SUCCESSFUL EXPERT SYSTEMS FOR SPACE SHUTTLE PAYLOAD INTEGRATION

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ABSTRACT

Expert systems have been successfully applied to solve recurring NASA Space Shuttle orbiter payload integration problems. Recurrence of these payload integration problems is the result of each Space Shuttle mission being unique. The NASA Space Shuttle orbiter was designed to be extremely flexible in its ability to handle many types and combinations of satellites and experiments. This flexibility results in different and unique engineering resource requirements for each of the payload satellites and experiments. The first successful expert system to be applied to these problems was the Orbiter Payload Bay Cabling Expert System (EXCABL). It was developed at Rockwell International Space Transportation Systems Division. The operational version of EXCABL was delivered in 1986 and successfully solved the payload electrical support services cabling layout problem. As a result of this success, a second expert system, Expert Drawing Matching System (EXMATCH), was developed to generate a list of the reusable installation drawings available for each EXCABL solution. EXMATCH was delivered for operational usage in 1987. As a result of these initial successes, the need for a third expert system was defined and awaiting development. This new expert system, called Technical Order Listing Expert System (EXTOL), will generate a list of all the applicable reusable installation drawings available to support the total payload bay mission provisioning and installation effort. This paper describes these expert systems, the individual problems that they were designed to solve, their individual solutions, and the degree of success they have achieved. These expert systems' successes instantiate the applicability of this technology to the solution of real-world Space Shuttle payload integration problems.

INTRODUCTION

Rapid advancement of expert systems technology is contingent on wide-spread acceptance. To be widely accepted, expert systems must successfully provide needed solutions to existing real-world engineering problems. Providing examples of solutions to trivial generic problems does little to instantiate the applicability of expert systems technology to solve these nontrivial real-world problems. Providing examples of successful expert system application solutions to NASA Space Shuttle payload bay integration design problems does. The purpose of this paper is to disseminate knowledge of these successful applications, the problems that they solve, and the degree of success that they have achieved. Hopefully, this knowledge will be of some benefit to the expert system technology community as a whole and will play some small part in the advancement of this technology.

THE TOTAL PAYLOAD AND CARGO INTEGRATION AUTOMATION PROBLEM

The delivery of satellites and experiments into low-earth orbit by the Space Shuttle involves many preflight engineering planning, design, and integration tasks. These tasks include the following: selecting appropriate satellites and experiments to make up a mission payload set, locating each payload element within the payload bay, determining standard and unique services required by each payload, developing and documenting the payload to Space Shuttle orbiter interface requirements, selecting the individual cables necessary for providing the electrical services, preparing the electrical services cabling layout schematic, and preparing the technical instructions for mission payload installation and integration.

These tasks are carried out by teams of engineers, using both common and specialized engineering tools. Any changes in planning and design methods have to take the use of these existing tools into consideration. Because of their interdependence, the products of these teams are integrated into a master mission plan and schedule. Team technical support is supplied by highly trained experts who are rapidly reaching retirement age. Loss of an expert, is an undesirable event, not only with respect to the affected team's productivity, but also to the total payload integration task productivity as a whole.

Real-world space flight mission provisioning experience has shown that the ability to make mission manifest changes is mandatory. Other changes are to be anticipated because of further engineering analysis or design refinement. Changes caused by corrections of erroneous data, design omissions, and errors are also to be expected. Thus, change is a normal mode of operation and must be provided for, even close to launch time.

A major goal for all payload planning, design and integration tasks is to minimize this mission to mission change. This in turn will reduce paperwork, labor hours, and turnaround time. Standardization and automation are two powerful methods used in the payload integration process to minimize these changes.

In summation, Space Shuttle payload and cargo integration tasks are a collection of iterative interrelated activities, using specialized tools, responding to change, and led by vanishing experts. Automation, in order to be successful, must be tempered with these considerations. The following major objectives were established for each planning and design automation effort:

1. Reduce engineering labor hours

2. Retain technical expertise

3. Reduce end-to-end process time

4. Adapt to existing operating techniques and environment.

PAYLOAD BAY CABLING LAYOUT PLANNING AND DESIGN AUTOMATION

The Problem

The Space Shuttle payload cabling layout planning and design problem involves provision of the details required for the installation of cables to connect orbiter electrical services to the individual payload elements. Each Shuttle mission entails a different payload manifest, constituting a recurring planning and design problem. Mission payload manifest changes compound the problem further.

Standardized orbiter electrical services are provided through cables that connect the experiments and satellites to either the forward or aft orbiter payload bay bulkhead using standard electrical service panels. Cables are then routed from specific payloads to port and starboard standard interface panels. From these panels, cables travel to covered cabling trays for further routing to either the forward or aft bulkhead service panels. For efficiency, these cables are prefabricated and provided from a standardized inventory.

Because these standardized cables must service all payloads, regardless of their location within the payload bay, they are usually too long. The excess length of each cable must be dispositioned by forming a foldback or a loop (double foldback) within the routing tray. The trays are closed by covers that are located at designated locations along the tray. Cables with a diameter greater than 0.62 inches cannot be folded within the normal dimensions of the trays, because of radius bend constraints. Therefore, a special height appending foldback cover is required to replace the normal tray cover at the location of such a fold. Also, at the point where the cable leaves the tray to be routed to the interface panel or elsewhere, a special egress cover is required to replace the normal cover. Cables must also be separated by electromagnetic compatibility class through special channels provided in the routing trays.

Cabling installation practices are also governed by numerous other constraints and standard operating procedures. Based on heuristic knowledge, the above considerations, and the specific payload manifest, the cabling expert generates a hand drawn schematic that describes the cable routing solution. This schematic is subsequently used by a CAD/CAM specialist to produce a technical order (TO) schematic drawing of the cabling layout.

The Solution

The NASA Space Shuttle's payload bay cabling design task was the first automation problem to which expert systems technology was applied. An expert system, the EXCABL, was completed in September of 1986 and has been in operation since delivery. An overview of the EXCABL system is shown in Figure 1. The EXCABL system has completely automated payload bay cabling layout planning and design tasks. The cabling expert needs only to define the mission unique payload requirements

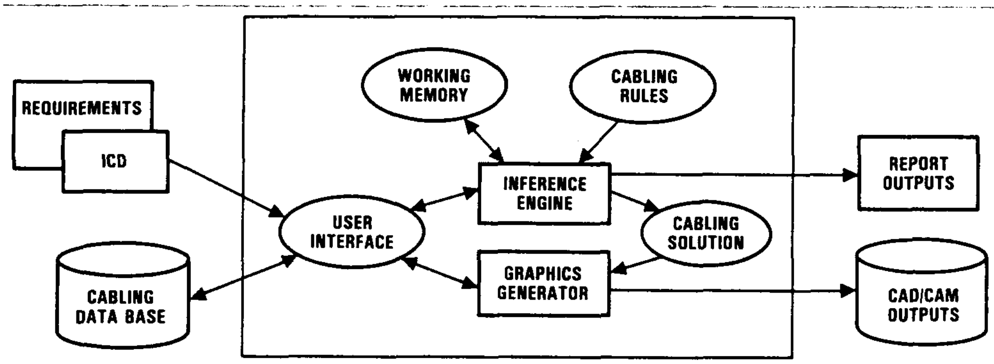

Figure 1. EXCABL System Overview

and constraints to generate the cabling solution CAD/CAM TO drawings and the printed reports. This was facilitated by the initial construction of a mission independent data base, containing all of the necessary payload bay hardware information required to perform Space Shuttle's cabling. The cabling experts' schematic solution is now automatically generated by the system as is the transfer of that information into CAD/CAM inputs.

All major automation objectives were met in the initial delivered system. The system has captured the required technical expertise and also provided a significant improvement in productivity. The cabling capabilities of EXCABL are such that a small percentage of actual cabling design tasks cannot be handled. Since the end product is a cabling installation drawing, any EXCABL solution can be manually modified or augmented to produce a more acceptable solution. The productivity improvement realized by this new capability is such that a typical mission cabling manifest, that formerly took a few labor intensive days for several cabling engineers, now takes only a few minutes.

The expert system portion of the operational version of EXCABL was implemented using Production Systems Technology's C-based version of OPS83 and the remaining portion was implemented using C. It is currently hosted on a CAD/CAM interfacing DEC MicroVax II system and integrated into the operational environment. The literature contains documentation of an early prototype version of EXCABL [Reference 2], problems associated with converting from a development system to a delivery system [Reference 3], and a case study of the development effort and lessons learned [Reference 1].

PAYLOAD BAY CABLE INSTALLATION TECHNICAL ORDERS

The Problem

The cabling layout solution schematic produced by EXCABL is only one of many Space Shuttle integration products necessary to accomplish the actual electrical services provisioning of its payload bay. Among the other products required are the installation configuration TO's for the cables and related hardware devices. These TO's contain the detailed instructions that are used by the payload integration crew to perform the actual cable and hardware device installation. The cabling installation TO's required for each flight are mission unique and dependent on the cabling solution generated by EXCABL.

To increase productivity, the concept of modularization was developed by the cabling design engineering group. This concept is to reuse previously generated TO's whenever possible, thereby eliminating the need to repeatedly redo labor-intensive documentation for the same installation. Implementation is accomplished by assigning basic TO numbers for each device, connector, or cable installation, and assigning dash numbers for the different configurations. If a needed TO does not exist, a new TO is generated, and a new dash number is assigned. This modularization, or reuse concept, is only made feasible by the standardization of cables, connectors, devices, and mounting positions, etc.

Identifying the set of all reusable cabling installation TO's for each given mission is a recurring integration problem. Since the set of cabling TO's for each mission is dependent on the EXCABL solution, any automation of this process must interface easily with existing EXCABL's outputs. Furthermore, maximum usage must be made of any intermediate information generated by EXCABL to support its final products. The desirability of integrating this process into the existing work environment, while cooperating with the EXCABL process, further constrains the design and development of any automated system solution.

Simply stated, the problem was to develop an automated system having the capability to identify and generate a list of all TO's required to perform the payload cabling installation for any Space Shuttle mission. The nonexistence of a required TO should be identified by the system to the user in order for the deficiency to be corrected and the process completed.

The Solution

There were two basic motivators for this project. First, was the demonstrated success of the EXCABL project. Second, was the practicality of automation based on the new concept of modularization and reuse. Furthermore, it was assumed that applying the experience and techniques gained from the EXCABL project would make this a low risk development effort [Reference 1]. Those assumptions proved to be correct in practice, and the entire development effort was straightforward and completed quickly.

An expert system called EXMATCH was placed in operational usage in January of 1988. The EXMATCH system has successfully automated the payload bay cabling installation TO generation task. Closely integrated with the EXCABL system, the cabling solution provided by EXCABL is automatically input to EXMATCH and a master listing of all required payload cabling installation TO's is generated. If a required TO does not currently exist, the system not only identifies this deficiency, but also identifies an existing similar drawing best match that may be modified to satisfy the deficiency.

To facilitate this system, an initial data base containing all current payload cabling installation TO numbers and data was constructed. For user convenience, the interface to maintain this data base was made an integral part of the EXCABL system. The development of the initial TO documentation and maintenance of the TO data base are the only functions not fully automated. Modifications to EXCABL were minimal. An overview of the integration of EXMATCH and EXCABL is shown in Figure 2.

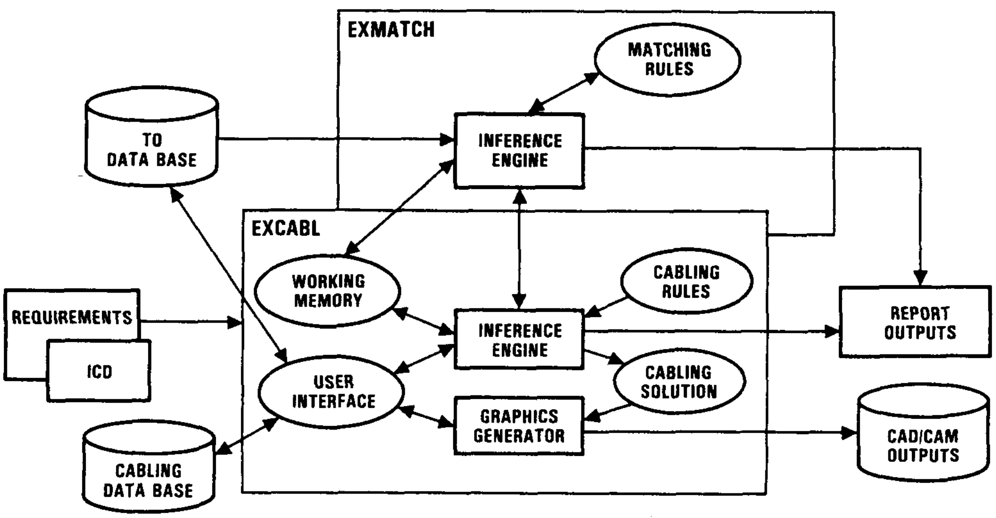

Figure 2. EXMATCH and EXCABL System Integration

The expert system portion of EXMATCH was implemented using Production Systems Technology's C-based version of OPS83. The remaining portion was implemented in DOD's registered trademarked language Ada. EXMATCH is currently cohosted with EXCABL on CAD/CAM interfacing DEC MicroVax II systems in the cabling design work place.

TECHNICAL ORDERS FOR TOTAL PAYLOAD INTEGRATION

The Problem

The Space Shuttle payload integration planning and design process culminates in the provision of a complete set of TO's containing the installation instructions needed to accomplish the total payload bay accommodation and installation task. To assist in the planning and installation process, a complete list of all applicable TO's for a mission is specified in a single document, the Mission Equipment Cargo Support Launch Site Installation (MECSLSI) drawing. Since each Space Shuttle mission is basically unique and design changes occur subsequent to initial payload manifesting, the identification of all required TO's for production of this drawing constitutes a continuing and complex integration problem.

Mission requirements are categorized as either mission common or mission unique. Mission common requirements are those requirements that once established, are standardized for all future missions. Mission unique requirements are dependent on each mission's objectives. Since each payload manifest is basically unique, the payload cabling layout schematic TO, produced by EXCABL is mission unique. However, it has been estimated that 90 percent of all mission requirements fall in the mission common category.

Based on flight requirements documentation, Interface Control Documents (ICD's), mission unique TO's, common TO's, and similarities to previous missions, etc., the MECSLSI development expert uses heuristic knowledge to generate the required drawing. If a design automation system could be developed to produce an initial MECSLSI containing only the mission common TO's labor requirements would be reduced considerably.

The Solution

A feasibility study was initiated in fiscal year 1987 to determine the practicality of developing an expert system to automate the production of the initial MECSLSI drawing. As a consequence of positive study results, it is expected that development of an expert system based design automation tool, EXTOL will be started in the near future. Not only will EXTOL produce the initial MECSLSI drawing but using heuristics and data from previous missions it will assist the user by producing a list of the best matches for nonexistent TO's in the mission unique category. If a close match cannot be found, it will identify that fact and provide further assistance to the user by presenting essential configuration information. It is expected that a working prototype could be quickly produced, and an operational system delivered shortly thereafter.

TOTAL PAYLOAD AND CARGO INTEGRATION AUTOMATION

EXCABL produces the mission unique cabling layout schematic TO product. EXMATCH uses information generated by EXCABL in its solution process to augment its knowledge and produce a list of all existing TO's that will be required to accomplish the cabling installation. If a required TO does not already exist, a best match or quite similar existing TO is identified as a baseline from which a new one can be constructed. When all of the required TO's are generated and this information is input to EXMATCH, it generates a complete list of cabling TO's. Together, these data will be furnished as electronic input's to the EXTOL system currently under consideration. These improvements should allow EXTOL to produce initial MECSLSI drawings that are over 90 percent complete. For TO's that are identified as needed, but not in existence, best match and configuration information, to greatly facilitate their generation, will also be produced.

EXCABL, EXMATCH and EXTOL constitute successful real-world demonstrations of the feasibility and benefits of applying expert systems technologies to the payload bay integration automation problem. Two of these successful systems have been integrated into the engineering work environment and cooperate to automate the overall payload integration management task. The third when completed will be integrated with the other two to further the goal of total payload bay integration automation. Since each expert system feeds its outputs directly to its successor, the productivity improvements of the group as a whole is greater than individual standalone systems could achieve. An overview of the integration management of these expert systems is shown in Figure 3. Using these systems as the core, other expert systems aimed at supporting the automation goal are in the concept development stage.

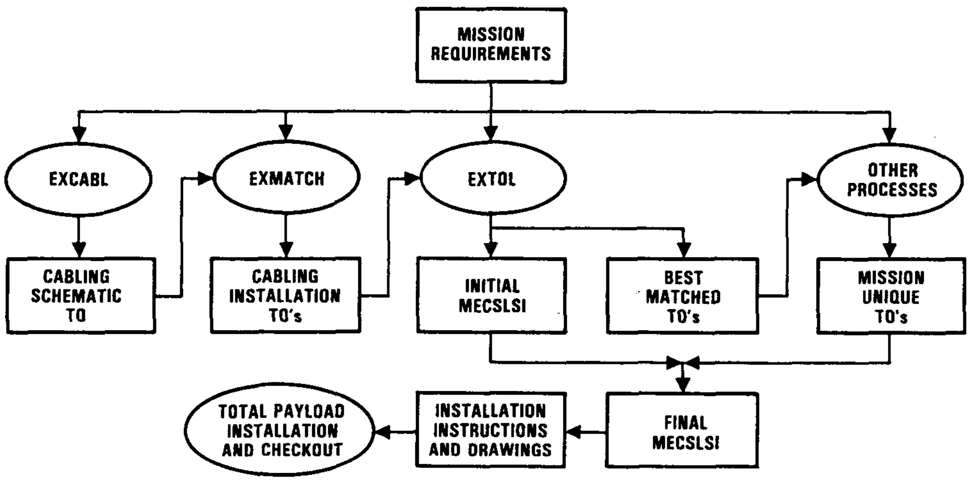

Figure 3. Payload and Cargo Integration Management

CONCLUSIONS

The high level of flexibility to handle diverse payloads provided by NASA's Space Shuttle orbiter presents present-day recurring payload and cargo integration problems. Expert systems technologies are being successfully applied to these real-world problems to provide automation where other approaches have failed.

EXCABL and EXMATCH are two highly successful examples of the applicability of using artificial intelligence techniques to solve these real-world integration automation problems. Both systems met the automation design objectives by reducing engineering-labor hours and end-to-end process time, capturing corporate technical planning and design expertise, and demonstrating that expert systems methods can successfully be integrated into existing operational systems and workplaces.

Successful development of a third expert system based integration automation tool is expected since much of the implementation methodology has already been successfully used by the EXMATCH system. These separate expert systems will work together to support overall payload integration management automation.

It is important to the advancement of expert systems technology that the knowledge of such successes as these be made public. Many successes are needed to instantiate the applicability of expert systems to solve real-world Space Shuttle payload integration problems.

ACKNOWLEDGMENTS

The author would like to thank Gil Nixon, Beshad Rejai, and Chuck Giffin for their contributions and support.

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