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Technology Advances for Space Shuttle Processing

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ABSTRACT

The Space Systems Integration and Operations Research Applications (SIORA) Program was initiated in late 1986 as a cooperative applications research effort between Stanford University, NASA Kennedy Space Center (KSC), and Lockheed Space Operations Company (LSOC). One of the major initial SIORA tasks was the application of automation and robotics technology to all aspects of the Shuttle tile processing and inspection system. This effort has adopted a systems engineering approach consisting of an integrated set of rapid prototyping testbeds in which a government/university/industry team of users, technologists, and engineers test and evaluate new concepts and technologies within the operational world of Shuttle. These integrated testbeds include speech recognition and synthesis, LASER imaging systems, distributed Ada programming environments, distributed relational database architectures, distributed computer network architectures, multi-media workbenches, and human factors considerations.

1. INTRODUCTION

An initial primary design objective for the thermal protection system (TPS) of the Shuttle was centered on providing a barrier to the intense thermal environment present during reentry. This objective has been fully realized with the present Shuttle tile system. During the design phase little consideration was given to optimizing the TPS design for operational maintenance efficiency. This has resulted in a TPS whose maintenance program can be characterized as being man-power intensive and time consuming. This is due to the fact that the TPS maintenance program uses manual techniques for inspection and measurement, mostly paper databases, no networking between pertinent electronic databases, manual scheduling of operational flows and a quality control and reliability program based on a paper information system.

Introducing new technologies and operational concepts into a critical system, like the Shuttle TPS, requires a careful assessment of the appropriate systems engineering approach. The SIORA Program chose a non-linear systems engineering methodology which emphasizes a team approach (design engineers, system users, technologists) for defining, developing and evaluating new concepts and technologies for the operational system. This is accomplished by utilizing rapid prototyping testbeds whereby the concepts and technologies can be iteratively tested and evaluated by the team. In addition to the skill mix of the team, it is also equally represented by the government, industry and university sectors. This later feature of the SIORA teaming is significant particularly in the areas of rapid acquisition and introduction of state-of-the-art technologies. It also assures that the system derived from this process will be commercial viable and maintained in the future.

In considering the application of automation and robotics to the TPS several important questions must be asked. First, what technology can be applied which will produce significant productivity gains and second, what functional processes and procedures are present which loose their purpose in an automated system? The first question was surprisingly easy to address since all of the technologies were commercially available. We found that the difficult task was the integration of the technologies into an efficient and productive operational system. The first step in identifying applicable technologies was to divide the TPS maintenance system into functional process areas. This produced the following primary areas: multi-media (speech, graphics, imaging systems, text) information capture, distributed computer networks, distributed database architectures, windowed displays, software environment, simulation environment for training, and human factors considerations in system designs. The initial prototype included technologies which addressed each of the above functional areas. It was also determined that a number of functional processes would be eliminated in an automated system. These revolved primarily around procedures to validate and verify information which resided on paper databases. The interactive electronic system eliminates the need for these activities.

2. SYSTEM ENGINEERING METHODOLOGY

Before starting into system engineering methodology it is important to establish a general definition for what a system is. The definition we will use is that a system is a complete solution to a defined need in its full environment over its prescribed lifetime. For the SIORA Program, system engineering is then viewed as a process by which user requirements are defined and understood and are subsequently implemented in a system design. The iterative interaction between the users, technologists and design engineers during all phases of a project is critical to make the appropriate transition from perceived user needs to system specifications.

A key element to the system engineering methodology is the formation of the system engineering team. As mentioned previously, a teaming between system users, design engineers, and technologists is essential. Each brings a unique skill and knowledge to the project. The mutual educational interaction of this triad establishes an integrated and iterative engineering process resulting in a system implementation which closely tracks the dynamic and evolving user requirements and pertinent technologies.[1]

Another key element to the system engineering methodology is the utilization of rapid prototyping testbeds in parallel to the ongoing operational systems. These testbeds serve several vital functions. First, they provide an environment which allows the system user/design engineer/technologist triad to obtain quick and unconstrained hands-on experience with new concepts and technology. It is also an environment where design concepts and technology can be modified quickly or discarded if flaws are found. The SIORA Program also emphasizes the importance of having the triad formed out of equal representation from the government, industry and university sectors. Each sector receives unique benefits from its participation in the project. The government sector benefits by being able to evaluate new technologies and concepts outside the formal procurement process without jeopardizing future competitive system procurements, by working with university students who will be the next generation of engineers and scientist which can be recruited as future government employees, and by being exposed, at the working level, to state-of-the-art technologies from industry and the university without having to make long term commitments to that technology. The university sector obtains a rich applications environment to implement and test new ideas and also has a real-world educational environment for its students. Industry benefits in three ways: obtains a high fidelity test environment for its internal R & D, has the opportunity to recruit personnel from the student participants, and establishes a means to better understand the system needs/ requirements for future government directed systems.

The final aspect of the methodology is how the results of the prototyping is integrated into the operational environment. This will be slightly different for the two categories of systems, existing (i.e. Shuttle TPS) and new (i.e. Space Station) systems. For automating and/or upgrading existing systems, the process is carried out in the following way. In the initial stage the prototyping team (operations users, design engineers, technologists) identifies the operational functions of the system. The technologists will then identify applicable technology for each of the system functions. This will then be iterated with the system users and prototype design engineers to determine the design options for the system. Some options can be tested with high fidelity computer simulations while others may have to be fabricated into bread- or brass-board prototypes for evaluation by the team. Test and performance criteria are established and agreed to by the prototyping team. In addition, system user productivity gains and cost reductions are carefully evaluated and documented. The primary objective is to rapidly iterate on the prototype until user productivity and cost reductions are at an acceptable level. Since a small cadre of operations personnel have been participating in the prototyping process, the transition of the prototype final design has, in essence, been initiated. The functional specifications derived from the prototyping process is then formally documented and used as inputs to a competitive procurement process for the new operational system. At this same point in time, considerable effort must be spent by the prototyping team to develop off-line prototype training modules to educate and train operations personnel. The new and old systems must be operated in parallel until new prototype system elements have been integrated and validated and the operations personnel fully trained.

3. AUTOMATED SHUTTLE TILE INSPECTION SYSTEM

The automated work authorization document system (AWADS) consists of three major sections. First, the thermal protections system (TPS) quality control technician inspects the thermal protection system after each flight using voice data entry to identify anomalies. The inspector voices in the part number, the dimensions of the anomaly, and other necessary data which then produces an automated problem report in the central database. Second, the problem report is dispositioned by the TPS engineer using keyboard entry to identify the proper repair procedures for the particular anomaly. The problem report then proceeds through an electronic signature loop until final approval. Third, the TPS technician uses voice data entry2 to enter buy-offs on each work instruction and to enter work control data. On specific work instructions, the TPS technician will also use automated instrumentation such as LASER scanners to scan the tiles for critical dimensions of step and gap measurements between adjacent tiles.

The programming language environment used for SIORA applications has been selected to be Ada. Because this system will be in operation throughout the Space Station era, migrating to an Ada software environment is a prudent and necessary step since Space Station core systems require full utilization of Ada. An Ada environment provides excellent portability, rich set of programming functions and tools, and a uniformity of code documentation. Also, Ada allows for multi-tasking which is critical for real-time processing. The prototype database management system chosen for this task is a commercial relational database (RELATE/DB - Computer Resources, Inc.) written in Ada. This database is also easily transportable with less than 5% equipment specific code.

The hardware architecture approach used is the distributed concept. A central node will house the main database with other remote nodes on the network. The remote nodes can download the portion of the database necessary for the task at hand. Using this method, the technicians can work independent of the rest of the network. This reduces network traffic and prevents work stoppage in case of a failure. The network will be configured to adhere to ISO interface standards and will evolve to an Open System Interconnect (OSI) configuration as these standards are established. This will allow easy access to other networks in which access is needed. The network will be connected to the NASA Program Support Communications Network (PSCN) to enable critical data to flow between essential NASA centers and Shuttle contractors.

An expert system is being developed to handle automated scheduling and quality assurance/reliability trend analysis which is critical at Kennedy Space Center. The development of the expert system will take place simultaneously with the prototyping effort such that the knowledge base can be derived from the appropriate domain experts (tile processing personnel). The implementation of the expert system will occur in the second phase of the program after the initial prototype has been fully evaluated and specified.

This task is being accomplished by the rapid prototyping process. The prototyping triad team (users/design engineers/ technologists) are building the prototype in an iterative design process. While each software module is being developed, the team reviews and comments to allow for immediate design change. By this process, the end result will, by necessity, meet all of the functional needs of the tile processing operation.

Each software module is operationally tested and evaluated against criteria established by the prototyping team with the strongest input from the system users. If the module is successful, it then is ready for final review. After final review, the next module is ready for design. After completion of the system, parallel processing begins to evaluate the modules as a complete system. This processing continues until all users are satisfied with the integrated prototype and enough data has been gathered to compare the automated system with the manual system in terms of productivity gains and cost-effectiveness.

The hardware is also being tested by the rapid prototyping method. The network and nodes are being tested to arrive at an optimized solution. Only functional requirements and interfaces are being tested to prevent producing vendor specific requirements. The rapid prototyping methodology quickly addresses many of the technical questions which arise during the user needs to requirements to specification process. It is apparent that if this methodology works well in the Shuttle processing area it will work equally well for Space Station processing tasks.

At this time, the module testing is in process. Different system architectures are also being tested to find an optimized solution. Parallel processing is scheduled to begin in June of this year and proceed through January 1989. Also in June 1988, the specific requirements for the operational system will be determined. These detailed requirements should afford a shortened competitive procurement and system acquisition period. The operational system is scheduled to be in place in January 1989. While operational hardware is being acquired, facility modifications will be completed. Also, all software conversions and configuration management for the operational system will take place at that time.

To prevent a time lag during the acquisition of operational hardware, prototype training modules will be developed and the training of the work force will begin. System simulators will be prototyped so users are able to easily become familiar with the automated system. Training procedures will be established to handle new employees. For approximately six months, the prototype will become an operational prototype to determine any final changes in the system. This will provide a smooth transition to the final operational system when it is procured and implemented. The prototype system will then be discarded or will phase into other areas where the prototyping process is needed.

4. APPLICATION TO SPACE STATION

The application of this system engineering methodology to new systems requires a slightly different approach. Since it does not require modifying or evolving an existing system, the implementation process is much easier. Figure 1. indicates the important elements of the methodology for the period of time preceding the design phase of a project.

The user/engineering/technologists team is formed early to establish preliminary system requirements from a functional needs perspective. The triad team determines evaluation criteria for the design concepts and quantitatively rates the maturity of the preliminary system requirements. The team then proceeds to develop the spectrum of possible design concepts. These concepts, with their quantitatively rated system requirements, can be evaluated in one of two ways; by developing a prototype or by appropriate high fidelity simulation and computer modeling. Both processes are iterative until the concept is discarded or the concept specifications are understood for the concept to proceed to the tradeoff stage or even through the optimum concept selection stage. It is important to identify these "fuzzy" requirements so that additional prototyping can be performed in parallel to the design phase (Phase C). Although most prototypes will generally be "quick and dirty" point designs to test specific concepts or technologies, the specifications written into any competitive procurement RFP should only reflect the functional aspects of the prototype. To properly manage a project and keep it on schedule and within budget, all prototyping must be forced to adhere to the milestone schedule of the overall project. During the design and development phases, maintaining the prototyping effort on the same schedule as the overall project is critical to proper information feedback. It can be seen that the need for a prototyping team starts in Phase B (system definition) but continues through Phase C/D (design/development) and into the operations phase to test concepts for system evolution.

Although the Space Station Program did not have a formal, recognized rapid

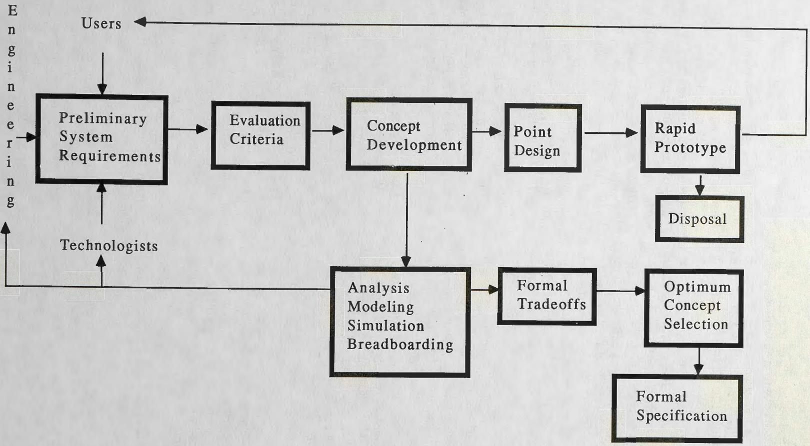

Figure 1. Iterative System Definition Cycle

prototyping effort during Phase B, considerable prototyping efforts have begun at the start of Phase C. These include the Science and Applications Information Systems (SAIS) Telescience Testbed Program, the DMS testbeds, Software Support Environment Testbeds and a number of others. A coordinated Space Station rapid prototyping program, integrating all of the testbed activities and placing them on the same schedule as the Phase C/D contractors is presently being formulated.

5. CONCLUSIONS

The non-linear system engineering methodology, with its team approach and rapid prototyping techniques, has clear advantages for the design of large complex systems as well as for the upgrading and evolution of existing systems. The SIORA Program will thoroughly test the methodology on an existing system, the Shuttle processing at KSC, while the rapid prototyping efforts for a number of aspects of Space Station Program will test the effectiveness of the methodology on a new, complex system. The future space program requires a new and innovative approach to system engineering such that operational systems are functionally productive and cost effective. The methodology described in this paper offers hope for a solution to this need.

6. ACKNOWLEDGEMENTS

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