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A' (A-PRIMED): A Case Study in Teamwork

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Abstract

June, 1993, the A-PRIMED project (Agile Product Realization of electroMEchanical Devices) was formed with a concurrent engineering team of product designers, analysts, CNC machinists, robotic assembly scientists, electronics communications developers, statisticians and human factors scientists at Sandia National Laboratories, to develop and demonstrate a process for a much faster design-to-production cycle for precision electromechanical devices. The team had to develop the culture and infrastructure to support communications between remotely located members, as well as demonstrate a shortened cycle time made possible by developing new technologies. These new technologies were then adopted by the team and introduced to their work partners to support new work processes. By March, 1995, the A-PRIMED team had used the new technologies and work processes to design and build qualified new products in only 24 days.

1 Introduction

Sandia National Laboratories is a multi-mission prime contractor to the DOE responsible for the engineering production and safe maintenance of the United State's nuclear weapon stockpile. The demands for quality assurance in the design and production of critical components is a driving factor in our product realization process. However, Sandia must also deliver quality products as cost effectively as possible. By minimizing labor costs, shortening the design-to-production cycle reduces the overall cost of delivering new capability. Demonstrating that this shortened cycle still assures reliably functioning product remains of critical importance.

Assessments of advances in computer modeling and simulation of products and processes indicated that new technologies were now capable of supporting a streamlined, greatly automated process that could deliver quality products much faster. It was also recognized that the essential disciplines needed to implement the new process were represented in the laboratories' population, since Sandia's engineering responsibilities require the development of technologies necessary to quality production.

Management from several organizations agreed to the importance of developing a new product realization process, and, recognizing the importance of concurrent engineering, committed the needed resources to create a project which could develop and demonstrate a new product realization cycle, using an unclassified electromechanical device that had potentially broad surety applications. This included participation by Allied Signal, Kansas City Division, Sandia's California site, as well as Sandia's New Mexico site, where most of the project activity took place.

The technical aspects of the project are described in several papers which will be cited throughout this paper, although aspects of the technical implementation for concurrent engineering are addressed here. The scope of this paper is to describe successfully applied strategies for the general team dynamics, without detailed description of the technical output of the team, which is only lightly treated for context. Those interested in concurrent engineering will find more in depth process description in the cited papers.

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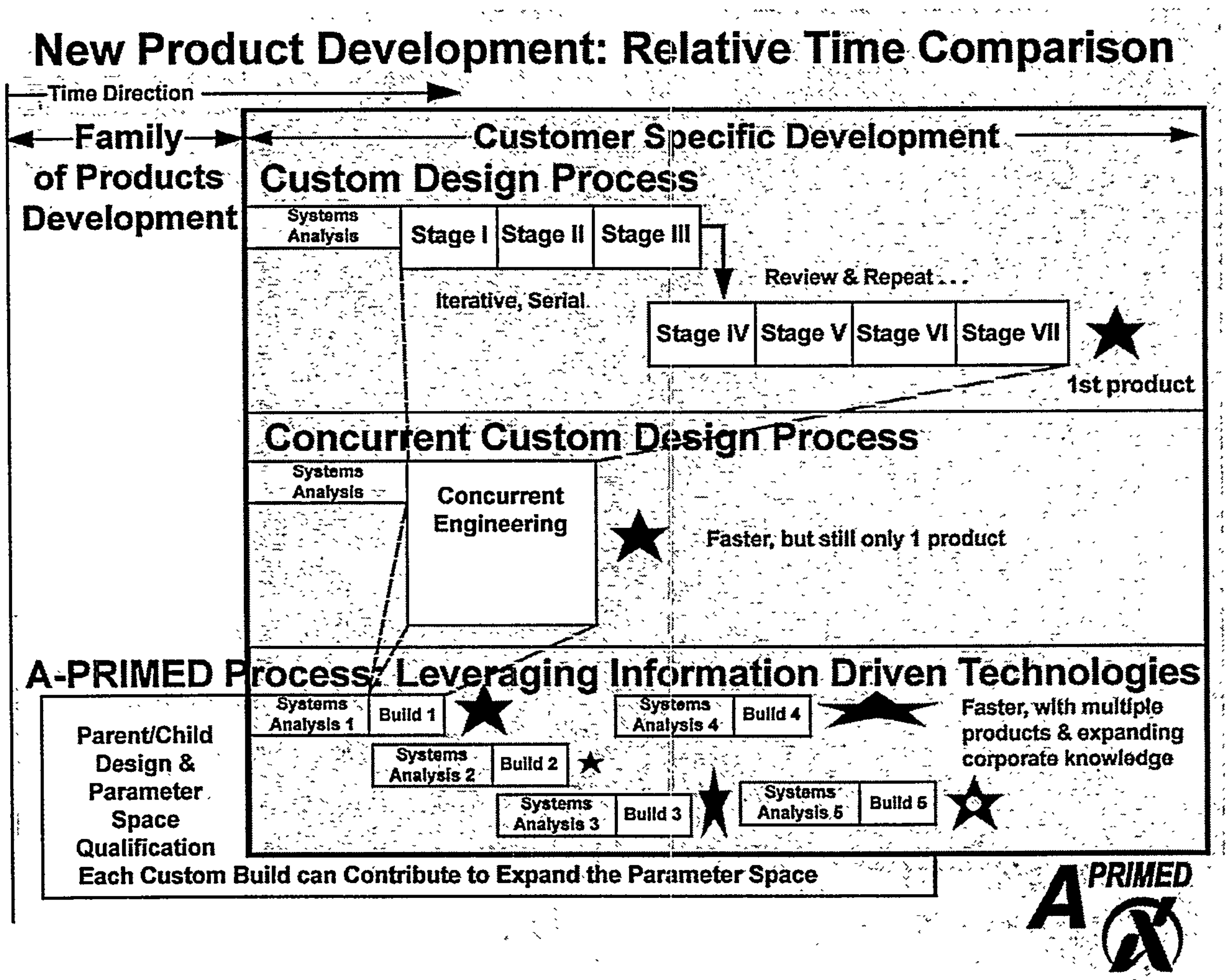
2 Project History

2.1 Team Recruitment and Project Strategy

The A-PRIMED project (Agile Product Realization of electroMEchanical Devices) was created to develop and demonstrate a more efficient product realization process. David Strip, the project manager, coordinated recruiting team members to attend a four day, off-site, initial project planning session. Management contributed people to a project planning course, with the commitment that those attending would become permanent members of the team.- Strip challenged the team to create a new product realization cycle by designing for a family of products to be reliably produced using computer driven automation technologies [1]. While a specific family of unclassified electromechanical surety devices was chosen for the team to design and produce, the new process was to be extensible to any electromechanical product.

Designing for a family of products, instead of creating a single point design was a major challenge, since a new methodology had to be created [2]. However, the development of a new approach to product realization was the mechanism chosen to achieve the enormous cost savings for new product development. The traditional product design approach requires unique design, analysis, parts fabrication and assembly, testing, and qualification for every custom product. The new approach would examine variations in a product concept that were expected to be of interest to customers (make the device faster, smaller, more robust), then test to set the boundaries for "qualified variations" that still produced needed functionality, while understanding the limitations of different variations [3]. Fewer analyses and tests would be needed, resulting in cost savings since any new product from the same family would have much in common with other products in the same family. See Figure 1.

Figure 1 The A-PRIMED Process Shortens New Product Development



2.2 Initial Planning: Teamwork Begins, June-Early August, 1993

The project began June 1, 1993, with a four day project planning and teambuilding course [4]. Erika Jones led the forming team through the steps of her course, facilitating discussions, and demonstrating planning methodologies. Project planning was the focus, with teambuilding growing out of the interactions of the participants as they worked together. Jones introduced concepts and skills needed for a high performing team, and described how R&D project planning differed from traditional approaches. She then facilitated the team members as they created a clear description of the project's organizational allies and enemies, and initial stakeholder's requirements. The team committed to later validate these stakeholder requirements with personal interviews, and strategies for successfully gaining stakeholder buy-in were practiced.

In the four days of planning, the foundations for project teaming were laid, as the team discussed the scope and goals of the project, and created a project charter. The team also created an initial workbreakdown structure and project plan of 125 identified tasks, and committed to further detailed planning. David Strip recruited Rodema Ashby as the team's project leader, based on the interactions within the team as the planning progressed, her earlier concurrent engineering experiences, and successful leadership of the Interactive Collaborative Environments (ICE) project [5].

Following the June course, the team met as the large core group (17 members) June 14-15, and June 23, during which the team completed the volunteering for task responsibilities, estimating task durations and creating more detailed descriptions for identified tasks. As the project reached a consensus about what work should be done individually, as small teams, and as the large group, the project leader named team leaders for coordinating activities.

This was an important "storming" phase for the team, as the project leader pushed for more large group communications to guarantee group buy-in for fundamental decisions, and to foster and practice a mode of consensus problem-solving where a "that's not my problem" mentality would not be tolerated. In creating mutually acceptable solutions during the planning, a shared model of the work to be done, and mutually understood vocabulary developed. The team also gained a greater sense of group belonging since they all had to suffer through the same contentious meetings together.

The team understood intellectually that everyone's expertise was needed to create a new product realization process. However, there is always emotional effort in meeting and learning to work effectively with others. Additionally, there was the burden of defining and understanding new communications responsibilities during the planning. In traditional projects, much of the planning was the responsibility of managers who handed out fairly specific work assignments, but with the new approach, the technical team was asked to plan for the extended work of defining a new work environment. The large group planning was therefore very difficult for all the individuals involved, who nonetheless persevered.

As the team determined how to accomplish the technical objectives, and continued to define what it meant to design and prequalify a family of products, the individual team members also had to learn new work skills. The technical work mandated a great deal of review, by relative strangers, of each individual's planned contributions, and entailed learning much more about how other disciplines operated, and therefore, how they could contribute to the work process. A common phenomena with engineers, who are intimately aware of the difficulties of the technical work they must individually achieve, is to view the work of others as of much less complexity, e.g. "what I do is difficult, what you do is trivial." This attitude had to quickly give way to respect for the complexity of others' work, and appreciation, or at least acceptance, for how others' participation could improve the project's output.

Agreements were reached as to how the work could be divided into smaller team activities, yet still keep a strong sense of group responsibility. See Figure 2: on the next page. The left half of the diagram summarizes the team contributions to qualifying the parameter space for a family of designs (Parent/Child concept), while the right half shows the rapid cycle once specific customer requirements are involved. The key manufacturing technologies are described in depth in separate papers: Parent/Child design [6], Accurate Computer Simulation [7], and Automated Assembly [8], and the surety product family, the Pin-In-Maze Discriminator [9]. The electronic infrastructure technologies are summarized in 4.3, Electronic Infrastructure Section, and described in greater depth in [10].

The technical teams needed time for their own planning, and continued to talk to others as they detailed their work tasks. Recognizing each team's importance in shortening the production cycle motivated the continuing communication between teams. Stakeholder interviews also took place as planned, to review the sponsor's requirements and expectations.

The entire project met again for another four days of planning, August 2-5, with teams coming and going as their contributions were worked into the plan. Exhausted, the group celebrated the completion of the detailed project plan, which was in sufficient detail to describe the entire project's schedule and budget.

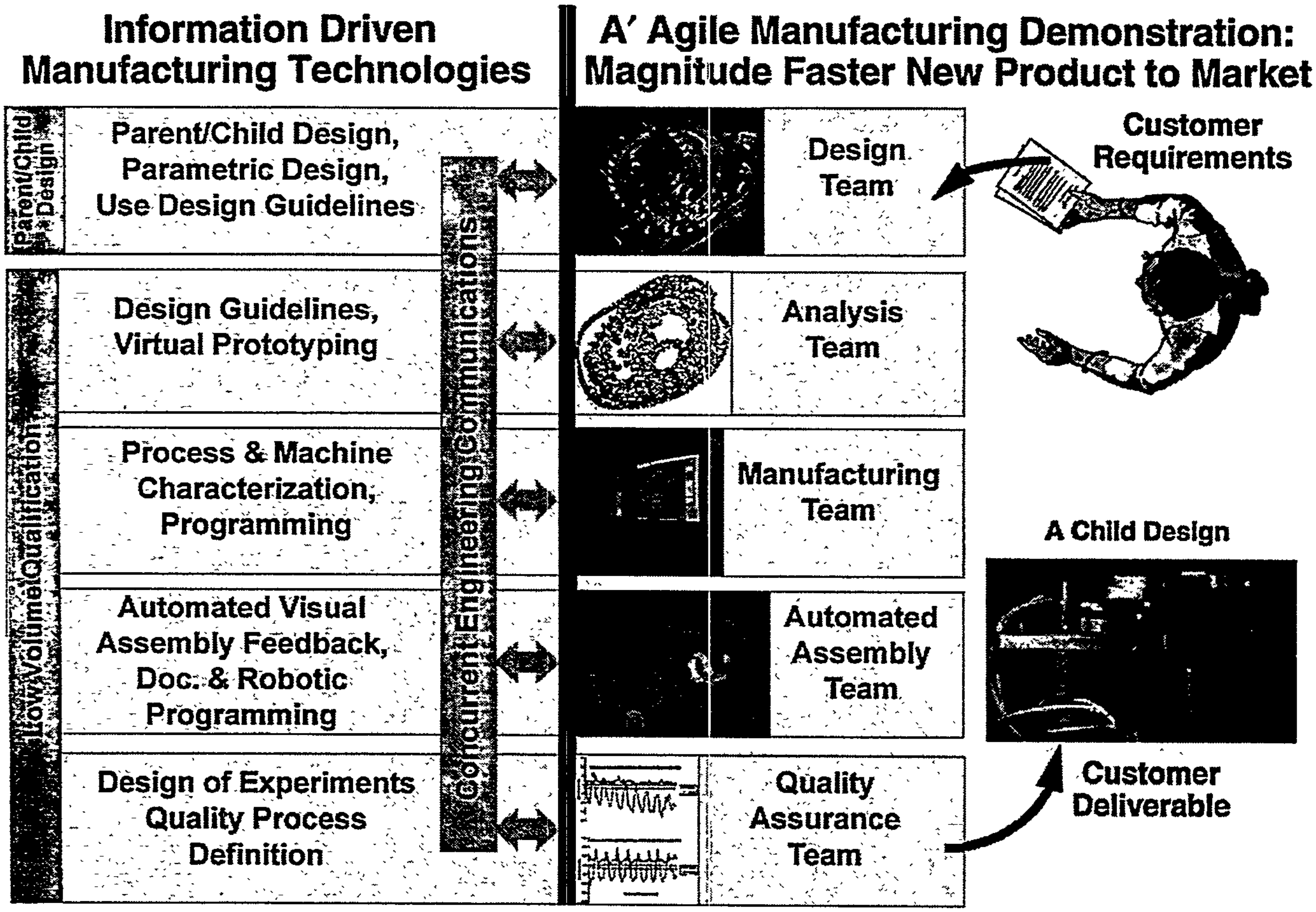


Figure 2 Teams Contributing Technologies to Product Realization

August 13, the A-PRIMED project hosted a group of upper managers who were pleased with the progress to date, and pledged their continued support of the work after seeing demonstrations of the technologies that would contribute to the new product realization process.

2.3 Detailed Needs Analysis, Procurement, mid-August-October, 1993

The project leader drafted a 15 page overview of the project plan, with one page descriptions of the challenge, the strategy, and the proof of success for each of the teams. The challenge for each team was a one paragraph description of the general contribution expected from the team. The strategy for each team consisted of technical and organizational ways to meet the team's challenge. The proof of success was a one paragraph description of mea surable, observable deliverables that would demonstrate the challenge had been successfully met. The project members reviewed and improved the plan, which was then reviewed by management, helping to create buy-in for the rest of the project.

Requirements for the product family were created and reviewed, and a parent device was selected. See [3], [6], for descriptions of the technical process. Some team members took a course led by Burt Huthwaite on concurrent engineering processes, which emphasized how working with others from different disciples could have surprising benefits [11]. He also introduced a method for measuring how well we were working as a team, which we tried..

Team discussions continued as the group defined what a parameter space meant, and how to qualify a family of products. Requirements for the communications infrastructure and the automated assembly robotic workcell were reviewed and hardware was ordered. The project began prototyping work processes.

2.4 Initial Implementation, Training, November 1993 - April 1994

Defining how to qualify a design space for a family of products was the continuing focus of work for the next months. Technical opportunities and limitations were explored, and greater consensus was reached for application of computer simulations and physical testing to qualify products before final inspection. Understanding and controlling the manufacturing processes allowed confidence that the product produced would operate correctly on the first try. The target parameter space variations were defined and parametric programming of selected variations was prototyped.

A major development at this time was greater reliance on the electronic infrastructure. While some groups had been effectively using computer systems for some time, others were being introduced to electronic tools for the first time. This created quite a challenge for those just coming "on-line", and necessitated group decisions for use of some standard tools where necessary, and ways to exchange information between the different tools needed by different disciplines. Tracking upgrades and changes to tools in use was also important to keeping people confident that they could rely on the computer communications.

Implementing the new work process included learning to effectively communicate in a variety of interaction modes. The "all hands" team spent November 3-4 learning about "Social Styles" from De la Porte Associates [12]. From questionnaires filled out by colleagues, each person's behavioral style was assessed. Rather than trying to psychoanalyze actions, the emphasis was on determining predominate methods for communication, and how to effectively present information for those who don't share your style preferences. The team members found the course so helpful that Rob Easterling printed "warning, Social Style on board" type signs for outside our offices, to help us remember how to best present information, and listen to other styles.

The technical process prototyping progressed well, and we presented demonstrations of the technologies at several workshops and sponsor reviews. Monthly reports were also opportunities for us to get feedback on how well our progress matched sponsor expectations. Facilitated meetings helped us review our internal work processes, and we instituted a continual process improvement document, to gain efficiency in areas that were targeted as wasting time.

As we tried various internal measures for project progress and communication, we decided that our principle external measure of cycle time was really the most beneficial, and seemed most reliable. Since we were not yet prototyping the entire cycle, the measured concentrated on individual process improvements. However, we continued to assess each process in terms of the entire product realization cycle, since we didn't want to optimize an individual process, but slow down others ability to work.

2.5 Partial Parameter Space Testing, May - September, 1994

The Quality Assurance team became the focus for technical discussions, as the mix of computer simulations and physical testing of materials and subassemblies was decided. The "parent" (family of product) design and attributes had been selected during the parent design selection and definition of the parameter space. Next, qualification criteria were defined for the product family, for example robust, reliable, and also for the manufacturing processes, including materials and acceptance processes. Test outcomes provided data that were analyzed to set the boundaries for variations of "child" designs which could be predictably qualified. This process is documented in [3]. The first product build was completed at this time, and reviews of progress and demonstrations for sponsor feedback continued [2].

An important collaboration between the design team and analysts occurred during this time. It was recognized that creating the automatic generation of design models to produce parts that did not exceed boundary conditions previously defined by analysis would assure the robustness of the parts. This would eliminate the need for further tests or analyses, since it would already be known that the parts met the qualification criteria, and would thus save cycle time.

2.6 Prototype Product Production, October 1994 - March 1995

The last six months of the project were devoted to prototyping the new product realization process. The process was originally defined using an AT&T methodology [13], and an additional process of capturing customer requirements and translating them into the parameter space variations was also developed and documented, using a modified Quality Functional Deployment matrix. In early October, we were asked to provide product for another project's demonstration, and using the new process, created three functioning units in 24 days. The translation from customer requirements to product specification and build is documented in detail in [2]. See Figure 3 on the next page.

A close working relationship between a machinist and a robotics scientist enabled fast, iterative experimentation to quickly field the automated assembly workcell for the

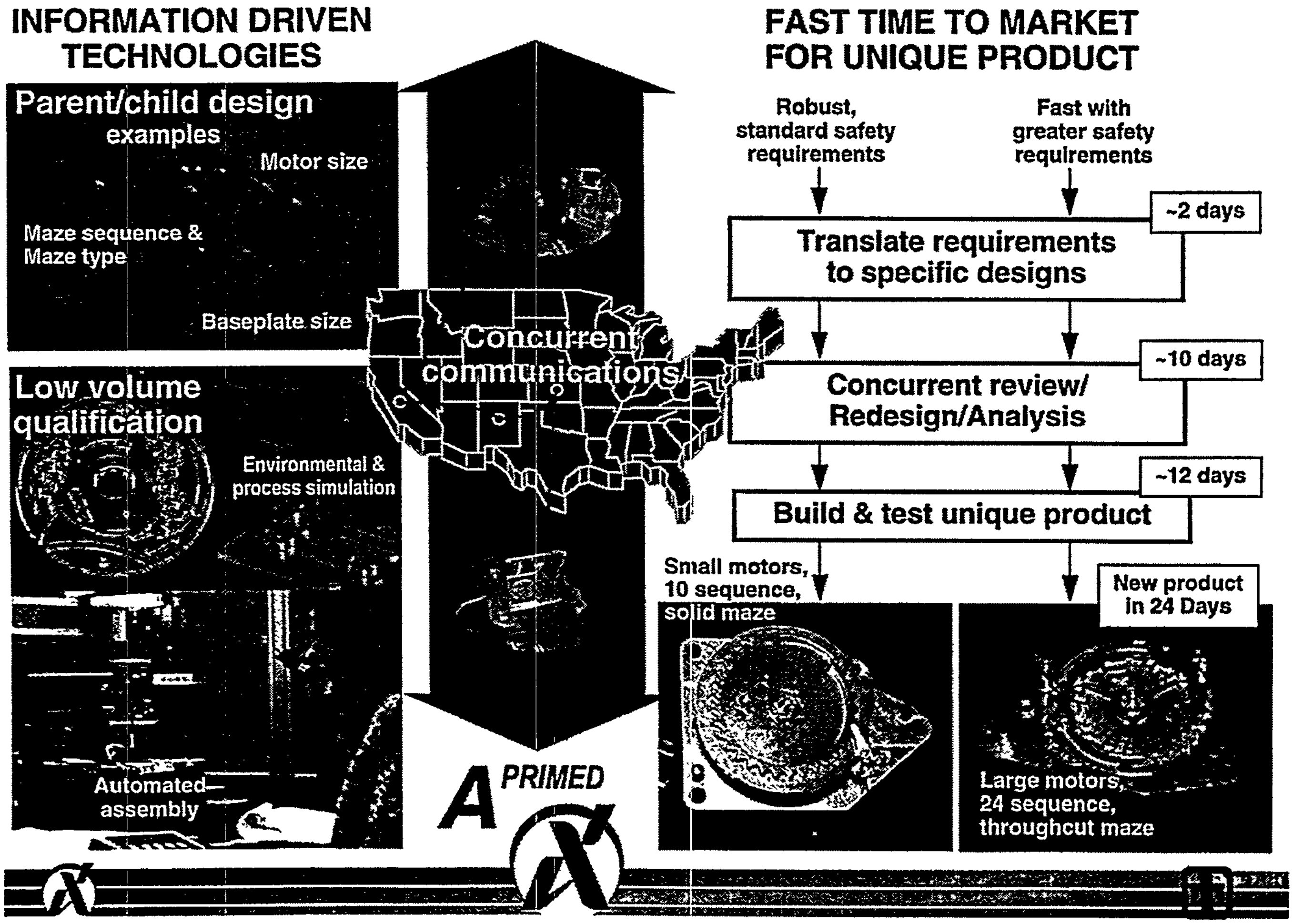


Figure 3 Overview of A-PRIMED New Product Realization Process

project. The machinist had considerable experience manually assembling the complex, tightly toleranced (clearances of .0006") gear subassemblies. As definition of the robotic assembly progressed, his expertise aided the robotics scientist in creating a gripper capable of controlled handling of 16 different precision parts.

3 The Basic Team Culture

3.1 Motivated Individuals

The pressing need for improvements to our product realization cycle in order to fulfill our national commitments to the country helped to create a sense of urgency for the project. Sandia's corporate culture was already being changed through quality initiatives which stressed metrics and teamwork. As U.S. industry lost more and more jobs to overseas competition, the National Laboratories were encouraged to transfer our technologies to U.S. businesses, helping them to modernize and reduce their costs.

Sandia's primary cultural attribute has always been a "can do" attitude, and the team members who were contributing to the advanced technologies to implement the new product realization process were excited to get a chance to demonstrate how their technologies could reduce cycle times [7], [8], [9], [10].

Team members worked as empowered contributors, not passive recipients of directions from others, and actively volunteered their expertise. Although the project leader and manager occasionally had to clarify hard boundaries or directions for the project, which they believed to be necessary for its success, nearly all the important decisions were made by consensus of the team, after discussion of options. The teamwork developed during the planning and executing of a shared vision, although we also explicitly discussed how we were working, and took explicit actions to foster communications to improve our problem solving. The different teams, composed of individuals from many different organizations, tracked their own schedules and budgets and made group decisions when resources had to be redistributed to meet changing goals.

This model of teamwork is very different from a strictly hierarchical one. There were still clear levels of responsibility. The project leader and manager set the direction, continually monitored how the project was progressing, and acted as the central point of contact for others outside the project. However, the team leaders, and all the team members continually volunteered their talents where needed. The general pattern of team communications was not similar to a coach giving plays to a sports team, or a conductor directing an orchestra. The diversity of talent, and continually changing demands on the project would not have allowed such predefined, static roles, and centralized control. Instead, the fluid give and take was more like a jazz ensemble. The team clearly operated as a group with a collective goal, but with ever changing leads. Players dropped in or out and changed instruments as required and capable, and quality of performance was gained from the volunteered skills of all the performers, carefully listening to one another.

3.2 Multi-Disciplinary Team Composition

The project's teams were not comprised of members of only one organization. Instead, the teams represented functional units that used members with whatever skills were needed for that work. For example, the design team was originally composed of members of the component design groups that had responsibility for discriminators, CAD model users to create the needed computer descriptions of parts and assemblies, computer scientists to parametrically manipulate the product's solid model for creation and checking of automatic variation, the electronic controller designers in Ca., and the production designer at Allied Signal in Kansas City, Mo.

The project leader was not a member of the project manager's organization. The Quality Assurance team was composed of members of the other teams, a testing engineer, and was led by a statistician with extensive product and process qualification experience. The communications team was lead by a cognitive psychologist. The project leader had previous experience with communications technologies, and could contribute technically to this area, but wanted the communications team leader to primarily analyze the human information and task flow. By first defining the desired communication processes, the communications team leader was able to provide clear priorities and direction to the many technology experts fulfilling the project's communications infrastructure needs.

Team composition changed throughout the project, according to the ongoing demands. There was a rather small core set of people that created stability in the project and maintained adherence to the original vision. However, because of the clearly articulated goal and objectives of the project, new people were successfully assimilated into close working relationships with other team members. The primary interactions were between the project and team leaders, between the team leaders and their teams, and the Quality Assurance team members. Initially there were at least monthly "all hands" meetings, but this need decreased as the project's processes were more completely defined, and the communications proved sufficient to coordinate activities and reach team milestones.

4 Fostering Communications within the Team

Some methods to encourage information exchange have already been described in the history of the project activities, and creating the team culture. Additional opportunities for fostering communications were also instituted. Because of the geographic distribution of the participants, and being unable to co-locate team members, communications were recognized as of utmost importance to the project, and resources focused on enabling better communications between team members as quickly as possible.

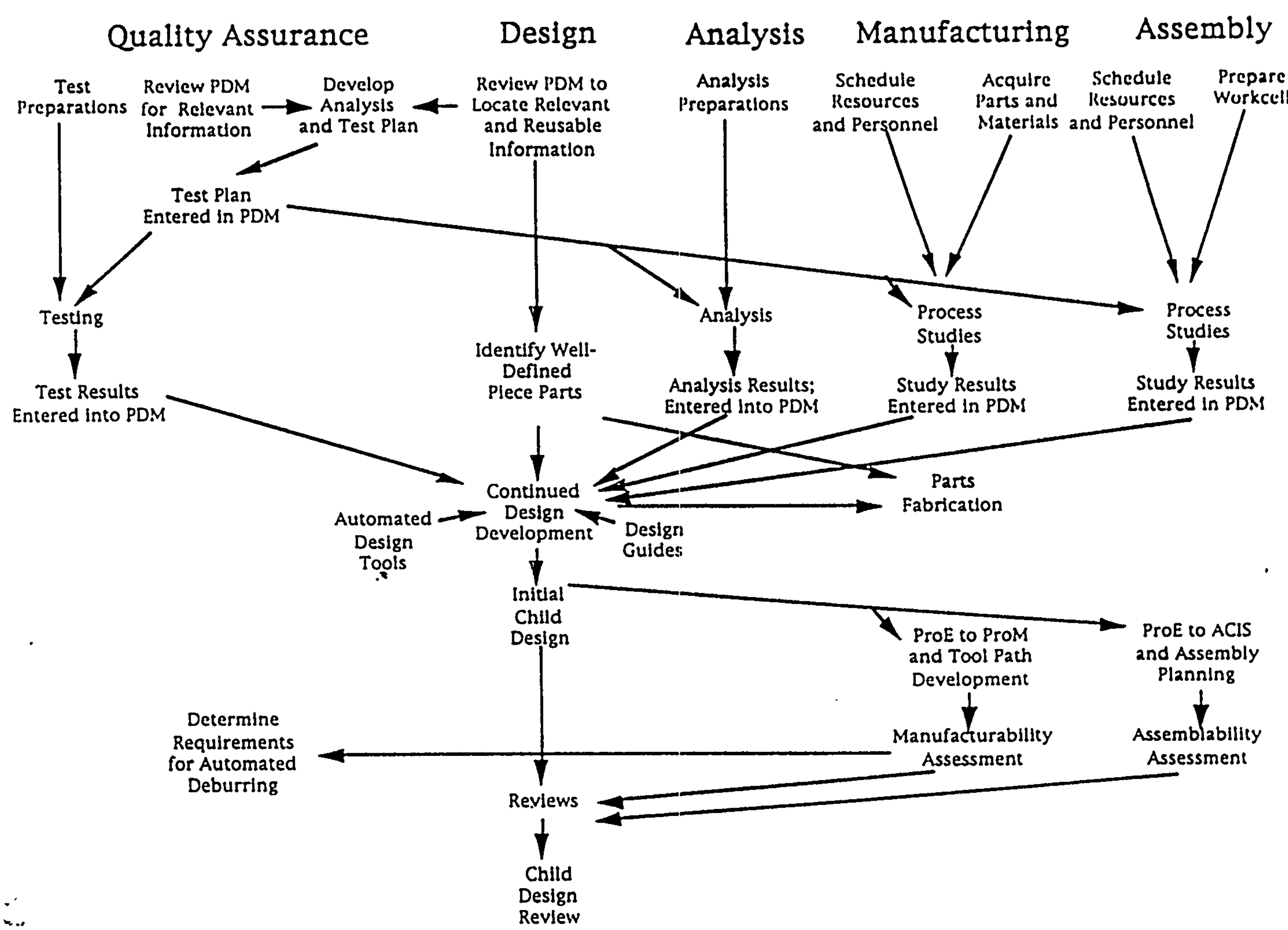
4.1 Group Learning

Taking classes together, e.g. the Erika Jones Project Planning, Social Styles and Concurrent Design did more than give us a common vocabulary and understanding of some concepts important to our tasks. The interactions between participants in the classes were crucial to team-building. We gained understanding of how others on the team operated, what issues were critical to their success, and gained respect for other's problem solving abilities. We also took advantage of having experienced, neutral facilitators present (the teachers) to enable conflicts to be aired and worked through as a group, without winners and losers. The more practice we received for consensus problem solving, the more efficient our conflict resolution became.

Tours of all the team's facilities, and introduction to their technologies were other important group learning experiences. For example, one of the early tours was of the Interactive Collaborative Environments (ICE) lab, which demonstrated how members of the team could manipulate and review computer models of the product from different locations [5]. By watching experts manipulate their tools, others could learn quickly, in the same way one learns by watching over an expert's shoulder, but in this case, over considerable distances.

Being introduced to the capabilities of others on the team helped us spot new opportunities for improvements, and helped increase the ability of all members to meaningfully contribute. Some organizations had a long history of merely taking orders, acting on information thrown over the wall, and others weren't eager to hear from those from the other side of the wall: life seems simpler without feedback, until the deliverable gets rejected for not meeting the customer's expectations. Knowing our success depended on our collective cooperation motivated the teams to learn how to better interact. Although different teams had the explicit responsibility for their assigned deliverables, there were continuous contributions across team borders, as daily collaborations took place. An example of the formal collaborations during the child design definition activities is shown in Figure 4.

Figure 4 An example Network of Collaborations



4.2 Regular Face to Face Meetings

We knew collocating the team would be impossible, but we hoped to have at least a neutral (not owned by any one organization) group space where we could regularly meet, put up announcements and planning charts, and have lab space. We were only able to procure space that was in a corner of the NM location, about 10 minute's walk form the nearest participant, and about 25 minutes from the farthest. While we used this area for some meetings and initial review of plans, it was not located centrally enough to be regularly utilized. The space was also only available for a few months of the project.

The project's deliverables, and tight coordination between several disciplines necessitated frequent, short communications between many individuals by phone, fax e-mail, and face to face informal meetings, but we also set up regular formal meetings to be sure we were keeping our resources focused on the highest priorities. A teamleader's meeting with the project leader was scheduled for the same time and location each week. Minutes from this weekly meeting were distributed to the entire team by e-mail (or fax until everyone had a reliable electronic connection).

Each of the teams also had regularly scheduled team meetings to coordinate their activities leading to deliverables for the project. Most teams had their own technology deliverables (e. g. how what they were creating would decrease the project's cycle time for new product). Each team had a need to train others how their tools could be used.

The communication's team had particularly heavy training responsibilities, since they were responsible for getting the infrastructure for the project teams in place. This involved coordination with many different network managers and technology providers, innovative use of technologies and customizations of applications, and introduction of the team members to using new technologies. Having a cognitive psychologist for the communications lead, helped us define the information flow for the project, using task assessment methodologies, and assess the impact of some technologies on users before the "improvement" was fielded, and received user testing [10].

The Quality Assurance team held regular meetings and had a strong coordinating function, since agreements for quality assurance needed to be negotiated between the teams. The responsibility for correctly functioning product being produced ultimately rested with QA, but every team had a stake in assuring the project output met or exceeded the highest expectations. In addition, the QA team's description of how to qualify a parameter space was a principle deliverable for the project.

"All Hands" meetings were held monthly for the first several months of the project, as agreements for group cooperation and operating procedures developed. They were frequently facilitated, to encourage getting down to tough issues, and reaching decisions. It was tough work, but was the price to pay for not living behind walls, and the payoff was much faster product development.

Because of the pressure of formally working together on tight schedules, regular social time was also available. A regular time for project participants to gather at the cafeteria for a weekly lunch together was optional. Different sets of people showed up depending on their schedules, and guests dropped by as well. Sometimes activities were announced in advance, or materials handed out to those that showed up, but usually it was just a social time. Work nearly always was discussed, but in a relaxed manner.

4.3 Electronic Infrastructure

The geographic distribution of the team has already been mentioned. It was apparent from the start of the project that depending on face to face communications would create insurmountable bottlenecks to the information exchange. So planning for the use of electronic communications to support "virtual co-location" began immediately.

E-mail was already in wide use by some on the project, but unknown to others. Sandia's strict security requirements also meant team members were not using networks with the same security levels. Therefore, getting e-mail communications to all the team was non-trivial, but services from Sandia's corporate networking organization were available. Besides the team leader meeting's minutes being regularly distributed by e-mail, soon the weekly status reports from the team members were being sent in by e-mail. Other team's meeting minutes were also distributed, and discussion topics circulated in messages with ever increasing notations.

Of course, short individual messages comprised the greatest traffic. One process improvement was a description of how to construct effective, easy to read messages with clear response requests. The reliance placed on e-mail became clear anytime there were any network disruptions for any length of time. The corporate system managers considered the A-PRIMED team to be their first alert: if something was wrong, an A-PRIMED team member would likely be reporting it.

The widespread use of e-mail contributed to a rich electronic archival of project history. Although many traditional reports were also produced, the informal short discussions give a good indication of the tone of the project's interactions.

Voice mail use was being promoted by Sandia, and was another quick way for individuals to communicate. It became a project norm to change your greeting daily, to let others know if you were available, or on travel or vacation. Quick replies to queries for information eliminated the need to make direct contact, unless interaction was needed. Telephone tag was reduced by encouraging team members to ask for what they wanted, and state when they'd be available if they needed interactive communication.

X-Application sharing, and videoconferencing links were used for exchanging information that was in engineering applications. It was useful to be able to interactively review drawings and test results remotely, using the Sandia developed ICE technologies [5]. One source of information for many conferences was the central database repository for the project, CMS/Pro.

CMS/Pro was a commercial database customized for the information relationships the A-PRIMED team needed between the product and process teams. Queries were defined to enable quick access to designs that met specific customer requests. By having a central archive, communication bottle necks were reduced since information was available to anyone on the team, whenever they needed it.

Towards the end of the project, when we were getting more and more requests to describe our work, we created a World Wide Web site, not only to communicate A-PRIMED information, but also to encourage collaboration with industry, to create tools helpful for everyday work, and for accessing current information about agile manufacturing on the internet.

(http://www.sandia.gov/agil/home_page.html)

4.4 Social and Fun

Learning a new way to work with new people took a great deal of effort, and we knew we were in for a challenging 22 months. To mitigate the pain, and as another way to get to know one another, regular celebrations and parties were planned. Clearly, parties aren't any fun if people don't want to play or are uncomfortable with one another. Our first celebration was more grim than fun, coming directly after an exhausting week of project planning. But once over the hump, we developed a positive talent for potlucks and barbecues.

People began volunteering ways to lighten things up, e.g. making balloon animals, doing magic tricks, giving silly gifts for the winter holidays, and sending around jokes. Poetry (limericks and doggerel) became an expected feature at celebrations. Special team vocabulary developed. And the T-shirts given out at one celebration became the focus for another activity: "A-PRIMED will travel" photo opportunities rangred from team members standing in front of their car wreck in Utah to vacationing in Hawaii.

A logo was developed early in the project to identify A-PRIMED documents and output. David Strip suggested the project leader give A-PRIMED stickers to team members as quick recognition awards. Since the project leader had taught school, and led a Girl Scout troop, handing out stickers to other adults didn't' seem like a great idea. However, many stickers were created and given to all the team members and sponsors, to give to one another as seemed appropriate. There was an unlimited supply, and there was no exchange expectation: you didn't get anything for getting several stickers, just the stickers.

The stickers really worked well. They operated as quick, tangible thank-yous, and were given to people outside the project who pitched in unexpectedly. Getting a sticker could mean you did something outstanding, or just made somebody laugh. They were usually displayed on one's computer, but could be used anywhere.

Other "certificates worth the paper they were printed on" were also given out. These were project leader or team member to team member recognitions that had more to do with fun than any serious recognition. Yet it helped people feel recognized, and that they were part of a group.

5 Sustaining the Team

Retaining enthusiasm during a long project, and keeping focused on continuous improvements was challenging. Recording and reviewing progress in formal reports and demonstrations was important both for the team and to collect timely sponsor feedback. Metrics on process improvements were tangible measures reminding us of how far we had come. Formal presentations and demonstrations of our capabilities for others also gave us a perspective on our accomplishments. Our brochure, video, and double-sided technical briefs for informing others about our technologies also helped us stay current with what other teams were accomplishing. Occasional recognition from management within Sandia, and awards from review teams from outside organizations were also important perks. However, quality interactions with others, knowing that colleagues would appreciate your best efforts, were critical to maintaining the sense of purpose, and motivation for excellence.

6 Legacy of the Team

An important goal for each team in A-PRIMED was to permanently improve Sandia's product realization process. This was achieved by integrating new technologies into the normal workflow of organizations, and by permanently changing the previous process. The technology improvements are now being used to benefit many other projects.

Documenting our processes, as we build on our previous work, is another important legacy. But most important is the camaraderie developed during the project. The understandings and close working relationships continue to help with collaborations across the labs as we take on projects too difficult for single discipline organizations to successfully solve.

7 Summary and Conclusions

The concurrent engineering focus of A-PRIMED made teambuilding and communications a priority for the project from the beginning. Our investment of resources for upfront, in depth planning, and teambased learning forced rapid, significant communication between individuals of different disciples and backgrounds. This resulted in an explosion of creative activity, which paid off in significant technical progress. By creating a team culture that continually encouraged open communications, and focused on an agreed set of metrics, measurable technical progress was deployed throughout the Laboratories, and to our industrial partners.

Acknowledgments

The A-PRIMED team members contributions are obvious, but the immediate and upper management oversight that supported the teaming deserves separate mention. Gary Ferguson's creation of the Integrated Manufacturing and Design Initiative provided the initial focus on the importance of concurrent engineering in shortening the product realization cycle, ensuring needed teambuilding resources were available to A-PRIMED. Charlotte Acken continued the emphasis on teaming. The preliminary teaming of the several organizations contributing the people and technologies to A-PRIMED was orchestrated by David Strip, and enabled by many upper managers' recognition of the need for a new product realization process and their continuing support for the technologies that make improvement possible. The authors would also like to thank Gaye Garrison for help with graphics preparation for this paper. For a complete listing of A-PRIMED principle contributors, see [2].

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