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MILITARY PRODUCTS FROM COMMERCIAL LINES

VOLUME IV - LESSONS LEARNED

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February 1999

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Materials & Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, Ohio 45433-7734

NOTICE

This technical report has been reviewed and is approved for publication.

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13. ABSTRACT

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines" (MPCL) is an Air Force Manufacturing Technology program contracted to TRW Avionics Systems Division and subcontracted to TRW Automotive Electronics North America. The mission of this program was to demonstrate the commercial manufacture of military electronics modules, and measure and migrate results. This volume of the MPCL final report includes a collection of lessons learned from the program. These write-ups are intended to capture anecdotes of MPCL for documentation of progress and for the benefit of organizations that will apply MPCL and commercialization concepts in the future.

Each write-up has been cleared for public release through the ASC Public Affairs office, ASCPA, at Wright-Patterson Air Force Base.

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FOREWORD

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines" (MPCL) is an Air Force Manufacturing Technology program contracted to TRW Avionics Systems Division and subcontracted to TRW Automotive Electronics North America. The mission of this program is to demonstrate the commercial manufacture of military electronics modules, and measure and migrate results. This volume of the MPCL final report includes a collection of lessons learned from the program. These write-ups are intended to capture anecdotes of MPCL for documentation of progress and for the benefit of organizations who will apply MPCL and commercialization concepts in the future.

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a) The IBAHRS Comparison, ASC-96-0096
b) Merging of Military and Commercial Electronics Development Processes, ASC-96-0094
c) Non-Intrusive Integration of CIM Upgrades, ASC-97-0005
d) Commercial Parts for Military Designs, ASC-96-0095
e) Manufacturing Process Development for Low Volume/High Cost Products, ASC-96-0097
f) The Business Case for Building Military Products on Commercial Lines, ASC-96-2263
g) Cultural Disparity Between Military Contractors and Commercial Manufacturers, ASC-96-2265
h) Concurrent Engineering Environment for Distributed Project Teams, ASC-96-2264
i) IBP Component Reliability Test No. 1, ASC-97-0007
j) CIM High Level Design Documentation, ASC-97-1587
k) Evaluation of Industrial Surface mount Plastic Encapsulated Microcircuits for Military Avionics Applications, ASC-96-1525
l) MPCL CIM System Integration, ASC-98-2066
m) Design Guidelines for a Combined Military and Commercial Product Development Team, ASC-97-0006
n) Commercial Suppliers and Government Purchasing Restrictions, ASC-98-0042
o) MPCL Commercial Item Determination, ASC-97-1588
p) The Roadmap to Military Products from Commercial Lines: Commercial Item Determination and the Use of Price Analysis, ASC-98-0041
q) MPCL ASIC Lessons Learned, ASC-99-0738
r) MPCL Lessons Learned: The Quality Model, ASC-99-0737
s) MPCL Lessons Learned: Product Data Management (PDM), ASC-99-0736

The IBAHRS Comparison

A study of differences in cost between military and commercial manufacture of the same product.

Introduction

"Military Products from Commercial Lines" is an Air Force Manufacturing Technology pilot program contracted to TRW Avionics and Surveillance Group (ASG), a defense contractor, and subcontracted to TRW Automotive Electronics Group (AEG), a commercial manufacturer. The pilot mission is to demonstrate changes in Business Practices (BP), manufacturing infrastructure, and process technology for the commercial manufacture of military electronics modules. An overall objective is the facilitation of Department of Defense business with the commercial industrial base. Demonstration vehicles include the Pulse Narrowband Processor and the RF Front End Controller, which are Communication, Navigation, and Identification (CNI) modules used for the F-22 fighter aircraft and the Comanche helicopter.

During the TRW pilot, the BP team was responsible for identifying BPs for change, defining their methodology, then beginning some analysis. The challenge to the team at this stage was in scoping those BPs which the pilot can affect and which will have high impact in breaking down the barriers for military-commercial integration. The IBAHRS Comparison was one of the tools the team chose to help identify BPs for change.

IBAHRS Comparison Approach

The Inflatable Body and Head Restraint System (IBAHRS) is an airbag system used in military helicopters. The IBAHRS crash sensor module is very similar in design to automotive airbag modules which TRW AEG builds at their manufacturing facility in Marshall, Illinois. The BP team's approach to the IBAHRS study was to give AEG a bill of materials for the IBAHRS module and have them quote labor, material, tooling, and overhead costs in order to build such a module in their facility. The costs then would be compared to actual cost data from TRW's ASG plant, where the military modules are built. Some of the AEG business practices assumed in this study are listed in Figure 1.

AEG Estimate

- Quoted manufacturer vs. distributors
- Quoted mechanically identical auto-grade parts
- Quoted radial vs. axial capacitors because they are cheaper and more reliable
- Quoted surface mount vs. through-hole resistors for automation purposes
- Quoted surface mount vs. dip ICs for automation purposes
- Quoted the test fixture, not recurring test charges for PWBs
- Quoted testing at product level, not component level

FIGURE 1

Results

The overall results of the IBAHRS Comparison study are shown in Figure 2. ASG costs are greater than AEG costs for labor, overhead, and material. Greater labor cost on the part of ASG may be attributed to more inspection requirements and much less automation as compared to AEG. High ASG overhead costs are attributable to labor and systems required to meet contractual BPs as well as some technical BPs, such as quality. Material costs for ASG are higher than AEG, most likely due to volume buys and parts selection and control. AEG costs are higher than ASG costs only in the category of tooling. This is due to the high degree of automation in the automotive electronics assembly plant.

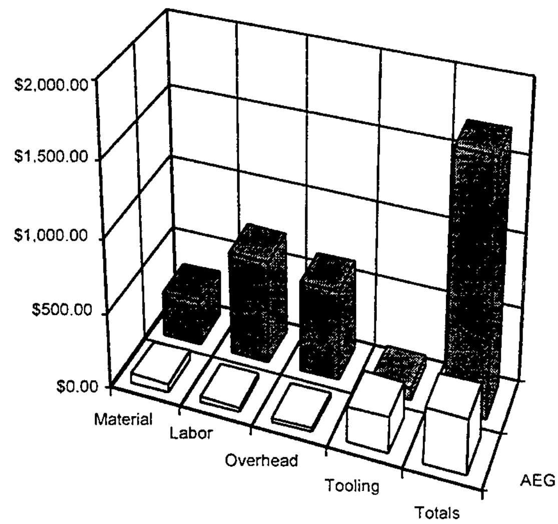

FIGURE 2 - IBAHRS Comparison Results

The graph shows that the total cost estimated for AEG to build the IBAHRS is 21 percent of ASG's actual cost to build the same product. It can be seen that commercial and military cost drivers differ markedly, with overhead cost a big driver in the military environment. Commercial firms leverage tooling to achieve economies of scale and lower unit recurring costs.

Pilot Application

Analysis was performed in the areas highlighted as cost drivers by both the IBAHRS study and a quality function deployment (QFD) analysis. In the QFD, macro processes were ranked by ASG and AEG according to importance (see Figure 3). Further analysis showed that the issues to be addressed in the top two macro processes, Design and Manufacturing, were parts selection and control. Other high priority issues were inspection, oversight, and designing for highly automated, flexible manufacturing. These issues overlapped significantly with those indicated by the IBAHRS study.

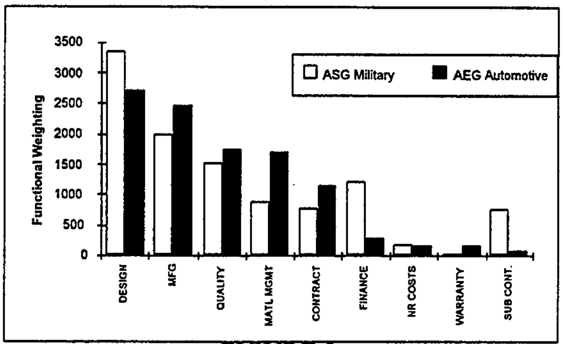

FIGURE 3.

The IBAHRS Comparison highlighted and quantified differences in military and commercial manufacturing costs. It was a significant data point for the BP team and was a key tool in selecting the approach the team should take to meet pilot goals.

Merging of Military and Commercial Electronics Development Processes

Curt Pflasterer, TRW Avionics Systems Division

Objective

The objective of this paper is to describe how a military avionics development process was merged with a commercial electronics development process for the manufacture of military avionics modules on a commercial automotive electronics production line.

Background

The TRW Avionics Surveillance Group (ASG) teamed with the TRW Automotive Electronics Group (AEG) on the Industrial Base Pilot (IBP) program. TRW/ASG designs and manufactures military avionics systems and is a team member on the F-22 program. TRW/AEG manufactures a variety of electronic products for the automotive market. The goal of the IBP program is to manufacture two of the F-22 CNI avionics modules on one of the TRW/AEG Marshall, Illinois production lines. Both the ASG and AEG organizations have the capability to design and manufacture their own products. The challenge for the IBP program is the merging of the two organization's processes to allow cooperative development of the avionics products.

Discussion

Merging of the military and commercial processes involved several steps including the analysis of the two organizations products and processes. An important criteria imposed on definition of the merged process was to not force changes on the commercial organization (i.e. AEG). This criteria originated from the realization that a commercial company is not going to change its business methods so that it can manufacture low quantities of military products. Even though the IBP program is a pilot program, it must function as if operating in the normal commercial environment so that the lessons learned are transferable to the general industry. There is one exception to this criteria, if the commercial company has planned to make changes, which would allow the manufacture of military products, the military company could help accelerate implementation of those changes.

A comparison of the AEG and ASG products reveals that they operate in similar environments. The temperature ranges are similar, vibration parameters vary only in some frequency characteristics, and humidity requirements are similar. There are greater differences in altitude and dust environmental conditions.

In general, the military avionics products are more complex than the automotive electronic products. The AEG automotive products have a greater analog content and some low density digital logic. The ASG military products have a greater digital content including high density ASIC devices.

Due to product differences and customer requirements, the two organizations have selected different CAD tools. This results in incompatible source data files, which would require significant data re-entry and translation effort if the design data were to be transferred between the two CAD systems.

The processes used by the two organizations are different due to product design and product liability. ASG performs a significant amount of simulation of its complex designs while AEG performs fewer simulations and more prototype build and test cycles. In addition, the government releases ASG from liability for product failure, while AEG is held responsible for product liability. Due to these differences, the two organizations use different processes, as illustrated in Figure 1. The dashed lines in the figure indicate points in the two processes where the products have reached comparable levels of development maturity.

AEG uses a design center and manufacturing plant methodology of operation. AEG has a design center, located at Farmington Hills, Michigan, which designs products for manufacture at several plants located in North America and Europe. The AEG plants may also manufacture products designed by its customers. For example, the Marshall, Illinois, plant manufactures diesel engine controllers designed by Caterpillar. The result is that the Marshall plant works with multiple design centers, even though each design center uses different CAD tools. This is possible because the designs are transferred from the design centers to the Marshall plant in neutral data formats. Therefore, there is no need to re-enter and translate data between CAD tools with incompatible data formats.

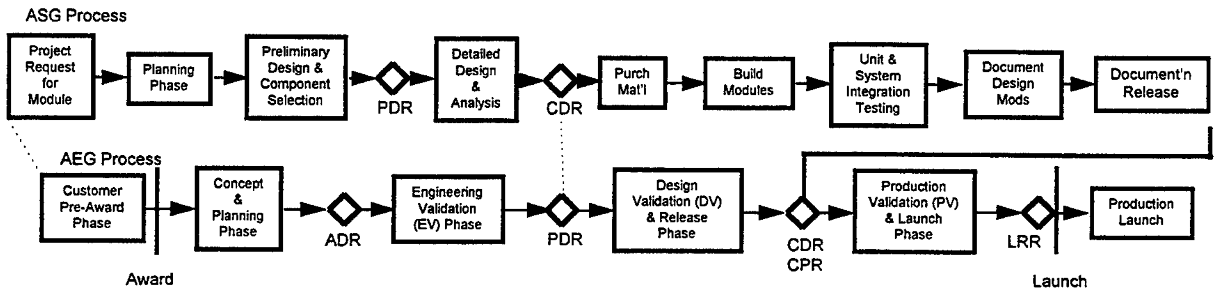

Figure 1. ASG and AEG Processes

ASG uses a similar interface for the transfer of design data to manufacturing. ASG has one design center and one manufacturing plant, both located at San Diego, California. Although the ASG structure allows very close integration of design and manufacturing functions, commercial design and manufacturing tools are not yet closely integrated. As a result, ASG also transfers design data to manufacturing via neutral data formats.

The analysis of the processes shows that the methodology used by both ASG and AEG is compatible, for the transfer of design data to manufacturing. Implementation of a design transfer interface between ASG and AEG/Marshall may require the purchase or development of data format translation software. The result will be that the ASG design center will be able to work with the AEG Marshall plant in the same manner that the Caterpillar design center works with the Marshall plant, as illustrated in Figure 2.

The successful development of a product requires the design and manufacturing centers to work closely together. As described earlier, the ASG and AEG development processes are different due to product complexity and liability issues. Commercial companies with an emphasis on profitability of high volume production lines, cannot be expected to adapt its process and business practices to capture military business needing low production quantities. Therefore, the military organization must adapt to the commercial company's methodologies. Based on these criteria, the IBP program adopted the concurrent engineering development process, illustrated in Figure 3. This process utilizes the concurrent engineering concept, which is enabled by the definition of PCB design rules and a common component database. The PCB design rules and component database are defined by a cooperative effort of the two organizations. The PCB design rules are negotiated to provide the component density needed to implement the design while confining the required manufacturing processes to those available at the manufacturing facility. The PCB design rules and component database are accessed by both design and manufacturing engineers throughout the product development effort. The ASG and AEG team is distributed to four locations: San Diego, CA; Dayton, OH; Farmington Hills, MI; and Marshall, IL. Access to product data is provided by a distributed client/server Product Data Management (PDM) system. The PDM system allows team members to access product data for information extraction, design review and comment. The PDM system also provides configuration management and data backup functions. The PDM system communicates via the existing TRW Wide Area Network (WAN).

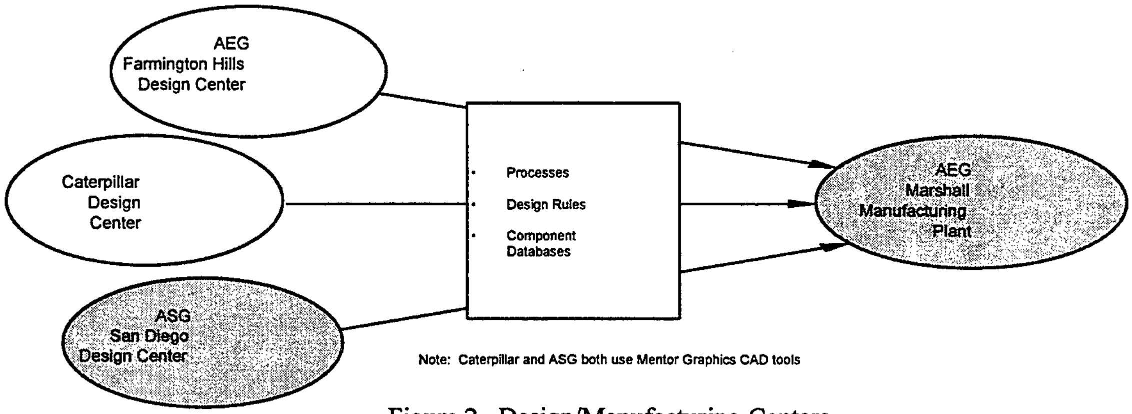

Figure 2. Design/Manufacturing Centers

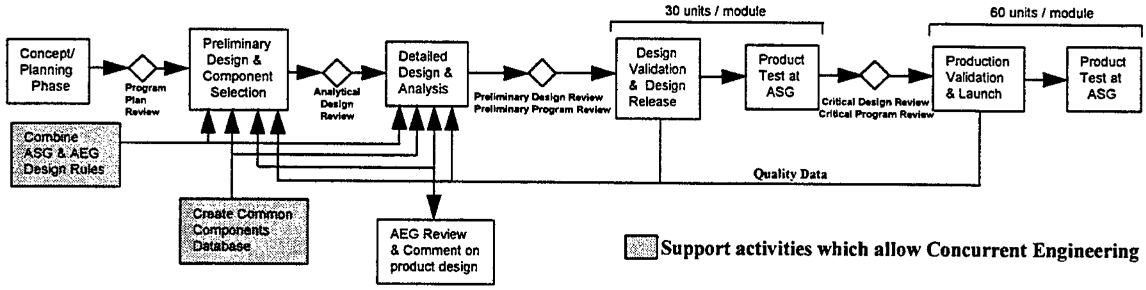

Figure 3. IBP Development Process

AEG uses a series of 33 milestones, listed in Figure 4, to guide the product development effort and monitor progress. The IBP program has adopted this group of 33 milestones as a checklist for synchronization with AEG's normal development process. Use of these milestones allows the distributed IBP team to coordinate tasks and measure progress.

Conclusion

The TRW ASG and AEG organizations have defined a methodology for working together and a process for development of avionics products for manufacture on an automotive production line. Because the particular process derived contains characteristics that are unique to the ASG and AEG organizations, the process may not be transferable as a whole. However, elements of this effort, such as the particular analysis steps performed, the issues considered and the conclusions reached, may be of value to other companies. Other organizations which wish to perform a similar production of military products on commercial production lines, will need to perform a similar analysis and consider many of the same organizational characteristics and issues.

Concept Development	Engineering Verificaton E.V.	Design Validation D.V.	Process/Product Validation P.V.	Production Launch
1 Kickoff Review 2 Business Award 3 Program Plan Review 4 Specification Review 5 Concept Design Review 6 Program Concept Review	7 Analytic Design Review 8 EV/DV/PV Test Plan Approval 9 Detailed Design Review 10 Order EV Parts 11 EV Build 12 Prototype Tooling 13 Component Supplier DV Build 14 First Sample Submission 15 Preliminary Program Review	16 Critical Design Review 17 Order DV Parts and DV Build 18 DV Test 19 ERA and Signoff 20 Design for Manufacturability Review 21 Procure Long Lead Parts 22 Award Business/ Tooling 23 Critical Program Review 24 Second Sample Submission	25 Launch Readiness Review 26 Order PV Parts 27 PV Build 28 PV Test 29 Initial Sample Warrant Submission 30 Customer Launch Readiness Review	31 AEG Job 32 Customer Job #1 33 ECRs for Continuou Improvem

Figure 4. IBP Process 33 Milestones

Non-intrusive Integration of CIM Upgrades

Rob Hovsapian, TRW Avionics Systems Division
Mary Kinsella, AF Wright Laboratory ManTech Directorate

Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines" is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. The program includes the use of commercial parts and testing them for the military application. This paper will describe the processes needed to implement a new computer integrated manufacturing (CIM) system which will support high volume automotive electronic manufacturing and low volume military electronic manufacturing with minimal or no impact to the existing high volume production. The AEG plant in Marshall, IL has an existing CIM system which supports high rate low mix production. Under the IBP program, we will upgrade the system to handle both high rate, low mix and low rate, high mix production. The CIM system upgrades must be made without sacrificing the original system's functionality. The major factors involved in meeting this objective are described below.

Extensive Use IPTs

The IBP CIM development function makes maximum use of integrated product teams (IPTs). These assure all of the cross-functional requirements are considered and assure buy-in from the owners of the existing systems at Marshall. Continued support of the CIM System by both plant personnel and AEG executives is a key goal identified by the IBP team. The mechanism used to assure that all the requirements are considered and prioritized was the CIM Choice Selection Matrix. The matrix identified each requirement and their relative weighting, providing the team with an objective evaluation of functional elements. This removed any biases that may have been brought about by any particular team member. For example, a Choice Selection Matrix was used for selection of a CASE tool. A portion of this matrix is shown in Figure 1.

Attention to the Customer

To better enable the IPT process, the team chose to perform the design effort at the plant in Marshall, rather than from a remote site. This will cause minor inefficiencies during the design and development process, however, the probability of eventual acceptance shall be higher because the users of the system are involved in its development. In the end, the success of the program within time and budget constraints is more likely.

Use of Existing User Interfaces

Production uptime and throughput are major drivers at Marshall. Changing the CIM system to add greater flexibility creates a potential for introducing new user interfaces that are unfamiliar to production operators. To mitigate this risk, changes to the front end user interface for existing systems, such as defect data collection, real time SPC charting, etc., will be minimized. The backend database access, however, will be changed to take advantage of a relational database engine. Using the same or similar user interface will provide a higher acceptance and trust among the user community.

	Feature / Function	ERwin	S Designer	Sys. Arch.	Visio	Oracle CASE
1	Integrated CASE Applications					
	• Separate Physical / Conceptual Model	1	3	3	0	3
	• Report and Form Generation	2	2	2	0	5
	• Having Sub Models and Global Model	1	3	2	0	3
	• Corporate Wide Dictionary Repository	1	3	3	0	4
	• Industry Format ERD Modelling	2	3	4	0	3
7	**Totals**	**7**	**14**	**14**	**0**	**18**
	Legend: 0 Unacceptable or N/A; 1 Marginal; 2 Acceptable; 3 Satisfactory; 4 Good; 5 Excellent					

Figure 1. Choice Selection Matrix used by the CIM IPT

Integration With Legacy Systems

Reference File Number: MI-CIM-LL-001
Date: 16 October 1995

Familiarity and confidence in existing systems at the plant is high. The flexibility these systems provide in their database architecture, however, is severely limited. To support use of the existing systems while allowing flexibility, the new data model will encompass legacy database elements. In addition, to support historical data review and reporting, the system will provide interfaces to import legacy data into the relational database.

Switchable Systems
To allow for maintenance and service of the enhanced CIM System, a special black box is being designed. This black box will allow the Programmable Logic Controller that supports the conveyor control to be separated from the CIM System Control of the production process. Separating the conveyor control system from the CIM system was essential for buy-in from the existing support and maintenance organizations.

Use of Simulation

The enhanced CIM System will provide a mechanism so that the existing data and systems can be migrated to the new system "seamlessly." To this end, the team used a CASE tool to model the existing and planned data functionality and relational database system. The team learned that the non-relational model of the existing system did not lend itself to a relational architecture, and that data migration will need to be performed to provide backward compatibility. In addition, the back end database calls of existing systems will need to be modified to support a relational database architecture.

Summary
The single most important theme that transcends the integration of CIM at Marshall's existing systems is the notion that the "Line" must be up. Downtime due to any reason is unacceptable. The implementation techniques being used on the IBP support this premise. By using the approaches described here, the CIM team is maintaining a smooth transition from original systems to a more flexible CIM capability.

Commercial Parts for Military Designs

Mark Myers, TRW Avionics Systems Division

Objective
Describe the issues associated with procuring commercial parts for military designs.

Background
The United States Air Force, Wright Labs Manufacturing Technology Directorate, contracted TRW ASG (Avionics and Surveillance Group) to lead in developing an Industrial Base Pilot (IBP) for producing military products on commercial lines. Under the pilot program, TRW will produce two Communication, Navigation and Identification (CNI) electronics modules for the F-22 Advanced Tactical Fighter and the Comanche RAH-66 (Reconnaissance Attack Helicopter) on production lines established for ongoing automotive production at TRW Automotive Electronics Group, using "best commercial" practices. To support this production, the modules selected need to be redesigned for compatibility with the fully automated automotive production lines. The ground rules for this redesign included:

1) Compatibility with the automotive production line processes.
2) Rapid interchangeability (flexibility) of the line to contend with military small lots intermingled with automotive production.
3) Commonality of parts and packages to the ongoing production.
4) No basic module level I/O changes (hardware must have the same function as the military production version).

Commonality of parts and packages and compatibility with the automotive production line processes, without electrical redesign of the modules, made it necessary to pursue repackaging of the ASICs and MCMs used on these modules.

Discussion
The two selected modules, RF/FEC (Radio Frequency/Front End Controller) and PNP (Pulse Narrowband Processor) use six Application Specific Integrated Circuits (ASICs) and one Multi-Chip Module (MCM). The military (F-22) ASIC and MCM die manufacturers are noted in Table 1. The die complexity represents a common cross section of dense military electronics with high end digital and mixed signal devices from 100 to 350 I/O with up to 300k gates. The MCM contains a 300 I/O ASIC, C31 microprocessor and memory. Due to the level of die complexity, the program elected not to respin ASICs/MCM logic devices.

To pursue repackaging these devices, TRW elected to distribute RFIs (Request For Information) to ASIC and MCM suppliers. Included for source selection were the current military packaging resources for these devices, ASIC sources utilized by TRW's Automotive Electronics Group (AEG) and sources known to both ASG and AEG to be commercial ASIC and MCM suppliers. RFIs were distributed by both ASG (military) and AEG (commercial) procurement personnel.

The specifications for the packaged parts were developed by taking the military version of the part specification (usually a SMD, Standard Military Drawing) and the TRW SCD (Source Control Drawing) and stripping out all military requirements for the packaged part. (These specifications were

Table 1. IBP ASICs/MCMs

ASIC/MCM	F-22 DIE MANUFACTURER
RTP (Receive/Transmit Processor)	Motorola
NBP (Narrowband Processor)	Motorola
MTC (Module Test Controller)	LSI
CBU (CNI Bus Interface)	LSI
MAME (Master Message)	LSI
DMAD (Dual Monolithic A to D)	Tektronics
DSP MCM (Digital Signal Processing)	Motorola, TI

MIL-M-38510, MIL-I-38535, MIL-STD-883 and supporting/tiering documentation that govern military design, test and procurement of ASICs/MCMs).

Included in the specification were maximum part ratings (DC input/output voltage, current, etc....), and the part operating conditions (voltage, temperature, power consumption), where the part was expected to be used, the likely duration of use, die size, biasing, test points and other information necessary to package the part.

The RFI was divided into two groups: A group that could bid die fabrication/test and packaging, and a group that would assume TRW would consign known good die (Reference Table 2, Column 2). The RFI requested that the vendors:

1) Select preferred package for the die.
2) Select "Best" assembly flows for these parts.
3) Perform package screening, burn-in and test as they deemed necessary.
4) Provide ROM costs to TRW for recurring and non-recurring tasks.

Vendors were asked to bid as many possible package styles with emphasis on lower recurring cost solutions. The vendor list and responses are included in Table 2.

Table 2. IBP ASIC / MCM VENDORS

VENDOR	TYPE OF RFI	RESPONSE
Motorola	Die and Packaged Part	No Bid
LSI Logic	Die and Packaged Part	Bid
Tektronics	Die Only	Bid
Hughes	Packaged MCM	Bid
Amkor	Packaged ASICs / MCMs	No Bid
Hyundai	Packaged ASICs	No Bid
Kyocera	Packaged ASICs	Bid
TI	Packaged ASICs / MCMs	No Bid
Pantronics	Packaged ASICs	No Bid
Space Electronics	Packaged ASICs	Bid
Elmo	Packaged MCM	Bid
Hestia Tech	Packaged MCM	No Bid
National Semi-Conductor	Packaged MCM	No Bid
Diceon Electronics	Packaged MCM	No Bid
Valtronics USA	Packaged MCM	No Bid
MCC	Packaged MCM	No Bid
SCI Systems	Packaged MCM	No Bid
APTA	Packaged MCM	Bid
Aeroflex	Packaged MCM	No Bid
NChip	Packaged MCM	Bid
IBM	Packaged ASICs	Bid

A surprising result of this activity was the very high rate of "No Bid" responses, over 60%. Analyses of the "No Bids" are noted in Figure 1.

Another result was a uniform question in response to the RFI, "What do you mean by "Best Commercial Practices" and "Where are the specifications to build to.... ". Some responders were not comfortable selecting process flows for parts with military applications, even when the application environment was specified. Other responses included no bids due to non-compete agreements for military electronics and market exit positions. Of the bid responses, packaging selection of the vendors was as noted in Figure 2.

Only 30% of the package responses selected plastic, even though plastic is used for 98% of all electronics packaged today. This response shows caution of the unknown impact of using plastic encapsulation with large ASICs/MCMs in a military environment. Also, 42% of the vendor's selected a PGA for the devices, a technology that is unsuitable for densely packaged electronics such as the CNI hardware, as the necessary real estate for through hole devices cannot be accommodated.

Conclusions

Larger than expected inertia exists in packaging "high end" complex military packages. The lowest risk approach to commercialization is to pursue equivalent packaged components with moderated (reduced) screening and test. This also results in the lowest reduction in recurring production cost as most military packages are expensive ceramic/hermetically sealed devices.

Low volumes of military parts fail to create interest from the commercial base to implement new packaging of existing military die. New military designs should address commercial packaging before non-recurring engineering (NRE) is invested in the original package. New military designs for die,

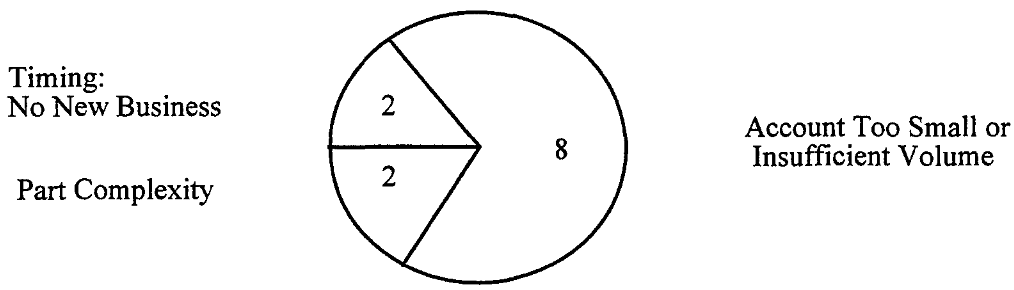

Figure 1: Distribution of Responses

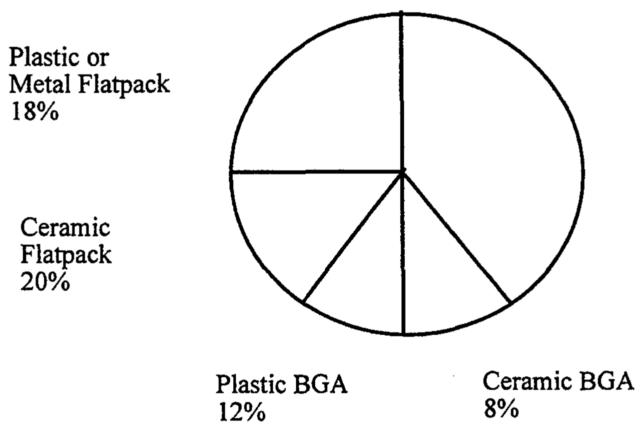

Figure 2: Packaging Selection

coupled with commercial fab flows for the die and commercial package materials and assembly flows, will enjoy faster success.

The PGA package is widely used, tooled and implemented in high end commercial ASICs / MCMs. While it has wide spread use for commercial applications, real estate size limitations for most military applications have forced designs to surface mount package configurations. This design is unable to accommodate through-hole packages, such as the PGA.

When military producers attempt to procure custom devices from commercial suppliers, several impediments can be expected:

1) Commercial suppliers disinterest due to lack of volume.
2) Non-compete agreements with military suppliers prohibit pursuit of this business.
3) Commercial suppliers (and former military suppliers) exiting military business markets.

These barriers exist even when commercial procurement personnel attempt to procure this hardware.

The ideal dual use pursuit of best commercial practices for custom active devices will result from concurrent engineering of the die and package by military designer, commercial fabricator, and commercial assembler. This will ensure design reliability and integrity at the lowest cost.

Manufacturing Process Development For Low Volume/High Cost Products

Steve Murphy, TRW Automotive Electronics Group
Mary Kinsella, AF Wright Laboratory ManTech Directorate

Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"[1] is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. This paper will recommend a new approach for developing manufacturing processes in a high volume, commercial factility when a large number of sample builds is not feasible due to costs.

The normal TRW AEG development cycle for new products and processes must be altered to allow for the low volumes and high component prices of the F-22 and RAH-66 modules. Automotive electronics' bills of material (BOMs) are typically in tens or hundreds of dollars as opposed to tens of thousands of dollars for military electronics. The low automotive electronics BOMs allow AEG to build hundreds of sample units prior to going to full scale production. The sample units are assembled and tested and then re-designed based on the results of the testing. This cycle may occur several times until the product and process designs are correct. The high material costs of the F-22 and RAH-66 modules preclude this approach, so "first pass success" becomes a necessity, requiring a modification to the AEG development process.

Current AEG Development Process

New products and processes are rarely revolutionary in the TRW AEG business. In fact, the TRW AEG Concurrent Development Process (CDP) approach is not designed to handle revolutionary changes in products or processes. Development is generally an evolutionary process based on the previous experience gained from past design successes and problems. This knowledge is applied to the next product generation. Designs are often dubbed GEN (generation level) I, II, IIA, III, etc. Most new development involves customizing the products for varying interface and reliability requirements.

TRW AEG customers are continually requiring lower costs while increasing the functionality and durability of the products. TRW AEG parts and materials costs must be controlled commensurately. Using more inexpensive parts allows the building of numerous prototypes for testing and process development to collect empirical data. The prototypes can then be re-designed and re-assembled several times until the performance and manufacturing process bugs can be worked out. This normally happens during the engineering validation (EV) cycle and may involve several dozen prototype units being assembled. This is followed by the design verification (DV) cycle in which products are assembled in a process as close as possible to, but not necessarily the same as, the expected final process in quantities of 25-50, depending on customer needs beyond the 22 units typically needed for DV testing. Any problems noted at this stage can be related back to the design group and re-designed for the production validation (PV) cycle. At the PV level, all production components, materials, tooling, fixtures, etc. must be in place. Build quantities for PV testing are usually in excess of 300 units to meet minimum sample size requirements.

In addition to the BOM items required for the EV/DV/PV builds (which either go into test cycles or to customers), there are also component and material requirements for process development. Process development includes fixturing, component placement, soldering profiles, etc. Normally 5-10 sets of components and circuit boards are required for each iteration of the design as it changes later in the development process. All processes must achieve a C_{pk} (process capability measurement) of 1.33 or greater to prove its capability, requiring machines to place several thousand components (due to the many types and sizes of components placed. This exercise is part of the acceptance procedure for new equipment.

Given the high cost of military electronics components, adopting the above process for producing military products on commercial lines would be prohibitively expensive. This drives us to develop new solutions.

Planned IBP Development Process

Due to the high component and material costs, as well as the low volumes for this program, the typical AEG process development cycle must be augmented. In order to keep costs down on the project, every component and PCB, as well as other materials, such as solder paste, must be tracked and its intended use fully planned out. Using several thousand parts to verify placement accuracy is out of the question due to the cost of the components. The following paragraphs define a new process that

[1] Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group

emphasizes the use of "known-good" processes where possible, building a history of knowledge in a "waterfall" pattern that uses the lessons learned from earlier developments and combining the use of nondestructive and destructive test techniques. Also, serialization is proposed to trace all components and prevent losses from misplacement and aid in the planning of their usage during the development.

The easiest way to cut development costs is to utilize "known-good" processes; i.e., processes that have a proven process capability. For TRW AEG, this means the process has a C_{pk} of 1.33 or greater. By using these proven processes, noise conditions which may slow down the process development cycle by adding additional levels of tests are eliminated. Also, component classes which are not new to AEG can be assumed to have processes that meet the minimum capability requirements. An example would be chip capacitors, resistors or SOIC (small outline integrated circuit) packages. These are used in several products on several production lines, so spending time and parts to prove that our processes work is not necessary even if the part numbers are different or different suppliers are used.

Design of experiments (DOE) is another approach which minimizes parts and materials usage during development. To provide an understanding of solder attachment strength for IBP materials and components, an experiment has been designed. The DOE evaluates critical parameters for process development. Critical parameters include four different solder pastes, two different circuit boards, the ball grid array (BGA) components, and the leadless chip carrier (LCC) components. This array of parameters creates multiple combinations of variables. In order to minimize part usage, a table was set up to track all the components in a flow-down, or waterfall, pattern. Initially, processes are developed for the unknown combinations. As the development continues for the different arrays in the DOE, these processes are developed and made capable. At each level, however, it is unnecessary to repeat the development for the "known good" processes; i.e., they are flowed down to the next level. For example, once the temperature profile for reflow is in place for one type of solder paste, it is not required to repeat the profile analysis for another type of paste. In this manner, fewer and fewer components and materials are needed at each level of the process development.

Process capability measurements are still a problem for the new ball grid array (BGA) components, but re-using parts and using non-destructive test techniques can provide some aid. The Marshall, IL facility of AEG will be using a Universal GSM1 machine for most active components. This machine has been through an acceptance procedure involving the placement of components and measuring the offset of the component leads to the pads on the circuit board. New equipment must have a C_{pk} measurement of at least 1.33 for x, y, and theta (twist) before it may be used in production. The acceptance for the GSM1 included the placement measurement of 5,134 components of 25 to 50 mil lead spacing, but none of the components included BGA. While assumptions can be made that the machine is capable of placing components accurately, the programming involved in placement of the odd-form components (i.e., BGA) must be proven out. For the DOE build, we are placing the components on two-sided tape on the circuit board then checking for alignment, removing, and then re-using if necessary (BGA components are fed to the machine from a matrix tray, so it is unnecessary to put them back into a reel). By checking the alignment with non-destructive analysis, such as x-ray, and then re-using the parts, we can prove the capability of the equipment for specific types of components without using a large quantity of parts.

Finally, it is necessary to develop a plan on how each part and material will be used for process development. This will identify how much material will be required. Best case, worst case and most likely scenarios can be developed to determine the quantities required. In this manner, a bare minimum number of components are actually consumed by the process development. Some must be used for reflow profiles as well as additional components for solderability analysis, but all other components can be cleaned and recycled. Serialization of the components aid the tracking of the components through all analysis and testing.

Recommendation

In summary, the following methods should be employed for low volume process development:

- Use as many known good processes as possible in order to reduce noise conditions
- Examine historical data for possible correlation and build a history of process knowledge
- Re-analyze and re-use components and materials
- Utilize non-destructive testing to proof the development
- For all materials and components to be used in process development, plan how they are to be consumed, when they are needed, and how they will be tested
- Use some type of serialization, wherever applicable to track which components have been through each type of process or analysis

Performing these activities cannot guarantee capable processes, but they will provide a heightened sense of where problems may lie and how they can be controlled.

The Business Case for Building Military Products on Commercial Lines

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Mike Nanzer, TRW Avionics Systems Division
Mary Kinsella, AF Wright Laboratory ManTech Directorate

Introduction

There is potential for significant gain on both sides when a military supplier joins forces with a commercial manufacturer to supply hardware for government contracts. The military contractor can acquire reliable hardware at a significantly reduced cost. The commercial supplier can develop profitable new business, while gaining ready access to technology that may not normally be available. To realize the benefits of this relationship, however, military products must be evaluated from a commercial business perspective.

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"* is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. A commercial manufacturer will typically evaluate the attractiveness of a new business opportunity using a financial model. The IBP program has adapted AEG's model to determine the business case for building military modules on the commercial line.

Cost Models

The contrasts between the military and commercial cost models are identified in Figure 1. In contrast to the military model, the commercial cost model drives an emphasis on cost reduction. A commercial manufacturer is thus rewarded with higher profits for reducing costs. Military firms have no such incentive, given the typical cost-plus-fixed-fee contracting business model used by prime contractors and the US government.

Military Model

FIXED FEE = COST x FEE RATE

Commercial Model

PROFIT = PRICE - COST

Figure 1. Military vs. Commercial Financial Model

The Business Case

To attract commercial firms to do the military's manufacturing requires the development of a business model that balances the commercial firm's desire for reasonable profits and restriction of access to cost data with the military's desires for lower cost products. The IBP program has developed a model that addresses these key requirements and can serve as the basis for future contract relationships between military contractors and commercial manufacturers. The concept for the model is that first, the financial case for a good business opportunity is made, then any further business barriers are eliminated (Figure 2). The model determines a price for government hardware and profit for the commercial supplier, without the government requiring the supplier to disclose cost competitive data.

Starting with a performance specification for a product, the commercial firm estimates the bill of material (BOM), labor, and non-recurring engineering (NRE) costs to produce the product on its commercial manufacturing line. Control mechanisms in the

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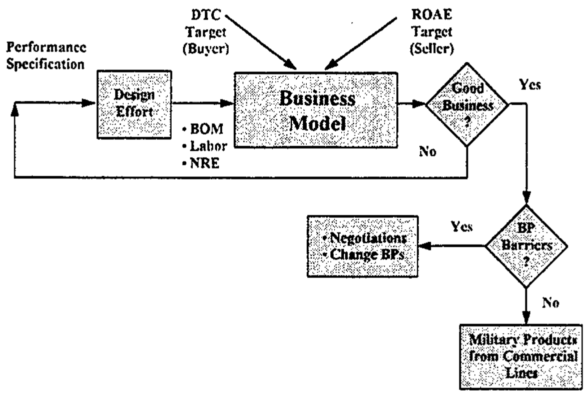

Figure 2. Business Model Conceptual Flow

model are the return on assets employed (ROAE) target of the commercial firm and the design-to-cost (DTC) target of the military customer. Components of the model are shown in Figure 3.

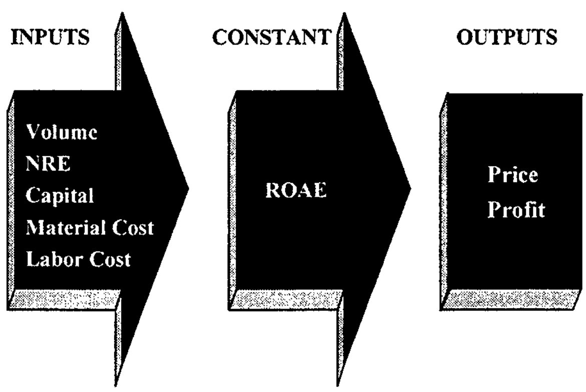

Figure 3. Business Model Components

On the IBP program, this model has been employed (Figure 4) and has indicated favorable results. While the military can achieve significant cost savings compared to baseline modules built on dedicated military production lines, the commercial supplier can achieve reasonable profit. For the IBP modules, the cost model shows an average savings of 30-50% from the military baseline.

Once a favorable business case is established, various business practice barriers must be abolished to bring commercial suppliers into the defense industrial base. The elimination of military specifications and standards and passage of the Federal Acquisition Streamlining Act (FASA) has put some momentum into this objective. Other efforts within the IBP specifically target business practice barriers. For example, numerous contract flowdown clauses are a major barrier to subcontracting with commercial manufacturers. The IBP is working to define the demonstration modules as commercial items, thus eliminating the requirement for these flowdowns. Also, the IBP is recommending how to define requirements without military specifications and standards and using industry standards where appropriate.

Business Model Characteristics

- Supplier's Return on Assets Employed (ROAE) is kept constant
- Inputs: volume, BOM, capital requirements, NRE
- Assumes multi-year procurements over several production years
- Volume is a significant factor in driving down price
- Supplier will assume limited NRE
- Future price reductions are negotiable
- Typical commercial warranty is factored in (manufacturing defects only)

Figure 4. Business Model Characteristics

Summary

To fully exploit the cost reduction potential for military programs from utilization of the commercial manufacturing base, the government must address the key concerns that commercial firms have about doing government work. Specifically, there must be normal profit potential, and the business practices must be analogous to those employed in the typical commercial contract. The implications of deploying a successful business model for military contractors and commercial manufacturers will be that government budget dollars go farther, and the commercial industrial base gains access to new sources of revenue.

Cultural Disparity Between Military Contractors and Commercial Manufacturers

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Introduction

There is potential for significant gain on both sides when a military supplier joins forces with a commercial manufacturer to supply hardware for government contracts. The military contractor can acquire reliable hardware at a significantly reduced cost, while the commercial supplier can gain ready access to technology that may not otherwise be available. However, there are dramatic differences in the methods by which the two organizations typically operate.

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines" [*] is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. Although both contractor and subcontractor have the same parent corporation, there are significant cultural differences in the two businesses. The lessons learned in the IBP endeavor serve as guidance for future military programs using commercial manufacturers. This paper describes the cultural differences between military and automotive electronics manufacturers for the benefit of future participants in dual use manufacturing.

A Perspective of Military Manufacturing

For a military contractor, system performance is typically the key deliverable. Program Offices usually press for more technology at higher risk. The design performance is the primary driver. Electronics manufacturing systems and lines are designed to produce low volume with high performance. The lines are manual or semi-automated systems which permit flexibility in product change over. There is very little if any standardization of products to utilize volume manufacturing techniques and obtain the resultant cost savings. Financial systems are established to track hours and material and payments are made when certain milestones are completed. The customer owns the labor and material involved from the inception of the program until the final milestone is completed. Product requirements are controlled by military standards that typically require stringent process control. As the products are very expensive, product testing is limited to small quantities. Operating systems such as accounting and configuration management are also defined by standards. Profits are regulated by law. When there is a conflict between system or product performance versus manufacturing capability, modification of the manufacturing capability is the usual result.

Commercial Manufacturing by Contrast

While automotive electronics manufacturers develop products that have performance, safety, and reliability requirements that are similar to military requirements, the automotive electronics manufacturer's approach to manufacturing is significantly different. A commercial electronics supplier relies upon volume manufacturing and low production costs to realize profit. While profit percentage is not regulated, cost pressure by the competition is fierce. Unlike the military supplier, the commercial organization owns all the value added to the product until it is actually sold to a customer. All the costs to produce the product are accounted for in the piece price, including capital equipment, process development, infrastructure improvements, facilities, and overhead labor. As a result, a commercial supplier must standardize products as much as possible to take advantage of work done previously. Equipment must realize very high levels of utilization despite the machine time consumed for process development. Manufacturing lines are developed to run continuously and pump out large volumes of product. Change over is done infrequently and only when absolutely necessary. Additional capital or processes are added only when it is determined the result will be a decrease in the cost to make the product. The time required to go

[*] Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group.

from raw materials to shipped product has to be as short as possible. Process controls are focused on the key process parameters identified from a large experience database. Product qualification is done on large quantities of parts and may take many months to complete. When there is a conflict between product design and manufacturing capability, the result is usually a change in the design. A commercial supplier will not invest time or money to modify processes to meet requirements for small volume manufacturing.

The IBP Experience

In the early stages of the IBP program the impact of the different cultures was underestimated. TRW AEG did not understand the complexity of the military requirements to provide product for government customers and potential impact to current manufacturing standards and guidelines. By the same token, TRW ASD did not understand that the small volume requirements for their product would result in some inflexibility to modify current processes and systems to meet military requirements. TRW ASD did not understand the business case justification[1] necessary for TRW AEG to agree to manufacture a military product. Resolution of these issues meant that each organization - government and industry, military and commercial - had to become aware of the differences in business, motivational, and operational cultures. It meant determining what each participant required in order to be successful. The issues were resolved by the IBP project team by securing management commitment to these requirements via the "four-win" scenario, Figure 1.

In order for military and commercial suppliers to become successful partners it is imperative that both parties take the time initially to establish clear operating guidelines. Since the cultures are so different, it is important that both parties compare and mutually agree to strategic and tactical objectives of the business relationship. For AEG, the strategic value of participating in the IBP program is the infusion of computer-integrated manufacturing (CIM) technology and new process technologies that will increase flexibility. Tactically, AEG benefits from the additions to sales and profits. For ASD, the strategic importance is the competitive advantage that is gained by having a partnering relationship with a low cost producer of electronic hardware. Tactically, ASD sees value in being exposed to the lean practices of a world-class manufacturer.

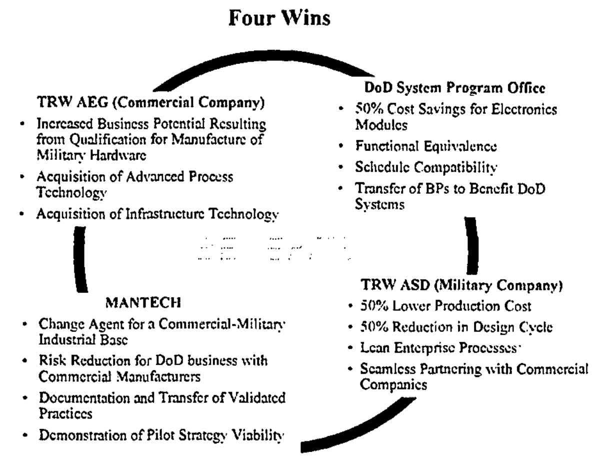

Figure 1. IBP Four Win Scenario

For firms that do not enjoy the advantages of interdivisional access to world-class manufacturing sources, an approach that assures win-win results can be employed to address the cultural differences between military contractors and commercial manufacturers; for example, the development of a plan that includes schedules, capital requirements, development methodologies, and supplier strategies. For the military supplier, gaining a cost advantage requires major changes to manufacturing guidelines. In the same vein, the commercial supplier needs to understand that military requirements for reliability cannot be compromised. Once barriers between the cultures are broken down, the two parties can establish a partnership which benefits from the strengths of each. In the case of the IBP, significant cost and quality benefits are expected on the military side (Figure 2), while favorable profit and potential business are expected on the commercial side. This then serves as sufficient incentive to make dual use manufacturing a reality.

Module Cost	• 30-50% Savings
Process Quality	• Order of Magnitude Improvement
Mfg Cycle Time	• 95% Shorter

Figure 2. IBP Benefits to the Government

[1] *The Business Case for Building Military Products on Commercial Lines*, 30 Jan 96, File No. BP-LL-001.

Concurrent Engineering Environment For Distributed Project Teams

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Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"* is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives.

The IBP team is distributed across four locations: 1) IBP product design is performed at the ASD San Diego, California site, 2) Design For Manufacturing (DFM) standards are established by the AEG Farmington Hills, Michigan site, 3) The manufacturing process development and product manufacturing is performed at the AEG Marshall, Illinois site, and 4) The Concurrent Engineering Environment (CEE) is administered from the ASD Dayton, Ohio site. The challenge for the IBP program is to establish a development environment which allows the distributed team to work concurrently. This paper describes the environment created by IBP manufacturing infrastructure engineers for concurrent engineering and discusses the implementation considerations for a distributed engineering database.

CEE for IBP

The ASD and AEG organizations merged their unique development processes to establish one process (Figure 1) that would meet the IBP program objectives. A close concurrent working relationship was required between the ASD design engineers and the AEG manufacturing engineers to implement the IBP process. A Component Database was established so that the entire development team was working from the same data. Printed Circuit Board (PCB) design rules were established to guide the design of PCBs which could be manufactured on the AEG production lines. Establishing a concurrent working relationship was complicated by the geographic distribution of the team. Handling the teams communications by conventional telephone, FAX, and overnight mail methods would have resulted in a long development cycle, possible engineering data configuration management problems, and possible reductions in the quality level of the final product. The IBP program identified the need for a CEE with several features: 1) Quick and easy electronic interchange of e-mail messages and data files, 2) Access to component data by the entire distributed team, 3) Productive review and comment of design data by the distributed team, 4) Design data configuration management, and 5) Data interfaces between design, manufacturing and management functions. These needs formed the requirements for the IBP CEE.

The CEE established for the IBP program is built on a foundation of Product Data Management (PDM).The PDM system (Figure 2) provides:

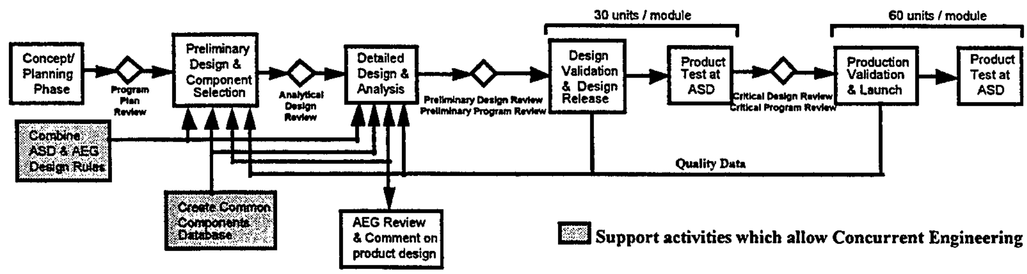

Figure 1. Development Process

1) A central vault for the storage of project data, 2) A hierarchical data storage structure, 3) Data configuration management functions built into the data storage/retrieval process, and 4) Access control for data security and process workflow control. All project engineering functions may access the PDM system for project data storage. The project data stored in the PDM Vault may be of any data type including engineering drawings, documents, component database, parts list, etc. Access control for data security and workflow control is accomplished with a shell of software around the vault. The data vault structure and process workflow can be uniquely defined for each program. The PDM system is based on a client/server architecture for distributed multi-user access. The PDM server is hosted on a UNIX computer and the client software is hosted on Macintosh, PC, and UNIX computers.

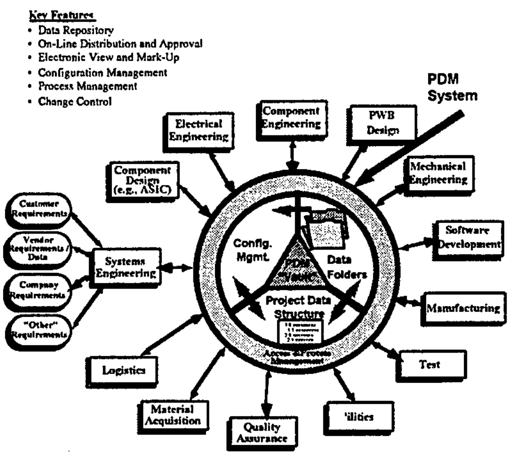

Figure 2. PDM Functional Diagram

The IBP program communications flow across a combination of the TRW Wide Area Network (WAN) and the Internet. Communications between TRW employees occur solely across the TRW WAN. Gateways are in place between the TRW WAN and the Internet to provide security for proprietary data. E-mail communications between TRW and non-TRW team members flows through the gateways, which; support the standard Internet data protocols. TRW team members are able to access the PDM Server, located at the San Diego site, using PDM clients on the TRW WAN. PDM Clients are located at each of the four IBP program sites.

A variety of computer-aided design (CAD) tools and utilities provide electrical and mechanical product development functionality. The more frequently used CAD tools are integrated with the PDM system to allow launching of the tools from the PDM user interface. As a result, the design data is automatically stored in the PDM system for easy access by designers and reviewers. View & Mark-up software allows engineers at the remote sites to review the design and store comments in the PDM system, as additional layers of the design drawings. Notification that design data is ready for review is accomplished with e-mail messages sent through the communications network. The product design effort also makes use of design reuse libraries and component libraries stored in the PDM vault. The Component Database contains component information approved for project use. The component data includes functional models, mechanical models, thermal models, component pad geometries, specification sheets, and vendor performance history. Bulk loading utilities are used to transfer data between the PDM Component Database and various CAD tool libraries. A Bill Of Material (BOM) Editor allows the design engineer to create a BOM by copy/paste of component information from the Component Database, to avoid the error prone process of manual reentry of component data.

The CEE enables the flow of data required by the design and manufacturing engineers throughout the development and manufacturing process. Figure 3 illustrates the data flow between the IBP program design and manufacturing organizations. The data is generated by the design engineers and stored in the PDM Server. The manufacturing engineers review the design data using the PDM Client and transfers comments back to the PDM Server. Upon design completion, the BOM is transferred to both the CIM and MRP II systems. Data collected during manufacture of the product is filtered and transferred to the PDM Server. This data is used to evaluate product manufacturing problems and perform product improvement.

Lessons Learned

Simply deploying a CEE system does not mean that users will accept and use it. People are naturally resistant to a change in process and the use of new tools. To win acceptance of users,

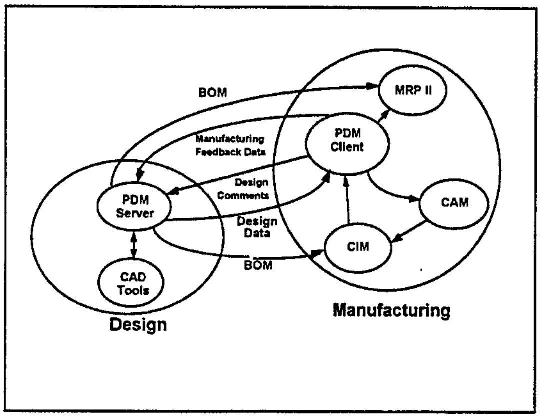

Figure 3. IBP Program Data Flow

the CEE system must provide the following features:

- The PDM user interface must be easy to use and intuitive to learn, because many users will access the PDM system infrequently.
- The CEE system must provide value added functions to the product development process. It must make tasks easier to perform, quicker to perform, result in better quality, or lower cost. Otherwise, the user will continue to perform tasks the old way.
- The CEE system must provide a performance level (e.g. data access response time) which is tolerable and productive enough to justify use of the system.
- The system reliability must be high. The system must be available for data access a high percentage of the time, and data loss/corruption must not occur.

The organization which provides administration of the PDM system must be sensitive to the following project and user needs:

- Responsiveness to project resource needs and the resolution of user problems.
- Infrequent and non-disruptive deployment of system upgrades.
- Appropriate and timely training on the system. Training should occur at the point on the program when the functions are needed and at the time when the PDM system is available. Although training on all the PDM system functions provides a good foundation, focused training on the specific functions that each user needs proves to be more effective.

Summary

The IBP program provides a good example of successful implementation of CEE. The lessons learned described herein delineate guidelines for future programs requiring development environments for distributed teams.

* Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group.

IBP Component Reliability Test No. 1

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Mark Myers, TRW Avionics Systems Division
Mary Kinsella, AF Wright Laboratory ManTech Directorate

Background

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"[1] is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. The program includes the use of commercial parts and testing them for the military application.

The Component Reliability Test #1 (CR1) is an IBP test vehicle for plastic encapsulated microcircuits (PEMs). After assembling the plastic devices to a circuit board at TRW's commercial electronics factory in Marshall, IL, reliability tests were performed at TRW's military design center in San Diego, CA. The CR1 build was not originally slated to be performed in the Marshall plant, however it was decided that doing so would provide some insights into future builds and the types of manufacturing problems that may occur. In hindsight, this was an excellent decision. Many issues were discovered and approaches identified that will lead to more efficient design validation (DV) and production verification (PV) builds later in the IBP program.

The assembly of CR1 took place on 7 July 95 at the Marshall plant's "Flex Line 6" using an MPM screenprinter, Panasonic MSH-I, MV-II, and MPA-40N placement equipment, and an Electrovert Atmos 2000 reflow oven. Twenty-three panels were assembled, with 48 completely populated assemblies (minus the EPROM). The boards were hand marked for tracking purposes, then routed, jumper wires added, and tested with a GenRad in-circuit test fixture. Solder defects were reworked after test. The final process was conformal coating, of either parylene or silicone, before going into the reliability testing. This paper will describe the lessons learned from the CR1 test vehicle, provide some insights into the differences between commercial and military manufacturing philosophies, and identify changes in design rules and project planning necessary to ensure smooth introduction of military designs into commercial manufacturing lines.

While the CR1 build was completed on schedule and CR1 test results were positive, the team discovered several lessons which will improve future test efforts. In general, more care in planning out the CR1 build would have resulted in significant improvements. Because the component packages were not new to the Marshall plant (with the exception of the ceramic resistor networks), it was felt this was not an assembly that warranted any process development or an extensive debug process for the equipment. If the DV checklist had been used, several issues which had caused problems could have been worked out far ahead of the build. The key lesson learned in this exercise is that all assembly projects, even those assumed to be relatively simplistic, must go through a fairly rigorous, detailed process to ensure there are not any missed steps. Specific CR1 lessons learned are summarized below.

Components/Layout

A pre-build checklist is now used to ensure all aspects of preparation are complete before the build (the checklist identifies the required number of weeks before the build that task items are to be completed). Among the problems encountered were pad spacing that was too narrow for the actual part. Changes to the design guideline that were identified during the design of experiment (DOE) phase and were not implemented would have prevented several problems. A physical check of the components and circuit board layouts will now be used prior to authorizing the start of a new build. Additionally, part libraries will be checked to ensure the design guidelines are compatible with the physical attributes of the components.

Placement

The fiducial data for CR1 did not match the component x-y coordinate data and thus required

[1] Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group.

Reference File Number: PT-AEG-LL-003
Date: 2 April 1996

manual offsets. This problem was consistent for all placement machines. Engineers are addressing the translation issues from the ASD design system to the AEG equipment to remedy the fiducial problem. Further builds will test the progress of this interface.

Reflow

A ceramic resistor network was used in CR1 that has a body style unfamiliar to the personnel at the Marshall plant. The fine pitch leads are difficult to see, and there were several solder defects that remained undetected until the in-circuit tester was in place. More reliance on the design engineers within TRW's military unit was required to aid in the development of an inspection and rework procedure. Even when the defects were found, the rework capability at the Marshall plant was insufficient. This component type will no longer be used, but an inspection and rework capability for other new types of components (e.g., ball grid array parts) is being developed. As an added precaution, more extensive reflow profiling will occur ahead of any builds to ensure that no "tweaking" will be required during the build.

Final Assembly

The start-up of CR1 in-circuit test was delayed at the Marshall plant due to some miscommunication. The panels had to be returned to final assembly for attachment of jumper wires. Future builds will employ the pre-build checklist, which has a line item for assembly drawings for any hand assembly work. Another item on the checklist requires the design engineer to be on hand to support this portion of the build. Had the checklist been used for CR1 final assembly, errors delaying in-circuit test would have been caught by the design engineer.

PEM Test Results

CR1 test results have validated the IBP design team's selection of plastic parts for the IBP modules. Of 1,244 PEM components tested, only seven components representing three component types had failures. Some of these failures were attributable to overstress conditions due to test fixture wiring errors. The 7 failed parts were then sent to a failure analysis lab for further testing. Alternate parts for the failed items have been identified as a precautionary measure. With these positive results, the IBP design team has pushed forward to begin preparations for the next round of component reliability testing (CR2). The CR2 build will validate the use of plastic ball-grid array (BGA) packages for large custom components. Additionally, the procurement of PEMs for the IBP design validation (DV) hardware has begun.

Summary/Recommendations

Characteristics of PEMs are summarized below in Figure 1. Use of PEMs is critical to the successful introduction of military products into commercial electronics assembly lines. Plastic parts are the dominant packaging technology in commercial markets. For the military to take advantage of the efficiencies that can be gained through the use of high volume commercial lines, there must be additional efforts to prove the reliability of PEMs and integrate them into military electronic hardware.

Figure 1. Summary of PEM Characteristics

Size	• PEMs available in more package varieties that are smaller than ceramic parts
	• Allow denser assembly packing
Weight	• Almost 2:1 reduction in component weight
	• 15% weight reduction per IBP module type
Performance	• Lower dielectric constant
	• Small lead inductance
	• Faster speeds with less loss
Availability	• 30%-40% more part functions available in plastic
	• 97% of all integrated circuits made are PEMs
	• Lead-time normally reduced due to constant product (exception is parts allocation)
Reliability	• Tremendous improvement in PEM reliability since 1975 (better molding compounds)
	• Considerable test data becoming available on PEM, especially in harsh environments

CIM High Level Design Documentation

Rob Hovsapian, TRW Avionics Systems Division

Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"* is demonstrating the commercial manufacture of military electronics modules. In this program, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. The manufacturing infrastructure required for the IBP demonstration includes a computer integrated manufacturing (CIM) system. The objectives of this paper are to describe the characteristics of the CIM system design documentation, to discuss the benefits of using a disciplined approach to documenting CIM system development efforts, and to identify practices that will enable future CIM development efforts to be done in an efficient manner.

Background

The CIM system consists of Factory Control System (FCS) and Work Cell Controller (WCC) subsystems. The FCS provides product configuration data to set up the factory, and reporting to the WCC. The WCC performs the bulk of the transaction processing as products are built on the factory floor. CIM system modules are identified in Figure 1.

Figure 1. CIM System Modules

Factory Control System (FCS)	WorkCell Controller (WCC)
Factory System Configuration (FSC)	Work in Process (WIP)
Configuration Management (CM)	Production Changeover (PCO)
Bill of Materials (BOM)	As Built Traceability (ABT)
Repetitive Scheduling /Work Order Management (WOM)	Alarm Management (AM)
Quality Model (QM	
Production Reporting (PR)	
Archive/Dearchive (ARC)	

The CIM system design documentation is comprised of a high level design description of each of the subsystems, along with modular data flow diagrams that delineate the type and level of support expected from each module within a subsystem. The data flows are user-based, meaning that they depict what the user of the CIM system will see at the workstation. The system documentation also includes descriptions of generic user forms that can be run on any user station, user screens which are specific to a class of machine, functional modules that perform some processing activity, and database tables that serve as the repository for all CIM system data. The documentation references additional documents that provide successive levels of detail. These are the CIM Requirements, the Operational Scenario, and Design Notes.

Discussion

The IBP team developing the CIM system is a distributed product team consisting of TRW military and commercial engineers, third-party supplier engineers, and Air Force Manufacturing Technology support personnel. This diverse set of talents has developed a set of documentation to describe the CIM system that will enable the partitioning of the design effort in a modular fashion. This approach eases the integration and test efforts and allows for transferability. The IBP Design Team determined early in the program to utilize formal design documentation based on industry standard data flow and related documentation methodologies to document the high level design.

The design document was essential for translating the deliverables from a requirement definition format to specific deliverable items with associated measurable effort, resources and calendar time. This clarity that the design document provided enables the team to successfully define the capability and constraints of the CIM system.

The design document also proved to be invaluable as a mechanism for providing the third-party suppliers of software design and

* Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group.

development services with a clear and concise product definition. The design document provided the platform for all discussions between design team members. Expectations were clarified, major interfaces between modules were understood, and the work-split between the TRW and its third-party suppliers was clear.

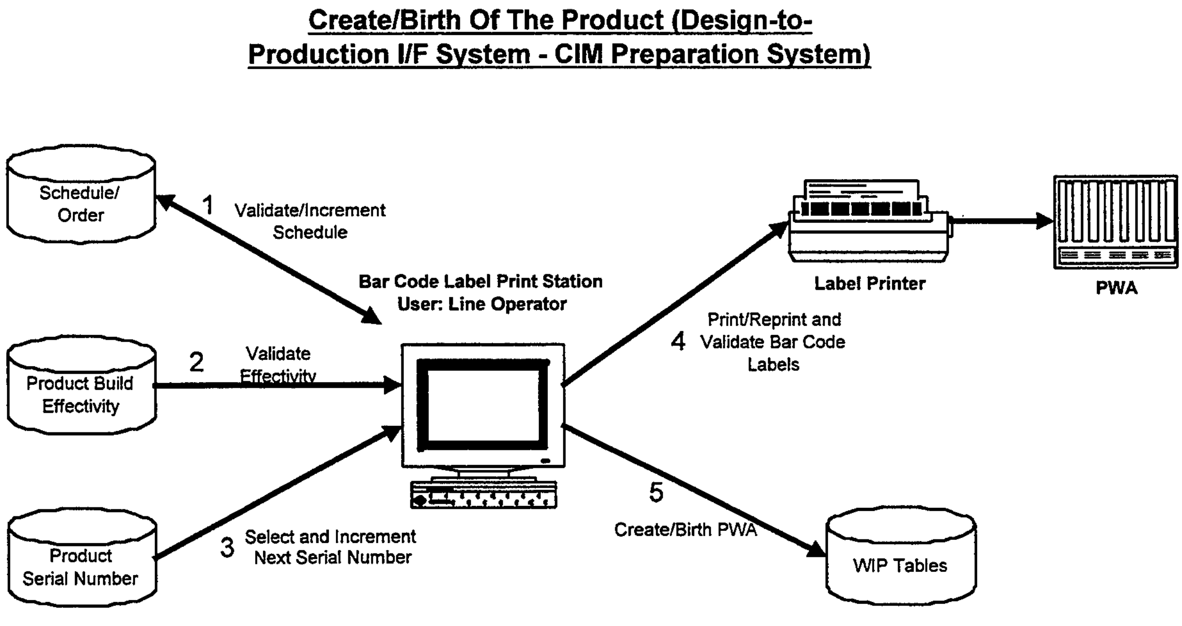
The modularity of the design document is also important, in that it simplified the bidding process during third-party supplier selection. The document is of sufficient detail to permit the suppliers to accurately propose their cost and technical approaches. Actual experience to date on the CIM system development indicates a close correlation between proposed and actual performance.

The IBP CIM High Level System Design (ref. CDRL A011 document, Phase II, Manufacturing Infrastructure) has been developed so that the development team could perform the detail design of the many subsystems within the overall CIM system. This document is being used by the development team to partition the detail design and development effort among the different teams at TRW and its third-party suppliers. The design document includes all major subsystems of the Factory Control System, detail about the different classes of the Work Cell Controller, all major interfaces to the external systems, and the major database interfaces among all subsystems. An example of a typical data flow diagram from the design document is shown below in Figure 2.

Summary/Recommendations

To successfully transition the manufacture of military products to commercial lines requires an integrated system for controlling the introduction of new products to a factory in a seamless fashion. The IBP program is developing and implementing a CIM system for accomplishing this objective using a disciplined approach to documenting the design requirements. In addition to providing the structure for system development, this approach has yielded the benefits of reducing the uncertainty associated with the use of third-party software development suppliers. Use of disciplined documentation approaches in the development of complex, integrated systems is recommended for future commercial-military integration efforts.

Figure 2. Data flow diagram.



Evaluation of Industrial Surface Mount Plastic Encapsulated Microcircuits for Military Avionics Applications

Mark Myers, TRW Avionics Systems Division

Background

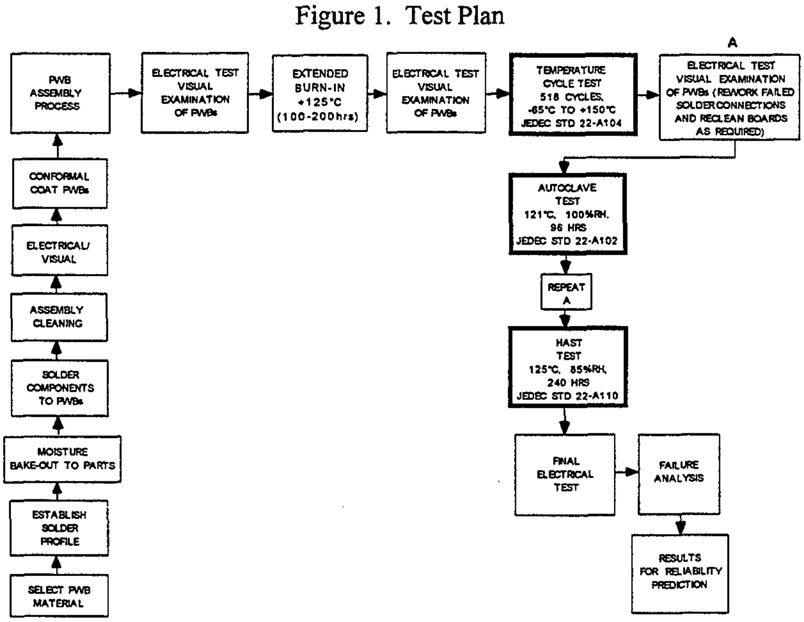
The Industrial Base Pilot (IBP) program, "Military Products from Commercial Lines," is demonstrating commercial-military integration by building military products on a commercial automotive electronics assembly line (ref. contract number F33615-93-C-4335). The Avionics Systems Division and Automotive Electronics Group of TRW have teamed up to demonstrate that the dual objectives of reduced cost for the military, and increased flexibility for commercial manufacturing firms can be accomplished. The objectives of this paper are to describe the test process and the results of tests performed on commercially-available parts that are being used by the IBP project to reduce the cost of military electronics; and to identify the important considerations for future insertions of commercial parts into military designs.

Surface-mount plastic encapsulated microcircuits (PEMs) are used in commercial and industrial electronics designs, primarily for their cost and size advantage. They are easily adaptable to automated assembly operations. As a result of their application in high technology commercial communications systems and automotive electronics, many improvements have been made in the package molding compounds to better withstand the environmental extremes of temperature and moisture. Today's military avionics designs, with requirements for high reliability, reduced size and low weight, are an obvious choice to take advantage of these improvements in the industrial microcircuit technology base, wherever possible.

Discussion

For this study, 1248 plastic surface-mounted (SMT) integrated circuits (ICs), representing 19 different part types from 9 different manufacturers, were reflow solder-attached to 69 high temperature BT epoxy circuit boards on an automotive electronics assembly line. Following assembly to the circuit boards, environmental tests were performed for the purpose of evaluating thermal cycling and moisture susceptibility of the plastic SMT Ics. The test process included extended burn-in, temperature cycling, autoclave, highly accelerated stress test (HAST), and parametric GENRAD testing. The testing for this experiment was performed in a serial

Figure 1. Test Plan



sequence (see Figure 1, test plan). Consequently, the boards were subjected to the cumulative

The primary purpose of the component reliability testing was to obtain experimental data that would evaluate long term survivability of surface-mount PEM microcircuits for a specific military avionics application. The final test results are summarized in Table 1.

Most of the microcircuits tested exhibited no failures through the environmental test sequence performed. There were 7 devices failures out of 1248 and all 7 were submitted for failure analysis to understand the failure mechanisms involved. The final analysis for these failures is still ongoing and additional results are expected in the future. For the devices exhibiting failures, alternate choices have been made. In general, the test results support the justification for the use of plastic encapsulated device types for an application that had previously been limited to traditional ceramic, military part types.

environments of extended burn-in, temperature, cycle, autoclave and HAST.

Recommendation

Of greater significance is the fact that this testing only represents an initial qualification effort designed to validate the feasibility of using specific, commercially available plastic encapsulated microcircuits for a specific military avionics application. In order to utilize existing commercial / industrial technology for future military avionics applications, a continued effort must be made to evaluate each new part type for each application. Ultimately, part qualification and reliability data should be obtained from part manufacturers. However, if this data is not available or not adequate, then accelerated tests similar to the ones presented here are recommended.

Table 1. Summary of Test Results

TEST	NUMBER OF BOARDS INTO TEST	NUMBER OF DEVICES INTO TEST	BOARDS NOT SUBJECTED TO TEST	DEVICE FAILURES FOR ANALYSIS AFTER TEST
STARTING QUANTITIES:	69	1248	–	–
EXTENDED BURN-IN	68	1230	1[1]	4[6]
TEMPERATURE CYCLE	63	1139	5[2]	–
AUTOCLAVE	50	906	13[3]	2[7]
HAST (168 hrs)	55	992	8[4]	–
HAST (240 hrs)	50	899	5[5]	1[8]

(1) 3C held out and designated as control board
(2) 4 Boards in retest/reclean; 23A held out for salt fog test
(3) 13 additional Boards in rework for resistor and board via failures
(4) 8 Boards still in rework for resistor and board via failures
(5) 5 Boards removed for analysis of low current after 168 hours of HAST
(6) 3-(U19) Comparators and 1-(U15) 20 bit buffer
(7) 1-(U15) 20 bit buffer and 1-(U7) Op Amp
(8) 1-(U19) Comparator

MPCL CIM System Integration

Rob Hovsapian, TRW Avionics Systems Division

Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines (MPCL)" is demonstrating the commercial manufacture of military electronics modules. In this program, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics North America (AEN), to accomplish the MPCL objectives. The manufacturing infrastructure required for the MPCL demonstration includes a computer integrated manufacturing (CIM) system. This paper describes the CIM system integration effort, discusses the approach used in performing the CIM system integration, and identifies the practices that will enable the future CIM system integration to be done in an efficient manner. Specific lessons learned are included.

Background

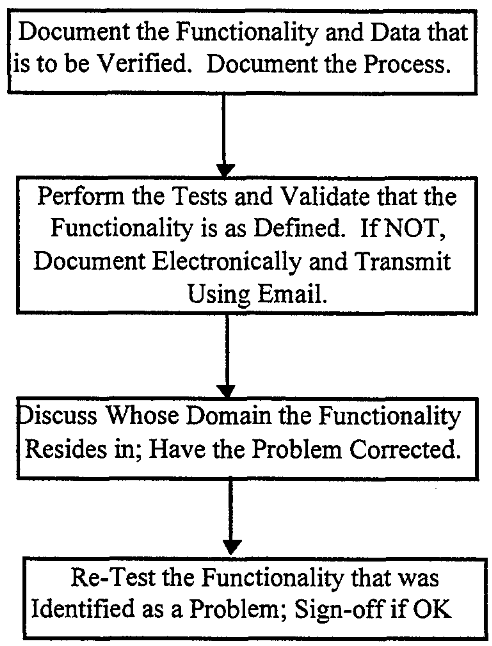
The MPCL CIM system was developed by three different TRW sites and three separate vendors. To provide for a systematic approach for the validation and verification of functionality, a well documented process was used. The figure shown to the right highlights the main process used to perform the CIM system integration. First, the CIM system functionality that was scoped in the design phase was to be documented in such a way as to allow the test user to understand what needed to be tested and how these tests were to be performed. Second, the actual tests were done, and the CIM system capability was verified against the document. In addition, graphical user interface errors and concerns were addressed here. If any problems were discovered, these were documented electronically and transmitted using Email. Third, the group made a determination of who was responsible for fixing the problem. Lastly, the corrected problem was verified and, if okay, closed.

To assist in the CIM system integration effort, two documents - the Test Plan Document (TPD) and the System Integration Document (SID) - were developed. The TPD defines the methods and procedures for how the testing and verification process is done. In addition it defines what tools are necessary to document and distribute the test information. The SID defines the high level functionality to be tested and the expected results. In addition, it defines the complete data set used to perform the CIM system integration.

Discussion

The system integration process and corresponding support documentation provided the reference point for all the vendors and TRW as to the scope and extent of integration, the functionality that was to be tested, and the types of integration issues and concerns to be addressed as part of the integration process. This helped the different vendors and TRW to know when the different vendors were needed on site and what was to be considered "acceptable."

Prior to the development of the TPD and SID, other military program system integration and test documents were reviewed. These documents were very elaborate in defining explicitly what functionality was to be tested, how the tests were to be conducted, and described all the major modes of interaction with the user and other system modules. The TRW-Marshall plant personnel and commercial vendors reviewed this approach. It was deemed to be restrictive and time consuming without efficiently achieving the end objective of providing a well integrated and tested CIM system.



The system integration process and corresponding support documentation defined the basic factory, user, and production line data

Reference File Number: MI-CIM-LL-004
Date: 11 November 1996

to be configured for the integration test database, along with a set of three product configurations to be built on the test production line, Flex Line 3. This helped the TRW Database Team at the Marshall plant create the database appropriately, the Test Users Team know the minimum integration data set to be configured, and the corresponding TRW Data Verification Team to efficiently verify that the data configured by the new factory control system (FCS) applications performed correctly.

The system integration process and corresponding support documentation defined the FCS and work cell controller (WCC) hardware environment for the testing process since the actual production line was not available for system integration testing. Because the SID clearly defined the expectations of the test environment, the computer hardware for the FCS stations, WCCs and peripheral hardware was able to be setup and verified quickly, with minimal impact to the system integration testing schedule.

The system integration process and corresponding support documentation defined the high level functional elements to be met, and left the user interaction level elements up to the test users and the system developers. This helped focus the system integration on the critical elements of the system. It further provided the flexibility for test users to interact with the system and provide explicit feedback on user interface issues as the overall goals were tested and verified.

The system integration process and corresponding support documentation defined the data validation process and tools along with the data. Since the expectations were clear, the Data Validation Group was able to define the SQL queries and reports to be generated. These in turn are now being used as a basis to create the factory user reports.

Prior to the system integration process at the TRW Marshall plant, module level testing was expected from all vendors and TRW development teams. One of the vendor teams had completed module level testing on some of the modules and had not even begun development of others. This was not discovered until system integration and caused some delays. In the future, a site visit and/or a more explicit and detailed status would be beneficial to identify such problem areas prior to the start of the integration effort.

Summary/Recommendations

To successfully perform system integration with a geographically distributed set of vendors and TRW sites, the clarity and scope of the system integration effort needed to be precise. This was essential to allow different groups of people to be present when needed to perform the particular test and resolve issues. In the future a more detailed development and test status of modules would be required with a possible site visit to each development team's environment. Use of a well documented process, along with well defined data and functionality proved invaluable to drive the efficiency of the group and the system integration process.

Design Guidelines for a Combined Military and Commercial Product Development Team

Mark Myers, TRW Avionics Systems Division
Mary Kinsella, AF Wright Laboratory ManTech Directorate

Introduction

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines"[1] is demonstrating the commercial manufacture of military electronics modules. In this program, the prime contractor, TRW Avionics Systems Division (ASD) has teamed with a commercial supplier, TRW Automotive Electronics Group (AEG), to accomplish the IBP objectives. The IBP Process Technology (PT) Team is responsible for designing and producing Military Avionic Modules. The design effort is located in San Diego, California and is staffed with designers from TRW ASD, a Military design and production capability. The production effort is located in Marshall, Illinois, and is staffed with manufacturing and test engineers and technicians from TRW AEG. This document serves to collect the experiences and nuances encountered in developing this dual use product.

The scope of this task involves redesign of two existing Military SEM-E Avionic modules. The design task is constrained by reuse of the existing rack, reuse of existing software, and no repartitioning of the modules. This fixes the mechanical envelop, the input/output (I/O) connector, and the silicon functionality of custom components. Therefore, this document will focus on Product Development Processes, Details of Part Selection, and Printed Wiring Board Design. Emphasis is placed on uniqueness of the dual use environment and not on design details.

Product Development Processes and Product Complexity

Details of the differences between military and commercial product development have been previously reported by the Manufacturing Infrastructure (MI) Team through its Concurrent Engingeering Environment (CEE) effort. (Reference MI-CEE-LL-001.) Some relevant points are reiterated here.

Both Organizations use a multi disciplined product development team. The membership on both teams is similar. One notable difference is that the leadership of the team for the military organization is typically the responsible design engineer (or of that background), while the leadership of the commercial product development team may be of either product design or manufacturing background. The commercial team then assigns "equal" team membership to the Responsible Engineering Manager (REM) and the Responsible Manufacturing Manager (RMM) under the program manager.

Product development milestones are also very similar. Both organizations use similar program management tools. The type of and points for design reviews are similar, and both involve the customer early in the product development cycle. The commercial organization performs very little design simulation in this schedule, and by contrast produces and tests much more hardware than the Military organization. The commercial process involves three hardware build cycles before production: Engineering Validation (EV) to construct the schematic, Design Validation (DV) to debug the schematic, and Production Validation (PV) to verify manufacturing, test and process preparedness. For automotive electronics, these builds can consume 500 to 1000 pieces.

Product Architecture and complexity varies greatly between these products. Automotive electronics attempt to maintain discrete designs without custom components. Device gate counts are nominally below 10,000, I/O's below 50 and unit I/O's below 25. The military modules extensively use custom ASIC's with up to 300K gates and 400 I/O, and use backplane interfaces with over 500 I/O. Automotive uses mixed technology boards, and military uses surface mount only.

[1] Contract No. F33615-93-C-4335, funded and managed by USAF Wright Laboratory Manufacturing Technology Directorate, contracted to TRW Avionics Systems Division, and subcontracted to TRW Automotive Electronics Group.

Design-to-cost (DTC) goals permeate the automotive design process to the penny level. End item product costs are usually below $100. Military designs have DTC goals usually at the tens of thousands dollar level and unit prices are in the $20,000 range. Both products' cost structures are roughly 80% BOM and the remainder manufacturing and test. Automotive uses highly automated processes to achieve this relationship, while military processes are typically manual batch.

Part Selection

Part selection in the dual use environment is vastly different than in the military only or the commercial only environments. In the commercial only environment, parts are selected by vendor, parts per million defects (PPM) levels, package type and long term pricing arrangements as much as by function. In the military only environment, parts are selected primarily for function, and the other attributes are ancillary. In teaming with a commercial supplier to produce an existing design, these philosophies needed to merge. Part selection guidelines developed by the PT team included:

- Use commercial off the shelf components to replace military devices if at all possible. Commercial parts selected shall be of the best performance level available (Automotive grade, Industrial Grade and last Commercial Grade)
- Use existing AEG components as much as possible. This leverages the commercial volume procurement capability and long term supply arrangements.
- Use vendors certified and partnered with AEG. This addresses PPM, supplier relationship and other vendor relationship issues.
- All parts must be surface mount reflow or wave solder reflow compatible. No manual attach of parts is allowed.
- Avoid mixing part packaging technologies. Select either all ball grid arrays (BGAs), or all quad flat packs (QFPs), or all pin grid arrays (PGAs).

Printed Wiring Design

Printed wiring design in the dual use operation is driven primarily by product complexity, and then by design for manufacture/design for assembly (DFM/DFA) rules. A new set of printed wiring board (PWB) design rules has been generated for the IBP program and has been submitted by the MI CEE team. A synopsis of the prominent design attributes and the differences follows.

- PWB line width and spacing for automotive applications was 15 mils. The agreed to value for the dual use products was 5 mils.
- Component spacing for rework in the military application was set at 50 mils. The agreed to revision increased this to 110 mils for active devices.
- In-circuit test (ICT) probe points are not used in the military application and are added for the dual use application. Likewise, pull ups are added to all SCAN part test points for this purpose.
- Component fiducials are used for the military application but are not necessary for commercial use.
- PWB's are panelized, in the case of SEM-E boards, in a two up mode, to create a common array size for the automotive applications. The military product was one up.
- Board identification uses bar code labeling, where the military application was ink stamped.
- Component geometries are built per IPC recommendations and tailored for the automotive facility. IPC had been the military baseline.

Lessons Learned

In executing this design, some valuable lessons learned for the dual use model were unearthed, and cover all the areas noted above. First, the design rule "negotiation and approval process" was very lengthy (16 months), so starting early and agreeing on non technical matters (format, approval signatories, response rates, scope) are critical. Second, the commercial enterprise depends highly on volumes of product and test data to establish designs and design rules. Compromise and culture differences are most evident here. Plans to allow extra resources or substitute tests/analysis should be published and agreed to as early as possible. And finally, merging of the product complexity differences and an existing design impact the commercial vendor and part selection process. "Blank sheet of paper" designs will more fully use this commercial leverage.

Commercial Suppliers and Government Purchasing Restrictions

Mike Nanzer, TRW Avionics Systems Division

Introduction

One of the key tenets of military acquisition reform has been the emphasis placed on buying commercial products when market research shows them to be available. This preference for commercial items on the part of military buyers and contracting officers comes at a time when commercial suppliers are becoming more selective in terms of which markets they will serve. This has been felt especially in the electronics sector where there are numerous high volume customers for limited electronics manufacturing resources. Several high profile electronics manufacturers have gone public with notice that they will no longer serve their traditional military customers. These firms' decisions are based both on the opportunity cost of serving military customers with their low volume requirements, and the bureaucratic nature of the military procurement process (unique specifications, standards, contract terms, and conditions). It is important for the military to reform its acquisition practices in order to ensure continuous access to the electronics manufacturing base.

This paper describes the problems faced by buyers and contracting officers in placing purchase orders and subcontracts with commercial suppliers under military contracting rules and regulations. Further, it identifies the emerging mechanisms for streamlining the process emanating from acquisition reform efforts on the part of the government.

Discussion

A major activity on the Industrial Base Pilot (IBP) program is the demonstration of commercial military integration through the manufacture of military modules on a TRW Automotive Electronics Group - North America (AEN) commercial assembly line. The military modules chosen for this demonstration are Communication, Navigation, and Identification (CNI) modules designed by TRW's Avionics Systems Division (ASD). These modules utilize application-specific integrated circuit (ASIC), and digital signal processing (DSP) technologies packaged in a compact standard electronic module (SEM) format. The IBP program Process Technologies (PT) team has redesigned these modules to utilize common commercial parts and processes so as to minimize the impact to AEN's commercial assembly line.

The selection of common commercial parts presented the IBP team with some obstacles in the procurement of these components. Commercial suppliers are increasingly reluctant to provide products and services to military customers. There are numerous reasons for this reluctance including excessive paperwork, unique changes in accounting systems to satisfy cost accounting standards and the Truth in Negotiations Act (TINA) PL 87-653, maintenance of extensive records to comply with Equal Employment Opportunity (EEO), small business, and labor surplus utilization acts, records reflecting compliance with inspection and testing requirements, technical manuals and provisioning requirements beyond normal commercial manuals, and a multitude of boilerplate provisions which require legal advise. Aside from these military-unique business practices, there are structural aspects of the defense market which discourage commercial supplier participation, as summarized below in Figure 1.

In summary, it is the combination of military business practices and defense market structure characteristics that serve to discourage commercial suppliers from participating in the market. To address these areas, the United States Congress passed the Federal Acquisition Streamlining Act (FASA) of 1994 which, when implemented in Federal Acquisition Regulation (FAR) in 1995 broadened the definition of commercial items. There is now increased latitude available to military buyers in defining items as commercial. Further, the flow down requirements for commercial items have been minimized.

Despite this streamlining, the IBP team found it necessary to contract with some commercial firms for the development of items that did not qualify as commercial items. One such item was the supplier of ball-grid array packaging services to IBP. Because of the dollar value and development content in this contract, TRW had to negotiate the acceptance of mandatory flow down requirements. This negotiation process involved reviews by technical performers, contracts representatives, law department representatives, and ultimately, division management. The advice of the firm's law department to refuse to accept the mandatory flow down requirements was ultimately overruled by division management. Ultimately, management decided to accept these requirements based upon the desire to further its ball-grid array technology development efforts. Technology won out over contractual issues.

Figure 1. Some examples of market imperfections and failures in the defense market

Free Market Theory	Defense Market
Many small buyers	One buyer (DOD)
Many small suppliers	Very few, large suppliers of a single item
Free movement in and out of market	Extensive barriers to exit and entry
Prices set by marginal costs	Prices proportional to total costs
Prices fall with reduced demand	Prices rise with reduced demand
Supply adjusts to demand	Large excess capacity
Market shifts rapidly to changes in supply and demand	7-10 years to develop a new system, then 3-5 years to produce it
No government involvement	Government is regulator, specifier, banker, judge of claims, sole buyer
Selection based on price	Selection often based on politics, or sole source or negotiation; only 8% of dollars awarded based on price competition
Competition is for share of market	Competition is frequently for all of none of a given market
Production is for inventory	Production occurs after sale is made
Size of market established by buyers and sellers	Size of market established by third party (Congress) based on annual DOD budget
Demand sensitive to price	Demand threat sensitive or responds to availability of new technology; almost never price sensitive
Relatively stable, multi-year procurements	Annual commitments with frequent changes
Buyer has choice of spending now or saving for later purchase	DOD must spend its annual congressional authorization

For another IBP supplier, a producer of ASIC components, the major issue was the imposition of FAR clause 52.211-15 Defense Priority and Allocation System (DPAS). This requirement obligates a supplier to prioritize DPAS rated work in front of non-DPAS rated work in the factory. This supplier had been subject to direct government intervention in the past due to the DPAS requirement. The firm's management had since instructed its operating units to no longer accept this requirement. In this case, the supplier was providing only components to IBP, not developmental services. The IBP team was able to define these components as commercial items under the new expanded FAR definition (reference FAR 2.101). The basis for the commercial definition was that the firm was providing TRW with the same product that it supplies to its commercial customers. Flow downs on this commercial item contract included only the required three socioeconomic FAR clauses (reference FAR 52.244-6).

Recommendation/Summary

These two case studies illustrate some key points about the move on the part of military buyers to commercial products. The first point is that military buyers should use the expanded definition of commercial items to minimize the flow down of military-unique business practices. Secondly, commercial firms are becoming more thorough in their analysis of new customer requirements. Part of this may be explained by the impact of national standards such as ANSI/ASQC ISO-9001. ISO prescribes a contract review process which requires a firm to analyze customer requirements thoroughly prior to submission of a proposal. As more firms implement quality systems in accordance with ISO-9001, the military can expect increased scrutiny of unique requirements. Finally, military buyers who cannot rely on commercial item acquisitions must work closely with suppliers to analyze mandatory versus advisory flow down clauses. This effort must focus on balancing the risk reduction achieved by the buyer and the cost of compliance.

Appendix A. IBP Required FAR/DFARS Clauses for Subcontracts

FAR/DFARS Clause	Title	Mandatory/Advisable Status & Recommendation
1. 52.209-6	Protecting the Government's Interest When Subcontracting With Contractors Debarred, Suspended, or Proposed for Debarment	Analysis: Mandatory subcontract flowdown on first-tier subcontract proposals only that exceed $25,000. Recommendation: Mandatory clause - include in subcontract.
2. 52.211-15	Defense Priority and Allocation Requirements	Analysis: Not a mandatory subcontract flowdown per FAR; however, per the Defense Priorities and Allocation System regulation (15 CFR Part 700.3(d), which is the basis for the FAR requirement, it is a mandatory flowdown to any supplier receiving a rated order. Recommendation: Mandatory clause - include in subcontract.
3. 52.222-1	Notice to the Government of Labor Disputes	Analysis: Mandatory flowdown in all subcontracts. Recommendation: Mandatory clause - include in subcontract.
4. 52.222-26	Equal Opportunity	Analysis: Mandatory flowdown in all subcontracts. Recommendation: Mandatory clause - include in subcontract. **One of three required flow down clauses for commercial items.**
5. 52.222-35	Affirmative Action for Special Disabled and Vietnam Era Veterans	Analysis: Mandatory flowdown in all subcontracts exceeding $10,000. Recommendation: Mandatory clause - include in subcontract. **One of three required flow down clauses for commercial items.**
6. 52.222-36	Affirmative Action for Handicapped Workers	Analysis: Mandatory flowdown in all subcontracts exceeding $2,500. Recommendation: Mandatory clause - include in subcontract. **One of three required flow down clauses for commercial items.**
7. 52.222-37	Employment Reports on Special Disabled Veterans and Veterans of the Vietnam Era	Analysis: Mandatory flowdown in all subcontracts of $10,000 or more. Recommendation: Mandatory clause - include in subcontract.
8. 52.223-2	Clean Air and Water	Analysis: Mandatory flowdown in all subcontracts. Recommendation: Mandatory clause - include in subcontract.

9. 52.225-11	Restrictions on Certain Foreign Purchases	Analysis: Mandatory flowdown in all subcontracts. Supplier is required by law to comply with the provisions of the Foreign Assistance Act. The FAR clause merely restates in the contract legal obligations already independently imposed on suppliers under the law. Recommendation: Mandatory clause - include in subcontract.
10. 52.242-15	Stop-Work Order	Analysis: Not a mandatory subcontract flowdown, however, considered advisable. Recommendation: Advisable flowdown - include in subcontract.
11. 52.246-23	Limitation of Liability	Analysis: Mandatory flowdown in all subcontracts. Recommendation: Mandatory clause - include in subcontract.
12. 252.204-7000	Disclosure of Information	Analysis: Mandatory subcontract flowdown. Required when the contractor will have access to or generate unclassified information that may be sensitive and inappropriate for release to the public. Recommendation: Mandatory clause - include in subcontract.
13. 252.225-7009	Duty Free Entry - Qualifying Country End Products and Supplies	Analysis: Mandatory flowdown when materials that are accorded duty-free entry are procured from certain foreign countries. Recommendation: Need to determine if supplier will be procuring materials that will fall under this clause.
14. 252.225-7014	Preference for Domestic Specialty Metals - Alt 1	Analysis: Mandatory flowdown in all subcontracts unless the item being purchased contains no specialty metals. Recommendation: Need to determine if supplier will be procuring materials that will fall under this clause.
15. 252.225-7025	Foreign Source Restrictions	Analysis: Mandatory flowdown if items procured contain any "restricted" items. Recommendation: Need to determine if supplier will be procuring materials that will fall under this clause.

16. 252.227-7013	Rights in Technical Data and Computer Software	Analysis: Mandatory subcontract flowdown if technical data will be provided by the subcontractor for delivery to the Government. Recommendation: Need to determine if supplier will be providing technical data under the subcontract.
17. 252.227-7018	Rights in Noncommercial Technical Data and Computer Software-Small Business Innovative Research (SBIR) Program	Analysis: Not a mandatory subcontract flowdown, deemed advisable flowdown to protect the prime contractor. Recommendation: Advisable flowdown - include in subcontract.
18. 252.227-7037	Validation of Restrictive Markings on Technical Data	Analysis: Mandatory subcontract flowdown in all subcontracts which require the delivery of technical data (except for commercial items or components). Recommendation: Need to determine if supplier will be delivering technical data under the IBP subcontract.

MPCL Commercial Item Determination

Jane Dillon, Wright Lab Contracts Negotiator

Mary Kinsella, Wright Lab Manufacturing Technology

"Military Products From Commercial Lines" (MPCL) is an Air Force Industrial Base Pilot (IBP) program administered by the Manufacturing Technology Directorate of Wright Laboratory. The program (ref. Contract number F33615-93-C-4335) is contracted to TRW Avionics Systems Division (ASD) and subcontracted to TRW Automotive Electronics Group North America (AEN). The program objective is to demonstrate the production of military components on a commercial line at lower cost and comparable quality to those produced on a dedicated military line. TRW AEN will produce military electronic modules compatible with the F-22 Raptor Advanced Tactical Fighter and the RAH-66 Comanche Helicopter on their manufacturing line which also produces commercial electronics, e.g., for General Motors and Caterpillar. The MPCL program provides a preview of the acquisition environment of the future, i.e., the use of quality commercial manufacturers for defense related products through streamlined acquisition procedures compatible with best commercial practices. This paper describes the process followed by MPCL to obtain commercial item status for the demonstration modules, thus allowing a simplified subcontract with the commercial supplier.

With the promise of the Federal Acquisition Streamlining Act (FASA) of 1994 and its attendant emphasis on using commercial items to meet government requirements, MPCL was poised to reap the Act's many benefits. In May 95, the program's Contracting Officer requested a legal determination from the cognizant Judge Advocate General (JAG) Office as to the commerciality of the electronic modules. Since FASA had not yet been implemented, the proposed rule issued pursuant to FASA (FAR Case 94-790: Acquisition of Commercial Items) was used as the basis for the request. The justification presented was that, prior to this contract, TRW AEN only performed work for non-governmental customers and their production items are of a type customarily used for non-governmental purposes. Therefore, since the military electronic modules would be manufactured using the same processes, the same equipment, and the same workforce, they meet the criteria that the items be of a type customarily used for non-governmental purposes and sold to the general public. The proposed rule also allowed for "minor" modifications that do not alter a commercial item's function or essential physical characteristics. These electronic components do not share all the traits of those manufactured for AEN's commercial customers, either functionally or in physical characteristics. However, allowance was made in the proposed rule for modifications of a type customarily available in the commercial marketplace, and TRW AEN does routinely tailor its products to specific customers.

The MPCL team provided yet another perspective, that AEN is a commercial contractor which offers products to several automotive companies. Each component AEN sells to its customers is unique, however, because each requires a different "form, fit and function." Consequently, the common product which is sold to the public, and now to the Government, is the design, development, and production of a part.

In a negative response to this request, the JAG's position on 18 May 1995 was: 1) to apply a proposed rule under FASA to a subcontract not agreed to under FASA was premature; 2) this agency, the Manufacturing Technology Directorate, had not planned for acquiring commercial items early in the procurement process; 3) the nature of the prime contract (cost reimbursement, research and development) prohibits the application of commercial items, irrespective of the subcontract type; and 4) there was no clear indication that the benefits of FASA were ever intended to apply to other than new efforts.

When FASA was implemented in Oct 1995, a notable addition was inserted into the definition of "minor modification", as follows: "*.....modifications that do not significantly alter the non-governmental function or essential physical characteristics of an item....* ***or change the purpose of a process.***" The intent of this inclusion seems to be that the authors recognized that a common practice in the commercial sector is the modification of products to meet individual customer needs. A logical conclusion can be reached that if a customer's products can be made with existing commercial manufacturing processes (with minor modification to same) then under this commercial item definition, it is a commercial item.

Following the implementation of FASA, the MPCL team conducted a thorough review of the acquisition planning and strategies that facilitated award of the MPCL contract. Interim and final rules implementing recent acquisition reform legislation were also analyzed. The team found that many of the earlier JAG concerns were no longer issues. The team concluded:

1) The guiding principles in the Federal Acquisition Regulations (FAR) explicitly empower Contracting Officers to make decisions within their area of responsibility, and in so doing, to assume that, if a specific strategy is in the best interest of the Government and not addressed in the FAR nor prohibited by law, that the strategy is a permissible exercise of authority. In support of this position, the Comptroller General found, in <u>Komatsu Dresser Co.,</u> *Comp. Gen. B-255274,94-1CPD P119,* that the *"determination of whether a product is a commercial item is largely within the discretion of the contracting agency, and will not be disturbed by our Office unless it is shown to be unreasonable."*
2) The Manufacturing Technology Directorate had conducted a market research that identified a need for advanced research into ways to move the DoD into commercial item

acquisition. TRW ASD proposed a program which fulfilled this need by a technical demonstration of commercial manufacturing process capability to produce military weapon system components. Also, in essence, TRW ASD had performed a similar market research, and identified AEN as the F-22 component supplier for this demonstration.

3) FASA's preference for commercial items where possible clearly extends to sub components, and subcontracts under which those subcomponents are supplied, and TRW ASD's business arrangement with AEN is under a Firm Fixed Price (FFP) subcontract.

4) The interim FAR rule, issued April 1996 encourages appropriate modifications of existing contracts to incorporate other changes authorized by FASA.

In the meantime, TRW had prepared a determination that their subcontract was one supplying commercial items. Based upon these findings, the Contracting Officer endorsed TRW's commercial item determination. This endorsement was resubmitted for legal review and comment in August 1996, and was found to be legally sufficient.

The Roadmap to Military Products From Commercial Lines: Commercial Item Determination and The Use of Price Analysis

Mike Nanzer, TRW Avionics Systems Division

Introduction

"Military Products From Commercial Lines" (MPCL) is an Industrial Base Pilot (IBP) program administered by the Manufacturing Technology Division of the Air Force Research Laboratory. The program (ref. Contract number F33615-93-C-4335) is contracted to TRW Avionics Systems Division (ASD) and subcontracted to TRW Automotive Electronics Group North America (AEN). The program objective is to demonstrate the production of military components on a commercial line at lower cost and comparable quality to those produced on a dedicated military line. The objectives of this paper are to describe the process used by the IBP - MPCL program to integrate the use of price analysis techniques with commercial item determination in acquiring F-22 avionics modules from a commercial supplier, and to outline the steps used to conduct commercial item determinations and perform price reasonableness analyses. These processes resulted in the implementation of a subcontract change which enabled the team of TRW ASD, TRW AEN, and the Air Force to demonstrate the benefits of obtaining military products from a commercial assembly line.

Background

The IBP - MPCL program began in 1994 with the objective of demonstrating the process for overcoming the numerous obstacles to commercial-military integration. A key obstacle historically had been the DoD's narrow definition of commercial items. Early in the program, an effort was undertaken to have the demonstration hardware, Communication, Navigation, and Identification (CNI) avionics modules, declared commercial under the existing DoD definitions. This effort went as high as the Air Force Materiel Command Legal Office, where it was ruled that the military-unique nature of the demonstration hardware prevented a declaration of commercial status. The ruling came prior to the implementation of the Federal Acquisition Streamlining Act (FASA) in October 1995.

At that time, the IBP - MPCL program team began another attempt at defining the demonstration hardware as commercial items. FASA added language to the definition of commercial items which expanded the definition of minor modifications to include modifications which do not significantly alter the non-governmental function or essential physical characteristics of an item or component, or change the purpose of a process. The practice of modifying products and processes to suit an automated, high-volume assembly line is not unique in commercial industry. Commercial firms typically make product and process changes to suit customer requirements.

The modifications made to both the IBP - MPCL modules and the TRW AEN manufacturing process were intended to 1) ensure that the F-22 requirements were met, and 2) ensure compatibility between the IBP - MPCL modules and the processes used by AEN to build products for its commercial customers. AEN typically performs modifications to its processes for all customers. These modifications may involve off-line processes, or changes to an automated line. For the IBP - MPCL products, minimal off-line processing is required, and the use of standard commercial manufacturing processes is maximized. Considerable effort has been expended to ensure that negative impacts to the automated assembly lines are minimized. These efforts have focused on the implementation of a computer-integrated manufacturing (CIM) environment. The Air Force Manufacturing Technology (ManTech) Contracting Officer (CO) included the above rationale in a determination and finding document which established the commercial item status of the IBP - MPCL modules (reference lesson learned write-up "MPCL Commercial Item Determination"). The next step in the process was to establish price reasonableness via a technique known as price analysis.

Discussion

During October 1996, the IBP - MPCL team began to conduct a price analysis for the IBP modules. This was necessary as a follow-up task to the commercial item determination in order to pursue a special exemption from cost or pricing data requirements on the TRW AEN subcontract. Ultimately, this requirement was eliminated when the Federal Acquisition Reform Act (FARA) was implemented in 1996. FARA, as implemented in the Federal Acquisition Regulations (FAR), prohibits a CO from obtaining cost or pricing data from commercial item suppliers. Up until this point in the IBP - MPCL program, AEN had an exemption from cost or pricing data requirements for its labor that was granted by the ManTech customer. AEN did not have purchasing responsibilities on the IBP - MPCL program at this time, so an exemption from cost or pricing data requirements for material was not required.

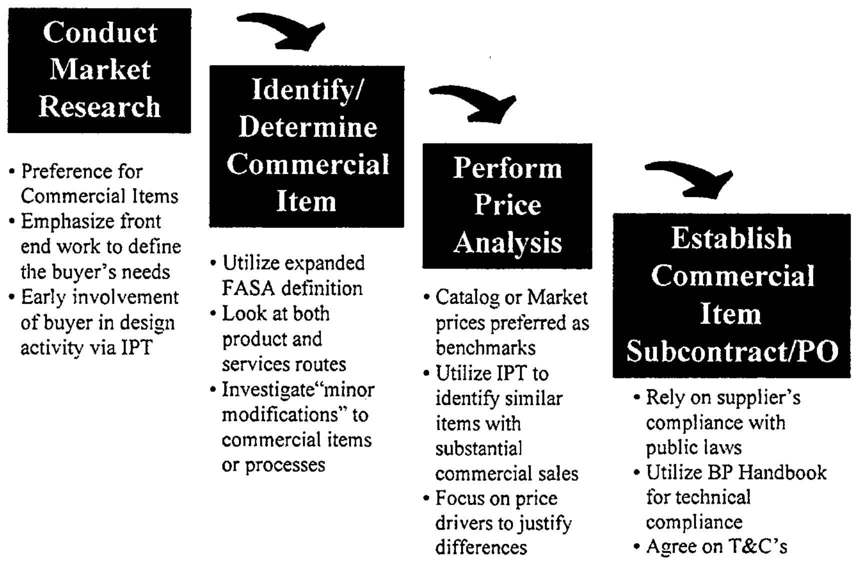


Figure 1. IBP - MPCL Commercial Item Roadmap

With the commercial item status came a planned subcontract change to authorize AEN to procure material for Production Validation (PV) modules. Up until this time, the plan was for TRW ASD to procure material and furnish it to AEN for manufacture of the modules. The change was necessary to demonstrate how commercial suppliers may purchase materials for military production programs in the future. This necessitated a complete exemption from cost or pricing data requirements, and thus, the price analysis. The price analysis approach was to compare IBP - MPCL modules to commercially available modules of similar complexity. Figure 1 illustrates the IBP - MPCL roadmap to commercial item determination, featuring price analysis.

The Business Practices (BP) team conducted market research and found representative commercial modules from several firms to use as comparable items to the IBP - MPCL modules in the price analysis during November 1996. These items were commercial digital signal processing modules that are used in data acquisition applications. These items are featured on published price lists at prices comparable to estimated IBP - MPCL module prices. In order to complete the price analysis the BP team obtained a bid from AEN for the PV modules. A request for quotation and bill of materials were sent to AEN during November 1996. The process of obtaining the AEN quotation was slow due to the novelty of bidding a military product. When the bid was received by the BP team in February 1997, the prices of the commercially equivalent modules had decreased dramatically such that they were no longer within 25% of the AEN price.

A customary benchmark of price reasonableness when using the "similar-to" analysis technique is that the items being compared be priced within 25% of each other. An alternate approach to determining the AEN price to be fair and reasonable had to be found. The BP team determined that if the prices of the custom application specific integrated circuits (ASICs) could be determined to be fair and reasonable separately from the rest of the modules, the remaining IBP module cost could be fairly compared to the commercial comparable items. This was true because the ASICs were huge cost drivers of the overall IBP module price, and the commercial comparable items did not have ASICs. An ASIC cost model tool was identified and an independent ASIC price analysis was conducted. This analysis showed that the prices TRW paid for ASICs in the modules was in line with prices predicted by the model.

With the price analysis step complete, the BP team focused on completing the final step, the implementation of a contract change to establish the IBP - MPCL modules as commercial items. This involved three basic activities:

1. Analysis of remaining applicable FAR clauses after commercial item determination and TRW AEN's ability to comply with these requirements.
2. Agreement on the technical business practice requirements of the modified contract.
3. Analysis of the prevailing contract terms and conditions in the commercial market.

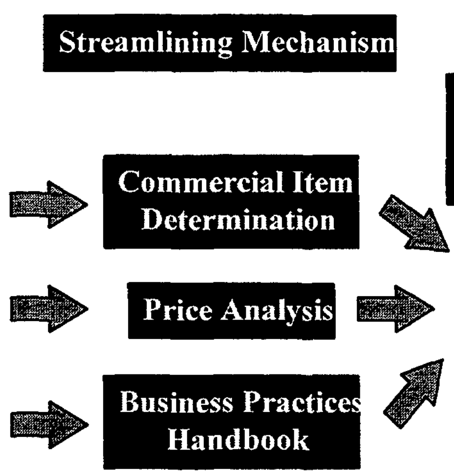
The BP team had earlier conducted an analysis of the applicable FAR clauses for commercial items purchased under a government contract. The applicable clauses are specified in FAR Clause 52.244-6 Contracts for Commercial Items and Commercial Components. There are three applicable clauses, which represents over a 90% reduction in required FAR clauses when compared with the original TRW AEN subcontract (see Figure 2). The other steps were accomplished via AEN's involvement in the development of the business practices handbook, and the use of the AEN Terms and Conditions of Purchase in the revised contract.

Recommendation/Summary

Many of the steps used by the IBP - MPCL team to establish commercial item status for its modules are transferable to other military programs. The roadmap shown in Figure 1 is the key to successful implementation. Starting with market research, military buyers must become more familiar with the market conditions surrounding the products and services they buy. It is also necessary to have a good grasp of important statutory changes such as FASA and FARA in order to take advantage of the streamlining these changes offer. A straightforward, yet often neglected, technique known as price analysis must also become one of the key tools used by military buyers. And finally, military buyers must include the supplier in the development of a streamlined contract for commercial items.

Clauses Applicable to AEN Subcontract at Award

Clause	Title & Date
52.203-7	Anti-Kickback Procedures (Oct 1988)
52.212-8	Defense Priority and Allocation Requirements
52.215-1	Examination of Records by Comptroller General (Feb 1993)--Note Buyer will assume costs associated with Seller's providing records to auditors in support of any audit under this requirement
52.215-2	Audit-Negotiation (Feb 1993)--Note Buyer will assume costs associated with Seller's providing records to auditors in support of any audit under this requirement
52.215-24	Subcontractor Cost or Pricing Data (Dec 1991)
52.215-27	Termination of Defined Benefit Pension Plan (Sept 1989)
52.215-39	Revision or Adjustment of Plans for Postretirement Benefits Other than Pensions (PRB) (Jul 1991)
52.220-3	Utilization of Labor Surplus Area Concerns (Apr 1984)
52.220-4	Labor Surplus Area Subcontracting Program (Apr 1984)
52.222-1	Notice to the Government of Labor Disputes (Apr 1984)
52.222-20	Walsh-Healey Public Contracts Act (Apr 1984)
52.222-26	Equal Opportunity (Apr 1984)
52.222-35	Affirmative Action for Special Disabled and Vietnam Era Veterans (Apr 1984)
52.222-36	Affirmative Action for Handicapped Workers (Apr 1984)
52.222-37	Employment Reports on Special Disabled Veterans and Veterans of the Vietnam Era (Jan 1988)
52.223-2	Clean Air and Water (Apr 1984)
52.225-11	Restrictions on Certain Foreign Purchases (May 1992)
52.227-1	Authorization and Consent (Apr 1984) - Alternate I (Apr 1984)
52.227-2	Notice and Assistance Regarding Patent and Copyright Infringement (Apr 1984)
52.243-1	Changes-Fixed Price
52.246-23	Limitation of Liability (Apr 1984)
252.203-7001	Special Prohibition on Employment (Apr 1993)
252.209-7000	Acquisition from Subcontractors Subject to On-site Inspection Under the Intermediate -Range Nuclear Treaty (Dec 1991)
252.225-7009	Duty Free Entry - Qualifying Country End Products and Supplies (Dec 1991)
252.225-7014	Preference for Domestic Specialty Metals (Dec 1991), Alt I (Dec 1991)
252.225-7025	Foreign Source Restrictions (Apr 1993)
252.227-7013	Rights in Technical Data and Computer Software (Oct 1988)
252.227-7018	Restrictive Markings on Technical Data (Oct 1988) -- (Note: Buyer will provide training to the Seller at the Seller's facility)
252.227-7029	Identification of Technical Data (Apr 1988)
252.203-7000	Statutory Prohibition on Compensation to Former Department of Defense Employees (Dec 1991)



Clauses Applicable to AEN Subcontract after Commercial Item Determination

Clause	Title & Date
52.222-26	Equal Opportunity (Apr 1984)
52.222-35	Affirmative Action for Special Disabled and Vietnam Era Veterans (Apr 1984)
52.222-36	Affirmative Action for Handicapped Workers (Apr 1984)

Figure 2. The Streamlining That Results From A Commercial Item Determination

MPCL ASIC Lessons Learned

Mark Myers, TRW Avionics Systems Division

Background

The Industrial Base Pilot (IBP) program "Military Products from Commercial Lines" (MPCL) has demonstrated the production of two Military Avionics Modules on a commercial manufacturing line. As part of the demonstration, the Process Technology (PT) team has redesigned the military modules to facilitate the commercial production factory and to reduce cost. As part of this redesign, the Application Specific Integrated Circuits (ASICs) were re-evaluated, re-packaged and used. This document attempts to capture some of the unique challenges faced in "commercializing" these complex ASICs.

Part Selection

The part selection hierarchy used for the program had special emphasis on the commercial partner and design for manufacturability (DFM) inputs. The selected priority follows:

1. Commercial equivalent components used in the TRW AEN system. These parts were deemed applicable to the military environment based on extensive use and supplier development performed by TRW AEN for Vehicle Safety Systems.
2. Commercial equivalent packaged off-the-shelf (COTS) parts utilizing the same die as military (SMD) equivalents. Industrial temp range preferred.
3. Commercial-Off-the-Shelf (COTS) parts from original equipment manufacturers (OEMs) used in #2, with the same family of packaging materials and construction.
4. Custom Die packaged in commercially used packaging techniques. (Plastic Ball Grid Array)

The ASICs described in this paper fall into Category #4 and represent considerable administrative and technical risk to the program.

IBP ASICs

The IBP program re-uses ASICs for the two modules redesigned for the commercial manufacturing line. The MPCL versions of these ASICs are repackaged in Plastic Ball Grid Arrays (PBGAs). In addition, a commercial digital signal processor is discussed here, as the lessons learned are similar. The parts are sub-grouped by foundry source.

Group #1: LSI Logic ASICs

Three (3) of the seven (7) custom devices were originally procured from LSI Logic, Sunnyvale, CA, in military compliant packaging and flow. LSI Logic had been selected due to the mixed signal nature of these devices. These devices are the Maintenance Test Controller (MTC), Master Message (MAME) and CNI Bus Interface (CBIU). The MAME and CBIU required second passes (respins) due to performance liens at the start of the MPCL program. These ASICs represent 100 - 300k gate devices of 0.7μ technology. The military versions of these parts were packaged in Fine Pitch (FP) hermetic ceramic flatpacks.

Considerable administrative issues challenged the procurement of these devices. First, TRW's business volume with LSI Logic is small by LSI standards, so a third party, Hamilton Hallmark, Inc, administers the account. This also required that Hamilton Hallmark perform the necessary non-recurring engineering (NRE) tasks to repackage these die. Tools for commercial packaging of the devices were not in house at TRW (only military packaging tools were in the tool library) which required software upgrades of the CMDE tool set (LSI Logic) at TRW. Design for repackaging of the devices was performed by TRW and forwarded to Hamilton Hallmark. Hamilton then verified the device, created test vectors and forwarded the redesign to LSI Logic. As errors were discovered at LSI, iterations of the cycle (design modifications and improvements, test vector changes) took several weeks per change, in a serial fashion.

Additionally, the MAME and CBIU ASIC have required respin of the die for lien corrections. LSI Logic refused to accept any packaging change to the die until the military version was tested and accepted by TRW. This put all IBP efforts in series with the military respin and approval. In the case of the MAME ASIC, this added six months to the procurement cycle.

Technically, there are several risks in the procurement. LSI requires "prototype" approval to release designs to production. We found that the prototype parts consisted of "production" like die (same flow, same foundry), but radically different packaging (globtop, quick-turn, domestic source BGA's) versus production (off shore, injection molded BGA's). The quality level and physical properties of the packaged parts were vastly different.

The larger technical risk in the procurement was the lack of ability to functionally validate the repackaged prototype ASIC. The packaged devices are only tested at 1 MHz room temperature at LSI. The only test vehicle available at TRW is a completed end item assembly (module), which requires the dedication of a complete set of hardware resources to the test of the component. To discover a hold time or race condition, entire module assemblies are required and all three untested chips would be represented. Isolation of the failed device is extremely difficult. Due to lack of a test method, TRW was forced to approve prototypes without additional testing.

The three devices procured from LSI in PBGA packages were significantly less expensive than the Hermitic QFP versions. The QFP's ranged in price from $595 to $995 while the replacement PBGA's ranged from $87 to $128 each.

Group #2: Motorola ASICs

Three (3) of the seven (7) custom devices were originally procured from Motorola CPTO, Chandler, Arizona, in military compliant packaging and flow. Motorola had been selected under competitive review to provide these digital ASICs. These devices are the Digital Signal Processor (DSP), the Receive and Transmit Processor (RTP), and the Narrowband Processor (NBP). The DSP and RTP required second passes (respin) due to performance liens at the start of the IBP program. These ASICs represent 100 - 300k gate devices of 0.6μ 3 layer metal technology. The military versions of these parts were packaged in Fine Pitch (FP) hermetic ceramic flatpacks or in Multichip Modules (MCM's).

Motorola refused to package the largest device, the RTP ASIC, in their PBGA package. The stated objection was retooling the PBGA laminate for the 15mm part was too difficult. Instead, Motorola offered to repackage the part after re-spinning the die to H4EP from the H4C process, thereby reducing the die size. The technical risks and costs to respin the die for a package change were not acceptable to TRW.

TRW then contracted with Motorola to provide only Known Good Die (KGD), and with IBM Microelectronics Division, Endicott, NY to package the parts. Unfortunately, this put TRW in a middle position for die quality to IBM and packaging process issues to Motorola. TRW elected to package all three (3) part types with the same vendor, IBM.

IBM modified existing open tooled PBGA substrates and converted test vectors provided from the TRW design libraries. Test vector conversion was very difficult, as IBM had no software tools to read the Motorola "Universal Test Instrument Code" (UTIC).

IBM also experienced considerable difficulties in performing die attach without damage to the Motorola die surface. Motorola refused to provide any mechanical sample (ink dot) die for evaluation. This resulted in very poor yields for KGD through package testing, as KGD were used for packaging validation. Early yield averages were below 50%. These yields were so poor that insufficient attrition die were ordered. To fulfill the contract hardware requirements, additional KGD were requested from Motorola. By this time, Motorola had eliminated the H4C process, and licensed a third party, American Microsystems, Incorporated (AMI), Pocatello, Idaho. Additional KGD are on order with AMI at the writing of this document.

Cost of the Motorola parts did not improve as much as the LSI parts as a result of the increased prices for third party packaging and test, and the increased exposure to yield loss. The hermetic QFP prices ranged from $820 to$1250 while the replacement parts at nominal yield in PBGA were $424 to $820.

Group #3: TI DSP

One (1) of the seven (7) custom devices were originally procured from Texas Instruments (TI), Austin, Texas, in military compliant packaging and flow. TI's C31 DSP had been selected for this product architecture. The Military C31 was acquired as KGD for an MCM application, or in a hermetic ceramic flatpack.

The C31 is a commercial catalog part, but is only available packaged in a plastic quad flatpack. This flatpack was too thick for use in a SEM-E configuration. As a result, KGD were procured to commercial flow and packaged by IBM to PBGA packages. The commercial off the shelf component cost is $54.

Procurement of the C31 as KGD from TI was difficult. TI had only a Mil flow for KGD test and truncated it for this procurement. The Mil flow included attachment of Tape Automated Bonding (TAB) to the die to adapt it to a test socket. (Bare dies are not tested for commercial flows, only packages are tested.) TI had numerous failures in attaching the TAB to the C31 and delayed delivery of the C31 die for almost 6 months. After delivery, the parts were packaged at IBM to PBGA's.

The next stumbling block with the C31 was test. TI was unwilling to provide test vectors for the C31 alone as it was considered proprietary information. Without test vectors, the only way to test the packaged part was to use a C31 emulator card from a third party and remove the C31 from that card. That C31 was replaced with a test socket and the C31 was tested in the emulator. This reduced the effective test coverage (both vector and temperature), but at a manageable risk as the part is fully screened at the module level.

The C31 in QFP was $585, the PBGA version cost $325 and the COTS part was $54.

MPCL Lessons Learned: The Quality Model

Rob Hovsapian, TRW Avionics Systems Division

Introduction

The Military Products from Commercial Lines (MPCL) program is an Industrial Base Pilot (IBP), sponsored by the US Air Force Manufacturing Technology Division, with the objective of demonstrating the commercial manufacture of military electronics modules. The program is contracted to TRW Avionics Systems Division (ASD) and subcontracted to TRW Automotive Electronics North America (AEN). A significant part of this effort includes the development of a computer integrated manufacturing (CIM) system that enables the integration of military products on the commercial production line. This paper reviews the Quality Model, an AEN best practice that is now automated and part of the CIM system. The approach used in selecting and developing the Quality Model system, suggestions and ideas for obtaining the maximum benefit from this tool, and "lessons learned" are all discussed.

Selection of the Advanced CIM Quality System

The MPCL system includes a number of tools to insure product quality. The configuration management features guarantee the correct material is used and the correct routing is enforced. When defects are found on the line, the Work Cell Controller has a state of the art defect entry system that uses a graphic of the board to allow input of the defect data.

During the planing stages, the MPCL team evaluated several advanced quality management functions based on systems used on commercial products in Marshall. Statistical Process Control and the TRW Marshall Quality Model were the main quality tools reviewed by the team for integration with the MPCL CIM system.

The Quality Model system was selected for development by the team rather than traditional CIM SPC functions. Traditional Statistical Process Control (SPC) functions are included in many manufacturing CIM systems with varying levels of success. TRW Marshall preferred a hand on approach to SPC and felt that the manual technique was preferable to the computerized approach to insure operator involvement and ownership. There are many SPC software packages such as SAS on the market that easily integrate with the MPCL system if the plant approach changes.

The Quality Model concept is unique to Marshall and is considered a "best practice". It was being performed by the Marshall commercial business manually. This manual effort was time consuming and required a lot of information and computation. It was clear that much of the required information to perform a Quality Model was already included in the MPCL system.

Unlike SPC, the Quality Model offers benefits for all levels of the electronic development and manufacturing processes. A new design can be modeled based on plant actuals so design engineering would understand the impact of various package types and design approaches at the initial design level. Design verification and process verification steps can be modeled to insure that quality is improving through the design cycle. It is also reasonable to model existing product to find the best opportunities for improvement, allowing a quality organization to best focus it's production resources. The scope and potential application of this approach to the military electronics business resulted in its selection as an element of the CIM system.

Background

The Quality Model effort is designed to allow the management of quality in much the same way a price model allows the management of product profit and loss. This model is intended to provide manufacturability and quality feedback to the design systems at the earliest design stages and through out the development cycle.

The model classifies all defect input parameters into four (4) categories. These categories include:

Design Quality - Design quality includes all defects due to issues with product design such as a poorly specified component tolerance.

Process Quality - Process quality includes all defects induced by the manufacturing process such as a missing component or solder bridge.

Supplier Quality - Supplier quality includes all defects that are due to issues with the supplier's design, process or their sub-supplier's problems that are present in sub-assemblies or components such as resistors and capacitors.

Verification Effectiveness - Verification effectiveness is a measure of how each type of defect will be detected by the manufacturing process or inspection and test activities.

Identification and tracking of the Quality Model factors provide visibility to parts per million defects (PPM) in a very specific and consistent manner. These factors help focus the design and system improvement efforts in a systematical fashion. This approach is intended to provide PPM quality levels a similar level of engineering attention that functional and cost factors typically receive.

Approach

The approach to automating this model was to first perform the analysis manually and then use the experience to automate the process. Six models were completed manually on each of the four MPCL boards (FEC A, FEC B, PNP A, and PNP B) and two Caterpillar boards (ADEM II and ADEM III) and analyzed. This manual effort refined the approach and obtained feedback on technique and reports for this tool. While much of this effort was semi-manual (excel spreadsheets) the base information was maintained in a manner that closely matched the planned data model.

The experience from these manual efforts was then applied to the development of the automated system. The data model was refined and a complete specification was generated prior to coding. The specification defined all user interfaces and data base tables. The system used the same three tiered approach that was implemented on the other MPCL functions. It was integrated into the main Factory Control System (FCS) since other tools in the FCS are required to successfully complete a Quality Model.

The resulting automated system used data modeling techniques and user interface design to minimize the amount of data input required to support the system. In the model, reference designator tracks Design factors. Part numbers track supplier factors and process factors are tracked by operation and package types. This model allows a set of default standards that are built automatically with every model, thus, the first model would be the most difficult to build with each successive model becoming easier due to existing data on specific part numbers and operation/package type information.

Implementation

An Implementation that maximizes the value of this tool should involve a gradual roll out and accuracy check. The accuracy of the tool is directly related to the accuracy of the input factors involved. All models must grow and improve over time to remain useful. This evolution involves comparing model data with actual results and the adjustment of input factors based on actual data.

Due to the nature of the tool, starting with one line and adopting the practice of modeling all products on that line and then proceeding to the next line is recommended. This implementation maximizes the benefit of the automated system since the first product on any given line requires the most data input. Once the first product is modeled, other products can be modeled quickly on the same line since they use many of the same processes and thus use the same default data.

The tool allows data input for a given product and line or data input for global values. The recommended focus would be on a product by product basis rather than on entering defaults. The tool provides interfaces that focus on an individual product, to support this approach. Verification effectiveness data can only be entered on a product by product basis.

Default data input capabilities are included in the system to support engineering organizations that have a generic focus. Supplier quality is a good example of such a structure since a supplier quality engineer likely has data on many part numbers used on different products. Such an engineer needs a method to input this data without having to enter what parts are used on what products. This alignment of part to product is done automatically by the system when a new product bill of materials is loaded.

Summary

The model effectively focuses the quality effort on the root factors thus facilitating the organization's ability to understand manufactured quality. Should engineers track process quality by operation and package type, for example, or by part number? The quality modeling tool breaks down total quality into its base elements, facilitating a better understanding of the total system. This approach assumes that all defects are due to one of the Quality Model factors. These factors include supplier-induced defects, design-induced defects, and process-induced defects. These root concepts help every engineer understand the impact of many decisions made during the product and process design phases.

The quality modeling approach is still considered an advanced tool that should be used early in a project to provide the best return. The adoption of this tool is tied to the adoption of the MPCL system in general. If the MPCL system is being used for early prototypes, the Quality Model tool will be directly applicable to products that are effectively "already in the system". The model can be used as a stand-alone tool without implementing the rest of the system, but some advantages of the integrated tool are lost. One advantage of this tool is the ability to model, track the results and improve the model for the next run, all in one system. The overall MPCL system tracks all material used, and PPM levels in a way consistent with the quality modeling tool.

Entry of the bill of materials is vital to the Quality Model process. The CIM system includes tools to facilitate this process. However, at this time software to fully automate this vital function is in place only for MPCL products due to differences in CAD systems. The adoption of the automated tool is dependent upon improvements in the design-to-production data base system.

MPCL Lessons Learned: Product Data Management (PDM)

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Introduction

The Military Products from Commercial Lines (MPCL) program is an Industrial Base Pilot sponsored by the US Air Force Manufacturing Technology Division. Its objective is to demonstrate the commercial manufacture of military electronics modules. The program is contracted to TRW Avionics Systems Division (ASD) and subcontracted to TRW Automotive Electronics North America (AEN). Part of the Manufacturing Infrastructure team's goal was to facilitate the transfer of design data and information among team members in the design area at ASD and the production area at AEN. This paper describes the Product Data Management (PDM) effort and discusses the approach used in performing PDM functionality. MPCL was not fully successful in using PDM. This paper discusses the lessons learned and identifies practices that will enable PDM to be used in an efficient manner.

Background

A large effort is required to prepare the technical information package for a typical production design, like IBP's effort for new module introduction to a manufacturing center. The Concurrent Engineering infrastructure involves the design, engineering and manufacturing disciplines to create the design and supporting process data and input the variety of data files such as Bill of Material Files, CAD drawings, Net list, etc. in a common, and controlled location for a successful and reproducible product with revision control to provide configuration management control. All team members, to concurrently do their respective tasks, then use this data. These tasks may include document review, view and mark-up of drawings and comment or approval of these documents and drawings.

Discussion of Lessons Learned

Prior to the MPCL program, TRW ASD partially utilized a customized PDM system that was accessed by TRW ASD personnel. This method operated only within this local environment. However when this same PDM system was integrated with TRW AEN's process to support IBP, problems arose for a number of reasons.

The first lesson learned was that, for a successful use of tools and technology, an update of the user interfaces was needed to support a common point and click graphical interface. The PDM was originally designed a few years prior to MPCL with a forms, text and command line interface. The TRW AEN process engineers are more familiar with the point and click interface. To alleviate this problem, the PDM system has been redesigned to support a Web Page based point and click environment that will support a more graphical user interface and have a simpler structure to traverse the data set for use by all with minimum training.

The next lesson learned was that, for successful utilization of this technology, user input from the "casual" user is required, and it is very difficult to learn a tool when the interface is continually changing. The end user previously consisted of TRW ASD personnel who had access to local Help Desk support and were accustomed to this approach of doing business. The users also had the opportunity to apply this PDM technology throughout their product lines. The TRW AEN process engineers are occasional users of the PDM. Since they support a variety of customers' and PDM methodologies, AEN engineers do not have the time for continuous use to become and stay proficient.

A final lesson learned was that a dedicated network or a dedicated bandwidth on which the PDM is accessed is required to provide an adequate and reliable response time between two geographically disjointed sites. Due to a shared TRW network connection to run the PDM between TRW AEN and TRW ASD, the response time was inadequate.

Conclusion

While the new Web-based approach is being developed, a temporary stopgap is used that includes the use of TRW email to transfer design and process data set into a "controlled" mailbox. Access to this mailbox is managed in a controller manner so that only the engineers that need access to this mailbox can subscribe to it, and others are kept out.

To successfully perform concurrent engineering, IBP needed an update of technology to the current PDM interface, and user input from the casual manufacturing center for effective use. Simply expecting new casual users who have different way of doing business to become productive with an older technology tool was ineffective. Reliable access to the network with adequate response time must also be provided.

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