How Process Implementation Underpins Design Strategy

Putting Best Practice into Practice: Experiences with WorkXpert

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1 Abstract

BAE Systems Avionics faced a number of challenges in its hardware engineering operation, ranging from the need to improve competitiveness to the need to standardise the design culture across a number of business locations. An implementation of Mentor Graphics' WorkXpert tools has enabled Avionics to deploy a common printed-board design process across all of its UK engineering locations, enabling a "design anywhere" strategy and simplifying support, training and process-upgrade activities. Over time, the scope of the managed process has been extended to include a common library and library-part development system, technical reviews, and interfaces to a PDM system. The process also provides input for the organisation's work-package estimating, progress reporting and process-performance metrics.

This paper describes how we were able to deploy a sophisticated concurrent board design methodology to multiple sites, in a consistent and coherent manner by using WorkXpert to define and manage the process. It includes examples of business benefits.

2 Why A Common Process?

As a major defence electronics contractor, BAE Systems places demands on the tools and processes it uses to develop its products, in terms of their capability, usability and business efficiency. An extra dimension of this industry is that the customers' platforms need to be in service, and be supported, for upwards of twenty years.

Avionics' hardware engineering teams are dispersed across a number of UK locations and the product lines they work on are varied (including electro-optical, radar, countermeasures and communications systems). It is a fact of life in this business that corporate re-organisations occur with some frequency; both internal re-groupings and externally-visible mergers or divestments. Each event brings a change of management emphasis, possibly different markets, and certainly different teamings with colleagues in other locations. However, there remains a core business which continues to engineer solutions to customers' needs. This requires a degree of continuity and of continuous improvement to deal with increasing product complexity and pressures on project costs and schedules.

A few years ago we defined a strategy to help provide some stability to our hardware engineering function. We needed a "design-anywhere" capability to make best use of our expert resources, wherever they are located; this required a policy of Group-wide collaboration and a drive to openly share good practices.

By adopting the Group-wide approach, we also aimed to benefit from economies of scale. We selected preferred suppliers of tools and gave them medium-term contracts for licenses and support. Also, with a reduced tool-set we were better placed to develop stable and focused training materials, and simplify technical and administrative support.

The dynamics of electronic technology mean that we must continuously improve our tools, methods and processes. If this is to be done efficiently, we must make each change once and ensure that the maximum number of engineers benefit from that change; so efficient process maintenance is another strategic building block. Finally, we must measure how well we are doing and use that data to guide the next improvement stage. This is so much easier if we have a common process from which to extract performance metrics.

3 What Form Of Process?

Up to the mid-1990s Avionics had used an essentially serial board-design process. This had worked for business units at a time when different brands of EDA tools were used in combination, and perhaps where different projects used variations of the design process. However, the serial approach had its limitations; tools were more likely to be interfaced rather than integrated and design iterations embracing circuit and layout changes were expensive and time-consuming. Schedule pressures on engineering developments, coupled with increasing complexity and denser functional integration on the board, meant that the serial approach was no longer the most efficient.

Mentor Graphics offered a concurrent board methodology (Figure 1) supported by data management tools which engineers were required to use to maintain design data integrity. Avionics had already adopted a strategy of "left-shifting" its engineering processes; this is an approach to reducing costs and time-scales by making early design decisions which mitigate technical risk later in the life-cycle. At the level of PCB design, performing physical design tasks while the circuit design was still maturing provided opportunities for early exposure of layout-related problems and for time-scale reduction.

However, concurrent working is innately more intricate than executing a serial process and introduces its own complications. By the end of the initial phase the circuit schematic must be sufficiently developed to support useful physical design. During the concurrent phase the physical and logical views necessarily diverge.

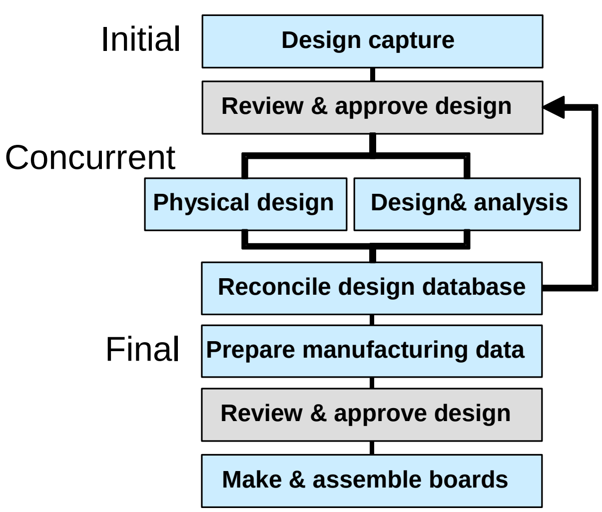

Figure 1. A simplified Concurrent Board Process

Without process management support, it was left to engineers to use data management tools to synchronise these views; bringing them back into line ready for the next iteration or the final design phase.

Having several engineers interacting throughout a number of work-in-progress iterations creates the need for careful version management to avoid confusion over the current state of the evolving design.

4 Implementation, Integration, Re-configuration

With the decision made to base our PCB design flow mainly on Mentor Graphics' tools, the next step was to engage with Mentor Consulting to plan the process encapsulation activity and determine how work was to be conducted. Over the years of development, this has settled into a collaborative effort with good understanding between key engineers.

4.1 Process Management Tool

WorkXpert is a family of tools targeted at the problem of managing and executing complex design processes. It provides a range of capabilities, starting with capturing what is perceived as best practice. While interacting with the user, the process is faithfully executed, managed and observed; process data is logged and reports may be created. Rather than being just a concept, the design methodology actually becomes the medium through which the engineers perform the design task.

The tool-set comprises:

- XpertBuilder – provides a graphical environment for building process templates, defining how they look and how they work
- FlowXpert – is a multi-user environment that uses a flowchart paradigm to guide people through the execution of the process.
- ProjectXpert – is used to manage related sets of live workflows and to view status information about them.

As a generic solution, WorkXpert can be applied to the management of any complex design process, be it a board process, a library process, an IC design process or whatever. As in the Avionics application, WorkXpert can manage design processes requiring a mixture of design tools from different vendors.

Other process management capabilities include:

- Control mechanisms to ensure that a user cannot perform an action when it is inappropriate to do so. It can also mean that necessary operations do not get forgotten, especially when iterations are being performed over a series of process steps.
- Quality gates, such as on-line reviews of the design.
- A permissions mechanism to dictate who is eligible to perform key operations within the process, such as sign-off.
- Checklist mechanisms that allow accountability to be built into the process.

In addition, a range of communication capabilities is provided. Process status is readily visible to all interested parties. As events occur within the process, email notifications can be sent out automatically to the affected parties. As process steps complete, details may be appended (either manually or automatically) to form a kind of electronic log-book which may be used as a design audit trail.

By removing the need to interpret process intent, an encapsulated process simplifies the engineer's life. Less experienced engineers, those who create designs infrequently, or contractors, are led through the process and add value to the organisation far more quickly. A WorkXpert flow shields users from inherent complexity in the process, allowing them instead to focus on the complexities of the design task itself. Indeed, a measure of success is the important fact that its easier for an engineer to do his job using the flow than would otherwise be the case.

4.2 Concurrent Board Methodology

The most obvious feature of the concurrent board process is the middle section where physical design and circuit design steps run in parallel (Figure 2).

Here, many of the features of process management are evident. The process stages are presented and enabled according to the state of the design data. User roles are defined for each of the two parallel limbs. Progress of each designer is communicated tacitly, via visible step status. This phase also presents the greatest challenges for design data management, in the form of:

- Diverging representations (physical layout versus logical schematic)
- Maintaining viewpoints with back-annotations
- Reconciling the design intent before conducting the next design phase.

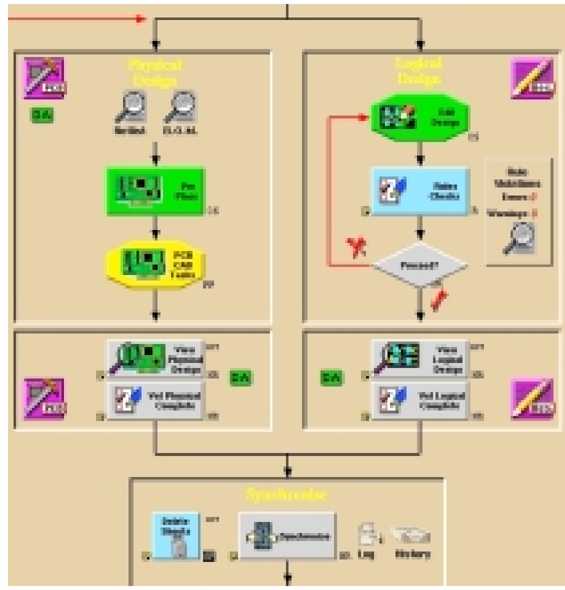

Figure 2. The Concurrent Phase

Most of this "housekeeping" is done behind the scenes in as automated a manner as possible. Necessarily, some design conflicts require brief manual intervention to select the appropriate option.

The second significant feature is that multiple roles need to be engaged in the design (e.g. designers, analysts, expert observers, design authority) if its quality is to be enhanced as early as possible. To achieve this we define the essential types of role and allocate them to individuals when we create the workflow instance for a particular design. Automatic email notifications and the easy ability to access design information mean that the right people are made aware of their obligations at the right time.

4.3 Library Part Creation

Another aspect of Avionics' design methodology, also common across the organisation, is a library-part development process. This uses a combination of a set of pre-defined WorkXpert flows and Mentor Graphics' Data Management System (DMS); the latter includes a class for implementing a part-request mechanism. The flows, which guide the creation of part views, are launched directly from buttons within the DMS GUI. The librarian is steered through the process of constructing each of the individual views of the part and validating that these views are consistent with one another. This provides a guarantee that the only data that reaches the library is good data; all the required tests and checks are *known* to have been performed before the part was added to the library. In addition, evidence and historical information is preserved which records the evolution of the part. As component technology evolves, the tests that are required to be performed on library parts also need to evolve; use of the library-part flows ensures that these updated tests are applied consistently.

The workload of an ECAD librarian is typically sporadic, often linked to the commencement of new designs. The common library specification and part-creation workflows mean that any librarian who is available, on any site, can commence work on a part-request. The requester gets a faster response and can be confident of the same level of quality in the delivered part, regardless of which librarian has fulfilled his request.

4.4 Tool Encapsulations and Flexibility

Avionics' PCB workflow relies mainly on tools from Mentor Graphics Board Station family. By virtue of the AMPLE extension-language capability, many of these integrations are tight and bi-directional, where data is passed from the flow to the design tool, and where (under the appropriate circumstances) data can be passed from the tool back to the flow. Our board process also includes integrations with third-party tools, including the "Saber" mixed-signal simulator from Synopsys and the "Enterprise 3000" DFM analysis tools from Valor. Appropriate data formats are created automatically to pass design information between tools.

However sophisticated, no process encapsulation can be too fixed in time because electronic technology continues to develop and present new design challenges. The Avionics implementation permits flexibility in daily use and in development potential.

Although recommended as a concurrent design process, there is no reason why it cannot be operated in a traditional - serial - manner. The schematic could be completed during the initial phase; from that point on only the physical layout steps would be executed.

Another usage option relates to user roles. Within a project team, we would normally assign a number of responsible roles but this feature can be tuned. In the extreme case, one person could design the circuit, do the layout, complete the manufacturing data pack, approve the work, and so on. So the rigour applied to process administration can be flexibly interpreted.

We also allow for cases where the use of verification tools may be configured on a site-by-site basis.

There are times when it is useful to drop out of the workflow process altogether. An established feature of the flow supports the ability to sub-contract the board layout to a third-party design-service. This part of the flow, during the concurrent phase, packages the design database and suspends process execution until a layout database is returned and re-loaded. The same process portal may be used when engineers need to build hardware breadboards for design proving. The important point here is that the process logic guarantees all the required data needed by the third-party is transmitted to them, and also guarantees the correct re-integration of data from the third-party into the design environment.

Periodically, new tools emerge and offer novel solutions to engineering problems or new ways of achieving results. Here are some examples.

We have successfully used ICX (for digital signal integrity analysis and guided board layout) in conjunction with the PCB workflow.

FPGAs in our designs typically have pin counts in excess of 1000 pins, so we need help to manage the interface between the device and the evolving PCB layout. We have evaluated I/O Designer alongside the workflow to automatically handle changes made in either domain, ensuring data accuracy and optimal electrical design.

Xtreme PCB is a new infrastructure technology which offers cycle-time reduction by permitting a number of layout engineers to work concurrently on the same physical design database. We have found a way to adopt this method of working in the context of workflow, even though the tool is not yet embedded in the flow.

4.5 Process Integration

The hardware design process does not exist in isolation. It requires input data and documents and it creates output data and documents. In addition to the ECAD library interactions, mentioned above, here are two more examples.

Prior to each technical review, the flow automatically transfers design data to the organisation's PDM system, Metaphase, using that tool's API. This ensures that the correct data is saved to the PDM system at the right time, without input from the designer and without scope for error. The PDM system also provides a universal viewing facility for reviewers who may not use the ECAD tools.

The performance of that part of the hardware design process managed by PCB workflow is closely related to the process that generates the schedule and cost estimate for the job. To monitor progress, and to gather data to refine our estimating procedure, we have linked the workflow to our project work-package management

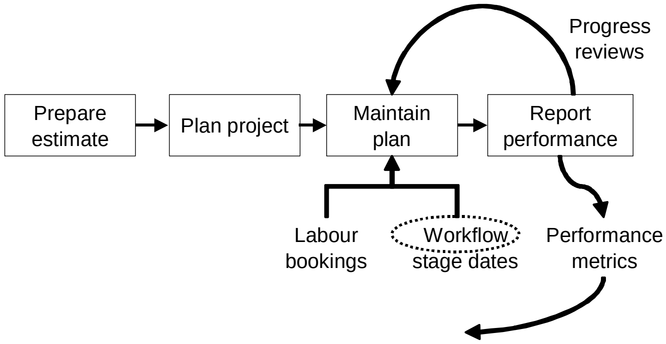

Figure 3. Work-package Management Process

process (Figure 3). We use the workflow activity log file to provide actual dates of completed design stages.

A further aspect of integration is the use of links, directly from the workflow, to our intranet. These include access to support documents (e.g. on-line training material), an on-line form to request a library part and a user-feedback form to comment on the workflow itself.

4.6 Re-configuration

The PCB workflow has evolved through a number of versions since its inception; this is necessary since methodologies *do* change over time. WorkXpert copes with this and allows process status, metrics and history information to be preserved when active flows are updated. Between version 1 and version 6, development has concentrated on the initial, three-phase concurrent board process described above. It has gained in sophistication and intricacy of the control logic; it has rooted itself in the business system by means of hooks to other parts of the infrastructure.

A recent development in our hardware design strategy has been the introduction of technical stage-reviews, (Figure 4).

Based on guidance contained in DO-254/ED-80, we have developed a management layer (the so-called "Module Design Process", MDP) which assesses the quality of the emergent design, at a number of defined stages, while identifying and dealing with technical risk. This has given rise to a complete re-configuration of the workflow (in what we call version 7). In this version, we have re-organised the process steps to directly map on to stages of the MDP. Most of the workflow steps are identical to the previous version but re-grouping them has resulted in a more relevant structure and a more meaningful presentation to the designer.

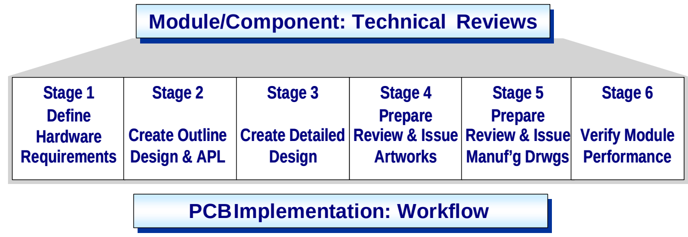

Figure 4. Technical Review Stages

Workflow ensures design information is consistent and available at the right times for review. We also have control over the progress of design implementation, coupled to the outcomes of stage review meetings.

Effectively, PCB workflow now delivers the technical management process to the engineer's desktop, *as well as* the design implementation process and embedded tools.

5 Evidence Of Success

In total, about 800 designs have been successfully implemented using one version or other of the PCB workflow. We also have over 6000 parts in our component library. In almost all cases, new design starts are implemented using the flow because it is the preferred route to manufacture for reasons of control, consistency and economics. When a new board design is first registered, a workflow instance for that design is routinely created as part of the project start-up procedure.

In general, because it is easier for the engineer to get his design done using the flow within the common process context, we adopt a single-minded approach to the provision of our training and technical support services, paraphrased by "Don't call us for help if you are not using the common process!" To that end, Mentor Graphics and Avionics have jointly tailored training material so that education of hardware engineers is delivered in context.

Recently, we probed our history of workflow log files and extracted stage duration metrics to compare with those in the new Module Design Process. Contrasting data from the year 2000 with data from designs completed in 2004, we identified the following:

- Proportionately, there is more design activity now in stage 2. That's good! We call it "left-shift" and it means we are spending more time getting the design concept right before moving into physical layout.

- The overall time to complete a design has reduced, on average. That's obviously good for business.
- And although we were not measuring it, we know very well that the complexity of our boards has increased considerably over the past four or more years. (By the way, we are now monitoring Opportunities For Defect (OFD) as a complexity indicator.)

We have long held an aspiration to obtain useful business information from the metrics we collect; now we have the technology to make this an easy reality.

The evidence from this simple metrics comparison should not be stretched too far. We are not claiming it is only workflow that has yielded the benefits. We do claim that the consistent strategy for hardware design, which led to workflow and the other developments described here, has strongly influenced, in a positive manner, the hardware engineering culture in Avionics.

6 Considerations

It's reasonable to point out a number of considerations you should bear in mind regarding the WorkXpert tools.

WorkXpert is not a solution that you can just buy and immediately use; rather, it provides a toolkit of enabling technology. You have to think carefully about how, or whether, to make use of the various levels of control that the tools make available to you. You have seen how sophisticated the Avionics process has become over the years. Not everyone may need this level of sophistication. The nature of your organisation will dictate how it is appropriate to use the technology. Some organisations will need, or desire, a very rigidly defined process. Others will want to give their engineers far more day-to-day freedom. It is possible to satisfy *both* needs using WorkXpert.

The task of implementing and deploying a WorkXpert flow is itself a process. As soon as you begin to combine your proprietary practices with a number of EDA tools, and hook all that up to a system for, say, component data management or product data management, you are embarking on a journey. You'll need a good map, a reliable pilot and clear visibility of where you'd like to go.

7 Conclusions

We set out to demonstrate that aspects of a high-level engineering strategy could be delivered and supported by a careful approach to design management processes. The work described has resulted in the adoption of a collaborative approach to electronic design automation across three locations; part of the UK defence systems industry.

The introductions of the workflow and, latterly, the Module Design Process have given rise to common vocabulary among hardware designers and created focal points for training, design administration, help-desk support and on-going process improvement.

We see geographically dispersed engineering effort working on a single design; this "design anywhere" capability is now being reinforced by new collaborative design tools. Our ECAD support engineers and librarians share their respective tasks; our process improvement teams comprise representatives from across the Avionics Group.

Engineers' daily lives are made easier, because they have more time to focus on the design task and feel confident in a secure and familiar design environment. Shared best-practice means that our processes and tools keep pace with technology and make us more capable at managing design risk.

Workflow has been instrumental in helping to achieve the previously unattainable goal of the common parts library, which makes quality parts available more quickly.

We are now in a good position to turn our process metrics data into useful information to inform the management of current tasks and to help determine areas for improvement. This capability also helps when we prepare our case for CMMI & ISO 9000 assessments.

We have leveraged value from our preferred tools suppliers, not only by volume leasing agreements but also by engaging them in the strategy at all levels.

We are beginning to see that our overall process performance is improving, even in the face of increased complexity (equating to technical risk) on our circuit boards. We have demonstrated that the results of our effort are amenable to evolution and transformation to fit the future needs of our challenging business.

8 References

DO-254/ED-80 "Design Assurance Guidance For Airborne Electronic Hardware", Federal Aviation Administration, April 2000

9 Acknowledgements and links

WorkXpert details: www.mentor.com/workxpert
BAE Systems corporate website: www.baesystems.com