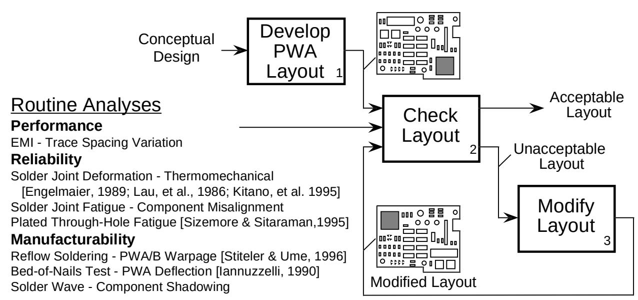


Figure 1 Routine Analysis in the PWA Design Process [after Peak, et al., 1993a]

When asked about such analysis problems, physical designers typically express the following needs:

- Tools that are easy to use and that automate tasks as much as possible.
- Predefined catalogs of common models, along with usage guidelines.
- Product-specific terminology for model interaction (e.g., for variable names).
- Design tools linkages with selective bidirectional associativity.
- Ability to utilize commercial analysis tools without becoming a tool expert.

- Insulation from analysis model details (e.g., node numbers), but access if needed.

To address such needs, we have coined the term **routine analysis model** to describe an established analysis model that is regularly used to support product design [Peak, 1993]. This concept leverages the repetitive nature of some design analysis processes and focuses on problems that are prime candidates for automation. **Routine analysis**, the process of employing a routine analysis model, emphasizes model usage, in contrast with **adaptive analysis** and **original analysis** which focus on developing new types of analysis models.

1.2 Routinization via the MRA Methodology

This paper focuses on the process of creating modules that represent routine analysis models - a process termed **routinization**. Figure 2 illustrates the overall multi-representation architecture (MRA) routine analysis methodology, which consists of routinization (module creation) followed by routine analysis (module usage).

The routine analysis phase employs an MRA implementation to integrate commercial design and analysis tools in a flexible, modular manner. Starting on the far right, solution method models (SMMs) are object-oriented wrappers around solution tools (e.g., FEA systems) that utilize an agent-based framework to obtain analysis results in a highly automated manner. Analysis building blocks (ABBs) represent engineering analysis concepts with rich semantics. ABBs generate SMMs based on solution technique-specific considerations such as symmetry and mesh density. On the right, product models (PMs) represent design-oriented details and provide a stepping stone to design tools [Tamburini, et al., 1996]. Finally, product model-based analysis models (PBAMs) are the actual analysis modules, explicitly representing the associativity between analysis models (i.e., ABBs) and design models (i.e., PMs).

With PBAMs, one can create catalogs of ready-to-use analysis modules for applications such as solder deformation and joint fatigue analysis [Peak and Fulton, 1993b; Peak, et al., 1995]. Cimtalay, et al., [1996] have demonstrated initial usage of PBAMs in a modular optimization technique.

2 MRA ROUTINIZATION PROCESS

Figure 3 highlights the major steps in the MRA **routinization** process (the process of creating routine analysis modules) and identifies the primary roles of people involved at each step. The designer and analyst first decide which routine analyses are needed. The analyst then works with the integrator to develop PBAMs and related entities to represent the identified models. After implementation, the end result is one or more analysis modules ready for designer usage. Depending on the size of the effort, note that the roles in this process may all be performed by a single person, or each role may itself involve several people.

The remainder of this section discusses each step with examples from a previous solder joint fatigue case study [Peak, 1993; Peak and Fulton, 1993b] and a simple PWB warpage model. Based on initial guidelines from these case studies, a comprehensive set of guidelines with detailed examples is under development [EIS Lab, 1997].

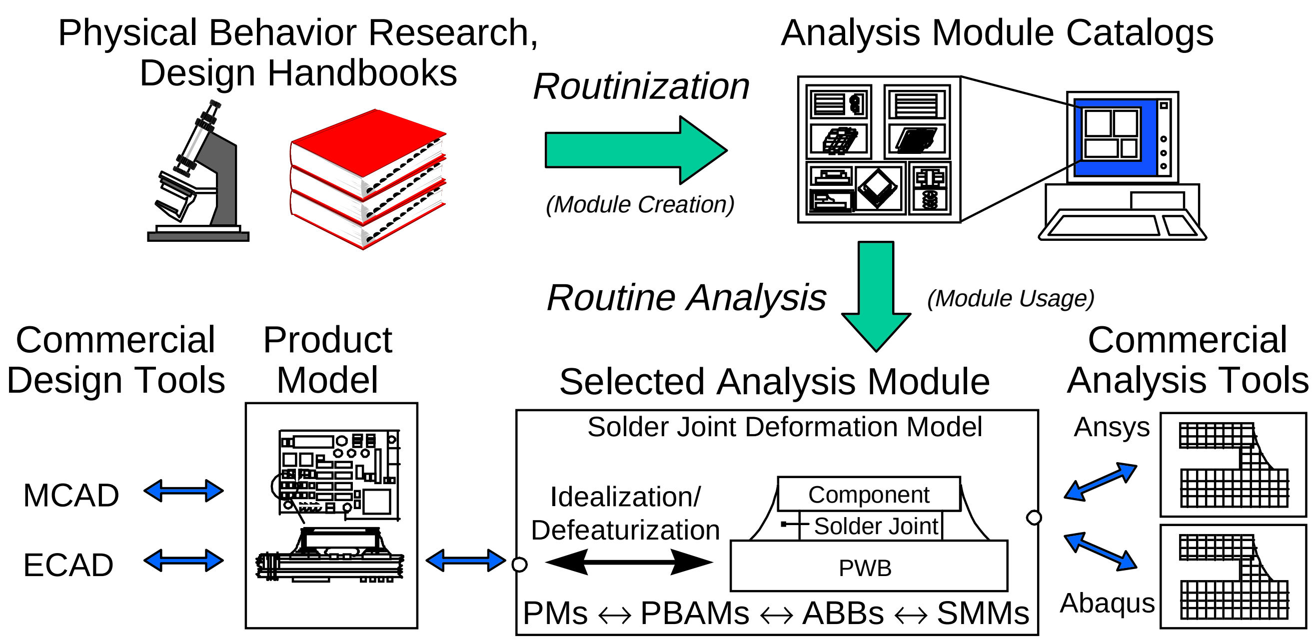


Figure 2 MRA Routine Analysis Methodology [after Peak, et al., 1995]

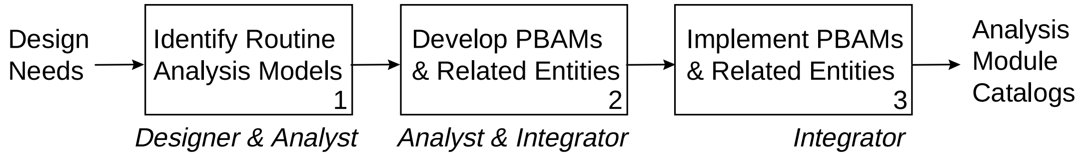


Figure 3 MRA Routinization Process

Step 1: Identify Routine Analysis Models

To start the routinization process, the Designer and Analyst first identify which routine analysis models are to be transformed into automated analysis modules. These two people should be familiar with the types of products and analysis models being considered.

If it is indeed a *routine* analysis model (one that is truly used regularly), a description of the analysis model will typically already exist in some form. If design needs call for a new type of analysis model, the Analyst can look to a variety of resources as starting points (Table 1). Alternately, the Analyst may go through an adaptive or original analysis process to develop and validate the needed analysis model. Some combination of merging models from existing resources and in-house development is often required.

Table 1 Starting Points for Routine Analysis Models

1. Journals	5. Corporate technical memos
2. Conference proceedings	6. Unpublished notes
3. Handbooks	7. CAE tool input files
4. Textbooks	8. Computer programs

The output of this step is an informal analysis model description containing the following:

Model Purpose - A brief statement about the model and what design needs it fulfills. It should indicate what design stages best benefit from the model - typically based on model accuracy versus computational cost.

Major Analysis Steps and Variations - A high-level, top-down view of the major analysis steps in the form of a tree/network diagram (Figure 4) or an $IDEF_0$ process model. Variations such as loading conditions and product configurations should be identified.

Analyst Sketches - Sketches of analysis models noting types of bodies, loads, and material models in product-specific terms.

Relations and Variables - Listing of relations and variables. For models that require processing via tools such as finite element analysis programs, for each tool it should list a relation whose variables are the inputs and outputs for that tool.

Model Limitations - Guides for the end user including model assumptions and acceptable ranges of inputs and outputs.

Model References - Background information about the model, including application to the product type at hand, as well as descriptions of the product-independent concepts.

Representative Datasets - Example values for input, intermediate, and output variables for major variations. This should include related solution tool input and output files (e.g., FEA preprocessor models and results files). In the best case, tool files are parameterized according to the associated relations and variables identified above.

With the resulting description, someone besides the Analyst should be able to "manually" walk through the analysis steps using the example datasets. "Manually" means that at a minimum someone can manually provide input to the appropriate tools and manually exchange data among these tools as necessary (e.g., using a calculator, creating and running a finite element analysis model, and exchanging information among such tools). This exercise also helps non-Analysts better understand the model and accelerates the below steps.

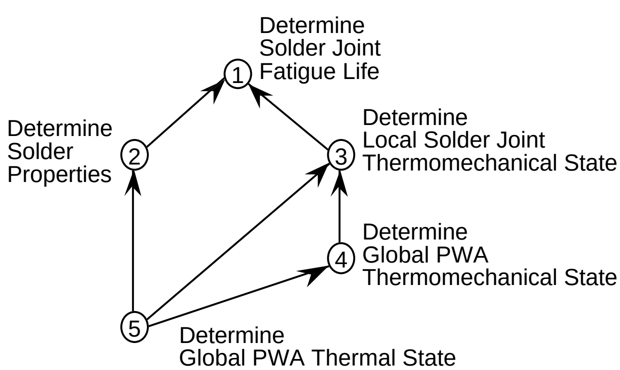


Figure 4 Major Steps in Solder Joint Fatigue Analysis

Step 2: Develop PBAMs and Related Entities

In this step the Integrator develops PBAMs and related entities that represent these analysis models, consulting with the Designer and Analyst as needed. PBAM development means transforming the informal descriptions from the preceding step into structured representations.

First the Integrator assigns one or more PBAMs/ABBs to perform each major step or variation identified above (e.g., Figure 4). These entities may then be further broken down into smaller PBAMs/ABBs, reflecting the modular, recursive, object-oriented nature of the PBAM and ABB representations.

Next, each PBAM/ABB that does not already exist from previous work is itself developed. This process ultimately results in populated PBAM/ABB structures - computer-processable knowledge representations of analysis models that combine object and constraint graph techniques [Peak, et al., 1995]. For example

Figure 5 gives the ABB structure of a thermal bending entity in STEP EXPRESS syntax [Tamburini, et al., 1996], defining variables and relations among those variables (see the WHERE rules). This ABB (a somewhat generalized version of a bimetallic beam model) can be used in potentially many product applications, and is thus expressed in product-independent terms.

```
ENTITY thermal_bending_system
  SUBTYPE OF( thermomechanical_system );

   (* Analysis Variables *)
  undeformed_length : positive_length_measure;
  undeformed_thickness : positive_length_measure;
  specific_coefficient_of_thermal_bending : REAL;
  total_deflection : length_measure;
   (* Subsystems *)
  (* none *)
   (* Semantically Mapped Variables *)
  (* none *)

  WHERE
   (* Analysis-Analysis Transformations *)
  aat1: deflection =
(specific_coefficient_of_thermal_bending *
undeformed_length *
undeformed_length * temperature_change) /
undeformed_thickness;
  aat2: temperature_change = temperature -
reference_temperature;

   (* Subsystem Conditions *)
  (* none *)

   (* Semantic Mappings *)
  (* none *)

END_ENTITY;
```

Figure 5 Example ABB Representation in STEP EXPRESS

Figure 6 is the PBAM structure of a simple analysis module that applies this ABB to PWB warpage. Analysis linkages explicitly represent the associativity between product model (pwb) and analysis model (deformation model).

```
ENTITY pwb_thermal_bending_model
  SUBTYPE OF(pwb_warpage_model);

(* Product Variables *)
  pwb : pwb;
(* Subsystems *)
  deformation_model : specific_thermal_bending_system;
(* Analysis Variables *)
  (* none *)
(* Semantically Mapped Variables *)
  undeformed_diagonal : positive_length_measure;
  undeformed_thickness : positive_length_measure;
  specific_coefficient_of_thermal_bending : REAL;
  temperature_change : temperature;
  elevated_temperature : temperature;
  reference_temperature : temperature;
  warpage : length_measure;

  WHERE
(* Analysis Linkages *)
  al1 : deformation_model.undeformed_length =
pwb.total_diagonal;
  al2 : deformation_model.undeformed_thickness =
pwb.total_thickness;
  al3 :
deformation_model.specific_coefficient_of_thermal_bending
=
pwb.specific_coefficient_of_thermal_bending;
(* Analysis-Analysis Transformations *)
  (* none *)
(* Subsystem Conditions *)
  (* none *)
(* Semantic Mappings *)
  sm1 : undeformed_diagonal =
deformation_model.undeformed_length;
  sm2 : undeformed_thickness =
deformation_model.undeformed_thickness;
  sm3 : specific_coefficient_of_thermal_bending =
deformation_model.specific_coefficient_of_thermal_bending;
  sm4 : temperature_change =
deformation_model.temperature_change;
  sm5 : elevated_temperature =
deformation_model.temperature;
  sm6 : reference_temperature =
deformation_model.reference_temperature;
  sm7 : warpage = deformation_model.deflection;

END_ENTITY;
```

Figure 6 PBAM Representation of a PWB Warpage Model

To aide the development process, the Integrator typically starts by sketching graphical views of the PBAM/ABB structures that are more human-friendly. Such views include constraint schematics (emphasizing relations among variables and subsystems - Figure 7) and object relationship diagrams (emphasizing object-oriented relationships such as entity-attribute and super class-subclass). In the end, each relation and variable identified in Step 1 should be reflected in the developed entities - either directly or spread among several entities per good object-oriented thinking.

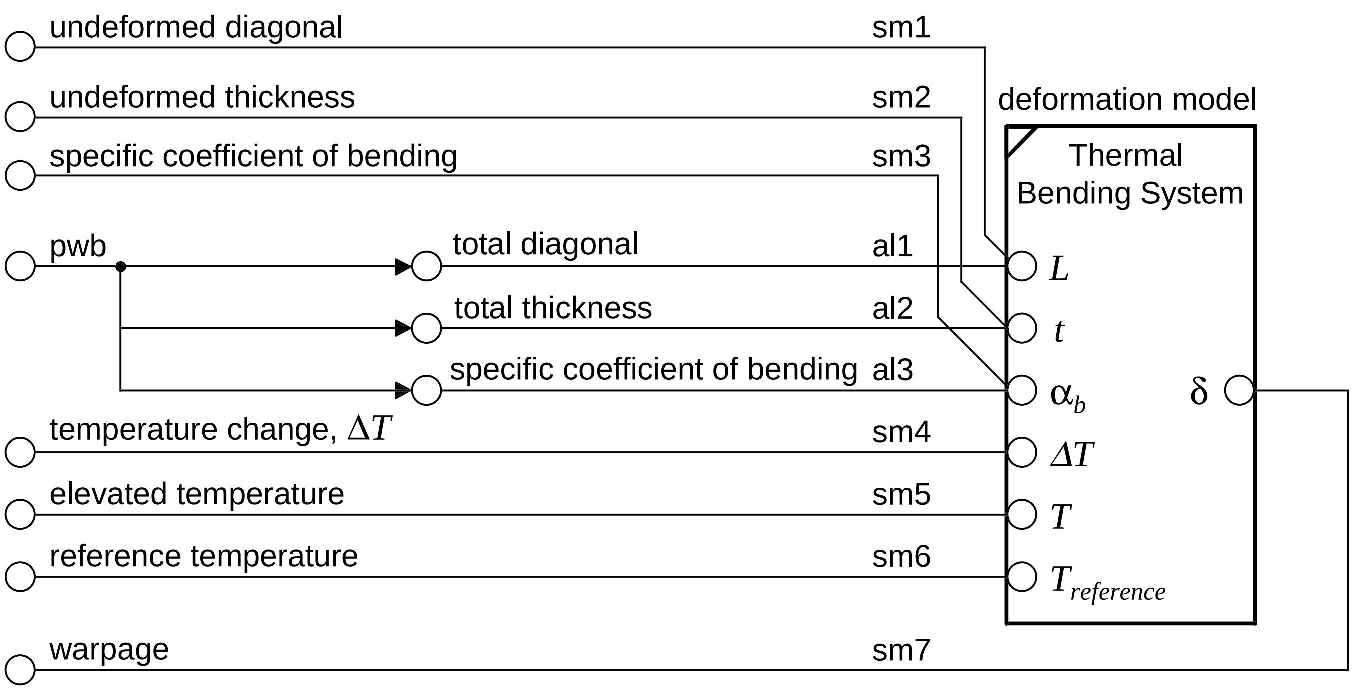


Figure 7 Constraint Schematic of a PWB Thermal Bending Model

The Integrator (a person familiar with the MRA and associated object and constraint techniques) must also perform other roles in this process (or interact with other people who do):

Product Modeler - Works with the Designer to identify the root sources of the design data used in the analysis models. Extends linkages between these design tools and the MRA analysis-oriented product model that drives the analyses, including supplying missing data and idealizations [Tamburini, et al., 1996]. Creates and maintains example datasets.

Parts Librarian - Similar to the Product Modeler, but specifically focuses on parts libraries (e.g., electrical components). Maintain links to, and coordinate data keys by which the parent reference the library entities (e.g., part number for PWA-component references). As analysis often requires, for example, component details like materials and parameterized 3D geometry not found in typical ECAD systems, the Parts Librarian typically needs to create a semantically richer integrated component library view with links to the other component libraries.

Materials Librarian - Similar to the Parts Librarian, except for materials. Again, a single richer library view may be needed with links to internal and commercial databases.

Tool Specialist- Someone for each design and analysis tool involved who understands the operation of the tool and the interfaces to it. Helps other people use the tool. Assists Analyst in creating exemplar solution tool inputs. Works with Integrator to wrap the tool for automated use via a framework.

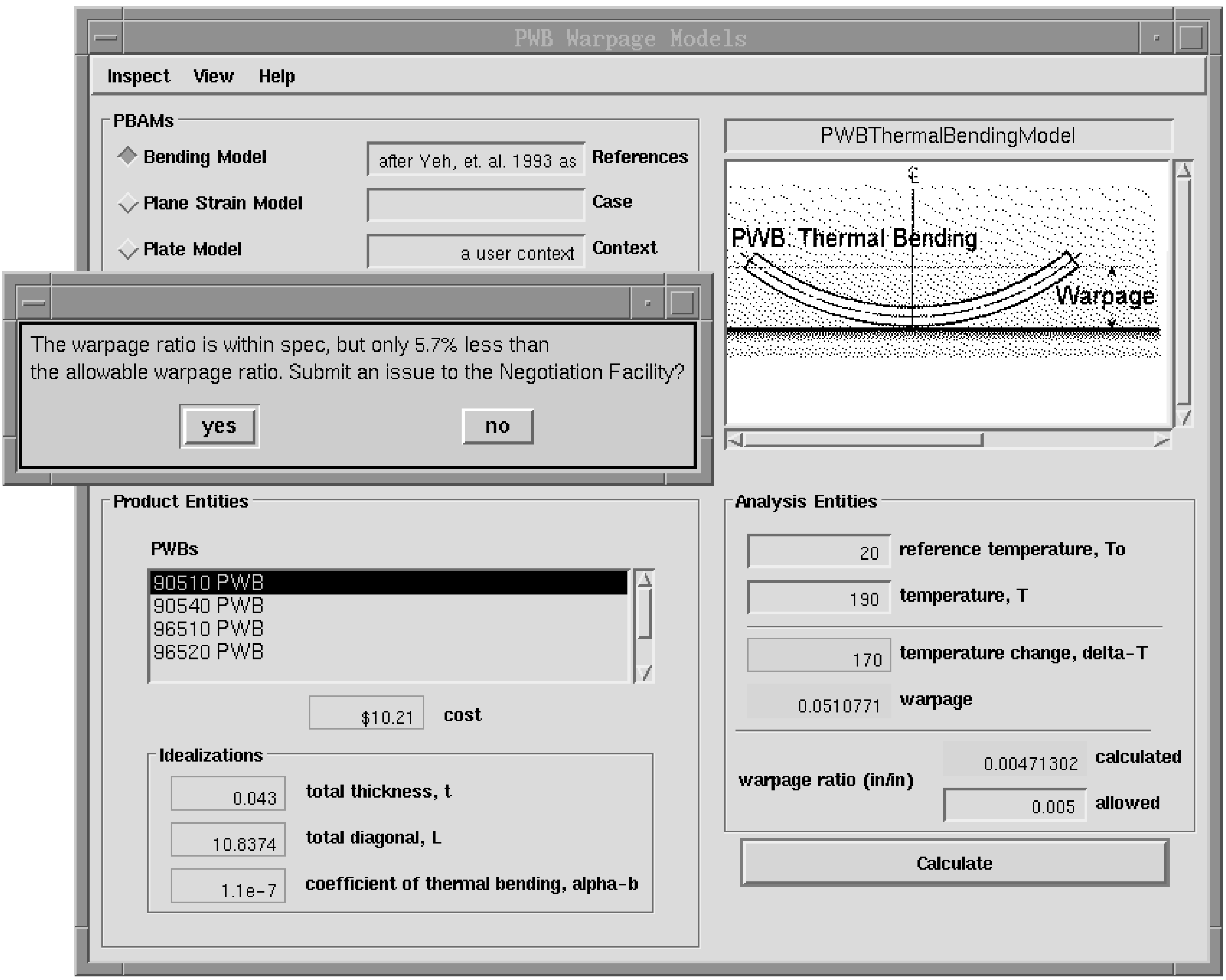
Step 3: Implement PBAMs and Related Entities

Based on the populated structural views developed above, the Integrator next implements new PBAMs and supporting entities in a specific computing environment. The present representative implementation, *DaiTools*, is a product-independent design-analysis integration toolset that facilitates finite element-based solutions using Ansys and Cadas SMMs, and maintains constraints using the SkyBlue constraint solver [Peak, et al., 1995]. The examples come from the PWA-specific analysis tool, *DaiTools-PWA*, built upon this generic foundation. A STEP AP210-based link with the Mentor Graphics PWA layout tool is underway in the TIGER Program [TIGER, 1996] which will utilize the technique described by Tamburini, et al. [1996].

Given the PBAM/ABB structure as a computer-processable spec, PBAM/ABB implementation is largely automated in *DaiTools*. Classes corresponding to each entity are automatically created. When a PBAM is used, an instance of the corresponding class is created which contains variables and relations (generated as constraints in a constraint graph). PBAM subsystems (other PBAMs or ABBs it uses) are recursively instantiated in the same automated manner.

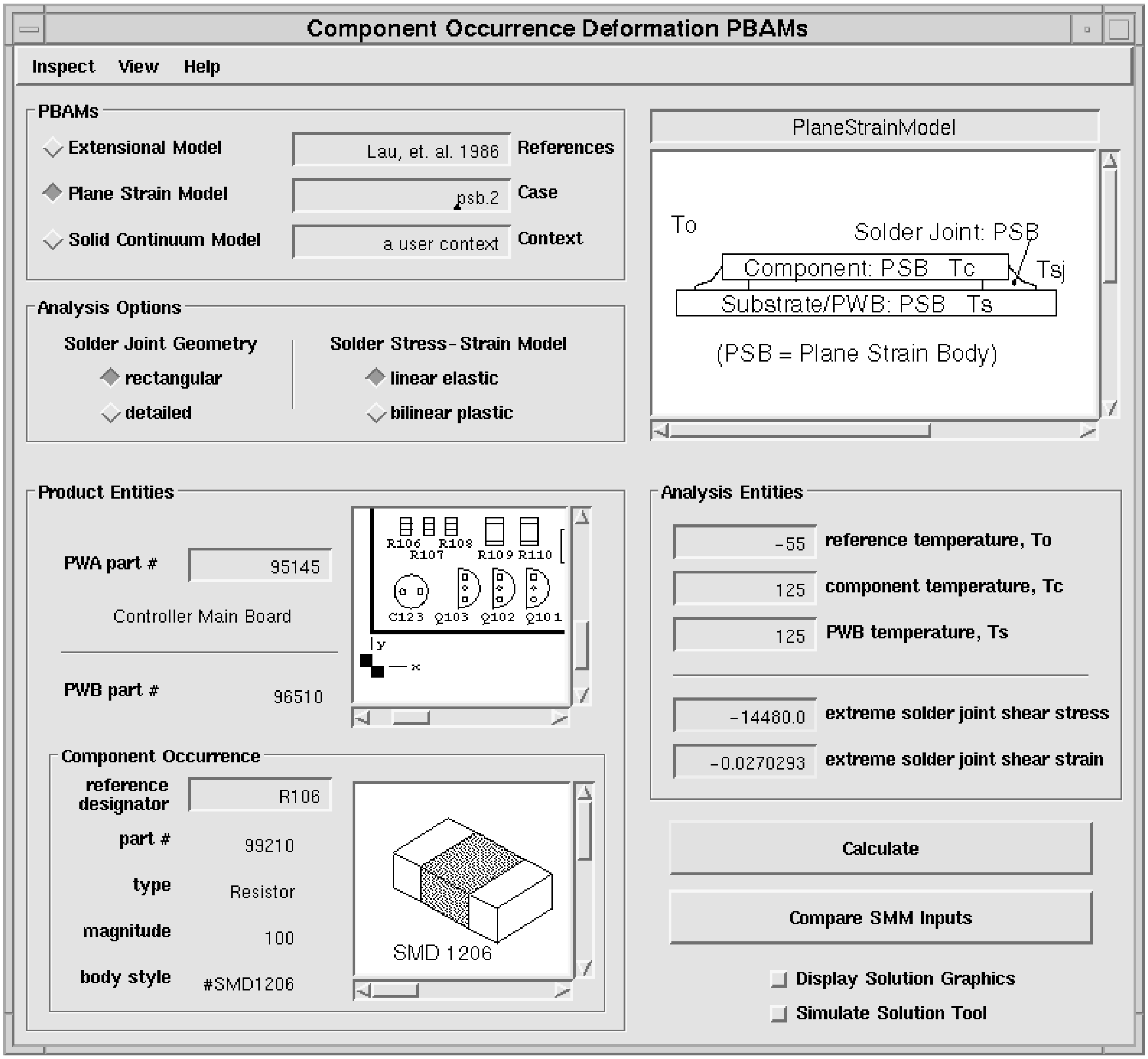
In a less automated manner, the Integrator implements graphical user interfaces (Figure 8) for each analysis module catalog (a family of related PBAMs). The Integrator also documents the modules in specs that include textual discourse, the PBAM/ABB structure and graphical views, and hyperlinks to related entities and references (Figure 9). Finally, the implementation and documentation is verified by the Analyst and Designer, using the example datasets as a reference.

After the analysis modules are verified, the routinization process is complete and the next phase of the MRA methodology is entered: users regularly applying the PBAMs to check product designs (Figure 2). Figure 10 shows such usage where shear strain results are automatically obtained from the 3D solder joint deformation module (from the Figure 8b catalog) using the Hitachi Cadas FEA system. Overall, the MRA methodology provides a way to create extendible, modular, product-specific routine analysis tools.



a) PWB Warpage

Figure 8 Analysis Module Catalogs in *DaiTools-PWA*



b) Solder Joint Deformation

Figure 8 Analysis Module Catalogs in *DaiTools-PWA*

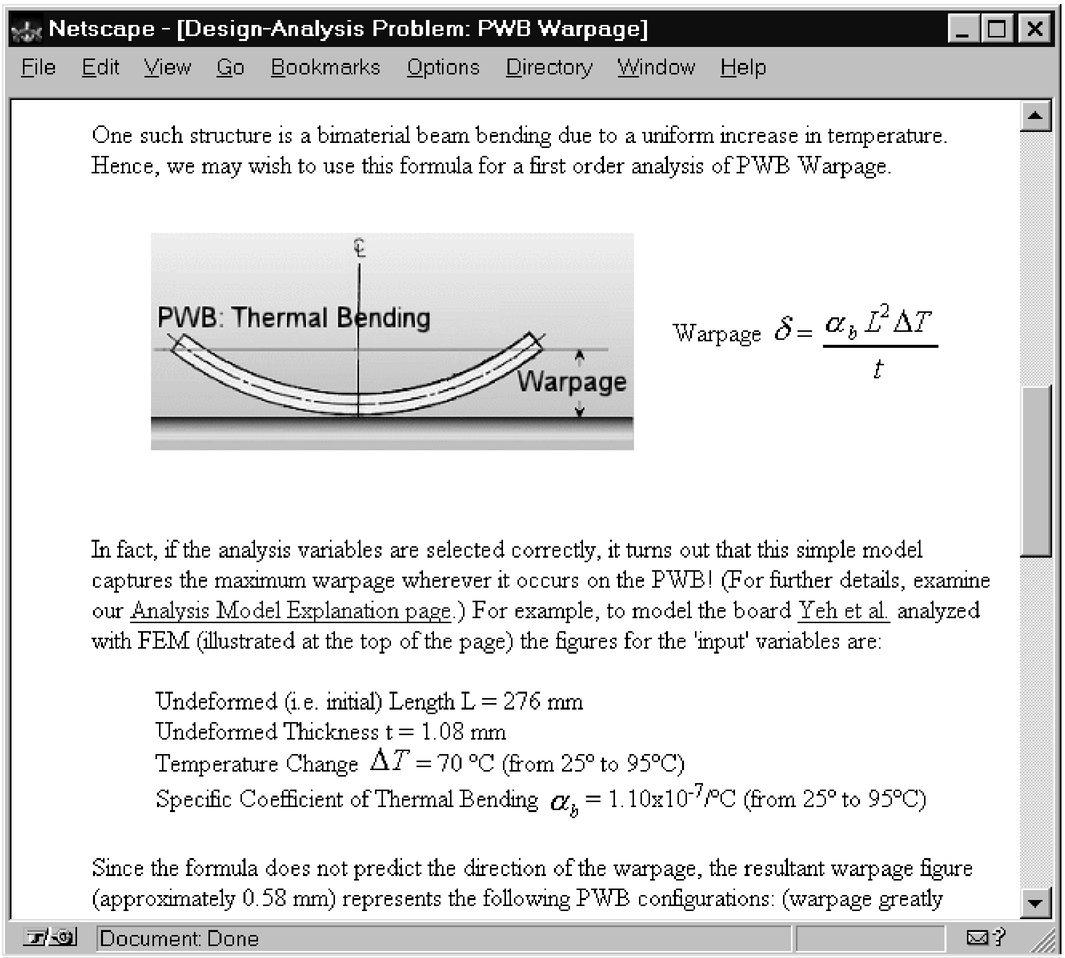


Figure 9 Example Analysis Module Specification

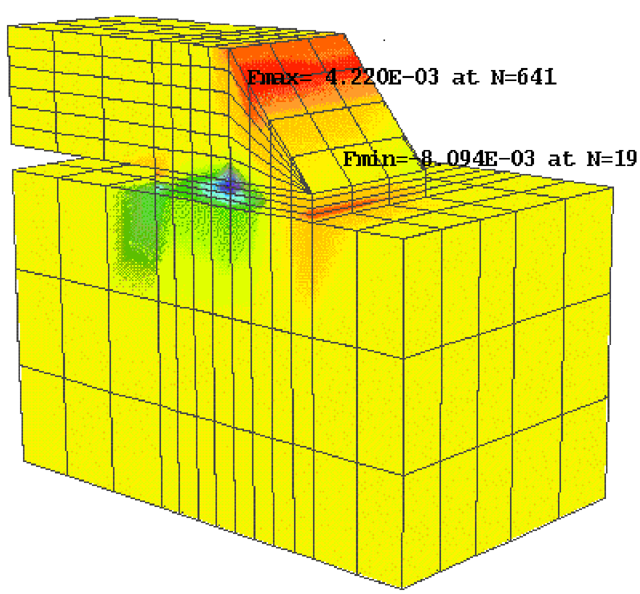


Figure 10 Autogenerated Solder Joint Shear Strain Results

OTHER EXAMPLES

In the TIGER Program [1996] analysis models are being routinized to aide engineers at a representative PWB fabricator (Holaday Circuits, Inc.) in reviewing STEP-based designs for potential warpage and plated through hole (PTH) expansion problems. In this case the manufacturing engineers play the role of PBAM User (vs. Designer above), the Analysts are researchers in the Georgia Tech Computer Aided Simulation of Packaging Reliability Lab, and the Integrators are researchers in the Georgia Tech Engineering Information Systems Lab.

PTH work by Sizemore and Sitaraman [1995] is being transformed into analysis modules to check if a PWB design might inherently have trouble passing the solder pot test. As in previous cases, one of the most valuable inputs to the Integrators has been parameterized versions of the FEA preprocessor input files. Much of the descriptive information in Step 1 of the routinization process can be inferred from such files.

Other routinization efforts underway include an initial PWA warpage model (with components) based on a product information-driven technique by Zhou [1996].

DISCUSSION

Some observations from experiences with the routinization process include:

Knowledge capture - The MRA approach to Design-Analysis integration is in part the construction of an expert system. (For example, refer to Figure 3 and replace the term 'Integrator' with 'Knowledge Engineer'.) The MRA can be conceptualized as a domain-specific expert system shell which allows the Integrator to capture 'knowledge' about:

- the specific input needs and output details of solution tools (stored in SMM objects, or 'frames' in expert system terminology)
- technique specific considerations, such as symmetry and mesh density for FEA (stored in ABBs)
- those product attributes which are analysis driven, such as temperature dependent material properties for PTH analysis (stored in PMs)
- the usage of idealizations necessary to link given analysis methods with given products. We term this usage design-analysis associativity linkages. (stored in PBAMs)
- the structured relationships among the MRA components- PMs, ABBs, SMMs, and PBAMs- which represent the use of analysis models. (stored in PBAMs and ABBs)

In brief, the MRA captures the expertise of the analyst and provides it as knowledgeable advice to the designer. As a frame based formalism for knowledge representation, the MRA enjoys the widely recognized benefits of expert system technologies: rationalization, improved quality, and positive organizational effects in companies [Puppe, 1993].

Synergy of specialists - Designers benefit from the routinization process by getting tools that meet many of their needs (Section 1) and help them design better products. Analysts benefit by their work getting more exposure. Without the modules, barriers like computing tool complexity can make regular application of their work unlikely. Thus, the analysis modules become a focal point of common ground between Designer and Analyst.

As the modules enable the *Designers* to perform *routine* analysis, Analysts also are freed from this task to focus on new challenges. As a side benefit, the precise nature of the PBAM structures sometimes brings out unknown gaps in analysis capabilities, thus revealing new potential research topics.

Catalyst for more analysis - Designers say they would like to have routine analysis modules, but often have few answers when asked what specific analyses they perform regularly today. Simply explaining the definition of routine analysis and a process like Figure 1 can spark curiosity and enthusiasm. As eluded to above, beginning Step 1 often leads to a detour or parallel effort to first develop an analysis model itself before attempting to routinize it. One can begin this adaptive/original analysis process by identifying what questions the Designer wants an analysis module to answer.

Ensuring proper usage - One concern sometimes raised is proper usage of the analysis modules, as their high degree of automation can potentially make it easier for someone to misuse them. The ABB and PBAM representations currently do not include explicit checks, for example, on assumptions being violated; such guidelines can be included in the textual specs, but automated checks are admittedly more desirable.

Usage by non-Designers - The TIGER scenario has reinforced that engineers other than designers can benefit from routine analysis. Manufacturing engineers, with access to real-time process information, could use analysis modules to check how their processes are operating, as well as ensuring producibility of a particular design.

SUMMARY

This paper describes a methodology called routinization which creates product-specific analysis modules for usage by physical designers. The roles of Designer, Analyst, and Integrator in this process are identified. Example modules for solder joint fatigue, PWB warpage, and plated through hole deformation are discussed. Resulting modules obtain inputs from product design data and yield results using commercial analysis tools in a highly automated manner. Other benefits include capture of analysis knowledge in a persistent, computer-processable form.

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1 Some references are available at www.eislab.gatech.edu.