Development of a Work Control System for Propulsion Testing at NASA Stennis

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In 1996 Stennis Space Center was given management authority for all Propulsion Testing for NASA. Over the next few years several research and development (R&D) test facilities were completed and brought up to full operation in what is known as the E-Complex Test Facility at Stennis Space Center. To construct, activate and operate these test facilities, a manual paper-based work control system was created. After utilizing this paper-based work control system for approximately three years, it became apparent that the research and development test area needed a better method to execute, monitor, and report on tasks required to further propulsion testing. The paper based system did not provide the engineers adequate visibility into work tasks or the tracking of testing or hardware discrepancies. This system also restricted the engineer's ability to utilize and access past knowledge and experiences given the severe schedule limitations for most R&D propulsion testing projects. Therefore a system was developed to meet the growing need of Test Operations called the Propulsion Test Directorate (PTD) Work Control System. This system is used to plan, perform, and track tasks that support testing and also to capture lessons learned while doing so.

Nomenclature

TPS	=	Test Preparation Sheet
DR	=	Discrepancy Report
DOP	=	Detailed Operating Procedure
PTD	=	Propulsion Test Directorate
SSC	=	Stennis Space Center
CR	=	Change Request
TR	=	Test Request
WCS	=	Work Control System

I. Introduction

THIS paper will explain the requirements and steps taken to develop the current Propulsion Test Directorate electronic work control system for Test Operations. The PTD Work Control System includes work authorization and technical instruction documents, such as test preparation sheets, discrepancy reports, , test requests, pre-test briefing reports, and other test operations supporting tools.

The environment that existed in the E-Complex test areas in the late 1990's was one of enormous growth which brought people of diverse backgrounds together for the sole purpose of testing propulsion hardware. The problem that faced us was that these newly formed teams did not have a consistent and clearly understood method for writing, performing or verifying work. A paper system was developed that would allow the teams to use the same forms, but this still presented problems in the large amount of errors occurring, such as lost paperwork and inconsistent implementation. In a sampling of errors in August 1999, the paper work control system encountered 250 errors out of 230 documents released and completed, for an error rate of 111%. Errors in technical instruction

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documents such as the ones used in Test Operations can result in death, injury, loss of capabilities, or not meeting the project's objectives. This was unacceptable and our group responded quickly to rectify the problem.

The system developed needed to help the engineers and technicians communicate and prevent repeating past mistakes as well as prevent errors before releasing to work. By capturing critical data and tracking the progression of work, the proposed new PTD Work Control System would increase the work efficiency of engineers and technicians that support design, construction, activation, and testing of propulsion test projects at Stennis Space Center.

During the development of the basic system, additional goals were introduced; improving communications and collaboration between the many end users. I initially developed the E-Complex Work Control system in 1999 and released it for production in October 2000. Today's PTD Work Control system evolved by incorporating improvements and automations suggested by field technicians, test engineers, designers, safety engineers, and project managers.

The PTD Work Control System development leveraged existing investments in tools and products by expanding them into an integrated collaborative engineering environment. The technical problems were many and varied; the challenge has been to remain innovated and proactive in building this collaborative environment without spending vast sums of money. The path has been incremental and value-oriented. More importantly, it has increased the quality of work provided to our customers without increasing the cost of doing business with PTD at Stennis Space Center.

II. Design and Structure of PTD Work Control System

The foundation of the PTD Work Control System was built using an off the shelf software called FileMaker Pro[1]. In 1999 the software had already been used in the Test Operations areas of NASA and Boeing Space Shuttle Main Engine Testing. It was proven to be reliable and very easy to customize to our specific requirements. In today's lean testing environment it is imperative to design functional systems or also called data products as to decrease short term and long term reoccurring cost, i.e. overhead that is passed on to the customer. This tool met this need.

Utilizing the graphical interface tools provided within the software each screen was designed to meet the needs of various users such as: test engineers, designers, technicians, supervisors, auditors, configuration management personnel, and other support contractors. An example of an interface screen can be seen in Figure 1. When the basic interface screens were designed, automation of critical tasks and/or controls was programmed using the scripting language within FileMaker Pro[1], Figure 2. These two elements combined are known as a data product, which is a well defined electronic process that serves as a tool to accomplish a predetermined task. All of the data products used by Propulsion Test Directorate (PTD) to accomplish daily test operations are combined into one system and accessed through common screen and is known as the PTD Work Control Screen.

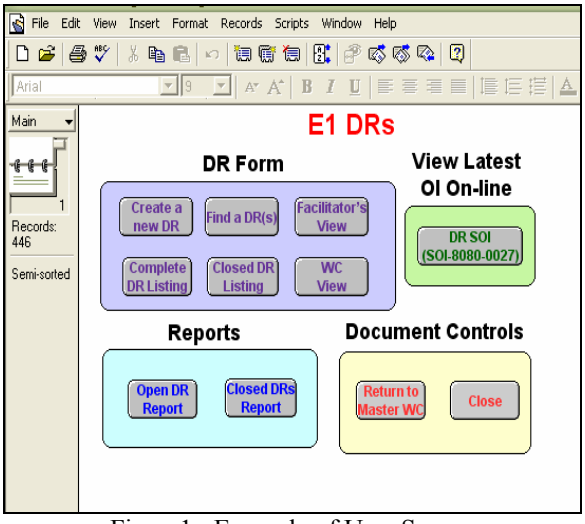


Figure1: Example of User Screen

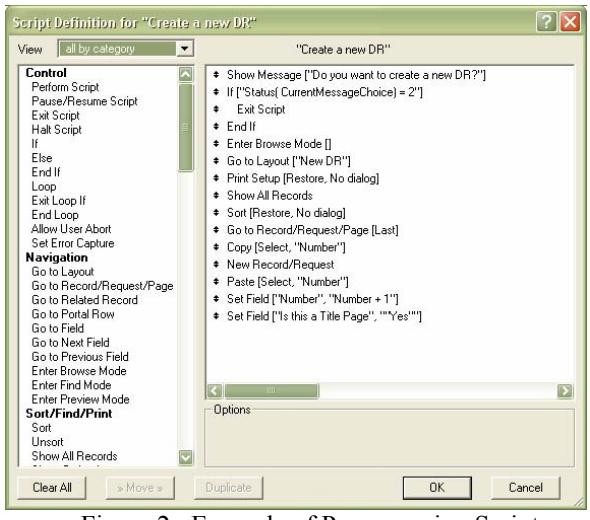


Figure 2: Example of Programming Script

The ease of programming and interfaces' customization found in the software's foundation led to a development process known as rapid prototyping. This allowed a typical data product to be created in the time frame of one week.

The most complicated data product designed and implemented took only two months to complete including user testing. The screens were designed to be simple and non-cluttered because this system is used daily and I found less human error occurred with the simpler interfaces.

Not only is does this system allow for easy development, it allows real time modifications or improvements to be made without taking the system offline. This feature is critical to test operations since they rely on the system daily to perform and track tasks that support mission goals. The only items that currently can not be changed real time are passwords and field definitions, because the fields are shared to multi-users (users are required to temporarily log out). Another useful feature of the parent software is that each data field is automatically saved after each entry. The structure of the software allows simple searches on any field or for more complex multi-criteria searches. Essentially the user entry screen can become an adhoc search screen in addition to the specialized search screens, The users often prefer defining their own criteria over other search techniques.

The total initial investment to create the system and provide it to all of PTD, 150 personnel, (using about 60 workstations) was approximately $6000 in 2000 and one-half of a full time employee (FTE). The only additional cost that has been incurred since the initial investment has been in consulting services to build additional screens and implement improvements at an approximate cost of $55K over three years. In early 2004 the production version of FileMaker Pro was upgraded from 5.1 to 6.0 that were included in a maintenance agreement of approximately $2500.

III. General Description of PTD Work Control System Components

There are many components of the PTD Work Control System (WCS). They support the various functions used in preparing for testing from planning work to recording discrepancies. The system has twelve primary data products or user interfaces, split into three groups, one per test stand, E1, E2, & E3.

Figure 3 shows the Main Screen for the system. The goal of the main screen design was to keep it simple and easy to identify what and where the data products are. Along with the primary data products, there are nine supporting data products. One critical support data product is the Test Open Items report, which summarizes all open items for a specific test stand and/or project that includes open electrical and mechanical TPSs and any open Discrepancies. This interface also offers four links to other PTD/Stennis systems They include an enterprise system that automates the configuration management of PTD's drawings/designs, a component portal that searches into four different component databases on site, a test data web site, and the PTD home page of SSC's Intranet.

Each button on the screens represents a script that controls user flow and improves quality. The WCS has over 300 scripts that perform various functions. Below the major PTD Work Control System data products' function and unique capabilities are described.

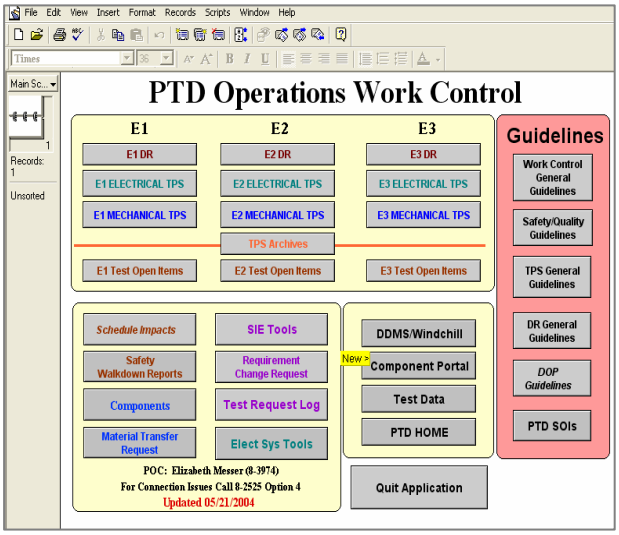


Figure 3. Main Screen for PTD

A. TPS – Test Preparation Sheets

The TPS is the heart of test operations. It is the vehicle by which technical tasks are communicated to those who will perform the tasks. It also serves as an approval document to do the work or tasks, safety and hazards identifiers, quality inspection requirements, and engineering verification that the tasks were completed to specifications.

The creation phase of the TPS offers the engineers an option to search for like activities within the system and duplicate content if needed. It also has built in help features that insure that the engineer enters hazards and that the appropriate personal protection equipment, PPE, is called out within the TPS. Other features include: 1. verification that each field is filled in with appropriate data, automated time and date stamps, 2. Verification that the TPS is ready to work, 3. Locking feature when the TPS is closed by the Work Control Coordinator, and many more. Figure 4 shows the entry screen for a TPS.

Upon completion by the engineer, the TPS data product has a built in workflow that allows the engineer or supervisor to know the status of the work. It provides multiple reports as seen in an Open TPS List with ability to set priority by the Test Director of the specified test facility.

Once the engineer is done writing the TPS, it is printed out and he or she obtains the required signatures. Then it is dropped in a box for the Test Operations Contractor's facilitators. The facilitator has their own user screen which helps them track status, parts, and cause of delays in working the TPS. An example of the Facilitator's screen can be seen in Attachment A. When developing this system, I with my management made the decision to keep the part that actually performs the work as a paper based system. This was due to the remoteness of the many test facilities from workstations and the complex safety issue of wireless computers in hydrogen environments. There was also an advantage to introducing automated data products in small phases; this allowed the work force to increase their comfort with using a semi-automated system gradually. The users responded with many suggestions to improve the system and therefore making it "their" system.

B. Discrepancy Reports

A Discrepancy Report is written when a discrepancy occurs which is defined as an anomaly or failure of a component, data, or system that requires repair, replacement, or explanation. Anyone is allowed to write a DR, but it must be reviewed by the facility's Test Director. He or she has technical responsibility for the test facility.

The PTD Work Control System has a title page where the discrepancy is described in detail. There is also an option to email the other TD's and the Office of Safety and Mission Assurance if the writer believes this discrepancy might impact others. This is known in the system as a Corrective Action Request. There is a recently added feature that allows the user to also create a "lesson learned" in the PTD Lesson Learned system that resides in Stennis's Design and Data Management System, (DDMS), from the main DR title page. DDMS is the system that controls configuration management of Facility and Project drawings, documents, and has a PTD Lesson Learned data product. DDMS was developed using Windchill Foundation[2] software and customizing it to Stennis's needs.

A Test Operations Engineer, TOE, is required to answer or research any logged discrepancy. They accomplish this by completing a DR Disposition. If the solution is not known they would number the dispositions as Partial Dispositions numbered 1,2,3, etc. When a solution is determined, the TOE writes a "Final Disposition" and closes the DR. The DR Disposition data product looks and functions the same as the TPS data product. It is also a work authorization document. The DR title page and subsequence dispositions all have the same number but can have different authors. This makes locating a discrepancy easier and has helped in identifying reoccurring problems that led to a resign of a critical component.

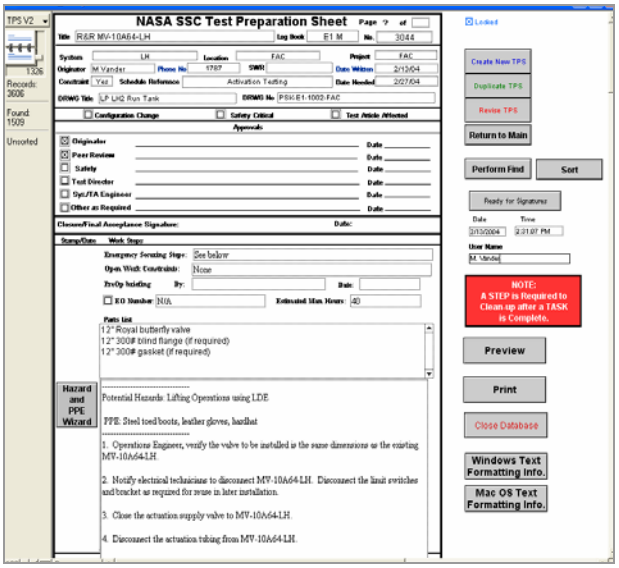


Figure 4. TPS Engineer Entry Screen

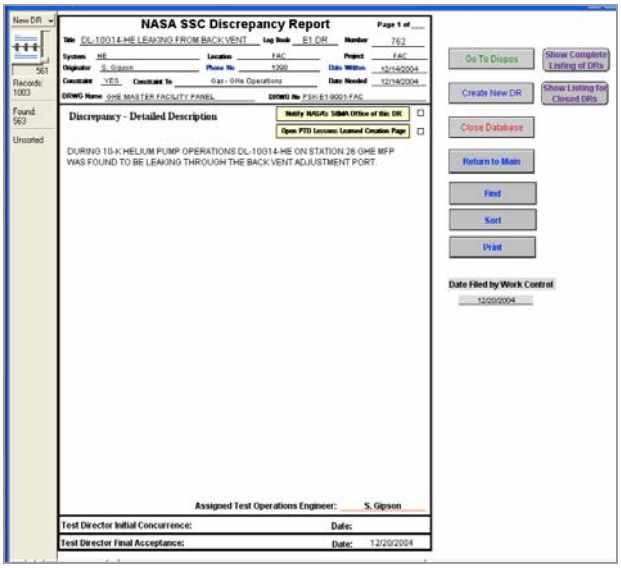


Figure 5. DR Title Page

C. Test Requests

A Test Request, TR. is written for each test by the assigned System Integration Engineer with customer input. This is the authorization to perform a specific test. The TR also details needed to set up and actually run a specific test are called out in the TR. The PTD WCS provides automatic numbering of the TRs and a generation screen for Flash Reports. This is a quick post test summary of the test results that is sent to all involved parties and their management. The Test Request typically has multiple attached Detailed Operating Procedures, DOP's that do specific tasks. These together with a pretest Open Item report, make what is known as a Test Package. The Test Packages are audited using the same method and interface as a TPS or DR. A typical Test Package has approximately seven Detailed Operating Procedures. The DOPs reside in the Stennis DDMS system and are under configuration management.

D. Installed Component Configuration Database

Another important component of testing is verifying that the components used to obtain test data meet specific design parameters and clean levels. This is most critical in the liquid oxygen, liquid hydrogen, and hydrogen peroxide systems. A data product was designed in the PTD Work Control System where component certification information from a TPS or DR is entered.

This data product is known simply as the Component Configuration Database. Although it is much more than a simple database, it has multiple input screens with pull down menus and re-certification reports. This system was only intended to keep currently installed component information. Out of necessity, the data product has been customized to keep previously installed components' information as well, called historical data. The data is beneficial to planning and designing for new projects or returning projects. An example of the user interface screen used by test operations, refer to Appendix A. A copy of the test stands Component Configuration Database can be retained for each test to show test stand configuration. Examples of the type of component information that is retained is locator number, manufacture, model number, serial number, clean level, service or medium intended for, drawing number, working pressure, and temperature range. There are approximately 52 different data field available for storing component information

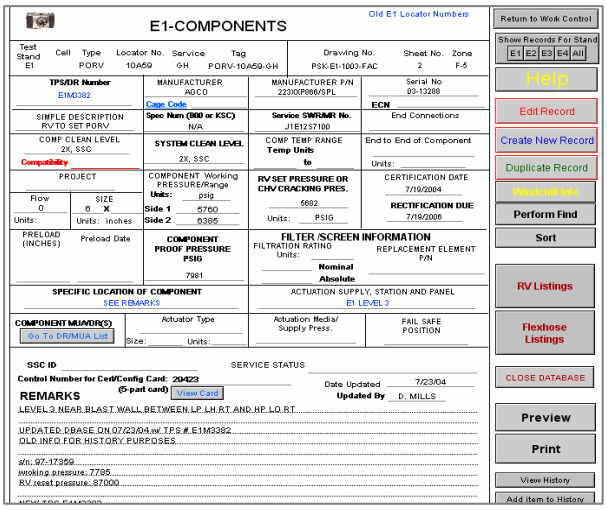


Figure 6. Component Configuration Database

E. Other Misc. Support Features

The PTD Work Control System also supports the System Integration Engineers, (SIE), group by making all of their tools and forms readily available. They use the PTD WCS to track, verify, and validate requirements. One of the most used tool is called a Change Request, CR, which is required to change a pre-agreed to requirement. This CR has the schedule and budget impact information as well as the signatures required to accept the change. Other SIE tools are Data Release forms, work flow diagrams for SIE processes, and schedule impact database. Examples of these can be seen in Attachment A. Many of the initial designs for the SIE tools were done by the SIE group leads, Ms. Christine Powell and Mr. Brad Messer.

Another feature of the PTD WSC is the Pre Test Briefing, which is a summary of all open TPS, DRs, and TRs for a specific test facility and project. When a Pre Test Briefing report is run for a specific project, all open work against the facility is shown with the project's open work. It is critical to see the facility work, because the project is so intertwined with the facility systems. Recently it was demonstrated that even the fail safe systems of the Control Building's fire alarm system can affect the project's testing by cutting the Several links to other systems used by TOEs are found on the main PTD WCS screen such as Component Portal, DDMS, Test Data, and PTD Home Page.

The Component Portal is a Search engine that looks into all of the various component databases. This is a useful tool to help locate stored components and also to find component data discrepancies. Stennis's DDMS, Design and Data Management System, is as a customized system built on Windchill Foundation and manages the configuration

of Drawings, Project Requirement documents, PTD Lesson Learned, and Detailed Operating Procedures. DDMS PTD drawings are linked to the component data housed in the PTD WCS's Component Configuration Database. Test Data is a web link to a secure server where all of the test data is stored and is password protected.

Also located on the main screen for the PTD WCS are best practices for writing, and verifying TPSs, DRs, and DOPs. They have been developed over 10 years of testing at Stennis and lessons learned from other test areas such as Marshall Space Flight Center's. A link to Stennis's official Work Instruction system, called Tech Doc, is provided for the engineers to access the latest Stennis Operating Instructions that are requirements for performing work in PTD.

IV. Measured Results of PTD WC System

After the initial system was in production for a couple of months, it occurred to me that we needed a way to gage if it was indeed decreasing our error rate in performing work. Two methods are used to gage effectiveness of the system, individual audits of each work authorization document and trending the data long term. The trending program was developed primarily by Mr. William (Bud) Nail of Technological Services, Inc. under a NASA contract.

A. Tracking of Tasks Work Errors

The audit of work authorization documents, i.e. TPS's, DR's and Test Packages, is performed by the group's Work Control Coordinator. She audits each document as it is turned in for closure, in paper form. She has approximately thirty quality items she looks for, that are best practices or requirements per the Stennis Operating Instruction, SOI-8080-0027[3]. Attachment B shows the entry screen for capturing error data and the types of problems that are checked for. If a new problem occurs, it will be added to the list for the next audit.

B. Long Term Results

Once individual data is collected, I run a program to collect all problems from the multiple test facilities and create monthly reports. Figure 7 shown below is a sample of a monthly report and Figure 8 is the trending report that is updated monthly as well.

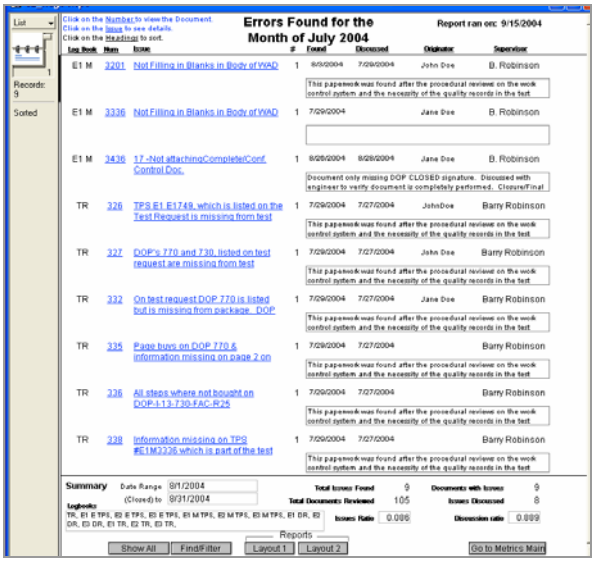


Figure 7. Sample Monthly Errors Report for WCS

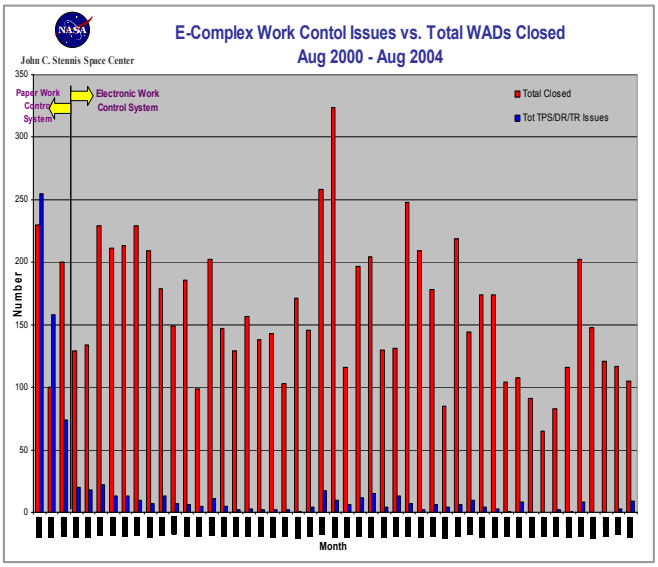


Figure 8. Four year Trend Report on WCS Errors

C. Limitations of System

The major limitation of the current WCS is that signatures are still obtained manually. During initial development this was the users' desire. Now that the users have become more computer savvy, they would welcome automated signatures. The engineers now desire automated signature capability because they are no longer all in the same vicinity and obtaining signature in a timely manner has become difficult. The other limitation is that the system does not have a built in work flow with notifications of completed dates missed. This could be programmed into the system, but a study on the return on investment needs to be completed first.

D. Ongoing and Planned Modifications

Currently the Test Area support groups such as Maintenance, Cryo Facility, Water Plant, and High Pressure Gas Facility are being moved from an all paper based system to the PTD Work Control System. Their requirements have been gathered and the beta version is expected to be completed by mid January 2005. Plans are being developed to link the PTD Work Control System & DDMS PTD Lessons Learned system with Active Risk Management, ARM [4].

Also in work is the integration of TPSs, DRs, & TR's with project schedules. This is being pursued to implement Earned Value Management to a lower level than is currently available. This would allow Test Operations to better report value of work performed and to respond quickly when corrections are needed to meet end project goals.

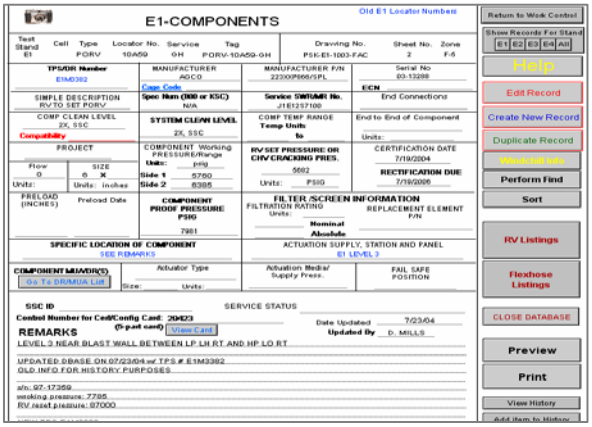
V. Conclusion

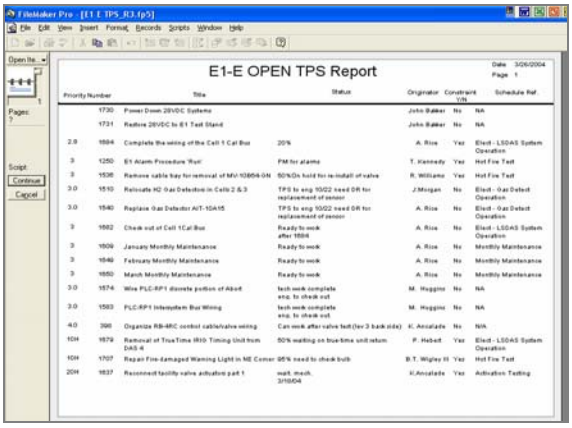
The PTD Work Control system is working today in great part to the high degree of user input to the design and modifications. This system continues to be the backbone of how work is done within the E-Complex Test Area. It's most useful feature, for supporting an R&D type of business like that of Stennis's, is its ease of customization and dependability. This PTD WCS system is only a tool and has not become a legacy system that requires more money and support to maintain it, than the actual cost of the work it helps conduct. Even though capturing knowledge and making it accessible were the end goals of this system, the system itself was not planned to be the only long term system ever needed; all data within the system can be easily migrated to future systems if needed.

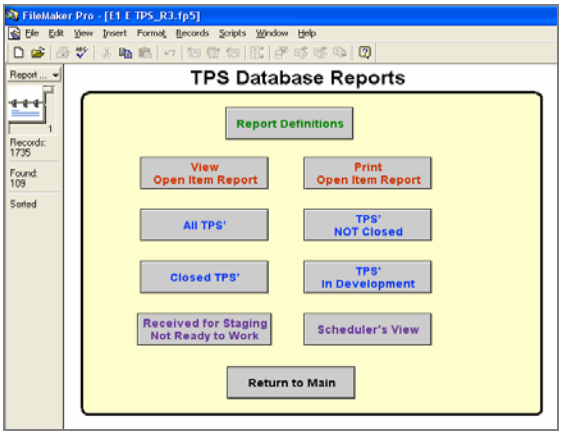
The contributions of the PTD Work Control System are hard to quantitatively measure; one method might be to measure lost productivity if the system were not there. In the world of Propulsion Testing cost is important, but for most of our customers, schedule seems to be the driving force for the projects. This is where user tools or systems that are responsive and easily modified can make the most impact. I would not say that the PTD WCS system is complete, because as we grow and learn so will the work control system.

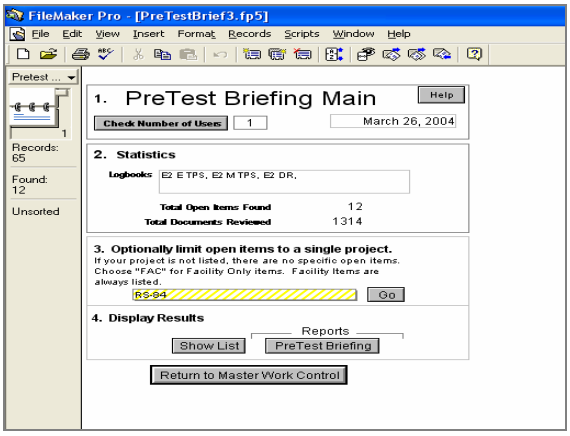
Appendix A

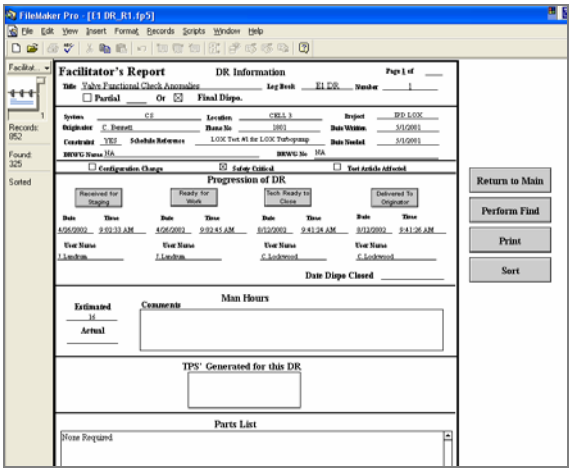
Samples of user interface screens and reports.

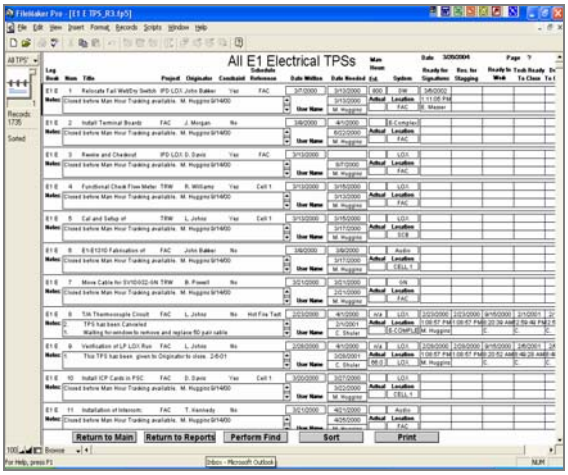






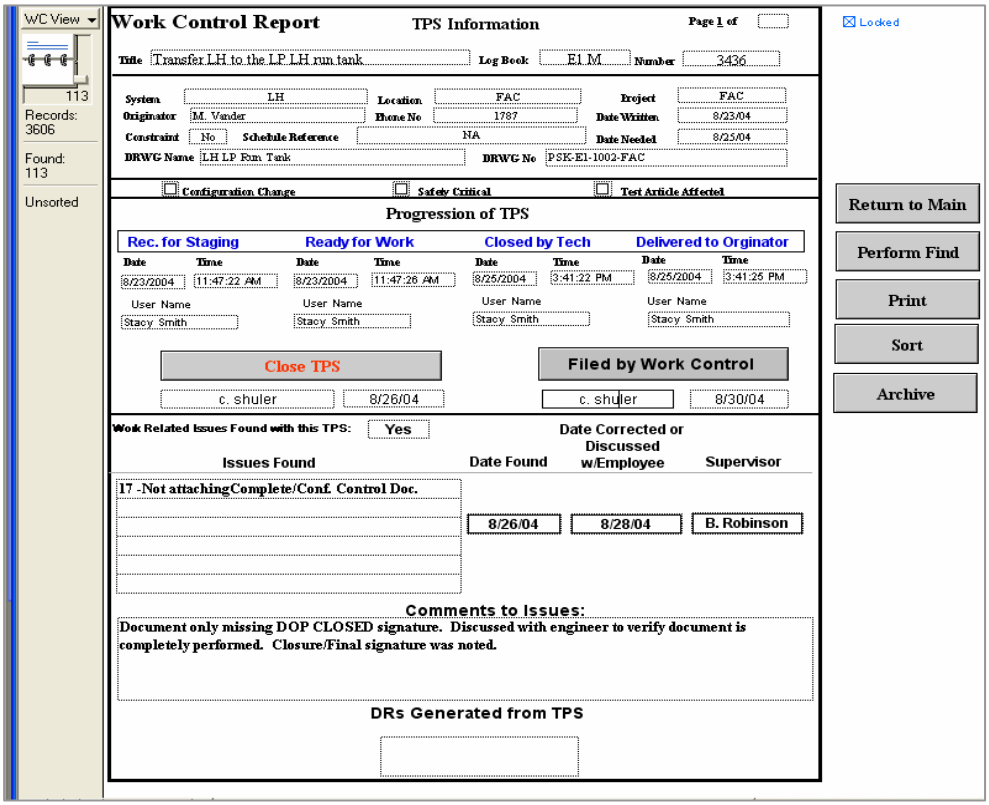






Appendix B

1. Work Control Coordinator's Entry Screen for performing audits.



2. Work Control Coordinator's List of problems to verify in performing an audit.

1- Not Identifying as Safety Critical per SPG 8715.1, SSC Safety Manual.
2- Not Identifying Drawing No.
3- Not providing a Need Date
4- Not listing Potential Hazards
5- Not listing Test Request No. on TPS
6- Not referencing DR No. on TPS when a problem occurred.
7- Not assigning TR No. to attachments.
8-Turned in Test Pkg w/o going thru System Integration Engineer or TD
9- Using Pencil on TPS/DR/DOP
10- Not Referencing EO for Conf. Change
11- Pre-Op Briefing not Signed/Dated
12- Worked Unsigned/Unapproved DOP
13- No Parts List
14- Not using red ink for changes
15- Not using Mandatory Inspection Points, MIPs, when required
16- Not including "TPS Complete" Step
17- Not attaching Completed Configuration Control Doc.
18- No Sign./Verification of Closure or Completeness
19- Not enough detail in instructions
20- No Estimated Man-Hours
21- Lost Original After Work Complete
22- No DR Discrepancy Page
23- No Peer Review Signature
24- No Safety Review/Signature
25- No Schedule Reference or Constraint
26- No TD Approval on DR
27- Not Buying all required Steps
28- Not Filling in Blanks in Body of WAD
29- Not initialing & dating changes/redlines
30- Not Ref. TPS on Attachments

Acknowledgments

I would like to thank William (Bud) Nail of Technological Services, Inc., Connie Shuler, Melissa Huggins, Stan Warren, Christine Powell and Brad Messer of NASA for their encouragement, assistance, and guidance in maintaining and modifying the PTD Work Control System to become a vehicle for continuous improvement.

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