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Y-12

OAK RIDGE
Y-12
PLANT

LOCKHEED MARTIN

Final CRADA Report
for
CRADA Number P-ES004-0077

RAPID RESPONSE MANUFACTURING (RRM)

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ABSTRACT

U. S. industry is fighting to maintain its competitive edge in the global market place. Markets fluctuate rapidly. Companies have to be able to respond quickly with improved, high quality, cost efficient products. Because companies and their suppliers are geographically distributed, rapid product realization is dependent on the development of a secure integrated concurrent engineering environment operating across multiple business entities. The way products are developed and brought to market can be improved and made more efficient through the proper incorporation of emerging technologies implemented in a secure environment. This documents the work done under this CRADA to develop capabilities, which permit the effective application, incorporation, and use of advanced technologies in a secure environment to facilitate the product realization process.

Lockheed Martin Energy Systems (LMES), through a CRADA with the National Center for Manufacturing Sciences (NCMS), worked within a consortium of major industrial firms - Ford, General Motors, Texas Instruments, United Technologies, and Eastman Kodak - and several small suppliers of advanced manufacturing technology - MacNeal-Schwendler Corp., Teknowledge Corp., Cimplex Corp., Concentra, Spatial Technology, and Structural Dynamics Research Corporation (SDRC) - to create infrastructure to support the development and implementation of secure engineering environments for Rapid Response Manufacturing.

The major accomplishment achieved under this CRADA was the demonstration of a prototypical implementation of a broad-based generic framework for automating and integrating the design-to-manufacturing activities associated with machined parts in a secure NWC compliant environment. Specifically, methods needed to permit the effective application, incorporation, and use of advanced technologies in a secure environment to facilitate the product realization process were developed and demonstrated. An important aspect of this demonstration was the implementation of a Product Information Management System that supports secure concurrent engineering in an open environment.

FINAL REPORT

Title: Rapid Response Manufacturing (RRM)
CRADA Number: P-ES004-0077
Partner: National Centers for Manufacturing Sciences (NCMS)

OBJECTIVES:

The U.S. defense complex faces many challenges in meeting the demands of deploying, supporting, maintaining and extending the life of increasingly complex weapons systems in an austere budget environment. In particular, the Defense Programs (DP) arm of the U.S. Department of Energy (DOE) faces an unprecedented challenge in maintaining its capability to re-manufacture and support fielded weapons and produce essential components in a no new production environment where the loss of vital expertise through attrition and downsizing are exacerbated by reductions in budgets and aging of facilities.

Secure high speed telecommunications between Nuclear Weapons Complex (NWC) sites has been identified as a critical technology need for integrating DOE Defense Programs (DP) activities and promoting efficient collaboration of geographically distributed design and production personnel. The Stockpile Stewardship and Management (SSM) Plan sets forth a weapons modernization strategy for manufacturing and surveillance that requires advanced information technologies and integrated computing and telecommunications environments. The Stockpile Life Extension Program requires high-speed classified connectivity for rapid assessment and quality solutions to weapons deficiencies. Current weapons programs have identified the need for secure communications technology to meet increasing programmatic requirements. Specific examples include the reduction in production response time for the W87 Life Extension Program (LEP) and the B61-11 modifications and the increased data transmission requirements of the Quality Evaluation (QE) surveillance program.

Similar requirements for secure communication exist within the U. S. industrial complex. While industrial needs to protect information and communications are not as restrictive as they are in the Nuclear Weapons Complex, the methods to implement and imposed the needed safeguards are similar and can be solved concurrently. The U. S. leads the world in technology research and development but U.S. industry has not been able to effectively incorporate these technological innovations into secure integrated product development environments. The entire development and deployment cycle for product realization has to be streamlined and made more efficient and cost effective. Much of the support technology needed to transition to a data-driven parallel-processing environment where product and process information is readily available, sharable, and accessible to the right people, but only the right people, at the right time in a computer interpretable form is not fully developed nor commercially available. This phase of the RRM project was established to leverage the expertise and resources of U. S. private industries and federal agencies to develop, integrate, and deploy secure technologies that meet critical needs for effective product realization.

RESULTS:
Through this CRADA, a secure geographically distributed integrated concurrent engineering environment with advanced automated manufacturing support applications was developed and demonstrated at Y-12 in Oak Ridge. Energy Systems implemented the RRM framework with a suite of customized applications in a secure DOE approved, integrated concurrent manufacturing environment supporting the manufacture and assembly of machined parts. The Y12 system was used to test and verify the types of security that can be imposed on telecommunications supporting e-mail, video conferencing, remote collaborative engineering, and product information sharing and transfer. Although Energy Systems' secure implementation was not exposed to the participating NCMS RRM members, relevant information concerning methods, techniques and lessons learned was shared. NCMS primary contributions were support projects that developed advanced applications for direct engineering, rapid prototyping, generative NC, tolerance analysis, information integration and exchange, product data management and analysis advisors.

BENEFITS TO DOE
There is an acute awareness within the DOE Defense Programs Office that to modernize and maintain core competency, the complex has to capture and integrate the knowledge of the complex in a streamlined design and manufacturing cycle that functions in a secure telecommunication environment. The Rapid Response Manufacturing project has developed a broad-based framework for automating and integrating the design and manufacturing activities involved with the production of mechanical products. Within this framework, there were several RRM projects developing technologies that are helping to provide direct benefits to DP programs at Y-12. The remainder of this section summarizes the areas of the DOE modernization efforts that were impacted by the work performed under this CRADA with NCMS.

Originally sponsored by the Digital SuperLab program and the Accelerated Strategic Computing Initiative (ASCI), the weapons design laboratories (LANL, LLNL, SNL) have recently implemented the first phase of high speed classified connectivity between all four of their locations. This network, SecureNet, operates over DOE's open Internet backbone (ESNet) using National Security Agency (NSA) approved encryption equipment. SecureNet is initially accredited for a limited set (telnet, ftp) of network services and operates primarily between host computers at DS1 speed.

This project helped establish at Y12 the first phase of the classified telecommunications infrastructure of the future downsized NWC. In February, 1997, Y-12 SecureNet Access Subnet was accredited. Telnet/ftp/X-11 protocols are available for use in Y-12 DP and Engineering. Early uses by the W87 LEP, W76, ASCI, ADaPT, and other DP programs have already validated its functionality as a strategic enabling communications resource for DOE Defense Programs. Under this CRADA, a prototypical integrated concurrent engineering environment operating in a secure telecommunication environment was implemented and demonstrated. In its initial state, concurrent engineering and information sharing capabilities were demonstrated by the exchange of:

200 W87 SLEP drawing files,
70 W78 part, assembly and drawing files,
20 WPP part, assembly, and drawing files,
50 NIF models and drawing files, and
300 Laser Workstation models and drawing files.

Included in this implementation was a secure Product Data Management capability for CAD/CAM data utilization and sharing. The architecture and underlying implementation schema was developed using work developed and demonstrated by our partners in the RRM program. Specifically, this project help provide the first phase of secure high speed telecommunications between Y-12 and the rest of the NWC which enables advanced planning for classified networking of PEIS, direct support of W87 SLEP and other program deliverables and directly supports Surveillance program deliverables

The RRM integrated framework was first demonstrated "live" on a simple prismatic part at the RRM central test bed in October 1994 at the Ford Alpha Center. In the demonstration, an engineer at the Ford Alpha Center modified the dimensions of a keyway on a component part in response to an electronic change request. A remotely located GM engineer was electronically informed of the changes as well as the parametric changes that had to be made on its mating component. The effects of the changes were examined and through negotiations with Ford a new design was approved and released. Definition of the two revised components was sent to Oak Ridge for first article manufacturing and inspection. At Oak Ridge, NC machining tool paths and CMM inspection programs were semi-automatically generated, post processed, simulated and verified. The NC tool paths were electronically sent to the Ford Alpha manufacturing facility where the components were manufactured. There were audio and visual links to each of the sites that were used for real time collaboration. It took less than 1-½ hours to complete the whole process and proved Y-12's ability to interface electronically within a geographically dispersed environment. Under this CRADA much of the technology that was demonstrated has been implemented and incorporated into the Y-12 DOE NWC Secure-Net environment.

The RRM framework was customized for a secure DOE DP application environment for automating the design and manufacture of certain classes of turned, milled and drilled parts. In particular, it is in an environment for automating the design and manufacture of high precision turned parts. NC machining tools paths are automatically generated from the design CAD system solid model for a class of turned parts. For this implementation, Y-12 supplied one of the RRM partner suppliers, Cimplex, the necessary "rules" for the production of the specified turned part family. Cimplex generated a turnkey system that automates the generation of NC tool paths for both the part and the support fixtures. This system has been demonstrated inside Y-12 and high precision parts have been machined and certified. There are plans to continue to develop this system under the Advanced Design and Production Technologies (ADaPT) program and put it into the NWC weapons production stream.

The RRM project developed and demonstrated many of the "soft" enabling technologies needed in the migration path from the traditional serial-processing methods of today to the data-driven parallel-processing environment of tomorrow where product data is readily available, sharable and accessible in a computer interpretable form. Some of the key core technology advancements were a manufacturing model that integrates product and process data in a consistent manner, an advanced computer-aided engineering environment, "knowledge-based" software aids for design and process planning, and new production technologies to make products directly from design software. The lessons learned within RRM regarding these "soft" technologies are being used in an effort to streamline and automate design and manufacturing processes for DOE NWC part production.

TECHNICAL DISCUSSION

Each of the major industrial participants, Ford, GM, United Technologies and Texas Instruments, was able to further demonstrate implementations of a customized RRM framework in a production environment. Y-12's implementation was a tailored instantiation in a NCW approved secure telecommunication environment that supports remote teaming, concurrent engineering, and manufacturing among the NWC laboratories and production sites. In each case, significant improvements in time-to-market, development and production costs, and quality were demonstrated. Each of the companies has plans to expand their implementations of the RRM framework and soft technologies to secure environments for other product lines.

RRM technology development was accomplished through the successful execution of a large number of pre-competitive technology pilot projects. The purpose of these projects was to demonstrate, develop and implement technologies supporting the principles of rapid response development and manufacturing. Each of the projects was built on a foundation of commercially available capabilities and implemented in an open architecture environment. In all, over 100 RRM projects were authorized. A complete list of RRM projects is contained in Appendix A. A synopsis of each of these projects is contained in [1].

The RRM reference architecture, a major component of enterprise integration, was defined to support integration of the commercial software and hardware products required to facilitate a collaborative product realization process. The architecture accommodates distributed, heterogeneous systems; providing protocols of service invocation and cooperation. The implementation mechanisms defined are dynamic and flexible to permit easy reconfiguration to support evolution and re-engineering of the product realization cycle and the construction of product-centric virtual enterprises. The RRM reference architecture is based on a three-tier client/server architecture implemented on top of a three-schema information architecture. This reference architecture provides a specification of a system for the construction of engineering environments which facilitates collaboration and information sharing among engineering and manufacturing disciplines. Each RRM implementation environment consists of a suite of tools, a framework of infrastructure services and a reference product and process information conceptual schema. A complete depiction of the RRM reference and infrastructure services architectures is contained in RRM documents [2], [3], [4], [5]. Y-12 developed and demonstrated a NWC relevant implementation of the RRM architecture in a secure environment. It was documented and established that all NWC security requirements for operating an integrated concurrent engineering and manufacturing environment could be satisfied and maintained.

RRM was able to develop and establish technologies that integrate product and process information across multiple applications in the product realization cycle. This included the development of a standards-based integrated product model that conceptually captures information on product, product structure, effectivitity, shape, shape representation, tolerancing, material conditions, and quality specifications. Each of the RRM industrial participants was able, with this product model, to establish engineering environments that supported a high degree of integration among all activities associated with product development and manufacturing for selected product families [6], [7], [8], [9], [10], [29], [30], [31]. Key to establishing these environments was the development of a common Integrated Product and Product Model (IPPM) for representing product (shape, form features, surface conditions, geometric tolerances, materials, assembly conditions, and product specifications) and process information (resources, capabilities, and tasks) [11], [12], [32]. This model extended the Standard for the Exchange of

Product Data (STEP) Application Protocol models currently going through the standardization process within the International Standards Organization (ISO).

The RRM Interoperability Work Group developed methods and capabilities that could be incorporated in an open architecture, client/server, object oriented, company specific heterogeneous engineering work environment. Product information integration across multiple engineering applications was partially achieved through the use of the RRM IPPM, an enhanced version of STEP AP 203. Numerous projects were piloted to test, validate and prove the feasibility of using the IPPM as a common neutral product and process data model [13], [14], [15], [16], [33]. Another enabler of product development efficiency was the development and demonstration of enterprise open architecture federated product information management systems [17], [18], [19], [34]. These systems made product data management functions accessible across multiple business functions and managed product data across multiple product data management products and installations. A major contribution from RRM was the leadership and guidance provided to develop and promote industry standards that enable interoperability between Product Data Management systems and a wide variety of other software systems. The result was a consensus Product Data Management Interface Specification [35] submission to the Object Management Group (OMG). This Specification is now undergoing the final OMG approval process before being adopted as an OGM industry standard.

One of the technological successes of RRM was the development of a formalized method for capturing and representing domain specific knowledge in an integrated unified engineering environment. The RRM approach was to create knowledge driven applications for specific part families in controlled product development environments. Within these environments, engineer was able to optimized designs and automated manufacturing process using best practice engineering and manufacturing principles based on accrued corporate knowledge. RRM adopted a methodology, Automated Concurrent Engineering (ACE), for prescribing the design, development and implementation of engineering knowledge-based applications [20]. Joint RRM application development (JAD) efforts defined application requirements for generative numerical control programming [21], variant design [22], feature-based engineering [23] and shape optimization [24]. Using the ACE methodology, the RRM application requirements were specialized for specific products and processes. Knowledge based applications for tolerance analysis [36], [49], process planning [37], [38], [48] generative Numerical Controlled machining [25], [26], rapid prototyping [27], rapid tooling acquisition [28], [39], direct engineering [8], [40], [41], [42], [43], [44], [45], [50] and analysis [46], [47] were piloted and put into production environments. From these pilots, efforts were made to establish methods to define and manage intelligent objects that could be quickly and efficiently be reconfigured for other knowledge driven applications.

Throughout the life of the RRM project, several commercial technology software products were enhanced to support RRM project requirements. A major thrust of the Y-12 effort was to demonstrate in a prototypical integrated concurrent engineering environment in which proper security safeguards are implemented. Specifically, it's imperative that appropriate security is invoked which allows individuals to access only the information they were authorized to access. The information also has to be secured from improper outside and inside attacks. The results on techniques, methods, requirements, and lesson learned about secure telecommunications infrastructure for concurrent engineering environment was reported in [51].

INVENTIONS

No inventions were made or reported

TECHNOLOGY COMMERCIALIZATION

Several software products developed from RRM project requirements are or soon will be commercially available. The following is a list of the companies and the products developed through collaboration with projects developed within RRM.

Concentra:

- ICAD/Parametric Technology, ICAD/RASNA, ICAD/SDRC and ICAD/STEP AP 203 Integration Toolkits
- Parametric Sketcher
- Glass Box Utility

MacNeal Schwendler

- Analysis Advisor
- Materials Characterization Database
- PATRAN/STEP AP 203 Interface

Unigraphics

- Tolerance and Physical Interface Analysis (Next Version)

FUTURE COLLABORATION

The RRM project was completed on 10/1/97. Its success was due, in part, to a highly effective working relationship established among the participating members of the RRM Steering Group. The exchange and sharing of valuable information on lessons learned in piloting new technologies was primarily accomplished through this relationship. The RRM project was successful in developing and implementing advanced integrated engineering environments to design and manufacture for selected product lines. The benefit available in the application of RRM developed information and communications technologies to manufacturing is just starting to be realized. There is an effort to develop another NCMS industrial consortia that includes many of the RRM industrial members with a new NIST ATP funded project for developing a generic interactive knowledge base accessible through the internet. Y-12 is monitoring this activity and may attempt to develop collaboration with this group in the future.

CONCLUSIONS

The RRM project is an excellent example of a consortia project that met expectations and benefited all of the participants. The companies involved were vastly different (i.e. size of company, type of industry, cost of products, and size of production lots), but through a compelling common vision were able to identify common problems, interests, and priorities, share investment, collaborate, and achieve all the major goals of the project. Each of the participating companies was able to benefit from the research, development and implementation of infrastructure technologies that, without resource leveraging, would not have been feasible.

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Appendix A

RRM PROJECTS LIST

RRM Project	Leader
RRM Program Metrics	TI
Direct Manufacturing	GM
Integrated Product and Process Modeling (IPPM)	GM
IPPM - Dimensional and Tolerances	GM
IPPM – Product Data Exchange	GM
IPPM – Features	GM
Engineering Environment Architecture	TI
Engineering Environment	P&W
Integrated Test Bed	LMES
Generative N/C Programming	TI
Variant Design	Ford
ACIS/ICAD Integration	Ford
Tolerance Management	GM
Concurrent Engineering Data	TI
Limit Stacks and Variation Simulation	GM
Shape Optimization for Molded Parts	GM
CIMPLEX/Unigraphics Gateway	Cimplex
Solid Model Exchange Using AP203	MSC
Ford/GM CAD Data Exchange	Ford/GM
Rapid Acquisition of Tooling	P&W
ICAD/Parametric Technology Integration Toolkit	Concentra
ICAD/RASNA Integration	Concentra
Rapid Distribution of Technical Information	GM
Integration of CAD & Analysis Functions	GM/MSC
Improved Engineering Design Process	GM
Mfg. Engineering Downstream Use of Computer Tools	GM/MSC
Rapid Prototype Tooling	GM
Geometry Creation Using a Parametric Sketcher	Concentra
Feature Based Finite Element Modeling	GM
ICAD Glass Box	Concentra/GM
Climate Control Direct Engineering Environment	Ford
PDGS/STEP Capabilities	Ford
Analytical Powertrain Workflow Management	Ford
Analytical Powertrain Expresso	Ford
Integration Technology Development	Ford
Features Theory Development	Ford
Analytical Powertrain – PFIS DCP Feature Integration	Ford
Analytical Powertrain STEP Machine	Ford
Knowledge Based Engineering Toolkit	GM
Thermal Analysis Project	TI
Visualization Project	TI
Variant Design Project	TI
RRM Initial Demonstration	Ford
RRM Central Site	Ford

RRM Project	Leader
STEP to Stereolithography	Ford
K-BAM Manufacturing Feasibility	Ford
Crankshaft Dunnage Design	Ford
Strategies for KBE applies to Generative N/C Programming	TI
Integrated Product and Process Modeling- Proof of Concept	GM
AUTO Pilot STEP Implementation-Proof of Concept	GM
CAD Data Exchange through PATRAN/STEP	GM/MSC
Knowledge Based Process Planning	Ford
NC Rapid Fabrication	Ford
ACIS-Parasolid Data Translation	Spatial
GM/Ford Data Exchange Using STEP	GM
Data Exchange between UG & CATIA utilizing STEP	GM
Desktop Video Conferencing	GM
Manufacturability and Cost Assessment	TI
TI Engineering Environment	TI
ICAD STEP AP203 Interface	Concentra
Re-engineered Tooling Design, Procurement & Documentation	P&W
CAD Driven Rapid Work Instructions for Rigid Tubes	P&W
GNC Re-evaluation	TI
Automated NC Tool Path Generation for Turned Parts	LMES
Design Re-use	TI
Tool Interoperability and Data Management Infrastructure	Ford
Single Access to Weld Spot Database	Ford
WYS/WYG GUI Techniques for Engineering Software	Ford
AP Projects On-line Help System	Ford
Systems Models for Variational Tolerance Simulation Analysis	Ford
AP CAE Analysis Data Management	Ford
Production Gauge Design Using Associatively	Ford
Tolerance Data Exchange	Spatial
Knowledge Based Interactive Process Planning	P&W
Interoperable PDM Product Structure Services Provider	TI
Automated Generation of NC Tool Paths for Milled Parts	P&W
RRM/KBE Multi-Media Project	GM
3-D Printer Technology Evaluation	All
Analysis Advisor	MSC
Thermal Analysis	TI
IPPM STEP Translation Center	GM
Knowledge Data to CAD	GM
Feature Based Geometric Dimensioning & Tolerancing	GM
Automated Process Planning	GM
Agent-Based Software Tool Integration	Ford
Manual Transmission Direct Engineering	Ford
Workflow/PDM Interoperability Project	LMES
Interoperable Materials Property Data Services Provider	MSC
Electrical & Fuel Handling Division- Direct Engineering	Ford
Analysis Advisor Phase II	MSC
Feature Oriented Mfg. Resource Master Database	CIMPLEX

RRM Project	**Leader**
Automated Design of Modular Tube Fixtures	P&W
Video Conferencing & Data Collaboration Across Phone Lines	GM
Federated PDM	TI
Distributed Knowledge Based Product Development	Cimplex
ICAD-SDRC Integration	Ford
STEP Based Die Processing Advisor	GM
Supplier Integration Associate	Teknowledge
Improving Software Lifecycle Practices Workshop	Teknowledge

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