NIMROD: A Customer Focused, Team Driven Approach for Fusion Code Development

H. M. Karandikar and D. D. Schnack

Science Applications International Corporation

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Abstract

NIMROD is a new code that will be used for the analysis of existing fusion experiments, prediction of operational limits, and design of future devices. An approach called **Integrated Product Development (IPD)** is being used for the development of NIMROD. It is a dramatic departure from existing practice in the fusion program. Code development is being done by a self-directed, multi-disciplinary, multi-institutional team that consists of experts in plasma theory, experiment, computational physics, and computer science. Customer representatives (ITER, US experiments) are an integral part of the team. The team is using techniques such as Quality Function Deployment (QFD), Pugh Concept Selection, Rapid Prototyping, and Risk Management, during the design phase of NIMROD. Extensive use is made of communication and internet technology to support collaborative work. Our experience with using these team techniques for such a complex software development project will be reported here.

Motivation

Integrated **P**roduct (“Software”) **D**evelopment (**IPD**) Teams will allow the development of comprehensive codes that meet customer expectations (in terms of the physics modeled, utility of results, and ease of use) in 18-24 months instead of many years.

IPD implementation has delivered significant benefits, such as dramatic reduction in development time and costs and increase in product quality, in the commercial arena as well as DoD weapon systems development.

IPD Techniques Used for NIMROD

- Team Formation and Training
- Quality Function Deployment
  - capture voice of the customer
  - requirements deployment
- Pugh Concept Selection
- Parallel Development
- Rapid Prototyping
- Risk Management
- Collaborative Technology
- Team Operation

Project Team

- membership driven by technical interests of the members.
- membership is diverse and dispersed.
- project participants attended two-day “teaming” workshop at project kick-off.

Organization	Location	Members (full time & part time)
SAIC	San Diego, CA	1
	McLean, VA	1
LANL	Los Alamos, NM	4
SNL	Albuquerque, NM	2
LLNL	Livermore, CA	2
Univ. of Wisconsin	Madison, WI	1
General Atomics	San Diego, CA	2
ITER	San Diego, CA	1
DOE (OFES, MICS, ...)	Germantown, MD	1

Customer on the team!

Team Formation - Good Practices

- Organize around outcomes, not tasks.
- Maintain team oversight of entire process.
- Those who use output of process perform the process (real/surrogate expertise).
- Those who generate information, process it.
- Treat geographically distributed resources as collocated-communications plan.
- Coordinate parallel activities during a process, not after it.
- Place decision authority where the work is performed.
- Capture information at the source.

Quality Function Deployment (QFD)

What is it?

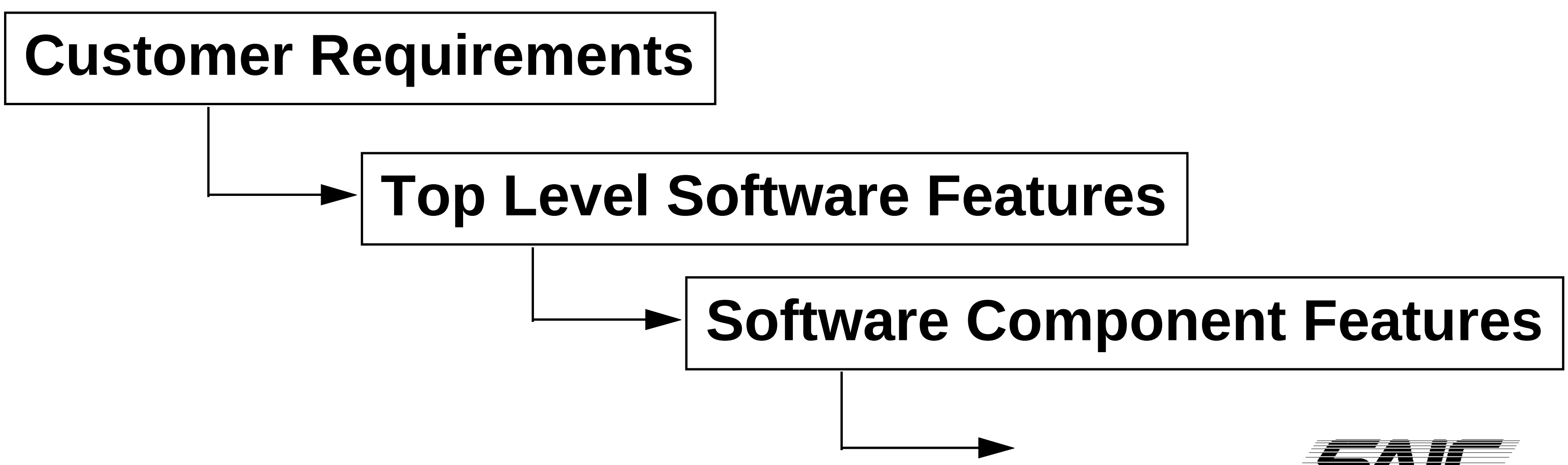
- A system for translating (deploying) customer requirements into appropriate product <NIMROD software> development requirements that can be satisfied by the functions of an organization <the NIMROD Team>.

When to use it?

- You would like to develop a "picture" of the relationship between customer requirements and product features.
- You would like to display relationships between several product issues and the components related to these issues.
- You want to incorporate the voice of customer in your planning process for product development.
- You want to design and deploy a strategic plan.

QFD Output

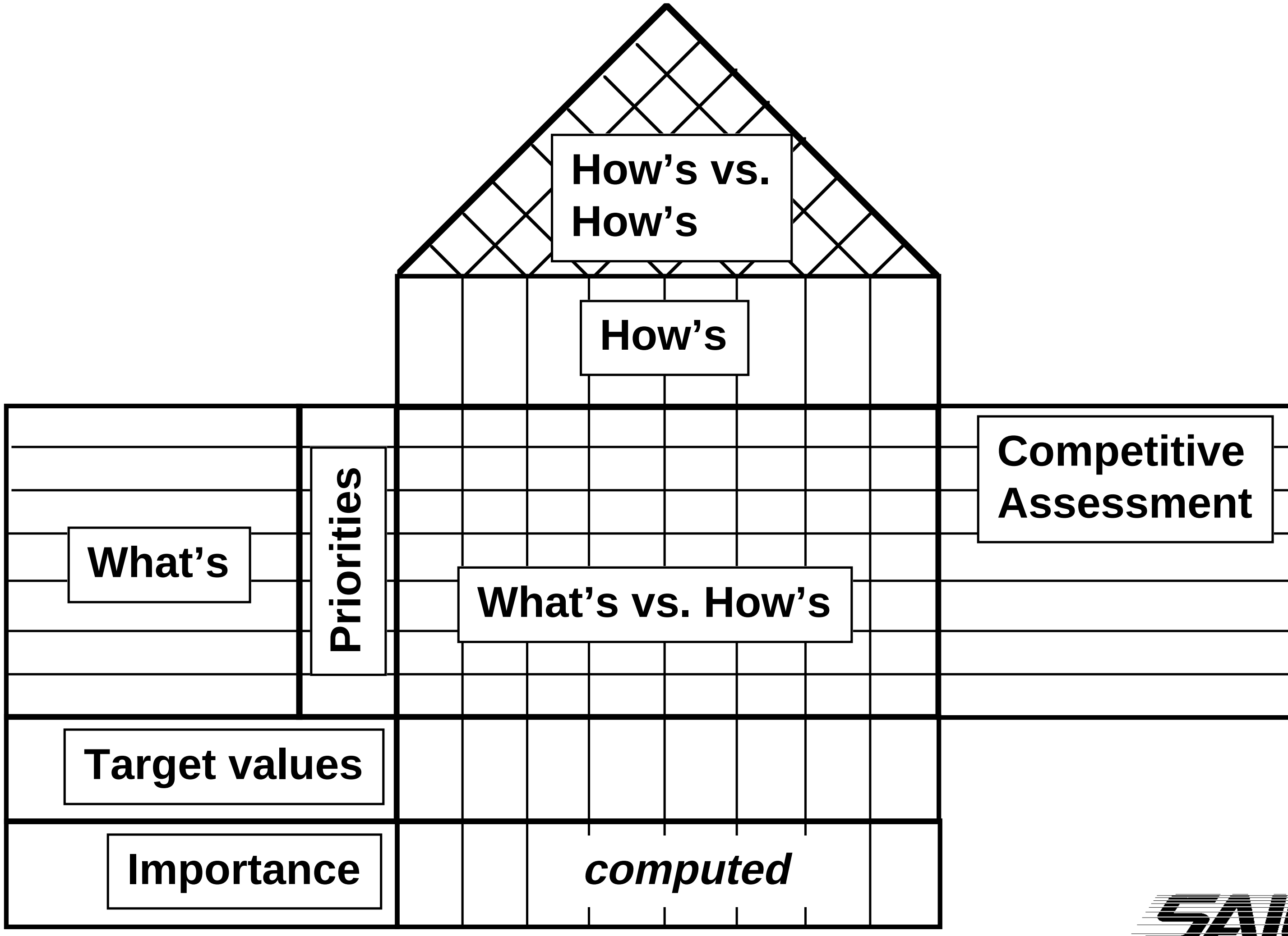
- The outcome of the QFD process is a set of matrices, (each matrix is a House of Quality) that capture the mapping of the customer requirements right down to the product components.



QFD Mechanics

- Start with requirements - the What's
- Prioritize the requirements
- Identify characteristics of the solution/product. These are the How's.
- The What's and How's intersect to form a matrix. Indicate the strength (strong, weak, medium, none) of the relationships between the What's and the How's.
- Indicate the target value for each of the How's.
- Identify any interaction between the How's.

QFD Matrix: “House of Quality”



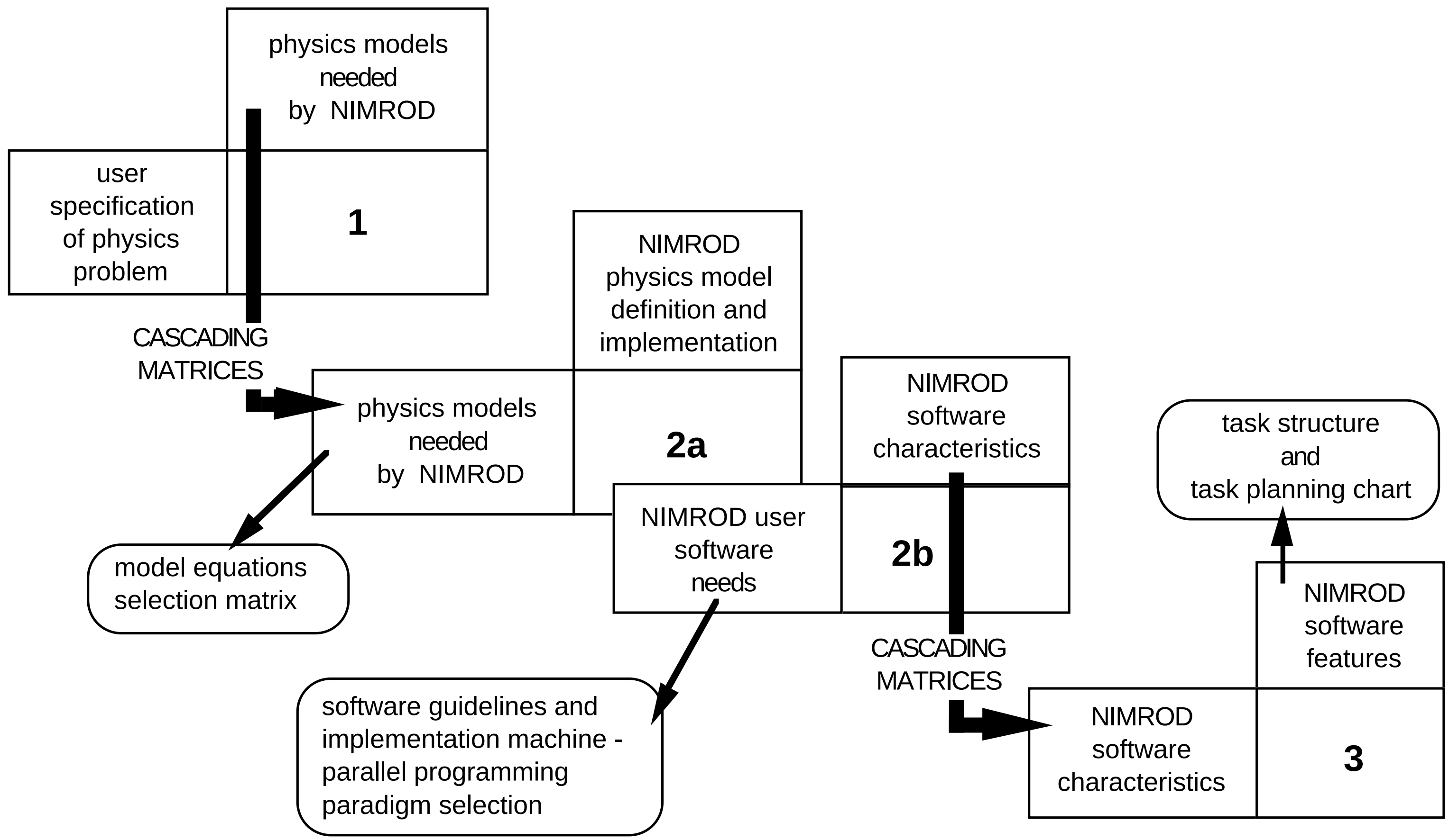
QFD Benefits

- Focuses on customer satisfaction and requirements
- Fosters team ownership of customer satisfaction and requirements
- Supports early planning among all functions–improves development time and cost by minimizing late discovery of problems (delay, scrap, rework)
- Integrates process planning with product planning
- Facilitates tradeoff studies at all levels, from concept to detailed planning stages
- Provides common view of evolving product and process plans
- Represents corporate memory in graphical and integrated form (starts with pencil and paper)
- Brings discipline to the product development process

QFD Caveats

- Payoffs from initial effort invested in QFD not realized until later
- Inexperienced teams may make QFD charts more detailed than they can comprehend
- QFD lacks dynamic representation capabilities - it must be complemented by workflow analysis and other project management tools
- The QFD charts must be reviewed and updated by the team periodically

Requirements Capture and Flowdown



NIMROD QFD Matrix - Level 1

Whats vs. Hows Legend		
Strong	●	9
Moderate	○	3
Weak	Δ	1

	Actual Geometry	Flow Effects	Non-ideal MHD effects	Neoclassical	Resistivity	Flow damping	Two fluid effects	Field errors	Discharge evolution/external coils	Sources (n,v,T)	Open field lines with plasma	Resistive wall	Energetic particles	Transport (n,v,t)	High temperatures	Scrape off layer
Non-ideal soft beta limits/real plasmas	●	○		●	●	●	●	●	○					○	●	
ELMS																
Extent (how deep)	●			Δ	●	○	○		○	○	●			●		
Geometry of ELM	●				●		●				●			●		●
Locked modes	●	●		●	●	●	●	●	Δ	●		●		○		
Sawtooth reconnection	●				●		●			●			●	●	●	
RFP current profile control					●		●		●	●		●		●		
Helicity injection (tokamak)	●				●		●		Δ		●					●

NIMROD QFD Matrices - Level 2

Whats vs. Hows Legend		
Strong	●	9
Moderate	○	3
Weak	Δ	1

	2 Fluid equations	Gianakon/Callen neoclassical bootstrap formulation	Spitzer resistivity	Chi_E*del_perp^2v_phi	Del_dot_kappa_dot grad T	Sub grid particle flux	Vacuum region	B_tilde at wall (b.c.)	Seperatrix (moving)	Resistive wall b.c.	Flux coordinates	Particle pushing Pi (kinetic)	E, rho_v, rho source terms (externally defined)	Circuit model/plasma coupling	External coils	Radiation (brem)	Implicit time solve
Actual geometry							●		○		●				●		
Flow effects	●			●													
Non-ideal MHD effects																	
Neoclassical		●			●												
Resistivity			●														
Flow damping				●													
Two fluid effects	●																
Field errors							○	●									
Discharge evolution/external coils				○	○	○			○	○	●			●	●	○	
Sources (n,v,T)													●				
Open field lines with plasma									●		●			○	○		
Resistive wall				○						●							
Energetic particles												●					
Transport (n,v,t)				●	●	●					○						
High temperatures	○		●		○												
Scrape off layer				●	●	●			●								
Island evolution times scales				○	○	○							○	○		Δ	●

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NIMROD QFD Matrices - Level 2

Whats vs. Hows Legend		
Strong	●	9
Moderate	○	3
Weak	Δ	1

	modular	pre-processor	post-processor	parallel architecture	software standards	GUI	documentation	version management	code validation	Milestones	Nov 1996 Prototype	July 1997 ITER Final	July 1996 Ultimate
Ability to interact with analysis codes		●	●								◎		
Easy to use	Δ	●	●			●	●				◎		
Physical effects selection	●					●	●				◎		
Portable	●			●	●							■	
Dimensional input/output		●									◎		
Good documentation							●					■	
Validated output							Δ	●	●		◎	■	
Interface to linear stability codes			●								◎		
Scaleable				●								■	
Reasonable results turn around time				●								■	
Flexible (extensible)	●				●		●	○				■	
Reproduce experimental diagnostics			●			Δ	Δ		●			◎	■
Parameterized input		●				○					◎		
Optimization seeking			●									■	
Interfacing to engineering codes		●	●			Δ					◎	■	
Technical support						○	●					■	
Thermal/electrical/mechanical stress on external components			●										■
Support different numerical algorithms	●	○		●		○					◎		

Features Milestones Legend	
Prototype	◎
Final	■

NIMROD QFD Matrices - Level 3

Whats vs. Hows Legend		
Strong	●	9
Moderate	○	3
Weak	Δ	1

	User interface	Read user input	Control program flow	Display results	Pre-processor	Set up IC's	Set up BC's	Geometry definition	Grid generation	Write input file for NIMROD	Read input from codes	Consistency check	NIMROD solver	Read IC's and grid	Advance solution (t->t+dt) with BC's	Quick diagnostics and status	Write solution and grid to file	Post-Processor	Read output from solver	Data analysis	Visualization	Write output files to other codes	Report generation
Te stepping algorithm		●	●			●	●								●				●				
Modular			○								○												
Pre-processor		●				●	●	●	●	●													
Post-processor				●															●	●	●	●	●
Spatial discretization algorithm														○	●		○				○		
Model equations									Δ						●								
Parallel architecture									○						●	Δ							
Software standards																	●		●			●	
Model boundary conditions							●	●							○								
GUI		●	●	●		○	○	○		●	○	Δ				●					○	○	○
Document																							
Version management																							
Code validation																							
Module validation															●								
Validation against know solutions						○	○								○					○	○		
Experimental validation						○	○								○					○	○		

... this information was used to synthesize a task plan

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Concept Selection: Pugh's Method

... was used for selection
of the model equations

	Concept 1	Concept 2	baseline
Attributes/ Requirements	+ ++	+ - 0	
Net score	**+3**	**0**	

→ ***better option***

++	-	much better than
+	-	better than
0	-	same as
-	-	worse than
--	-	much worse than

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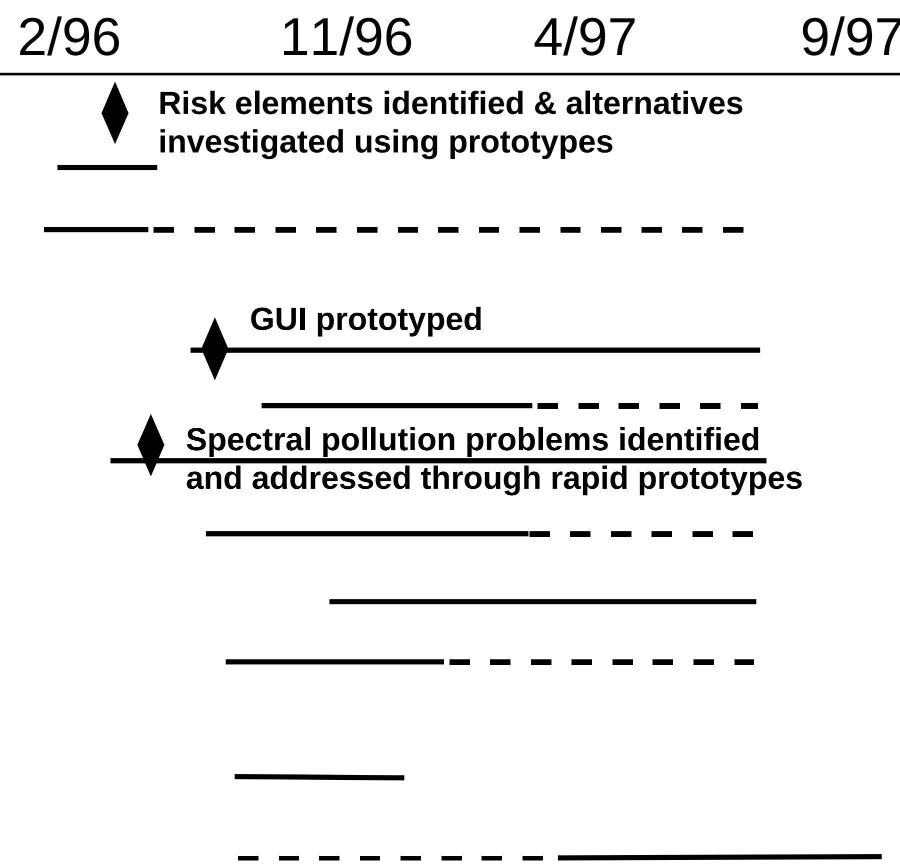
Parallel Development

(use of rapid prototyping)

Project Start: mid-February 1996

- Specification Development
  - Software standards
  - Physics approach
- Software Development
  - Graphical User Interface
  - Pre-Processor
  - Solver
  - Post-Processor
- Integration
- Testing
- Validation
  - Planning
  - Execution



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Risk Management

- Risk management practices:
  - Early identification of:
    - task dependencies and responsibilities
    - technical areas with high degree of difficulty
    - resource constraints
  - Alternate and backup approaches thought out and investigated.

Examples

- Use of implicit time advancement -- fall-back was the semi-implicit technique.
- Multiple graphics data packages such as XDRAW and Data Explorer, were explored in depth.
- Multiple approaches to GUI development were prototyped, e.g., using Tcl/Tk and Java/HTML.

Collaboration: Procedures and Technology

- Face-to-face Meetings: 5 meetings for the full group and 1 meetings of sub-groups to-date.
  - One of the meetings was for a week at the customer site.
- Telephone and video conferences
- E-mail and listserver
- Project web site and ftp site
- Document exchange using PDF format

Team Operation

- Team used an external facilitator during the development process.
- Team decisions are consensus based - decisions related to task planning, technical approaches, and addition of new members.
- Team members have felt a strong need for periodic face-to-face meetings to tackle the tough technical issues.
- Risk management used from the outset.

Issues

- Coordination of a distributed team and sharing information among the dispersed team members is a challenge on a fast paced project requiring many high impact technical decisions.
- Part time and changing team membership strains the development process.
- Severe budgetary constraints.
- Uncertain local management commitment.
- An extremely difficult technical goal.
- The QFD process was used for the development of a large code for a research problem which has a high degree of uncertainty.

The team feels that the IPD practices and judicious use of technology to support collaboration has made a major difference in the NIMROD code development process.

... they believe they will accomplish their ambitious 18-24 month goals.