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OAK RIDGE
Y-12
PLANT

LOCKHEED MARTIN

Final CRADA Report
for
CRADA Number P-ES001-0077

RAPID RESPONSE MANUFACTURING (RRM)

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ABSTRACT

Lockheed Martin Energy Systems (LMES), through a CRADA with the National Center for Manufacturing Sciences (NCMS), worked with 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 develop, create, and deploy infrastructure and support environments for Rapid Response Manufacturing.

A major accomplishment of the Rapid Response Manufacturing (RRM) project was the development of a broad-based generic framework for automating and integrating the design-to-manufacturing activities associated with machined part products. Key components of the framework are a manufacturing model that integrates product and process data in a consistent, minimally redundant manner, an advanced computer-aided engineering working environment, "knowledge-based" software systems for design, process planning, and manufacturing and new production technologies for making products directly from design application software.

FINAL REPORT

Title: Rapid Response Manufacturing (RRM)
CRADA Number: P-ES001-0077
Partner: National Centers for Manufacturing Sciences (NCMS)

OBJECTIVES:

The RRM project, initiated in October 1992, is a Department of Commerce National Institute of Standards and Technology (NIST) administered Advanced Technology Program (ATP). RRM is made up of a consortium of major industrial firms- Ford Motor Company, 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) - brought together by NCMS to develop, demonstrate and incorporate key technologies needed for establishing computer-integrated design and manufacturing environments. The five-year RRM ATP program funding was $48M. Lockheed Martin Energy Systems was a participant through a CRADA with NCMS covering RRM activities conducted during the second through fourth years of the project.

Pre-competitive collaboration in the RRM program focused on the development of specific CAE/CAD/CAM applications to support automated concurrent engineering and manufacturing. The CRADA objective was to define a generic framework, develop a work plan and demonstrate proof-of-concept of a Rapid Response Manufacturing infrastructure for product development that reduces the mean time to market, improves the quality-to-cost ratio, and improves product reliability for selected part families. The LMES part family was a class of high precision machined turned parts. LMES's role was to lead the effort to develop and implement a RRM test bed environment that supports rapid testing, insertion and implementation of new applications and/or requirements within the framework of the generic infrastructure defined within RRM.

RESULTS:

Through the RRM program, a customizable infrastructure for rapid response product development, design, and manufacturing was defined, developed, and established. A major achievement was the definition and development of a broad-based framework for automating and integrating the product and process design and manufacturing activities which support machining of high precision parts. This was accomplished by coordinating and extending the application of feature-based product modeling, knowledge-based systems, integrated data management, and direct manufacturing technologies in a cooperative integrated computing environment. Key technological advancements include a product model that integrates product and process data in a consistent, minimally redundant manner, an advanced computer-aided engineering environment, "knowledge-based" software aids for design and process planning, and new production technologies to manufacture products directly from design CAE application software. Each of the RRM industrial partners was able to customize the RRM generic framework, support it with commercial off-the-shelf application software and existing/emerging national and international standards, and demonstrate measurable order-of-magnitude improvements in time-to-market, cost reduction, and quality for selected part families.

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. 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 providing direct benefits to DP programs at Y-12. The remainder of this section summarizes relevant RRM thrust areas and their impact on DOE modernization efforts.

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. Much of the technology that was demonstrated is being implemented and incorporated into the Y-12 DOE NWC Secure-Net environment.

The results of another RRM project are being used in Y-12 to implement an open architecture system to manage, present, and distribute product certification information across the NWC complex. The RRM product information management prototype was demonstrated at the RRM Ford Alpha center in Dearborn, Michigan on May 12, 1996. For the prototype, a selected set of product data management services was implemented in an open systems architecture using CORBA. Demonstrated was the operation of a consistent set of product information management functions in an integrated enterprise environment using commercially available software. The demonstration showed how Y-12's legacy electronic file management system (EFM) could be incorporated and utilized in a comprehensive enterprise product information management environment. Product information were stored, utilized, and managed in many different electronic formats (i.e. CAD files, Word documents, plot files, etc.). World Wide Web technology was implemented for user friendly interface access and presentation.

The RRM framework was incorporated in a simulated DOE DP application environment for automating the design and manufacture of certain classes of turned, milled and drilled parts. In particular, the RRM framework was customized in an environment for 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 demonstrate implementations of a customized RRM frameworks in a production environments. In every case, significant improvements in time-to-market, development and production costs, and quality were achieved. Each of the companies has plans to expand their implementations of the RRM framework and soft technologies to 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 principle research and development objectives of RRM focused on identifying, developing, and integrating pivotal technologies needed to enable engineers to reduce the time required to design and manufacture products in response to rapidly fluctuating market demands. The basic technologies addressed were:

- Enterprise Integration built around object-oriented, distributed computing systems
- Product representation and product data management
- Knowledge-based applications that support the entire life cycle.

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 the 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 conceptual schema, the Integrated Product and Process Model (IPPM). A complete depiction of the RRM reference and infrastructure services architectures are contained in RRM documents [2], [3], [4] ,[5].

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]. 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]. 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).

A 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 to translate to and from [13], [14], [15], [16]. Another enabler of product development efficiency was the development and demonstration of enterprise open architecture federated product information management systems [17], [18], [19]. These systems made product data management functions accessible across multiple business functions and managed product data across multiple product data management products and installations.

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 generative NC [25], [26] , rapid prototyping [27], rapid tooling acquisition [28], and climate control direct engineering [8] 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. Concentra developed new software components that integrated ICAD with Pro Engineer, RASNA, ACIS, SDRC and STEP AP203. They also developed ICAD Parametric Sketcher and Glass Box Utility modules. MacNeal Schwendler developed an Analysis Advisor module for design engineers, a Materials Characterization Database, and an integration interface between PATRAN and AP203. Unigraphics added a geometric tolerancing capability in their solid modeler that supports assembly tolerance and physical interface analysis. SDRC built modules to support a set of RRM Product Data Management (PDM) Service Protocols supporting PDM business functions through a Common Object Request Broker Architecture (CORBA) to Metaphase. This set of PDM protocols was submitted to the Object Management Group (OMG) in response to their PDM Request For Proposal (RFP) to establish standard interfaces for the services provided by Product Data Management systems. These interfaces made available through object request brokers will provide the standard needed to support a distributed product data management environment as well as providing standard interfaces to differing PDM systems.

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 success of RRM 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. Although the RRM project was successful in developing and implementing advanced integrated engineering environments to design and manufacture selected product lines faster, better and cheaper, there are still many problems to resolve. The benefit available in the application of information and communications technologies to manufacturing is just starting to be realized. The RRM participating companies represent a credible representation of the U. S. industrial base and there are efforts underway to determine if there is a need and a desire for follow-on collaboration activities in areas that were not addressed or completed in the original RRM project.

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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