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Economical Development of Complex Computer Systems

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Economical Development of Complex Computer Systems

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"Knowing where you've come from and where you are is essential to knowing how to get where you want to go. Developing a new generation of products is a lot like taking a journey into the wilderness. Who would dream of setting off without a map?" [1]

Steven C. Wheelwright and W. Earl Sasser, Jr.

INTRODUCTION

This paper proposes a product development methodology (PDM) for complex systems evolving within the current economic climate of the United States, as well as the unstable state of world affairs envisioned throughout the decade. The PDM facilitates the development of systems that are "multipurpose, flexible, highly mobile, and incorporate maximum bang for the buck."[2]

Ironically, the unstable nature of the development environment within the defense community parallels the one encountered by the commercial sector over the last 20 years. Successful companies have responded by adopting a product development methodology that adapts to ever changing market demands and the concern for near term returns (profit).

The PDM exploits lessons learned from the commercial market analogy to establish a flexible, low risk, cost effective approach for technological progress. The approach suits systems development, especially those involving complex mission critical computer systems.

Examination of the commercial product development process reveals a strategy that can achieve the procurement flexibility needed by DoD. This strategy concentrates on leveraging the state-of-the-art in a cost effective manner. The strategy also addresses risk management.

The key to the technological success of this strategy relies on an incremental development process. The IBM PC serves as a perfect example. The i486 based PC resulted from successful sales of the 286, 386SX and i386 based versions. Incremental upgrades enabled IBM to respond to changes in market demand as well as facilitate the transition of the state-of-the-art. In this manner, IBM attained strategic flexibility.

The discussion starts at a basic level and progresses to a macroscopic perspective. This paper contains four parts: adaptation of a commercial approach, incorporation into an overall risk management scheme, application to an open architecture transition, and a summary.

The paper recommends using open architectures and commercial off-the-shelf (COTS) items to implement the incremental improvements outlined by the PDM. The summary includes guidelines for successful product development, as well as ideas for future work in this area.

ADAPTATION OF A COMMERCIAL APPROACH

Decreasing commercial product life cycles have required technologies to be developed at faster rates.[3] As a result, companies have devoted more effort to the product development process. The process differs from company to company; however, the *high tech* arena focuses on the time to market. Shortening the time to market enables a company to increase market share, adapt product characteristics to market needs, enjoy high margins typically encountered in the beginning of a product's life cycle, and shorten the payback period.[4]

This focal point requires a company to make decisions in what Preston Smith refers to as the *"fuzzy front end"* of the product development process.[5] Lack of quantitative information and organizational structure characterize the ambiguity of the "fuzzy front end." Decisions made at this time greatly affect the product's evolution. The expensive nature of changes made down the road heightens the significance of these up front decisions. As a product progresses from planning, through design, production, test and delivery the cost to correct an error increases.[6]

Smith offers a simple decision analysis technique to attack problems in the "fuzzy front end." The technique concentrates on the interrelationships between time, development cost, performance and profit. He prefers an approach based on estimates generated quickly. Smith believes complicated estimation tools waste time and lead to a false impression of the accuracy of the available data. His book presents several examples to demonstrate the merit of his approach. Therefore, this paper concentrates on the adaptation of Smith's ideas to complex systems.

At first glance, the lack of the profit motive within the government appears to create an obstacle to the application of Smith's approach to the development of complex systems. However, consider the savings the government can pursue when building systems. This viewpoint establishes the profit motive; when systems cost less, profits from savings follow. In other words, life cycle cost savings create a profit. The analogy between profit and cost savings permits a modification to Smith's model for product development in the defense sector. Figure 1 illustrates the product development framework that results when life cycle cost replaces profit in Smith's model. The arrows indicate relationships between the areas identified in the circles.

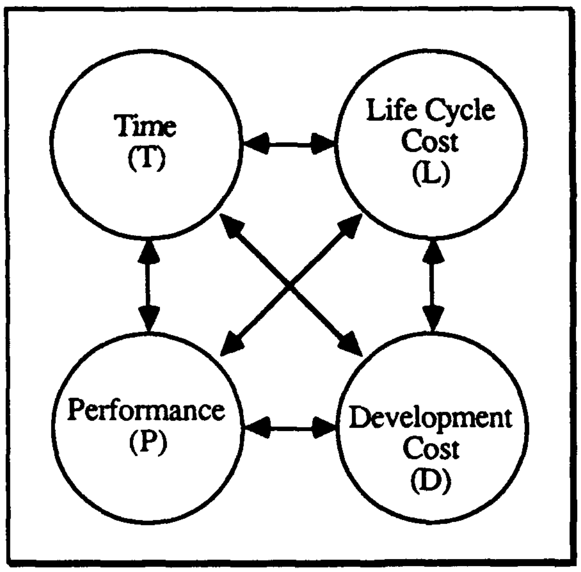


Figure 1. Product Development Framework

Note, this model separates development costs from life cycle costs. This definition differs from the definition of life cycle cost used in Naval acquisitions. For Naval acquisitions, life cycle cost is the sum total of the direct, indirect, recurring, non-recurring, and other related costs incurred, or estimated to be incurred in the design, research and development (R&D), investment, operation, maintenance, and support of a product over its life cycle.[7]

The product development framework fosters decisions based on time, performance, development cost and life cycle cost tradeoffs. To achieve savings, the product development framework must assume a baseline for time, performance and cost. An existing system functions as the baseline. The baseline system establishes cost and performance ceilings. Measure time, performance and cost in terms of the incremental contribution to the baseline system when developing new products for existing systems.

This paper uses qualitative reasoning to demonstrate the utility of the product development framework. A color coding scheme depicts the incremental contribution for each area. Ideally, the color coding scheme would use a traffic light pattern. Picture red for an undesirable rating, yellow for an indeterminate condition and green for a favorable estimate. Figure 2 exhibits the alternate color coding scheme used in this paper to facilitate duplication of the material.

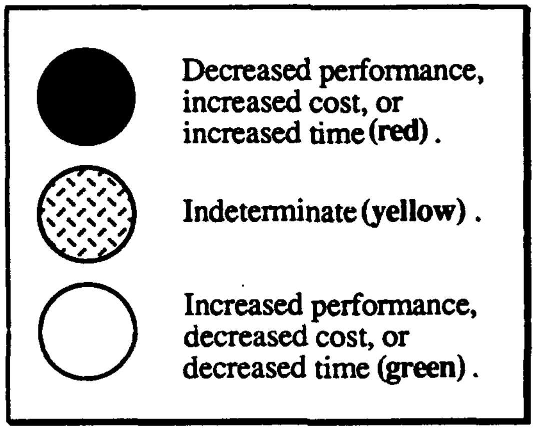


Figure 2. Color Coding Scheme

A quantitative analysis would eventually replace qualitative reasoning. The progression of time enables the analysis to improve as more information becomes available and decisions are revisited. Hence, the quantitative analysis gets fine tuned as the product becomes well defined.

This product development framework facilitates the assessment of life cycle costs, development costs, and development time for specific performance requirements. Continued appraisal will result in a set of performance requirements that meets cost goals.

One problem not represented directly in the framework is the difficulty mustering support for the acquisition of systems on the basis of life cycle cost. Opponents can attack the fidelity of forecasts beyond a 5 year period.

However, a shorter product development cycle addresses this problem by trimming the payback period. The payback period is the time it takes to recoup the initial development cost through life cycle cost savings. Reduced payback periods strengthen life cycle cost estimates. The incremental product development approach capitalizes on condensed payback periods.

The framework addresses issues on a discrete product basis. Examples of discrete products include: disk drives, power supplies, and stand alone computers. In contrast, complex computer systems represent an amalgam of discrete computer products. They require a technique that weighs each decision on a macroscopic level. The four element diagram cannot guide complex decisions without a higher level of abstraction. The next section outlines the higher level.

RISK MANAGEMENT FOR COMPLEX COMPUTER SYSTEMS

Many discrete technical approaches compete for attention in the *"fuzzy front end"* of complex computer systems development. The aforementioned product development framework expedites decisions on a case by case basis, but cannot manage a complex computer system in its entirety. A useful methodology must provide a map for macroscopic considerations. This consideration differentiates Smith's commercial technique from complex systems development. Nevertheless, Smith's framework forms a foundation for the map used in the higher level of abstraction.

Basically, the methodology sets the stage for each discrete approach to compete in terms of time, cost and performance. A three step process establishes a clear path from the *"fuzzy front* *end"* through product definition to a low risk development scenario. Figure 3 illustrates this process for the development of a complex computer system on the basis of cost.

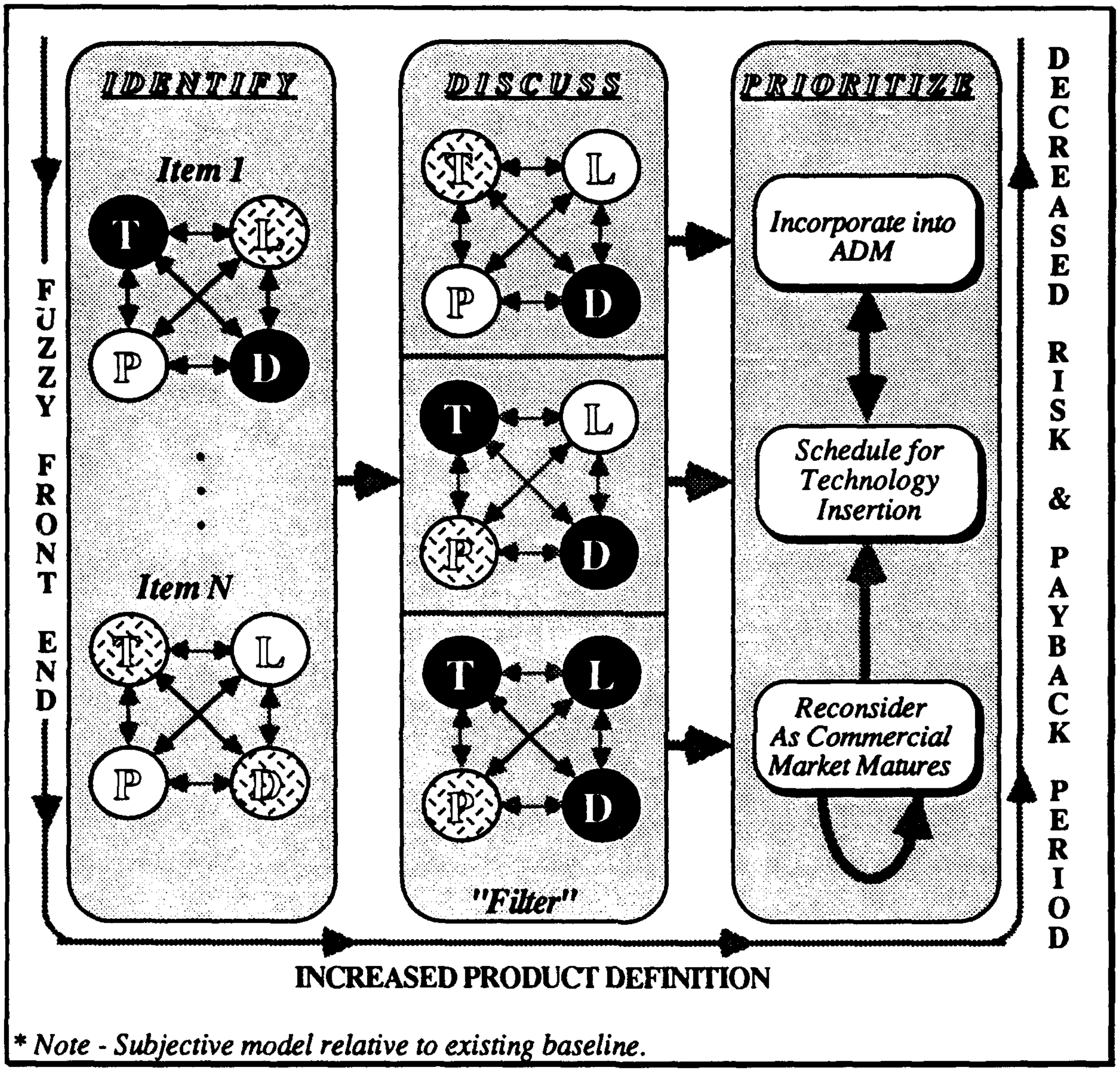


Figure 3. Product Development Methodology

The first step identifies each discrete candidate. Identification requires at least a subjective description in terms of time, performance, life cycle cost and development cost. In fact, subjective approaches accelerate the process. A plethora of candidate approaches typically overwhelms the front end of complex computer system development. A detailed quantitative analysis of each would consume time and money.

A RAND study of process plants demonstrates the lack of accuracy of data in the *"fuzzy front end."* Process plant estimates generated on the basis of R&D data alone, can easily overrun budgets by 100%. As the level of project definition and quantity of engineering data increase, overruns decline to about 10% at a full cost design stage.[8]

Ensure early efforts focus on the rapid development of high potential products, rather than up front detailed cost analyses. Get products into existing systems quickly. Keep the up front analysis simple to reduce development costs. Mitigating costs reduces risk. In the long term, the incremental product development methodology promotes a diversified development portfolio.

Breaking down the complex system development into a step-by-step sequence of limited challenges contains risk and cost. Northern Telecom's venture from analog into digital switching systems for the telecommunications industry serves as an example. Instead of going for the local DMS 100 switch right away, the company started with the development of a PBX (private branch exchange), which gave it a base for understanding important new technologies, digitization techniques, advanced programming languages, and network design. Treating the effort as a step-by-step sequence of more limited challenges allowed Northern Telecom to contain its development risk and keep development costs from going through the roof.[9]

The second step involves a discussion of each candidate approach. The discussion includes establishing fundamental criteria for advanced development, technology insertion and future consideration. Discussion challenges the subjective nature of the data.

The third and final step sorts the candidates into those considered for immediate advanced development, future technology insertion, and further consideration. At this part of the development process the high priority candidates require a detailed quantified analysis. Depending on cost goals, products can move to and from the advanced development model (ADM) and technology insertion. Existing ADM products replaced by candidates from the technology insertion area act as contingencies; they create a backup in case of product failures.

The identification, discussion and prioritization (IDP) of discrete candidates lead to system definition. Figure 3 shows how development proceeds from the *"fuzzy front end"* to clear-cut product definition. The process mitigates risk by giving priority to approaches that yield the biggest cost savings with the shortest payback period. As time progresses the product becomes well defined and information is available to make decisions quantitatively rather than qualitatively.

APPLICATION OF THE PDM TO AN OPEN ARCHITECTURE TRANSITION

Traditionally, combat system development requires a quantum leap in performance. Figure 4 exemplifies the computing throughput required by expanding sensor array configurations.

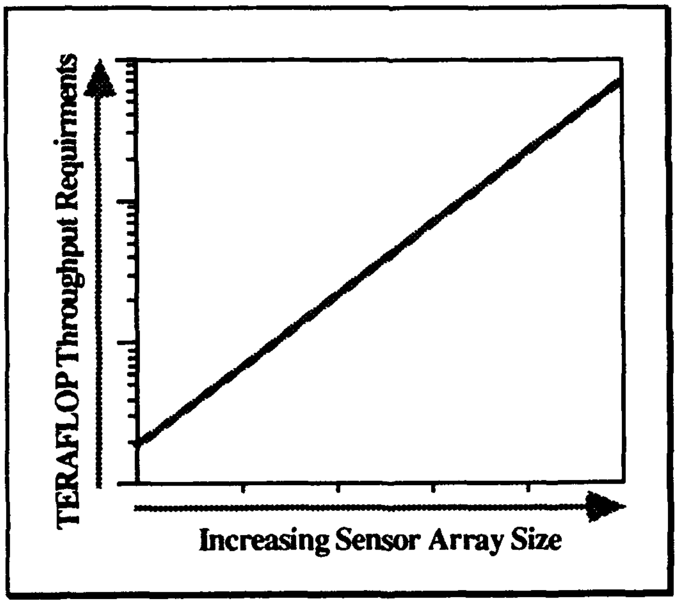


Figure 4. Quantum Leap in Processing Requirements

In addition to greater computational requirements, this trend also creates demands for faster communication links and denser memory configurations. One approach to meeting these demands involves the incorporation of an open architecture. Open architectures leverage fast paced commercial technology development by maintaining compatibility with commercial standards.

Case histories show building off existing foundations of core technologies generates success in the commercial sector. Companies that focus new products on extensions to a single key technology are far more successful than those that pursue technical diversity. "The best opportunities for rapid growth come from building an internal critical mass of engineering talent in a focused technological area, yielding a distinctive core technology that might evolve over time, to provide a foundation for the company's product development."[10]

Accordingly, the transition from an existing sensor processing system to an open architecture based system offers a prime example of the utility of the PDM proposed in this paper. The combination of the PDM and open architecture philosophies facilitates future technology upgrades for the sensor system. Hardware and software commonality contain costs.

Figure 5 shows an open architecture for a sensor processing system. The key features of this architecture are the sensor distribution network, the data distribution network and the common processing cabinets. The common processing cabinets fit into the open architecture scheme by utilizing a commercially available bus architecture for the backplane. Any vendor can integrate equipment into the system as long as they adhere to the interface standards.

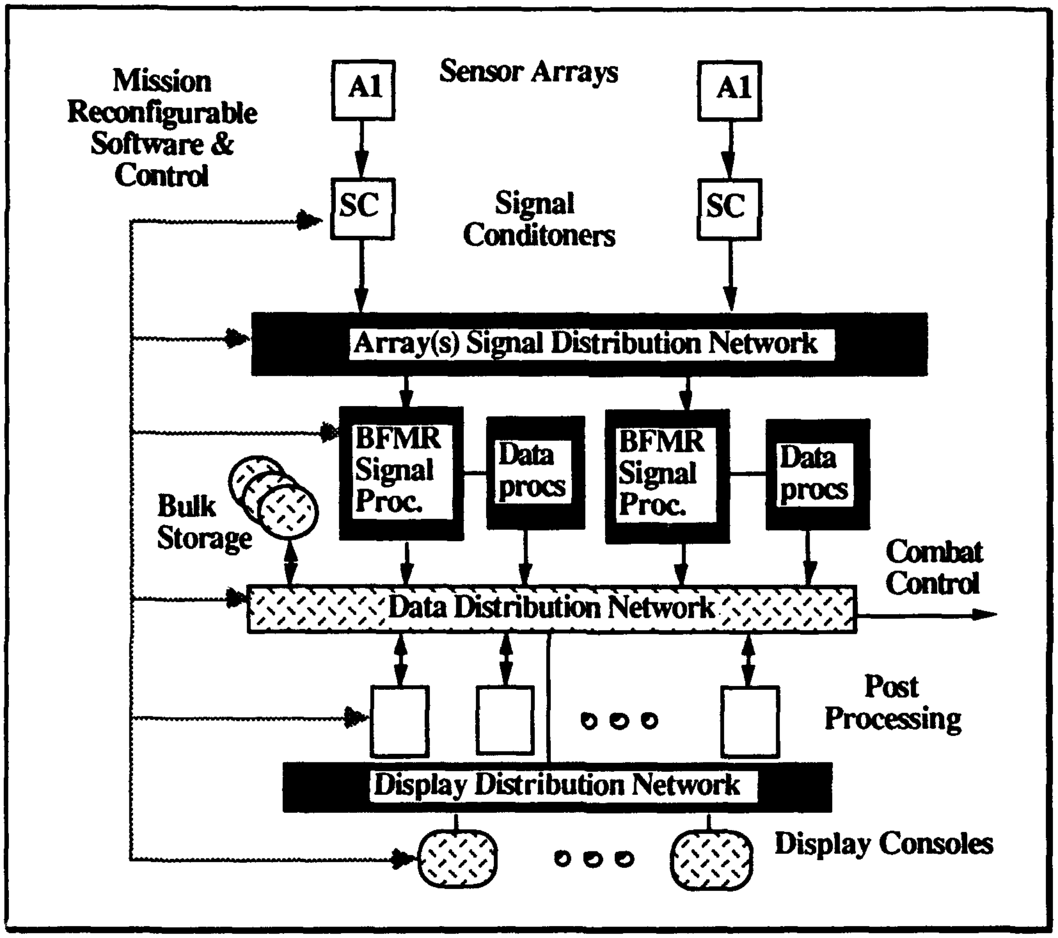


Figure 5. Notional Open Architecture

The lack of mature standards poses an obstacle to the implementation of open architectures. For example, many of the Next Generation Computing Resources (NGCR) initiative's interface standards have not been written. Therefore, cost and performance are indeterminate.

In addition, many existing combat systems do not possess open architecture attributes. On one hand, existing system baselines minimize development costs. On the other hand, open architectures facilitate life cycle development. The current fiscal environment within DoD does not favor system development programs with a high cost profile. Nonrecurring engineering funds are shrinking. An incremental transition from an existing system to open architecture would spread out the cost and mitigate the risk. The incremental approach also advances the long term goals of open architectures.

The product development methodology proposed in this paper helps attain this goal. Using an existing system as a baseline, the transition takes a low risk path to incrementally integrate open architecture concepts into the complex computer system. Figure 6 depicts this concept for a generic sensor processing chain.

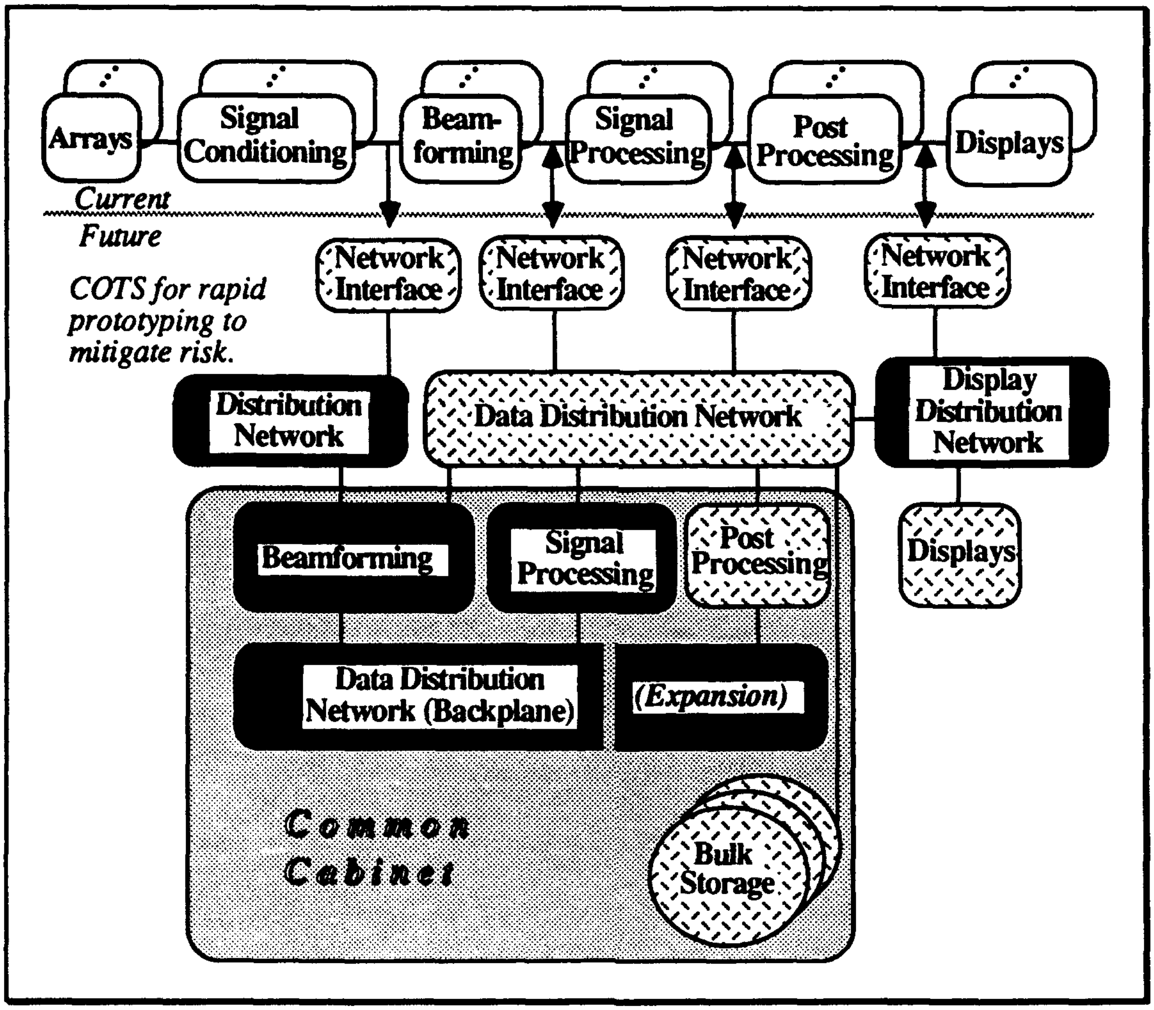
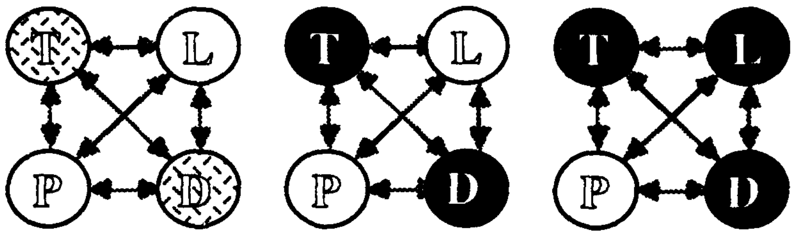


Figure 6. Incremental Approach for Open Architectures

The network interface builds an open architecture upon the strong foundation of the baseline sensor processing chain. First, tap into the processing chain. Next, insert the subsets of the open architecture through the network interface units. For example, evaluate a novel beamformer by bypassing the existing beamformer. Gradually change the system as technology becomes available at a suitable cost. Eventually, the open architecture replaces the baseline sensor chain.

The PDM facilitates consideration of various implementations for each functional block. Commercial off-the-shelf equipment serves as an excellent implementation for initial product development. COTS equipment maintains the cost for initial test and evaluation. Test the COTS prototypes for shock, vibration, temperature, etc., and deploy the equipment with acceptable performance. Militarize the COTS equipment if environmental test results fall short of expectations. Risk mitigation occurs because the government expends additional capital only for verified performance. In addition, the availability of the baseline system serves as a contingency to reduce the risk of product failure.

Table I clarifies the utility of the PDM for a next generation sensor system. In this scenario, a sensor system already in production serves as the baseline. Generic candidates for technology insertion includes today's technology, near term upgrades, and projected future commercial technology.



Processing Type	Today's Technology	Technology Near Term (<1 Year)	Future (>5 Years)
Conventional Beamformers	4,000 MIPS	4,000 MIPS	40,000 MIPS
Adaptive Beamformers	NA	0.3 GFLOPS	5 GFLOPS
Signal Processing	0.3 GFLOPS	2 GFLOPS	21 GFLOPS
Data Processing	70 MIPS	70 MIPS	300 MIPS
Data Processing	35 68030s	35 68030s	130 68040s
Data Processing & I/O	130 68030s	130 68030s	500 68040s

* All units represent effective capability on a per cabinet basis.

Table I. PDM Application to Open Architecture Technology Insertion

Note the equipment undergoing advanced development functions as an excellent augmentation to the baseline system. The technology insertion category would include near term signal processing and adaptive beamforming technologies. Future oriented technologies, which include parallel processors (e.g., iWarp, Paragon, Connection Machine) repackaged in multichip modules, do not demonstrate a definitive payoff. The PDM suggests reconsideration of these technologies when the commercial market brings down the cost. In the interim, develop the network interface units to facilitate the insertion of the advanced technologies as the market matures.

SUMMARY

This paper proposes an economical product development methodology for complex computer systems. The PDM exploits the commercial market analogy to establish a flexible, low risk, cost effective approach for technological progress. The strategy pursues the state-of-the art while addressing risk management. The key to the methodology is an incremental development process.

The PDM assesses discrete candidates and simplifies macroscopic decisions. The process provides the opportunity to pursue the state-of-the-art while concentrating on choices that emphasize low risk, cost savings, and short payback periods.

Several guidelines enhance the chances of attaining this objective:

1. increase performance/technology in an incremental fashion,
2. use subjective decision techniques to eliminate poor candidates from the start,
3. fine tune detailed quantitative analyses as the product becomes well defined,
4. create a diversified development portfolio directed at a quantum leap in technology,
5. use COTS equipment for rapid prototyping,
6. build products quickly to reduce development costs, and
7. cultivate products with short payback periods.

The methodology has particular application to complex mission critical computer systems. An open architecture transition illustrates the utility of the IDP product development methodology. The PDM sets priorities for a sensor processing chain by subjectively identifying the time, cost and performance characteristics of candidate technologies.

System engineers can use the product development methodology described in this paper by:

1. creating a detailed handbook to guide decisions,
2. devising an expert system to expedite the selection for technology insertion,
3. applying software tools which refine the hierarchical decision process, and
4. using the PDM as a basis for developing complex mission critical computer systems.

The PDM integrates the choices input at lower levels into higher level systems engineering decisions. System engineers could clearly define the affect of the paths from subsystem to system level design. Each candidate at the lower level contributes to overall cost, performance, schedule and risk assessments. In this manner, the PDM enables an efficient approach for systems engineering.

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