SERVICE MANUAL GENERATION: AN AUTOMATED APPROACH TO MAINTENANCE MANUAL DEVELOPMENT

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Abstract

In this paper, we describe an automated approach to generating preliminary maintenance instructions from Computer Aided Design (CAD) models and a haptics-enabled virtual environment for validating the instructions. The approach integrates modeling, simulation, information composition and virtual prototyping to allow a concurrent development of preliminary designs and maintenance manuals. We show how the maintenance manual development processes will be significantly streamlined with increased data integrity by extracting and using maintenance information directly from the engineering design data for automated composition and validation of a preliminary manual. As a result, labor-intensive tasks will be replaced by automation, allowing the maintenance analysts and technical writers to become more supervisory of the manual creation process. The immersive virtual environment will provide the analyst an early look at the maintenance data in action, providing a platform for identifying maintenance related design and documentation flaws. This revolutionary approach to maintenance manual development will help to provide more complete and accurate manuals while reducing development time and costs.

Introduction

Creating quality maintenance documentation requires pulling information from a variety of sources such as engineering design data, manufacturing assembly data and logistics data. This information is often dispersed and not organized for the purpose of composing maintenance instructions. Maintenance manual development is a labor-intensive task of searching for the required data and assembling the manuals, often in parallel with the design and under extreme time constraints. Due to the difficult nature of this development process, the costs are high and the quality of the resulting manuals is sometimes low. Errors and omissions are frequent, along with inconsistencies with the current configuration. Complex systems such as aircraft, power systems and appliances require timely, reliable and accurate documentation to support maintenance. Technical manuals with textual descriptions and exploded views of equipment describing how to remove, inspect, repair and install parts are necessary to keep many complex systems available and in working order. The documentation is an integral part of the maintenance process. Therefore, a thorough maintainability analysis should include the analysis of the product design and documentation, working together.

Maintenance manuals are typically one of the last items developed and delivered in a complex system. For instance, one of the deficiencies stated by the United States Air Force (USAF) Air Mobility Command (AMC) Strategic Plan 2000 was the continual fielding of equipment without a complete set of the supporting maintenance manuals [a]. Even with automation and information technology available today, the manual development process continues to lag the equipment development. The USAF is not alone. Many commercial companies are pressured with shrinking times-to-market and must field their products quickly to stay competitive, often ahead of the final maintenance manuals. The reason for the latency in technical manual deliveries is easily explained by today's near-sequential process: the manuals cannot be developed until the design is nearly frozen. Due to the enormous amounts of information required to describe all possible maintenance actions, developing the manuals is a large and complex task. For example, in 1998, the Boeing Company wrote enough manuals to create a stack of paper over 100,000 feet high[b]. The sheer volume of information takes many months, if not years to compose. This is due to the fact that maintenance manual development remains largely a manual process, requiring enormous amounts of labor hours. By the time the manuals are ready for review, the equipment or system is often in production.

In this paper, we describe the current maintenance manual development process, followed by a description of a new approach being investigated in the Service Manual Generation (SMG) research project.

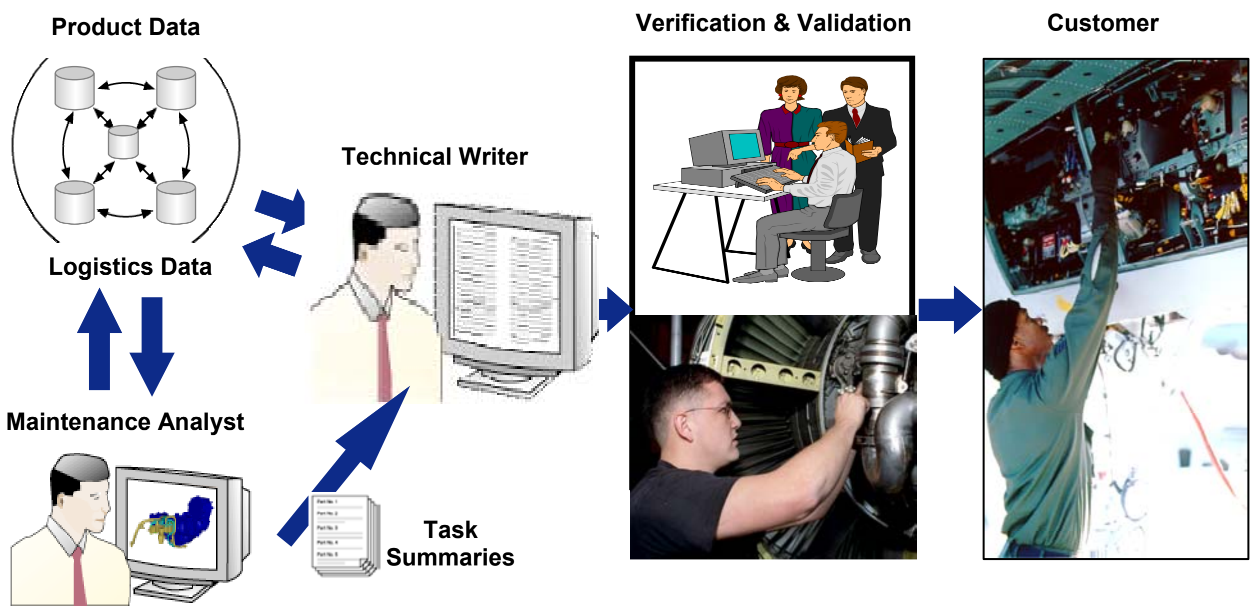
Current Maintenance Manual Development

The traditional process of developing maintenance manuals is depicted in Figure 1. The process typically starts with the assembly or maintainability engineer examining preliminary designs for assembly and disassembly requirements. At this early stage of design, the details may be sketchy and the engineer uses any information available including CAD drawings, engineering notes, parts lists, tooling requirements, etc. to generate a rough outline of the maintenance tasks needed to support the system. This outline is then forwarded to the technical writer to expand the preliminary information into a maintenance manual (this information is also valuable to assembly planners who use this type information to develop assembly procedures for production). The technical manuals are developed in an authoring system, which assists in the format, storage, retrieval and configuration control of the evolving manual. Once the manuals are completed, they are validated by the developer on the production equipment and then delivered to the customer.

Maintenance analysts must obtain data from numerous sources to assemble inputs for maintenance manuals. Along with the task descriptions and graphics, maintenance analysts must also obtain other logistics related information essential to maintenance such as: required tools, support equipment, consumables, etc. This labor-intensive task adds excessive time and cost to the development of maintenance manuals, particularly for complex systems such as aircraft [c].

Not only are the manuals expensive, they are often developed under extreme time constraints in a process that is not well integrated with the design, resulting in inaccurate, outdated, and incomplete maintenance documentation. These shortfalls result in more maintenance downtime, more lifecycle costs and may be a contributing factor in accidents [b]. Many reasons are cited for these shortfalls, but a major contributor is the lack of an integrated approach for maintenance manual development.

Figure 1: The Maintenance Manual Development Process



The sequential and non-integrated nature of product documentation development has haunted manufacturers for years. Huge advantages can be realized by concurrently developing the maintenance manuals in synchronization *with* the product design. During the past decade, concurrent engineering initiatives have placed an increased emphasis earlier in development on service related activities in an attempt to determine (exploit or assess) the impact of maintenance on product design. Design and analysis tools have been developed to assist early analysis of downstream factors such as maintenance procedures. These tools range from CAD visualization systems with virtual human figure models [d e] to virtual reality systems where engineers can "interact" with the system, using virtual input devices [f g]. Still, the problem persists that the maintenance manuals are not available for review during these early maintainability evaluations. To date, no known effort has successfully automated the creation of technical manuals directly from engineering and other product data.

In 2000, AFRL/HESS, The Air Force Dual Use Science and Technology Office, General Electric Global Research Center and Lockheed Martin initiated a Dual Use program to investigate an automated approach to maintenance manual development. The research and development program is called Service Manual Generation (SMG). SMG is a three-year research program to alleviate the concurrency issues with product maintainability by marrying product design and documentation. This teaming research effort, in a dual use arrangement, results in technology having an increased chance to be infused into both the military and commercial marketplaces.

Service Manual Generation

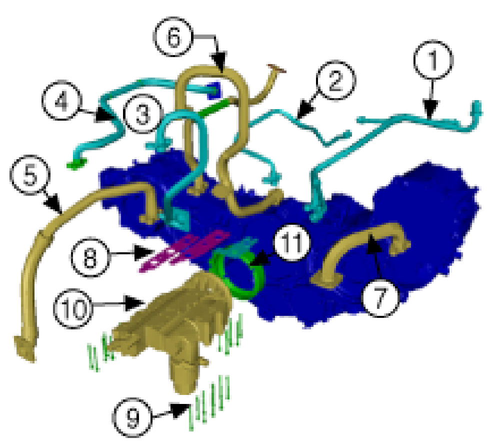
SMG is a new framework for maintenance manual development. SMG will automate many of the manual tasks related to searching and assembling maintenance data, significantly reducing development time and costs. It will change the maintenance manual development process to provide the maintainability engineer an earlier and more immersed view of the maintenance procedures (sequencing, access, position, tool use, etc)[de]. This change enables more concurrent interactions from a maintainability perspective, paving the way for critical design flaws to be corrected in a timely and cost effective manner.

SMG is based on three integrated modules: 1) Service Sequence (SS), 2) Task Generation (TG) and 3) Virtual Validation (VV). The SS module provides a disassembly sequence to be viewed by the analyst, the TG module composes a preliminary maintenance manual based on the disassembly sequence, and the VV module provides the immersion for realistic and meaningful maintenance validation. The end result is a more integrated process for developing technical manuals, providing higher quality information earlier in the process and with less cost.

Service Sequence (SS)

The SMG system starts with a three-dimensional representation of the design geometry in a visualization tool (such as GE's Galileo). The visualization tool is used as an interface to interact with the data and the Service Sequence module. The Service Sequence generates a set of possible disassembly sequences representative of actions used to perform a particular maintenance task as shown in Figure 2.

Figure 2: Solid Model Service Sequence Graphic



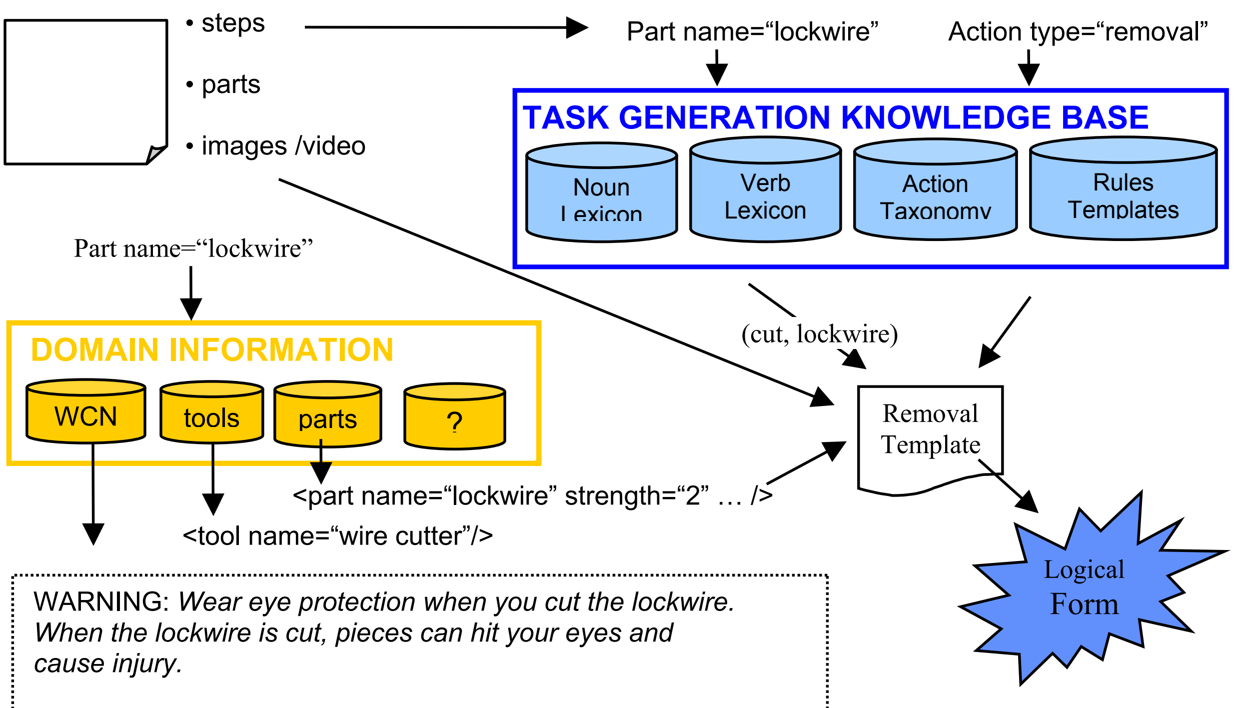
To determine a disassembly sequence, our approach uses a non-directional blocking graph (NDBG)[h]. The NDBG is a structure used to define the blocking relationships between pairs of parts in each direction considered for removal, and can easily be traversed for rapidly determining whether a part is removable for a specific part configuration. The output of the

Service Sequence module is an eXtensible Mark-up Language (XML) disassembly sequence describing the order and direction of part removal (including images and animations). Optionally, for Remove and Replace procedures, the XML sequence will contain reassembly information. The system is also adapted for the generation of exploded views for use within Illustrated Parts Catalogues (IPCs) and other technical documentation.

Task Generation (TG)

Generating maintenance instructions requires information beyond the geometrical model of the equipment, such as text descriptions of the maintenance task steps, safety warnings, required tools, repair parts, etc. The TG module takes the service sequences and related images as input and produces a language- and presentation-independent logical form in XML format. A diagram of the TG architecture is shown in Figure 3.

Figure 3: Task Generation – Creating a Logical Form



For each step in the sequence, appropriate domain information is incorporated into the logical form. A lexicon allows retrieval of the appropriate action verb in different styles or languages. In addition, the structure of repair and installation tasks is used to organize this information in a navigable and comprehensible way for the technician [ij]. The logical form's modular and output neutral design functions robustly, using available and current data in different product lines (e.g., fighter aircraft vs. commercial aircraft) and domains (e.g. aircraft engines vs. power turbines) over all phases of product development.

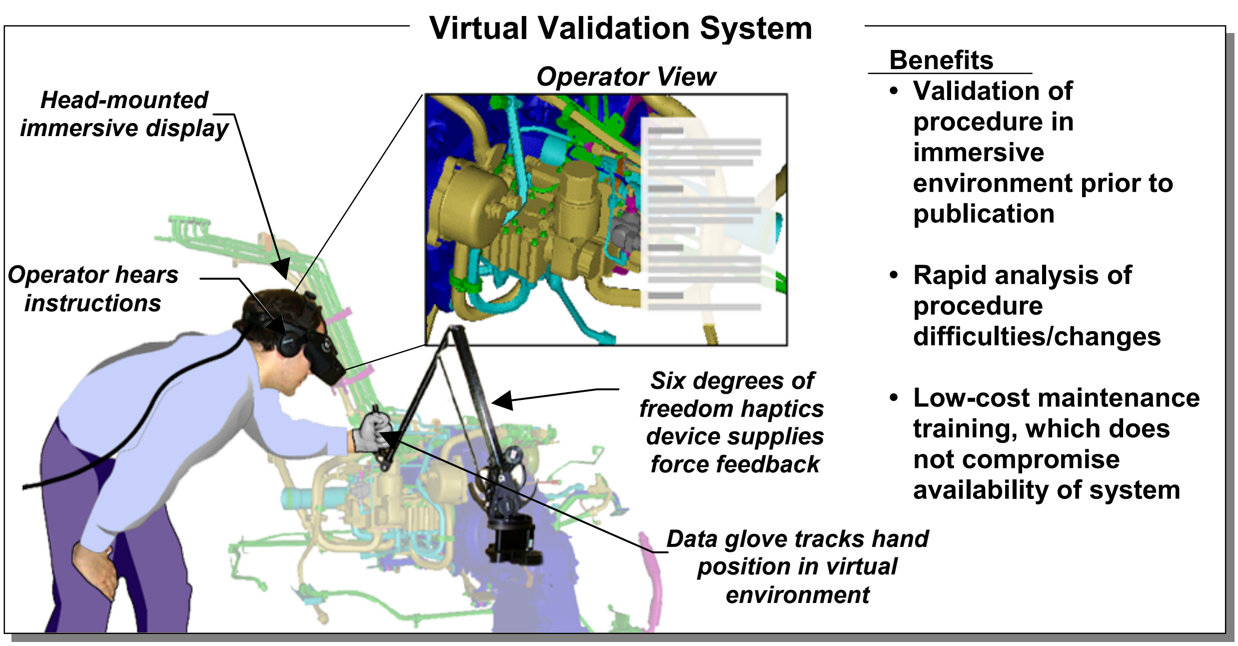
The logical form represents all of the potential interactions independent of the data requirements for a particular application and is thus flexible enough for multiple end-user applications. By defining the logical form in XML, different stylesheets may be used to transform the logical form to the desired presentation format. This enables the same logical form to be used to deliver the generated instructions to a virtual environment, traditional web pages in HTML, or to be used as input to another system, such as an authoring environment for interactive electronic technical manuals (IETMs).

Virtual Validation (VV)

The coupling of manual production and engineering design data in SMG provides a unique and innovative approach to maintenance procedure validation. The design information from the CAD environment is used within a haptically enabled virtual environment (see Figure 4), which runs on a desktop personal computer and integrates various virtual reality technologies (e.g. data glove, body trackers, stereo Helmet Mounted Display (HMD) and a haptic device[k]). The VV is used for two separate validations: one of the computed service sequence itself to ensure that the sequence is correct, and another of the TG output, to ensure that the collection of text and images is unambiguous and leads the analyst to carry out the task in an effective manner.

A diagram of the SMG virtual environment is depicted in Figure 4.

Figure 4: SMG Virtual Environment



The user (a maintainability/assembly engineer or a mechanic) wears an HMD that provides stereo visual information of the maintenance scene. Head movements are tracked by a magnetic tracker and provide a dynamic point of view of the virtual scene. The user will interact with the virtual parts or tools using a Cyberglove and a haptic device. Contact with a virtual object will be felt as a result of the force and torque transmitted by the haptic device.

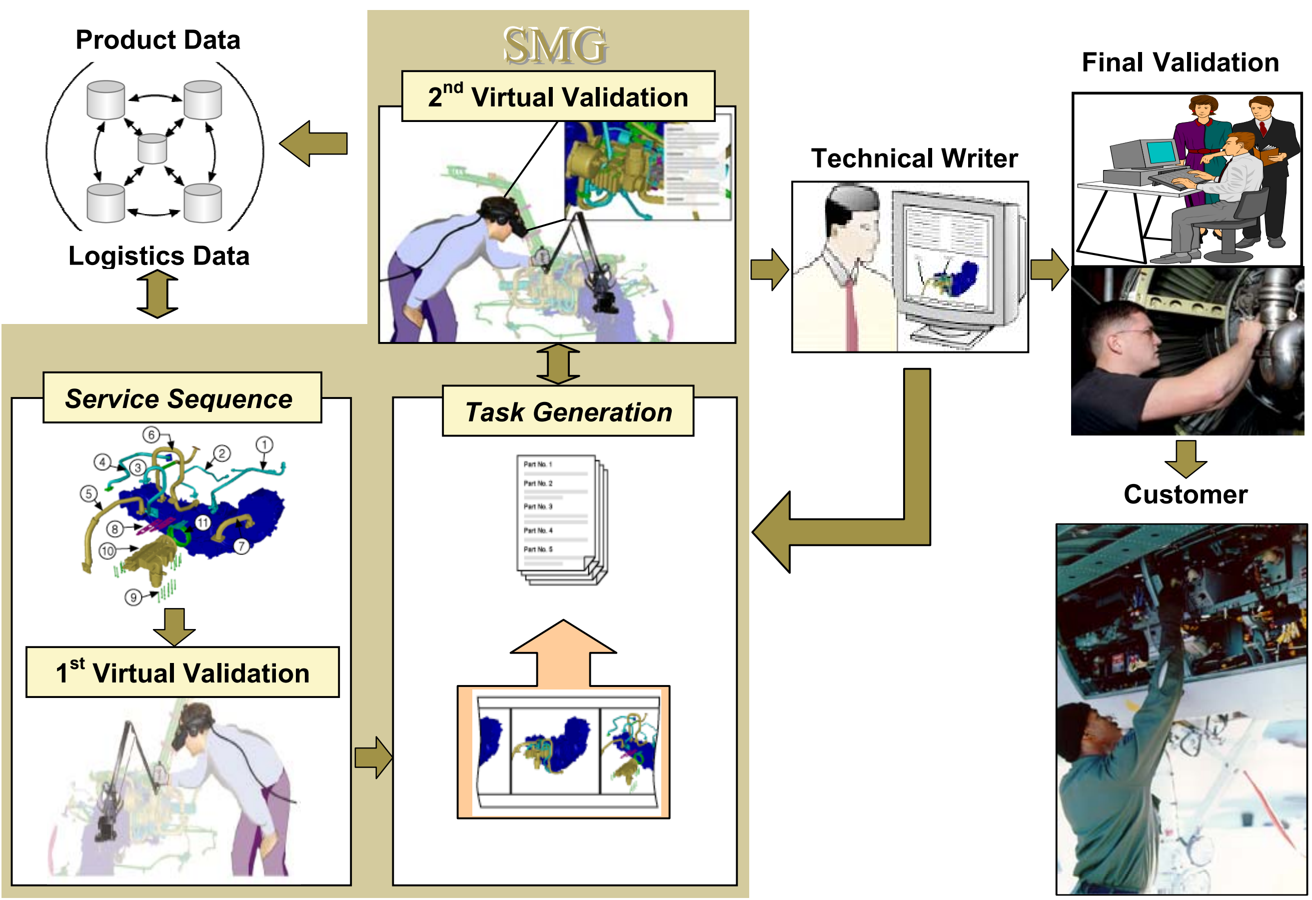
CAD Importation

The first step in setting up the SMG environment is to import the system design, embodied as native CAD data files. A conversion program automatically converts CAD files to a polygonal format as they are checked into a CAD database. The volume of space occupied by each part is sampled, encoding distance and direction information to the surfaces of the part. Individually sampled volumes are linked together to form a global volume of penetration. This sampled volume (penetration map) is used to do the collision detection. Relevant parts are determined from those involved in the service sequence and any nearby parts. Once the geometry is correctly imported, the initial validation of the service sequence can be performed.

First Validation (SS Validation)

The goal for the initial validation focuses on validating the sequence for a task without associated task descriptions as depicted in Figure 5. Using this approach, a Show-it/Do-it technique is used. The user will be able to view a disassembly animation sequence (Show-it) and intervene at any step to "perform the step" in the virtual environment (Do-it).

Figure 5: Maintenance manual development using SMG



Alternatively, after viewing the entire sequence, the user can start with the assembled sequence and attempt to repeat the suggested disassembly to validate order and maintainability. During the validation, annotations can be added to difficult steps in the sequence or on the design to suggest design modifications. The sequence order could be changed and fed back to the SS module to re-generate an alternative sequence. Tolerances can be set and monitored during validation. This information can be used to determine how close parts (particularly sensitive parts) come to other parts during the service event. The environment will also provide a selection of available tools and support the use of these tools in performing steps of the maintenance sequence. Once the service sequence is accepted, the information is passed to the TG module to compose an initial maintenance procedure as described earlier.

Second Validation (TG Validation)

The goal for the second validation is to validate the instructions generated by the TG module (images, movies, instruction, warnings/cautions, notes, consumable material, tools, etc.) for a task as shown in Figure 5. The main emphasis will be to determine, through rehearsal, if the steps can be understood and performed. The second validation is similar to the first validation in that the Show-it/Do-it approach will be keyed to the composed steps in the maintenance sequence. A virtual service manual will be viewable in the environment as appropriate. During the validation, hard to understand instructions, illustrations or omitted steps can be flagged. Better and alternate camera locations for viewing a sequence could be used to regenerate movies and images and exploited in the TG process. Once the second validation is completed, the technical information is saved in an XML file, which can be imported into a commercial authoring system.

Conclusion

In this paper we discussed a new and innovative approach to maintenance manual development being investigated by the USAF, GE and LM. The approach integrates modeling, simulation, information composition and virtual prototyping to allow a concurrent development of preliminary designs and maintenance manuals. New approaches to automating the preliminary maintenance manual development tasks were discussed. A desktop virtual validation environment was described. The proposed approach is currently being developed and will be tested on several commercial and defense systems.

By using SMG technology, many of the maintainability analysis activities will be moved forward in the development value chain. Tasks that were nearly impossible to perform due to the sequential nature of development are now possible due to this concurrent technology. Design and documentation flaws will be more easily caught and corrected before metal is cut, allowing for more affordable changes for the sake of maintainability.

The SMG environment will provide the platform to allow maintainability to become a serious design driver. Maintenance simulations are extracted directly from the design, coupling the maintenance and assembly actions to the design information. The virtual environment automatically imports the design and assembly information for easy interaction with the design and corresponding documentation. Design and documentation discrepancies can be easily annotated for design reviews.

An additional benefit of this technology is a training medium as a by-product of the new design and development process. The Show-it/Do-it approach is a great foundation for training. Although beyond the scope of the current research effort, the Virtual Environment augmented with on-line maintenance manuals will be available to the training community to incorporate training courseware for virtual maintenance training.

The long-term benefits of SMG will be faster repairs and fewer maintenance errors due to more accurate maintenance manuals. The overall development cycle time for manuals will be significantly reduced, further reducing the maintenance documentation lag when fielding systems. Finally, due to the amount of manual tasks being automated, the cost of developing maintenance manuals will be significantly reduced. Although the impact of this technology has not been measured, GE estimates a reduction in the cost of their service manuals of approximately 30%.

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