An analysis of use of automated tools for improving the process of software verification and validation in a Midwestern company

Darshak Dodiya
University of Northern Iowa

AN ANALYSIS OF USE OF AUTOMATED TOOLS FOR IMPROVING THE PROCESS OF SOFTWARE VERIFICATION AND VALIDATION IN A MIDWESTERN COMPANY

An Abstract of a Thesis

Submitted

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

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May 2014

ABSTRACT

As the use of electronics and software in the modern off road vehicles tend to increase, there is a huge challenge of getting the electronics and software tested before making it available for customer use. There are a lot of interactions between the hardware and software for the vehicle to function. And with the amount of interactions in the hardware and software come a lot of problems in verifying the functionality of the vehicle. If proper verification is neglected, the customer might end up getting an unsafe vehicle which can lead to serious consequences. To make these vehicles safe and more efficient, major manufacturers are using vehicle simulators where the test engineers can perform numerous automated and manual tests.

Once these tests are executed, the reports are gathered for further analysis of the faults occurred at various stages of testing. The analysis is further used to find the root cause of the failure to prevent it from reoccurring before the new product is passed for production. This study investigates the amount of time consumed on results reporting processes involved in the overall analysis of test results in a heavy off road vehicle manufacturing company in Midwest. The experiment and recommended improvements in this study will help make the company’s process of results reporting more efficient and effective. In the end of this study conclusion and some recommendations for further studies are discussed to efficiently utilize resources in software verification and validation process of this Midwestern Company.

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This Study by: Darshak Dodiya

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has been approved as meeting the thesis requirement for the

Degree of Master of Science - Industrial Technology

Date	Dr. Ali Kashef, Chair, Thesis Committee
Date	Dr. Julie Zhang, Thesis Committee Member
Date	Dr. Atul Mitra, Thesis Committee Member
Date	Dr. Michael J. Licari, Dean, Graduate College

DEDICATION

I would like to dedicate this work to my mother Late Smt. Kundanben L. Dodiya, who will be part of my life forever. Whatever I have achieved today is because of her immovable faith in me. She always provided the best of everything I asked for. Her great desire to provide her kids with the best possible education is still one of the biggest driving factors of my career. Her positive thinking, giving the best in whatever she did and always setting high standards won her great respect among everyone who knew her.

She never sighed away from criticizing me and along the way also encouraged me to take the right steps. She was also not afraid to take harshest of decisions which she thought was right for family. She was by far the strongest woman I have ever known. She came out of all hard times much stronger than before and taught me the same. Being a school Principal, she always thought about her students as if she would think about her kids and her school was like a second family to her. She taught me to be patient and injected the belief of choosing the right path no matter how hard it may look.

I will miss her throughout my life and firmly believe that she is feeling very proud while watching me from the heavens……..

ACKNOWLEDGEMENTS

I would like to thank all the people who helped me complete this thesis directly or indirectly. First and foremost, I would like to thank Almighty for providing me with the courage and determination to complete my higher education.

Next, I would like to thank my family. Specially my wife Vandana, the strongest pillar of my life without whom nothing would have been possible. Her unconditional love, support and belief keeps me going through toughest phases. Not to mention my two lovely daughters Vipsa and Diva who are responsible for injecting fresh energy every time I am feeling tired. Also to my father Lakshmanbhai Dodiya, who continues to be great support I can rely on. Big thanks to my brother-in-law Dharmesh K. Makwana and sister-in-law Saritha D. Makwana for being there through thick and thin.

I could not have been able to complete this thesis without the expert advice and support from my thesis committee members Dr. Ali Kashef (also my advisor), Dr. Atul Mitra and Dr. Julie Zhang. They have been there to help me on short notices and always given their best advice to complete the study.

A special thank you to Mr. Mark J. Klocke, Manager- Electronics PV&V and Mr. Albert R. Oberneder, Software Test Supervisor - PV&V for understanding and supporting at work so that I can complete my studies. Also to my colleague, Ryan Hanson for helping and guiding me in developing the prototype tool used in this thesis.

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CHAPTER I

INTRODUCTION

Electronics and software has become an integral part of our everyday life. Be it a laptop, a tiny music player or large vehicles. Whether one is aware of not, software is controlling our life in one way or the other. Every vehicle today is being controlled by some kind of software under the hood. More and more manufacturers are relying on embedded software for either the basic functionality or making thousands of decisions in a split second. Developing and relying on these highly complex software systems to perform such tasks requires the manufacturers to test these systems thoroughly.

In the process of developing such complex systems, lots of important engineering and management challenges are raised. This complexity gives rise to many problems to the manufacturers. One of them, developing and integrating embedded software in large vehicles is an expensive venture. A lot of investment is required to acquire technological and human resources. The other, which the author considers the most important, is that many projects are completed with defects to be fixed. Most of them are after the delivery and in the field, which results in poor quality products further customer dissatisfaction. Organizations are struggling for the challenge of integrating, verifying and managing a massive array of test results from number of various sources. In case of short-term difficulty, software managers attach more resources and engineers but at very high cost and with limited effectiveness. Frequently they still cease delivering releases of software with compromised quality and rather late.

The growing complicacy of embedded software development demanded a new more scalable and reliable testing approach that is efficient and effective. Companies developing embedded software for their products saw a need to scrap slower testing practices and put into effect automated software verification in order to detect and prevent more possible defects sooner and quicker.

The Electronics Product Verification and Validation (PV&V) department at one off road vehicle manufacturing company develops and executes embedded software test procedures for the entire fleet of large complex vehicle systems as per the requirement specifications. Test Engineers create all the possible test cases and execute those tests on the various types of simulators either manually or utilizing automated scripts. The test results are stored in local hard drives of the number of Model-in-loop (MIL), hardware-in-loop (HIL) and software-in-loop (SIL) simulators. Further, the test results are collected from each simulator and analyzed for defects. There are few HIL simulators, but the software and model based simulators can be installed by every test engineer in the company. The amount of test results generated in each simulator is enormous. To collect result data from these SIL and MIL simulators becomes very difficult, especially when a single test procedure is executed multiple times on the same computer for multiple days. This in turn consumes large amount of precious engineering time and resources. An improved process will improve the efficiency of engineers and PV&V process as a whole.

Statement of The Problem

As the amount of test procedure results generated from various software-in-loop, hardware-in-loop, model-in-loop and manual simulators increase, the amount of time taken to perform product verification and validation process increases. As a result there are cost overheads and delays in reporting issues which further delay product development process.

Purpose of The Study

More and more manufacturers are using hardware, software and model based simulators for testing their embedded software products before the final production. With the increasing amount of testing performed on the simulators of various types, a huge amount of test results is generated at the end of each execution of test procedure. Collecting and organizing these test results data creates some unwanted overhead for the companies in the form of engineering costs. Although it seems to be a very small part of the complete PV&V process in the company, its cost cannot be underestimated.

This study investigates the result reporting where the PV&V process can be improved for efficiency so as to reduce engineering costs. This study also investigates amount of time consumed and in the process by an engineer on gathering test results, organize them and present them in a reportable format. Various simulators were investigated to determine the amount of reports they generate in a period of time. Many benefits will be earned from improving the process of reviewing results. It will increase the efficiency of engineers by reducing the amount of time they spend finding reports. Reducing the amount of time taken just to collect and organize the results reports from the simulators will make the PV&V process much leaner, efficient and save engineering costs.

Need of The Study

With the influx of automated and manual tests from various simulators, the amount of test results increase manifold. Navigating to the destination folder containing large numbers of subfolders is tedious and laborious. Finding the right report from the folder becomes a challenge if the same tests are performed more than once in a short amount of time. Once the report is displayed on the screen, it becomes challenging to find the test parameter values from a stack of test case results. Since each test case is executed by the same automated script for that particular function, it again adds similar amount of test results to the storage location. Printing that report is another problem all together. Since the amount of pages in each report is very large, it ends up creating huge paper wastes once they are used. The overall process thereby wastes a considerable amount of engineering time and costs.

Executing tests on the same simulator machines, utilizes its storage disks to its maximum capacity. Storing the reports ends up creating storage issues on the local hard drive of the machines. Searching for reports in the simulator machines can be performed either physically at the locations or by sharing the root directory of the system. Sharing the storage disk drives makes critical and confidential data open to other unwanted entities thereby compromising the security of the company assets on the network.

Research Questions

In this thesis, we will discuss the following research questions related to the process of Product Verification and Validation.

1. Will implementing the recommended reporting process changes improve the complete process of PV&V?
2. How much average time does an engineer consumes on results reporting process before and after the implementation of the proposed improvement?
3. How do the recommended improvements improve the security of the testing assets?
4. Finally, how much time and engineering costs the company would save if the recommended improvements are implemented?

Assumptions

A central test reporting tool called ACRS (Automated Central Reporting System) will be developed to be integrated into possibly HIL, SIL or MIL test environments. The following assumptions are made:

1. Fatigue factor of Test Engineers is not affecting their ability of searching results.
2. All the Engineers utilize similar search methods.

3. The location of test result storage is consistent across all the simulators.
4. All the Engineers of similar grade level are paid equally.
5. All the Engineers utilize the test assets similarly.

Limitations

The following limitations are applied to the PV&V results reporting process improvement and study:

1. Limited experience with C# or PERL scripting language might lead to some bugs in the experimental tool.
2. Limited experience with National Instruments Labview and TestStand tools.
3. The tool might not be able to execute outside of the organization's network.
4. Matlab to be linked with c# and PERL libraries is a limitation to perform the experiment on model based simulators.

Definition of Terms

PV&V:	Product Verification and Validation; process to verify and validate a product before sent to production.
Verification:	Is the product doing as per the specifications?
Validation:	Is the product doing what users want it to do?
ECU:	Microprocessor based Electronic Control Unit

Simulator:	Portable hardware, software or model based system which mimics the real product.
IT4:	Interim Tier 4, an EPA emissions standard.
FT4:	Final Tier 4, EPA emissions standard which should be implemented by 2017
HIL:	Hardware-in-Loop, a technique used for developing and testing embedded software by electrically simulating components like sensors and actuators.
SIL:	Software-in-Loop, another technique for testing embedded software by using software to simulate components of an electronic system.
MIL:	Model-in-Loop, use of simulated product models to test.
NI:	National Instruments, automated test equipment manufacturer.
Labview:	NI programming environment used to develop measurement, test and control systems.
Bug/Defect:	A deficiency in the functioning of software
Stakeholders:	A person or group that has interest in a project.
TL:	Test language used to automate HIL and SIL tests.
I/O:	Input and output to any system.
TLA:	Three Letter Acronym to identity each application controller.
TestStand:	Automation tool from National Instruments.

Outline of Procedure

The following procedure will be followed during the study:

1. Initial investigation into the current PV&V process and in particular test results reporting process.
2. Identify and investigate simulators used by the engineers to perform test.
3. Collect data for amount of time spent on reporting process.
4. Collect data for storage space used over a particular period of time.
5. Design, Develop and implement an automated tool prototype on possibly one of the simulators.
6. Collect the new data for amount of time spent on reporting process after the implementation of tool.
7. Perform Hypothesis testing on the pre and post experiment data to get the conclusions.
8. Suggest future work.

CHAPTER II

LITERATURE REVIEW

In the last two to three decades, embedded software has infiltrated more and more products, which are traditionally results of mechanical and electrical disciplines. Be it a cell phone, home appliance or a satellite. They all are functioning and in most cases relying heavily on the underlying software to keep them going. There is hardly anything today which doesn't have some piece of software in it. Automotive industry has not been left behind as well. It has innovated along with other products in leaps and bounds in terms of software and electronics. So much is the increase in use of software and electronics in automotive that today the manufacturers of automotive products or vehicles are facing the challenge of finding a balance between production costs and maintaining reliability, quality and safety or their products.

Noergaard explains embedded systems model as the one which has at least one layer (hardware) or all layers(Application, system and hardware layers) in to which all the components fall. The hardware layer contains all the major physical components located on the embedded board whereas the system and application layers contain all software located on and being processed by the embedded system. (Noergaard, 2005, p.12). Figure 1 below represents a typical embedded systems model.

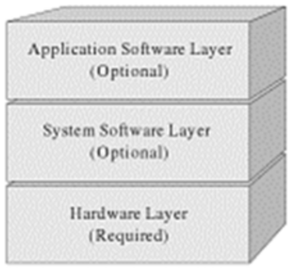


Figure 1: A simple model of embedded system.(Noergaard, 2005)

Capers Jones, an American specialist in software engineering methodologies and Christof Ebert, a German computer scientist and entrepreneur point out some of the very interesting facts in their research paper "Embedded Software: Facts and Figures." In economic terms, the worldwide market for embedded systems is about 160 billion euros, with an annual growth of 9 percent. In terms of engineering, the volume of embedded software is increasing at 10 to 20 percent depending on the domain and embedded microprocessors account for more than 98 percent of all produced microprocessors. Figure 2 below shows the amount of systems using embedded software per year and the size of the deployed software programs for each of such domains. It clearly shows the upward trend in terms of automotive software which is the focus of this study. (Ebert & Jones, 2009)

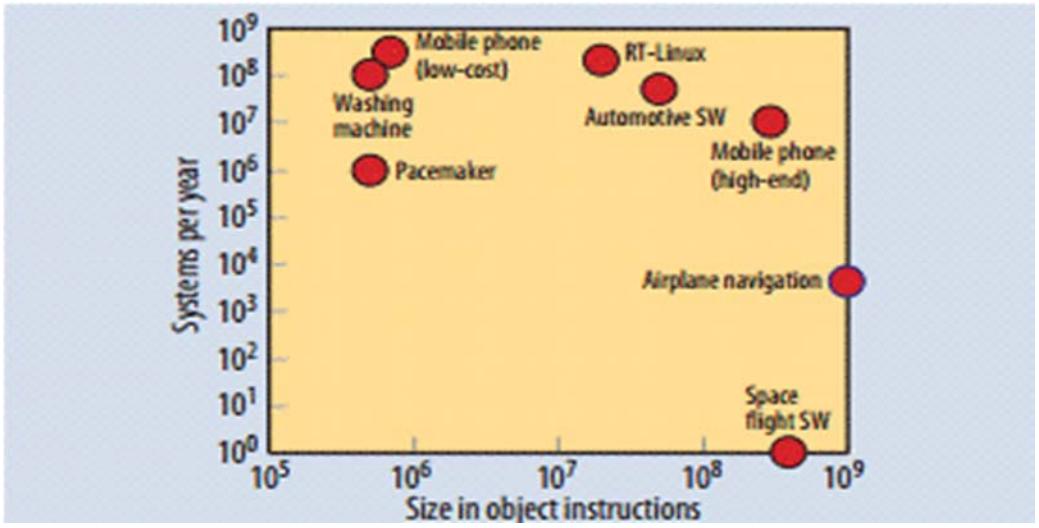


Figure 2: Embedded software size and deployment (Ebert & Jones, 2009)

With the increase in amount of software in these systems its complexity increases considerably. Graph presented in Figure 3, explains such facts about the trend of the complexity of software in various domains. It's the complexity of the automotive software which creates the most fascinating scenario. The increase of complexity further increases the amount of defects in each system. Thereby a considerable increase in chance of having a vehicle with various critical software defects on the field or on the road. Therefore, it becomes very important to verify that systems are established properly to prevent any catastrophic fatalities. Ebert and Jones observed that new cars for instance have around 20 to 70 ECUs with close to 1 Giga Byte of software in a premium car.

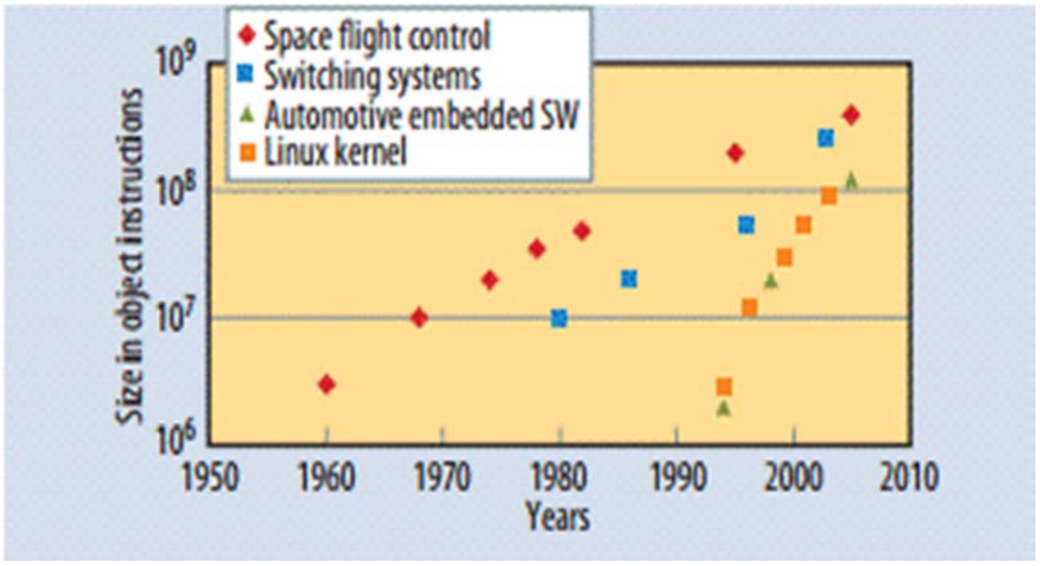


Figure 3: Complexity growth of embedded systems (Ebert & Jones, 2009)

Although model based, Figure 4 shows a typical development process. Dae-Hyun Kum, Joonwoo Son, Seon-bong Lee and Ivan Wilson describe this complete process of developing software for automotive applications effectively. According to their report published in 2006 titled “Automated Testing for Automotive Embedded Systems”:

> Development is started with requirement capturing and analysis. The success of any product development is depending on the creation of clear, complete and unambiguous requirements. Functional model should be created according to the requirement capturing document. The vehicle electronic system is too large to be addressed at a time. So it is often broken down according to the functional groups. Once the main sub-system has been identified, it is ensured that signals for input and output of the system are clearly defined.
>
> Virtual prototype of functional model enables us to test and validate the software functionality without hardware in the early stage. When behavior model is released, ECU software development and network system development are started at the same time. Once the system

design and ECU design have been validated on virtual environment, the designs should be moved into the implementation phase.

Finally all source codes including generated application code, I/0 drivers, communication kernel and operating system code are integrated. After test execution, the test results should be analyzed to unveil the error that caused a test to fail and discovered errors are needed to be fixed. Test results and related information should be documented throughout all test processes. (Kum, Son, Lee & Wilson, 2006, p. 4415)

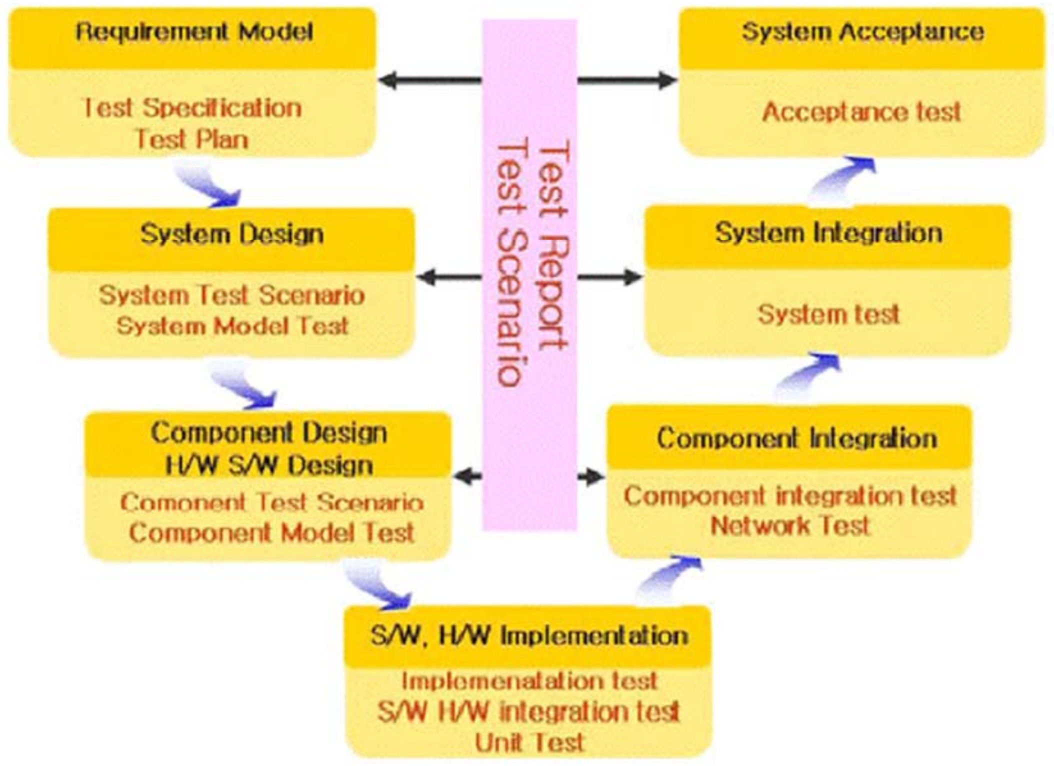


Figure 4: A typical software development process (Kum et al., 2006)

Failures and poor quality in embedded software can sometimes cause death or serious injury. As a result, devices like passenger vehicles and medical instruments have serious liability problems. Therefore highest quality control and testing practices are required in basically all of the domains of software development. NASA’s annual report on Independent Verification and Validation in 2006 pointed out that today, the percentage of software rework can approach 50% for large software projects (NASA, 2006). This has led the manufacturers to look at various practices which help improve quality and reduce costs. One such process is Verification and Validation (V&V), which involves rigorous testing of the product at various stages of its development.

"The correctness of embedded software functionality and performance plays a decisive role in the software quality, software testing is an important mean of software quality assurance."(Qian & Zheng, 2009)

McDonald, Murray, Lindsay and Strooper developed a pilot project for testing embedded software. Stessing on application that are very critical for safety of humans, they suggest to follow a Systematic testing approach. They decribe systematic testing as testing which is "planned, to permit design for testability; documented, so that the test cases can be understood and the adequacy of the test cases can be evaluated (for example, by external auditors or by measuring coverage of the software tested); and repeatable, so that the test cases can be re-executed after changes in the software." (McDonald et al., 2006),

Verification and validation are means by which the product is checked or tested, and by which its performance is demonstrated and assured to be a correct interpretation of the requirements. A continuous process of V&V must be actively applied throughout the software development cycle. (International Atomic Energy Agency, 1999)

“In general terms, verification is a quality control process that is used to evaluate whether or not a product, service, or system complies with regulations, specifications, or conditions imposed at the start of a development phase. Validation, on the other hand, is a quality assurance process of establishing evidence that provides a high degree of assurance that a product, service, or system accomplishes its intended use requirements.” (Maropaulos & Ceglarek, 2010)

Thomas Berling, of Ericsson Microwave Systems AB in Sweden, points out a different thought about verification and validation. According to him, there is a lack, in industry and in the software research community, of efficient and effective system performance validation methods. This is an important area since the cost of system performance validation often is high. The currently used methods in industry are of the engineering type, which means the engineers use the methods they find most appropriate. (Berling, 2003)

Keränen and Räty discuss about Model Based testing in HIL prototoype in their research paper “Model based testing of embedded systems in hardware in the loop environment.” They found that “the enhancement of test automation in HIL environments by using model-based test design and generation relieves manual testing and debugging tasks, which also induces cost savings.” (Keränen & Räty, 2012)

Rex Black, states that to be effective and efficient one has to understand how the testing process works and how it fits in the overall project (Black,2007, P.33). A generic software testing process is as shown in the Figure 5.

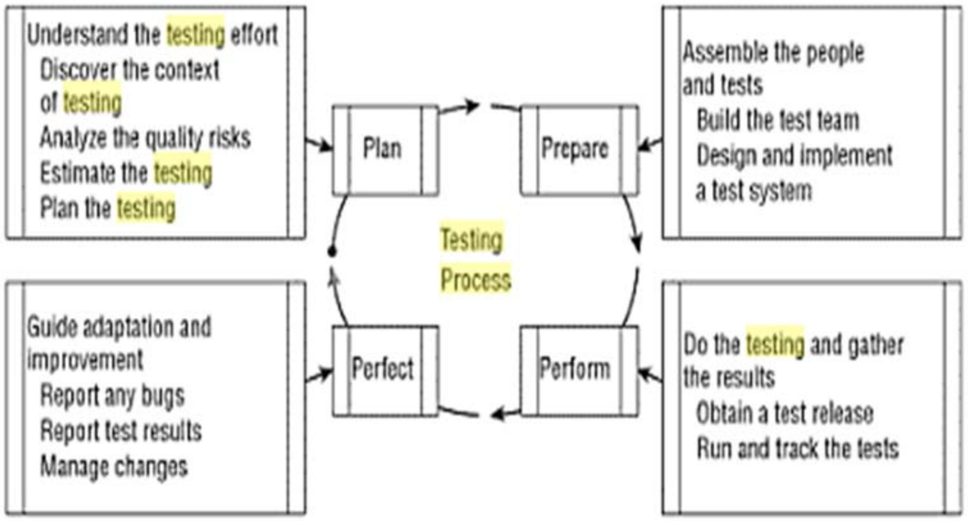

Understand the testing effort
Discover the context of testing
Analyze the quality risks
Estimate the testing
Plan the testing
Plan
Prepare
Assemble the people and tests
Build the test team
Design and implement a test system
Testing Process
Guide adaptation and improvement
Report any bugs
Report test results
Manage changes
Perfect
Perform
Do the testing and gather the results
Obtain a test release
Run and track the tests

Figure 5: A simple testing process (Black, 2007)

In other words, it contains the following basic steps:

1. Understanding the testing effort

In other words the first phase is identifying the testing needs. The purpose of test planning is to find the attributes which qualify as quality attributes of the software under test. Apart from finding the attributes this activity also covers the thoroughness with which the software will be tested, attributes which need or need not be tested. It also addresses the tools required for getting the testing done, manpower involved in testing and various techniques which will be applied to get as much test coverage as possible.

2. Assemble the people and tests

After the identification of the tests to be performed, the techniques which are selected under the first step are then applied to generate the test cases for each attribute. This step basically translates the product design requirements into a set of test cases after the identification of the test scenarios. This step also involves identifying the resources required to run or execute tests and the order in which they should be executed.

3. Testing and gathering results

Once the infrastructure and test cases are defined, the correct steps are defined to execute each test case correctly. Each test case is finally executed according to the defined procedure and tracked for its completion. After the execution of test cases, the results (success or failure) are gathered from all the resources where the tests were executed.

4. Guide adaptation and improvement

This is where the fate of the software product is decided if it is worthy of release or needs further fixes. This step basically captures the test results which are then communicated to the stakeholder with specific focus on the failures and if they are termed as legitimate issues, they are tagged as defects or bugs. A thorough analysis is performed on the performance of the software product under test and decided if it can be release for customer use. Improvements are recommended to the design and development team.

Rex Black, further provides a brief but very critical snap shot of importance of testing. He emphasizes on testing as an investment in quality of the software and uses Jim Campenella's basic technique to analyze cost of quality:

$$C_{quality} = C_{conformance} + C_{non\text{-}conformance}$$

Where,

$C_{quality} =$	Total cost of quality,
$C_{conformance} =$	Total cost of quality assurance to build the software
$C_{non\text{-}conformance} =$	Total cost due to failure of quality assurance

He describes conformance costs as prevention which includes costs involved in quality assurance tasks like code reviews or training for example. Planning test activities, developing test cases and data, and executing the tests identified as appraisal costs. Nonconformance costs are divided into two parts, one is internal when the test failure is detected by the internal teams of either test engineers or programmers themselves. There is always some cost associated with it. It then enters into a find fix, and release software for further testing process.

The second nonconformance cost is external according to Rex Black. He describes these costs as those incurred when, rather than being found internally, the customer or the end product user finds the bug. These are the costs which affect any organization the most. Apart from heavy costs involved in the fix and release process, companies procure intangible costs like angry customer, damage to company image, lost business and even lawsuits. (Black, 2007)

There is another aspect of testing, implementation of test automation tools for performing efficient testing. Fewster's article, "Common mistakes in test automation," highlights some of the common mistakes which organizations make in a bid to automate testing. According to Fewster, the main disadvantage of testing automation was costs, which include implementation costs, maintenance costs, and training costs. Implementation costs included direct investment costs, time, and human resources. Fewster found that if the maintenance of testing automation is ignored, updating an entire automated test suite can cost as much, or even more than the cost of performing all the tests manually. There is a connection between implementation costs and maintenance costs. Figure below implies that if the testing automation system is designed with the minimization of maintenance costs in mind, the implementation costs increase, and vice versa. (Fewster, 2001)

"If we are to minimize the growing test maintenance costs, it is necessary to invest more effort up front implementing automated tests in a way that is designed to avoid maintenance costs rather than avoid implementation costs."(Fewster, 2001, P.4)

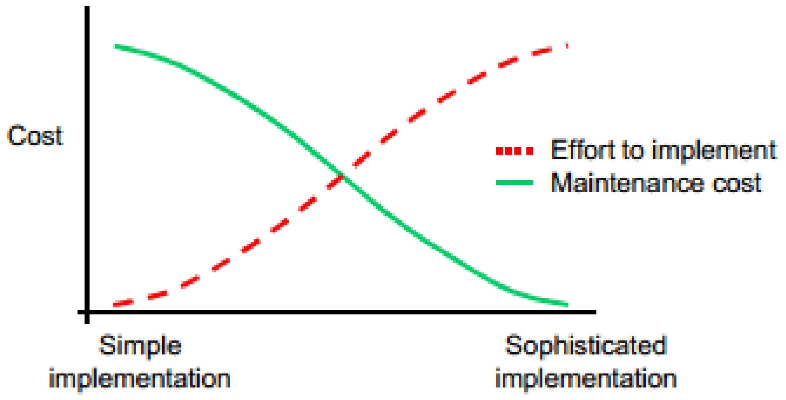


Figure 6: The cost of test maintenance is related to the cost of test implementation (Fewster, 2001)

“Automated software testing may reduce costs and improve quality because of more testing in less time, but it causes new costs in, for example, implementation, maintenance, and training.” (Karhu, Repo & Smolander, 2009)

One of the other fields where reporting is considered even more critical is the field of medical testing. Although used for different scopes, results reporting in medical or electronics field cannot be ignored. Any error in either of the fields can lead to potential danger to life.

“Improving newborn screening laboratory test ordering and result reporting using health information exchange” by Downs et al., focuses on use of electronics results reporting through health information exchange for newborn screening. It highlights that “the problems that are seen with failure to manage and follow-up on routine laboratory results are magnified in newborn screening situation when negative outcomes could be triggered by incomplete reporting, failure to recognize a critical result, and delays in completing the confirmatory or referral process.” (Downs et al., 2010)

Further , the article states that “during the initial screening process electronic data exchange helps to “close the orders loop” and make sure that all infants are tested and that a responsible clinician has looked at the results of the tests. For confirmatory testing, educational materials on the diagnosis and management of rare disorders can be provided along with the results of the test. The results of all hearing and metabolic testing can be brought together to simplify decision-making.” (Downs et al., 2010)

Nguyen, Thorpe, Makki and Mostashari in their article “Benefits and Barriers to Electronic Laboratory Results Reporting for Notifiable Diseases: The New York City Department of Health and Mental Hygiene Experience” found that electronic reporting of results and automatic uploading data improved timeliness as well as eliminated substantial data entry needs. They found that 65% of the 43,568 hepatitis C cases and 52% of the 35,884 chlamydia cases were entered into the health department through electronics reporting which was equal to 47,204 reports that would have been entered manually. Thereby they were able to apply the staff resources in dedicated field work which was more important than entering data. (Nguyen et al., 2007)

The current process seems to be implemented without thorough investigation into the importance of results reporting of automated tests. This study will focus on possible solution to results reporting which seems to be causing the cost overruns in EL PV&V department of the organization under study. This study will introduce few techniques for saving internal costs by improving the process of one of the most neglected but very important area of testing process, test results reporting.

CHAPTER III

METHODOLOGY

This chapter explains the methodology used for this study. The current process of electronics PV&V is studied and a detailed observation of the process from the time software is ready to be tested to being released for user trials is explained. Next, the sub process of results reporting in the current PV&V process is studied deeply and explained in detail with focus on areas which needs improvement.

Further, the chapter discusses the basic structure of a HIL simulator under study, Test Language (TL) which is a scripting language used for automated testing on the HIL simulator. Test Case Data Generation tool which is used to create possible test scenarios for a particular vehicle function is being briefly discussed along with folder structure, sample reports generated at the end of test execution, TL scripts and Macros. The chapter ends with a detailed explanation of the experimental setup and procedure employed during this study.

Electronics PV&V process

Figure 7 below shows the observed process of Electronics PV&V at the organization under study. Once the software is ready for verification and validation, the testing activity is requested by the project expert. The activity request is received by the PV&V assigner who further assigns the activity to activity engineer responsible for the completion of the testing activity. Once the request is received by the activity engineer, it is discussed with the requestor to establish test requirements, formalize acceptance criteria based on the product specification, product use database and organization information systems, and activity deadline is confirmed.

Only when the test requirements, acceptance criteria and deadlines are resolved and agreed upon, the next step is executed. If these items are not resolved, further discussions are held to come to an agreeable resolution. Once all the items are resolved, activity engineer starts developing test plan and procedures or uses the standard template for developing plan. A test schedule and estimation of cost is drawn for the testing activity before execution of tests for the requested product. The complete test procedures are executed as per the plan on various test infrastructures.

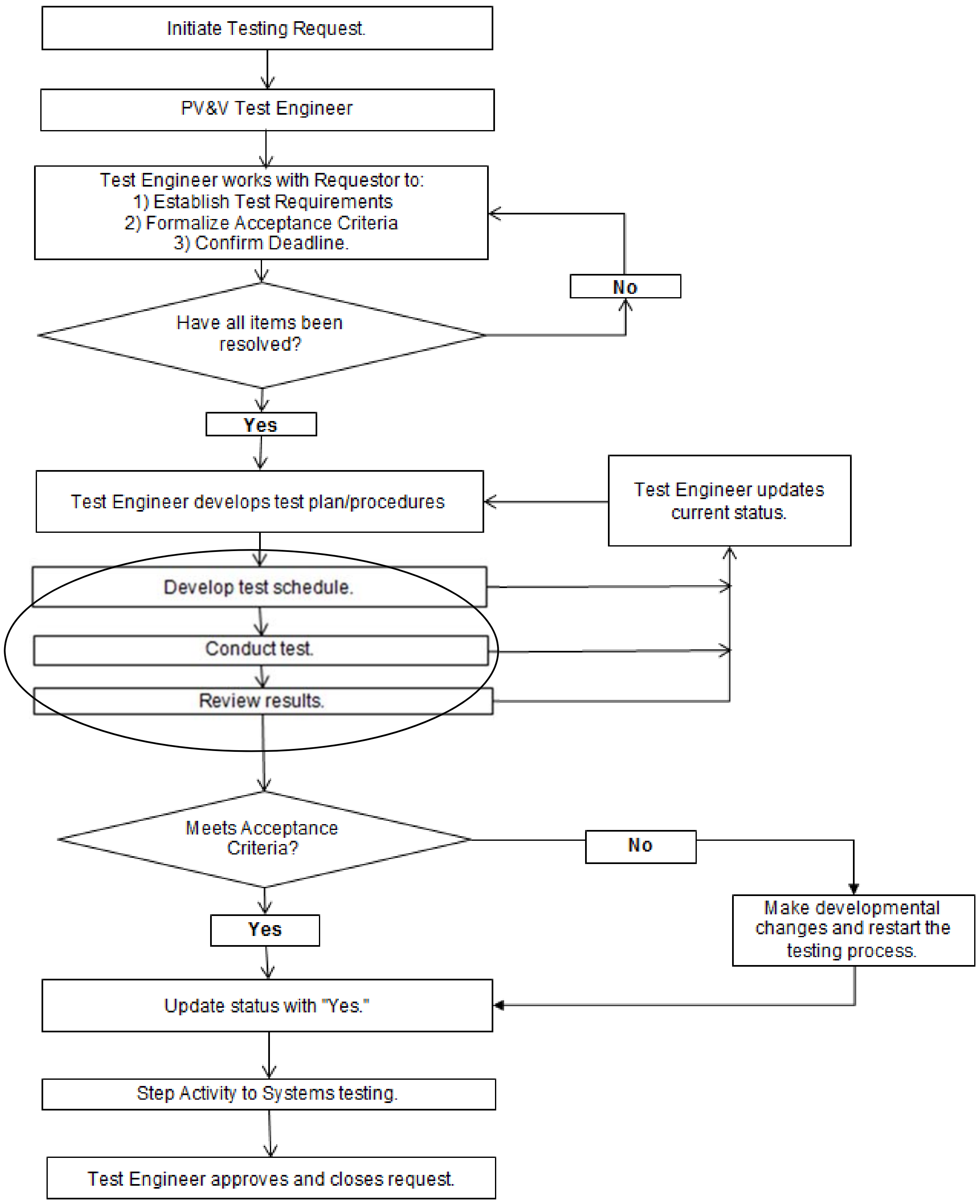

Initiate Testing Request.
PV&V Test Engineer
Test Engineer works with Requestor to:
1) Establish Test Requirements
2) Formalize Acceptance Criteria
3) Confirm Deadline.
Have all items been resolved?
No
Yes
Test Engineer develops test plan/procedures
Test Engineer updates current status.
Develop test schedule.
Conduct test.
Review results.
Meets Acceptance Criteria?
No
Make developmental changes and restart the testing process.
Yes
Update status with "Yes."
Step Activity to Systems testing.
Test Engineer approves and closes request.

Figure 7: Electronics PV&V process.

The testing results are then compared with the acceptance criteria for verification. If the test results meet the acceptance criteria, then the activity status is updated with a “yes” else it is updated with a “no” and supporting results data are attached. Once the supporting data is linked, the activity is forwarded to the reviewer. After the reviewer has reviewed the status and supporting data, the results are forwarded to the requester for their further action.

Current Results Reporting Process

Further focus on the test results reporting process at the organization under study provided further insight into the problem being investigated. Figure 8 below shows the current process of results reporting before being approved or disapproved for release. Once the test procedures are created by the developer and test engineer, whether they will be tested manually or using automated testing tools is decided.

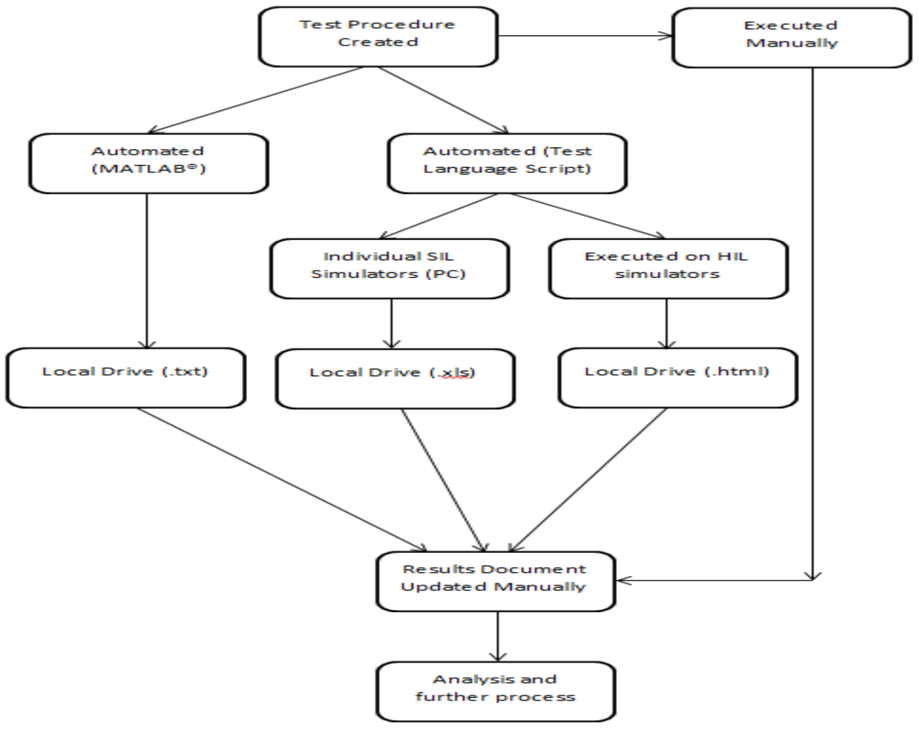

Test Procedure Created
Executed Manually
Automated (MATLAB®)
Automated (Test Language Script)
Individual SIL Simulators (PC)
Executed on HIL simulators
Local Drive (.txt)
Local Drive (.xls)
Local Drive (.html)
Results Document Updated Manually
Analysis and further process

Figure 8: Test results reporting process

Manual test procedures are either tested on the actual vehicle or on the simulators and their results are manually updated in the results reporting Excel file. Automated tests are divided further into two groups. The first group of tests is the ones which can be tested using Matlab or MIL simulated models. The other group utilizes the Test Language scripts for automating the execution which are further executed on the HIL or SIL simulators on individual’s desk. Automated tests executed on the HIL simulators generated reports in “.html” format and are stored in the local hard drive of the simulator PC. The tests executed on the SIL simulators generate reports in “.xls” format which are again stored in the local hard drive. And since the SIL simulator is a portable software package which can be installed on any individual PC, the amount of testing results generated is exponential. Reports generated through these testing methods are further manually searched and inserted into a common test results summary document which is further used for making decision to either accept the features which passed the tests or redevelop the failing features and retest the same.

This study discusses a possible solution called ACRS to organize, track and streamline the current result reporting process. It focuses on providing a solution to make the current process more efficient by saving engineering cost and time. It also discusses some of the other issues related to the security of vital information and the assets where the results are stored. It provides an experimental tool to automate the current reporting process and analyzes the outcome by performing hypothesis testing on the pre and post experiment data.

Hardware in Loop Simulation

The Hardware in Loop simulation system usually consists of the following components:

- A host PC (Operator Interface)
- A mathematical plant model
- Real time Processors and input / Outputs
- Multiple Electronic Control Units (ECU)

A real time processor acts as the main component of the HIL system. It executes most of the system components like logging of data, I/O communication and model execution. This real time system is very important for a successful testing system because it can provide accurate simulation of various pieces of the actual system which are physically present. The Figure 9 below shows the block diagram of a typical HIL system:

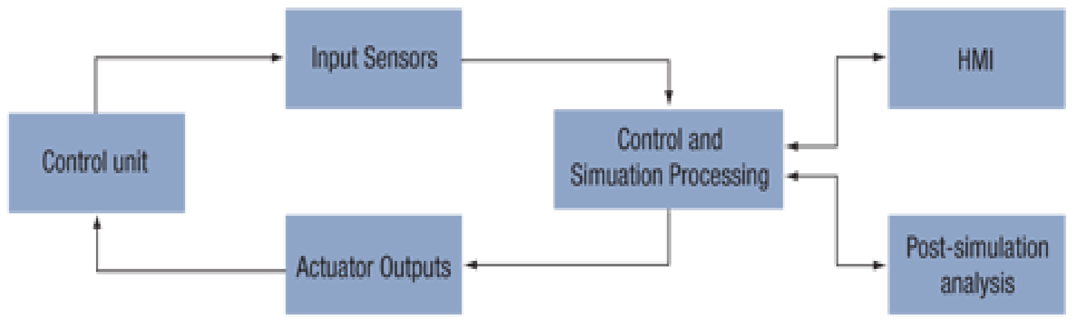


Figure 9. HIL system under investigation (Trimborn, 2005)

There are following main components which make up the HIL system:

HMI: This is the windows PC that runs either the Test System GUI or TL Compiler/TestStand. This PC also processes and stores the result reports after script execution.

Simulation Processing: Labview Real Time PC that runs simulations.

Control Unit: Labview Real Time PC that runs the Data Manager and controls the I/O hardware. This is the main server that is the system backbone.

Test Automation Language: TL

The Figure 10 below is a block diagram of the Test Language under study for automation of the manual tests. The intent of this language is to reduce the amount of time taken to complete some of the laborious manual tests. It has a set of instructions to create simulators and automation as well as manual testing. The TL script will be compiled in a TL Compiler and compiler will create a sequence in TestStand. Compiler used to compile this script detects the errors of invalid commands and notifies the user after aborting the script execution.

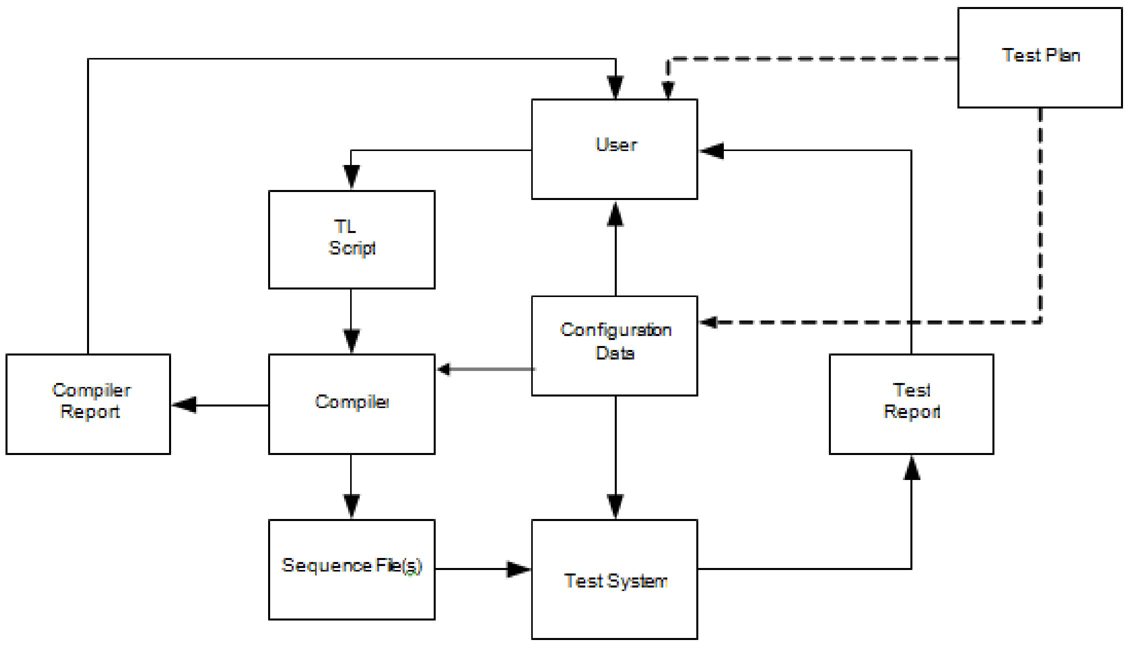


Figure 10. A block diagram of test automation language.

Some of the important components of TL system are:

1. Test Plan: The test plan is created by the user after carefully studying the requirements of the feature of a particular system under test. The test plan contains the date table with the possible test cases which will test each aspect of the requirements. The TL is developed to setup a framework for data driven testing, for re-using common macros without entering any data by hand in the TL script. The difference between the data driven method and the TL template is all of the data for the TL steps is in the Excel file. This data is passed from the Excel file variables to the main TL script FOR loop variables, then to the TL variables.
2. Scripts: The test language uses the script which contains a set of instructions which are fed to the compiler which checks for any errors before converting them to a machine readable format. If there is an error, then the compiler will generate a report for the user describing the location where an error occurred.
3. System Configuration: The system configuration is usually created by the user to mimic different models of the vehicle with different features. The configuration is also read by the compiler to make sure the user has referred the correct configuration in the automation script.
4. Test system: Test system is the back bone of the complete simulator which controls the hardware and I/O. it contains the hardware simulated

sensors and actuators. The compiled instructions are fed to this system for execution.

5. A test report is generated in .html format at the end of each script execution. The report contains the results as passed or failed for each executed instruction. The test reports are stored in the local computer running the user interface at a pre-defined location.

<u>TL Scripts</u>

In progress TL scripts can be located anywhere on the C:\ drive of the windows PC. TL scripts that are working and that need to be archived need to be placed in folder (C:\Testing\Test Scripts)

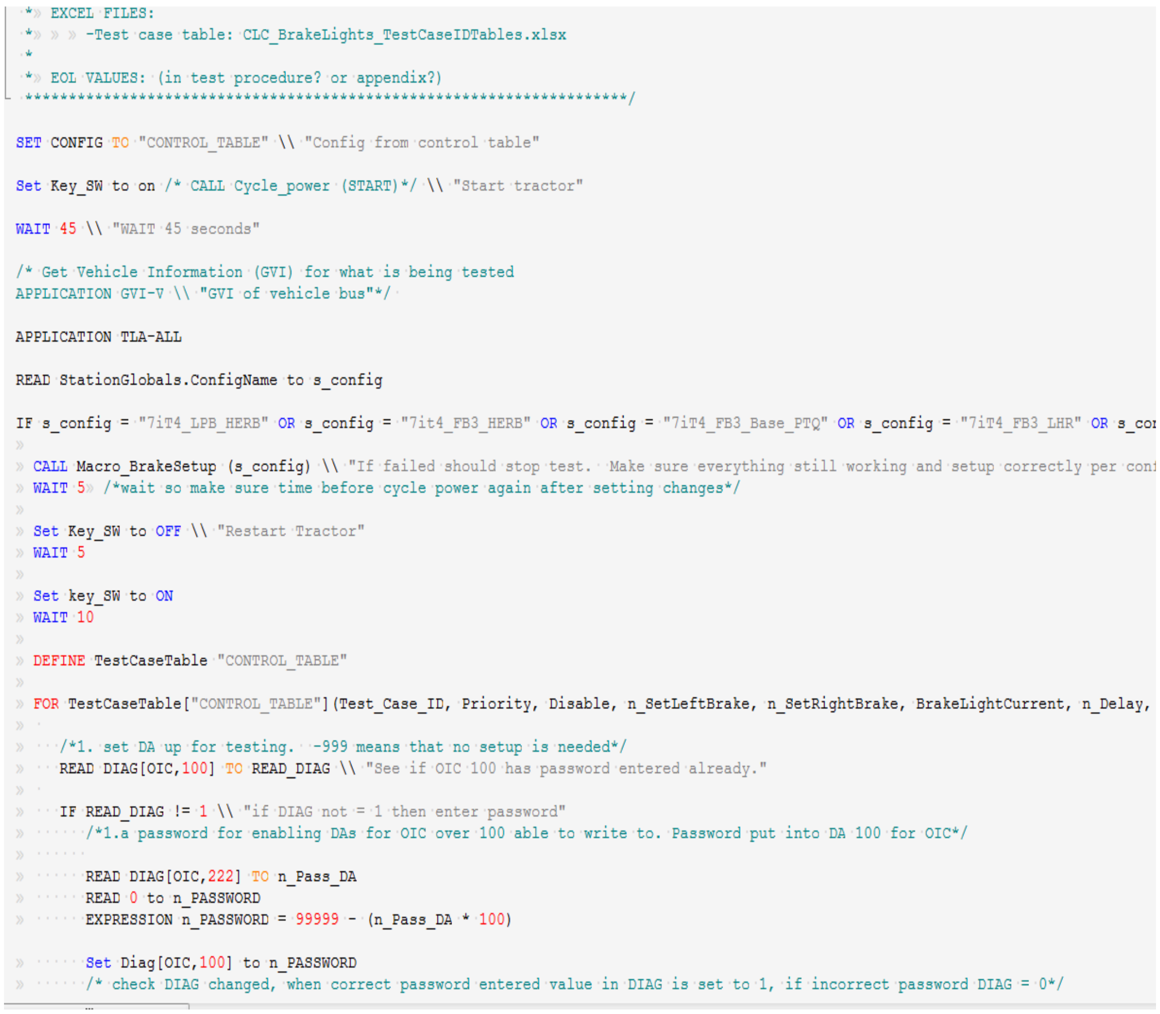
The Test_Data folder is dependencies for the archived scripts. This folder will contain any tables that the scripts use and need to be placed in folder (C:\Testing\Test Scripts\Test_Data).

Figure 11 below demonstrates a sample TL script used in the experiment. It basically consists of three main components: command, operator control / identifier and Value. Once compiled, Command instructs the real time machine to perform a certain task on the Identifier specified in the syntax of the instruction.

Syntax format:

<Command> <IDENTIFIER> TO <VALUE> <Optional commands>

Identifier can be a “signal,” “CAN” message or any other operator control defined by TL enterprise document.



```
 *   EXCEL FILES:
 *           -Test case table: CLC_BrakeLights_TestCaseIDTables.xlsx
 *
 *   EOL VALUES: (in test procedure? or appendix?)
 *******************************************************************/

SET CONFIG TO "CONTROL_TABLE" \\ "Config from control table"

Set Key_SW to on /* CALL Cycle_power (START)*/ \\ "Start tractor"

WAIT 45 \\ "WAIT 45 seconds"

/* Get Vehicle Information (GVI) for what is being tested
APPLICATION GVI-V \\ "GVI of vehicle bus"*/

APPLICATION TLA-ALL

READ StationGlobals.ConfigName to s_config

IF s_config = "7iT4_LPB_HERB" OR s_config = "7it4_FB3_HERB" OR s_config = "7iT4_FB3_Base_PTQ" OR s_config = "7iT4_FB3_LHR" OR s_co

    CALL Macro_BrakeSetup (s_config) \\ "If failed should stop test.  Make sure everything still working and setup correctly per con
    WAIT 5    /*wait so make sure time before cycle power again after setting changes*/

    Set Key_SW to OFF \\ "Restart Tractor"
    WAIT 5

    Set key_SW to ON
    WAIT 10

    DEFINE TestCaseTable "CONTROL_TABLE"

    FOR TestCaseTable["CONTROL_TABLE"](Test_Case_ID, Priority, Disable, n_SetLeftBrake, n_SetRightBrake, BrakeLightCurrent, n_Delay,

      /*1. set DA up for testing.  -999 means that no setup is needed*/
      READ DIAG[OIC,100] TO READ_DIAG \\ "See if OIC 100 has password entered already."

      IF READ_DIAG != 1 \\ "if DIAG not = 1 then enter password"
         /*1.a password for enabling DAs for OIC over 100 able to write to. Password put into DA 100 for OIC*/

         READ DIAG[OIC,222] TO n_Pass_DA
         READ 0 to n_PASSWORD
         EXPRESSION n_PASSWORD = 99999 - (n_Pass_DA * 100)

         Set Diag[OIC,100] to n_PASSWORD
         /* check DIAG changed, when correct password entered value in DIAG is set to 1, if incorrect password DIAG = 0*/
```

Figure 11: Sample TL Script

TL Macros

Common functions which are used multiple times in a script or by different scripts which utilize these functions are saved as Macros. These macros are called during the main script execution to verify that certain functionality of the software is still intact. TL macros can be placed in 3 locations:

1) C:\Projects\Lib\Macros – This location is for common macros for all

systems.

2) C:\Projects\Testing\Library\TL\Macros – This location is for system specific and test macros.
3) The folder or any sub-folder of where the main TL script file is – This location is for script specific macros.

The Teststand sequence file created from all of these macro locations will be created the same way as the main script sequence. It is created in a sub-folder of the sequences to be created by the compiler called Macros. The script or macro filename should have the *.tl extension to be classified as TL script. The name of the file could be anything unless the file is a macro file then the name should match the macro name defined in the file.

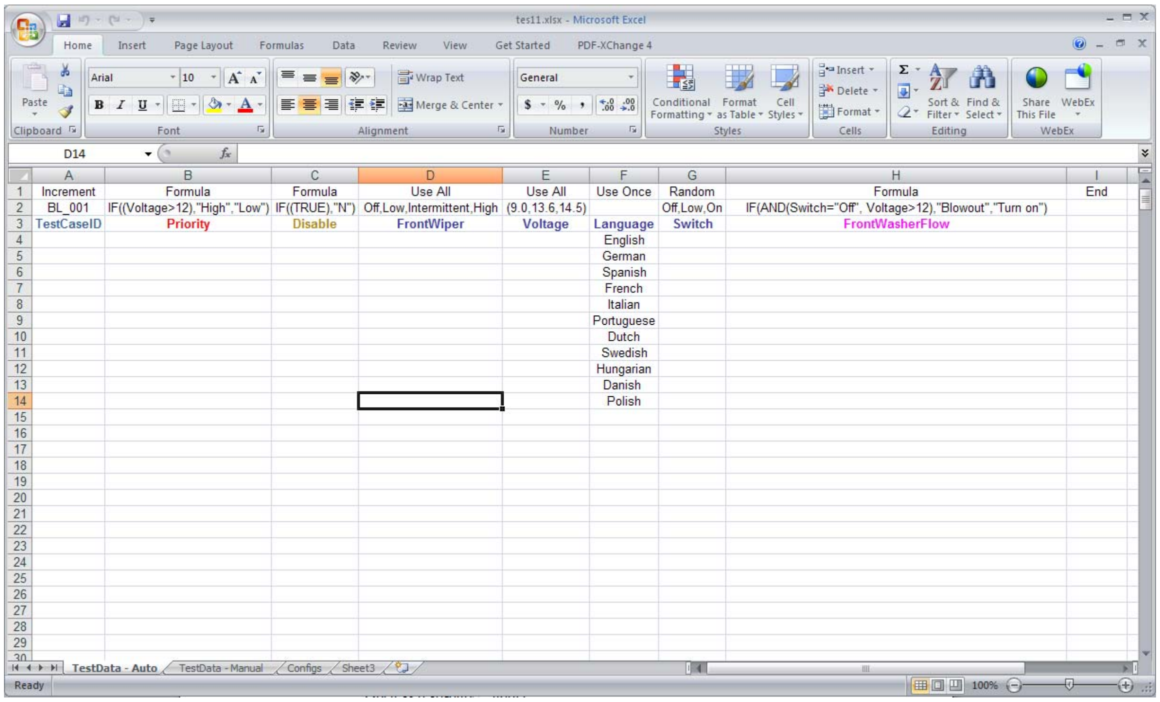
MACRO SetTemp (tempValue)

END MACRO

For example, a file containing the above sequence of instructions must be named “SetTemp.jdctl”

Test Case Data Generation Tool

The test case data generation tool uses the data driven testing approach. This tool allows the user to automatically generate test cases of the requirement from a modified Excel file. It creates the Excel file test cases automatically for the user. With this tool the user still has to create the CTL script. The modified Excel file in Figure 12 uses keywords (i.e. increment, formula, use all, etc.), input data, and headers to generate the test cases. The input data is populated in each column based on what the keyword is. The user interface used to run this tool is shown in Figure 13. It allows the user to select a file path to load the modified Excel file from and a path to save the new table to. When the tool is executed, the output in Figure 14 will be generated.



	A	B	C	D	E	F	G	H	I
1	Increment	Formula	Formula	Use All	Use All	Use Once	Random	Formula	End
2	BL_001	IF((Voltage>12),"High","Low")	IF((TRUE),"N")	Off,Low,Intermittent,High	(9.0,13.6,14.5)		Off,Low,On	IF(AND(Switch="Off", Voltage>12),"Blowout","Turn on")	
3	TestCaseID	Priority	Disable	FrontWiper	Voltage	Language	Switch	FrontWasherFlow	
4						English			
5						German			
6						Spanish			
7						French			
8						Italian			
9						Portuguese			
10						Dutch			
11						Swedish			
12						Hungarian			
13						Danish			
14						Polish			

Figure 12. Modified Excel file

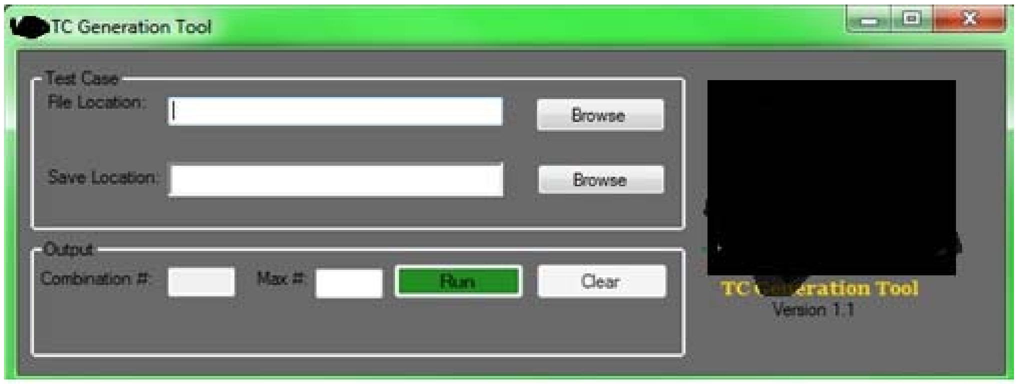
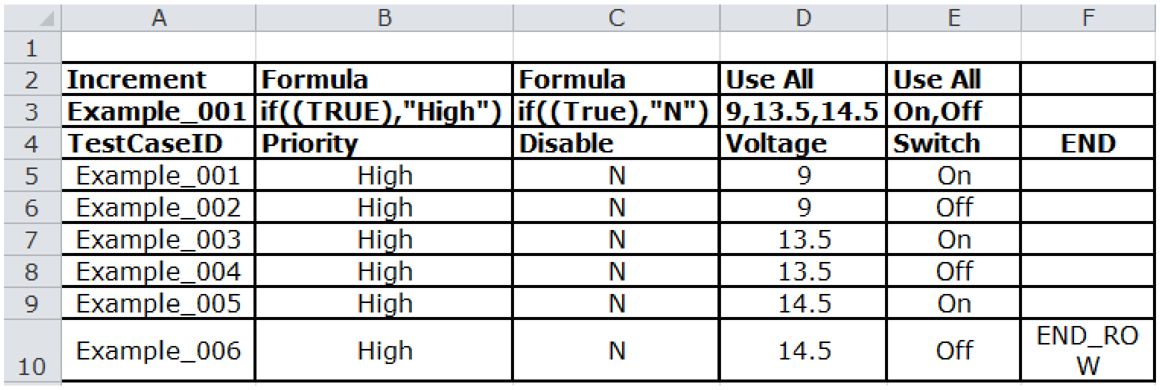


Figure 13. Test case generation tool

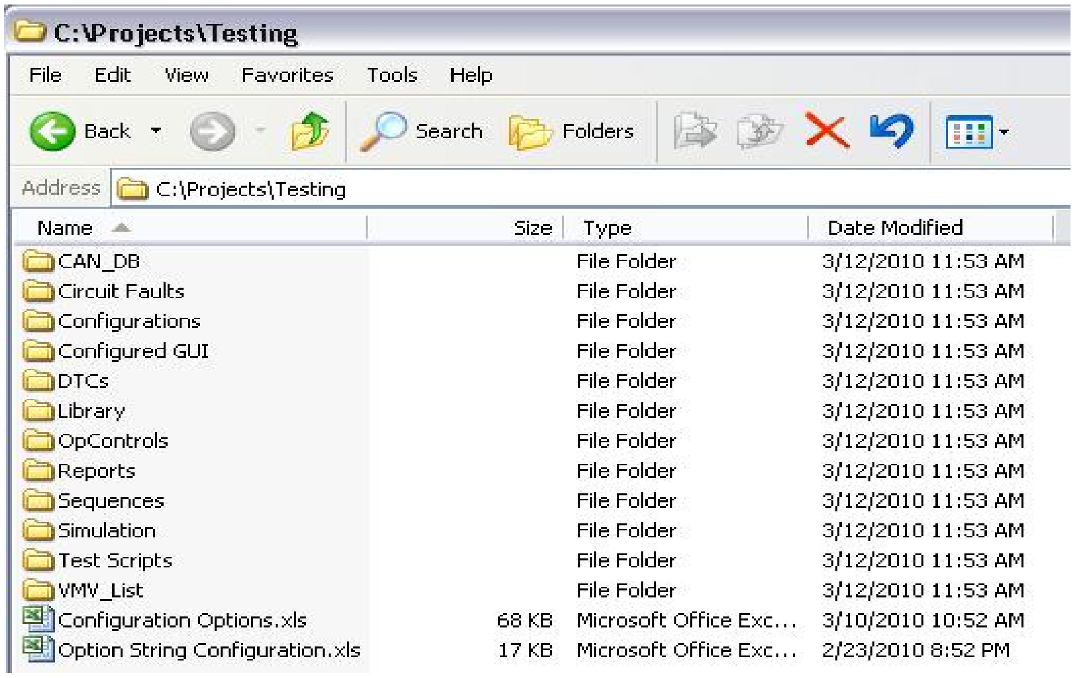


	A	B	C	D	E	F
1						
2	**Increment**	**Formula**	**Formula**	**Use All**	**Use All**	
3	**Example_001**	**if((TRUE),"High")**	**if((True),"N")**	**9,13.5,14.5**	**On,Off**	
4	**TestCaseID**	**Priority**	**Disable**	**Voltage**	**Switch**	**END**
5	Example_001	High	N	9	On	
6	Example_002	High	N	9	Off	
7	Example_003	High	N	13.5	On	
8	Example_004	High	N	13.5	Off	
9	Example_005	High	N	14.5	On	
10	Example_006	High	N	14.5	Off	END_ROW

Figure 14. A sample auto generated test case Excel document

Folder Structure

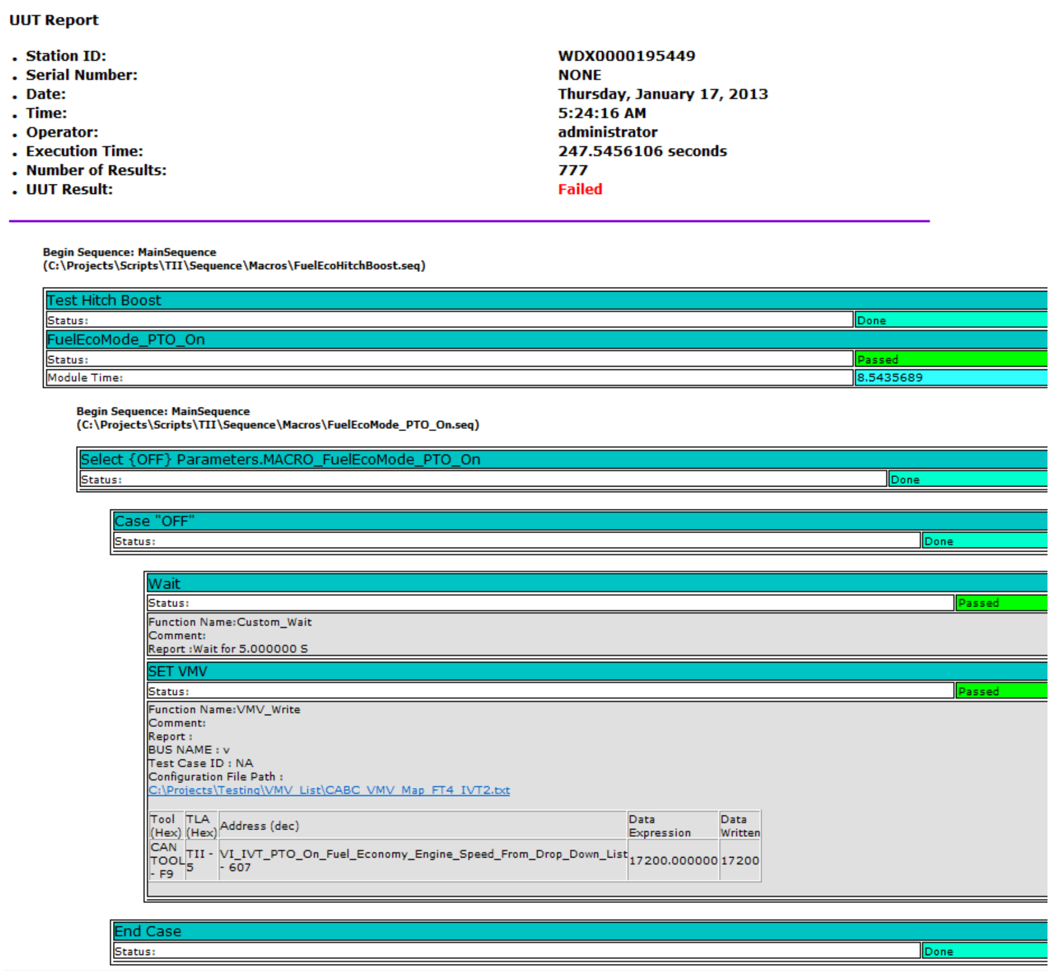
Figure 15 shows the folder structure which contains all of the test system configuration files, support files, TL report files, TL library files, and TL macro files.



Name	Size	Type	Date Modified
CAN_DB		File Folder	3/12/2010 11:53 AM
Circuit Faults		File Folder	3/12/2010 11:53 AM
Configurations		File Folder	3/12/2010 11:53 AM
Configured GUI		File Folder	3/12/2010 11:53 AM
DTCs		File Folder	3/12/2010 11:53 AM
Library		File Folder	3/12/2010 11:53 AM
OpControls		File Folder	3/12/2010 11:53 AM
Reports		File Folder	3/12/2010 11:53 AM
Sequences		File Folder	3/12/2010 11:53 AM
Simulation		File Folder	3/12/2010 11:53 AM
Test Scripts		File Folder	3/12/2010 11:53 AM
VMV_List		File Folder	3/12/2010 11:53 AM
Configuration Options.xls	68 KB	Microsoft Office Exc...	3/10/2010 10:52 AM
Option String Configuration.xls	17 KB	Microsoft Office Exc...	2/23/2010 8:52 PM

Figure 15: Folder Structure on Simulator hard drive

The report folder is located under the “c:\Projects\Testing\.” Once the execution of any TL script is completed, a results report is generated in “.html” format. This report contains results (passed/fail) for each and every command in every macro executed in the process of testing a feature. A sample report is shown in Figure 16 below. The report is stored under the subsequence subfolder of the main folder which contains the name of the “main” script. It can be a table which contains a queue or list of all the feature scripts to be executed or it can be a main script which performs subroutine calls to various macros.



UUT Report

Station ID:	WDX0000195449
Serial Number:	NONE
Date:	Thursday, January 17, 2013
Time:	5:24:16 AM
Operator:	administrator
Execution Time:	247.5456106 seconds
Number of Results:	777
UUT Result:	Failed

Begin Sequence: MainSequence
(C:\Projects\Scripts\TII\Sequence\Macros\FuelEcoHitchBoost.seq)

Test Hitch Boost

Status:	Done

FuelEcoMode_PTO_On

Status:	Passed
Module Time:	8.5435689

Begin Sequence: MainSequence
(C:\Projects\Scripts\TII\Sequence\Macros\FuelEcoMode_PTO_On.seq)

Select {OFF} Parameters.MACRO_FuelEcoMode_PTO_On

Status:	Done

Case "OFF"

Status:	Done

Wait

Status:	Passed

Function Name:Custom_Wait
Comment:
Report :Wait for 5.000000 S

SET VMV

Status:	Passed

Function Name:VMV_Write
Comment:
Report :
BUS NAME : v
Test Case ID : NA
Configuration File Path :
C:\Projects\Testing\VMV_List\CABC_VMV_Map_FT4_IVT2.txt

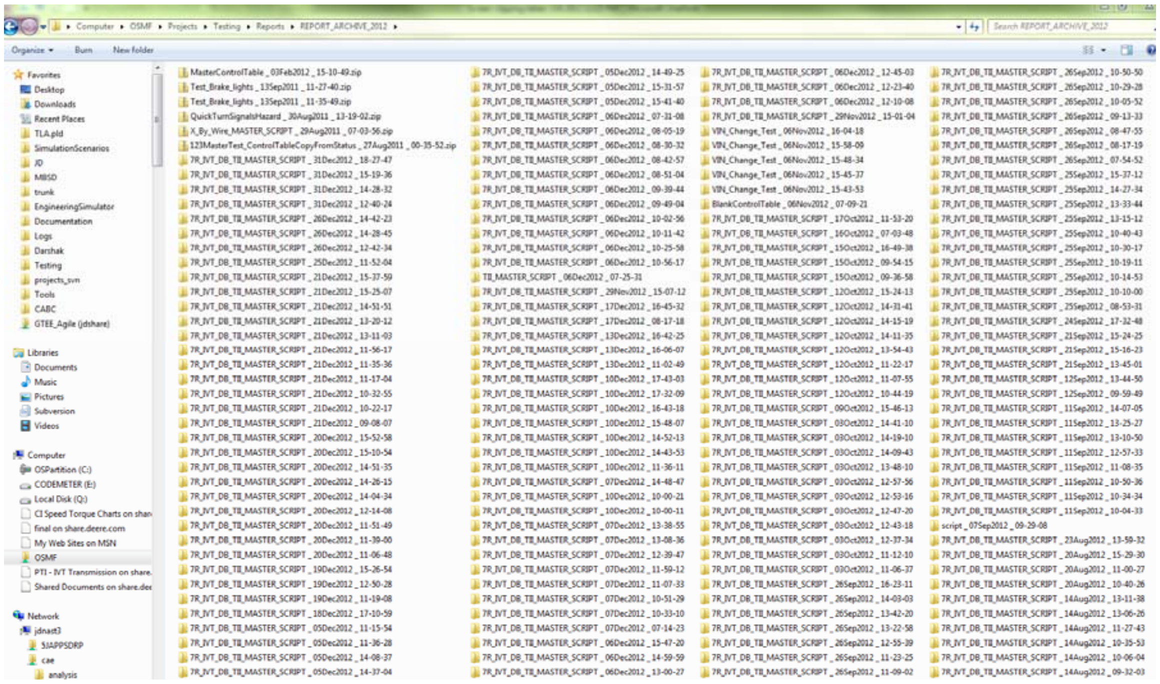
Tool (Hex)	TLA (Hex)	Address (dec)	Data Expression	Data Written
CAN TOOL - F9	TII - 5	VI_IVT_PTO_On_Fuel_Economy_Engine_Speed_From_Drop_Down_List - 607	17200.000000	17200

End Case

Status:	Done

Figure 16. A sample report generated at the end of script execution

Figure 17 below shows a snapshot of the "reports" folder containing hundreds of reports generated after the automated script execution. The amount of reports generated is visible in the snapshot, and since the naming conventions are similar for most of the folders, searching a particular report becomes very difficult. The Figure 17 shows a long list of folders with similar name but different time stamps indicating the number of times a particular script is executed.



```
MasterControlTable _ 03Feb2012 _ 15-10-49.zip
Test_Brake_lights _ 13Sep2011 _ 11-27-40.zip
Test_Brake_lights _ 13Sep2011 _ 11-35-49.zip
QuickTurnSignalsHazard _ 30Aug2011 _ 13-19-02.zip
X_By_Wire_MASTER_SCRIPT _ 29Aug2011 _ 07-03-56.zip
123MasterTest_ControlTableCopyFromStatus _ 27Aug2011 _ 00-35-52.zip
7R_IVT_DB_TII_MASTER_SCRIPT _ 31Dec2012 _ 18-27-47
7R_IVT_DB_TII_MASTER_SCRIPT _ 31Dec2012 _ 15-19-36
7R_IVT_DB_TII_MASTER_SCRIPT _ 31Dec2012 _ 14-28-32
7R_IVT_DB_TII_MASTER_SCRIPT _ 31Dec2012 _ 12-40-24
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Dec2012 _ 14-42-23
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Dec2012 _ 14-28-45
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Dec2012 _ 12-42-34
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Dec2012 _ 11-52-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 15-37-59
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 15-25-07
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 14-51-51
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 13-20-12
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 13-11-03
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 11-56-17
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 11-35-36
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 11-17-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 10-32-55
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 10-22-17
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Dec2012 _ 09-08-07
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 15-52-58
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 15-10-54
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 14-51-35
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 14-26-15
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 14-04-34
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 12-14-08
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 11-51-49
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 11-39-00
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Dec2012 _ 11-06-48
7R_IVT_DB_TII_MASTER_SCRIPT _ 19Dec2012 _ 15-26-54
7R_IVT_DB_TII_MASTER_SCRIPT _ 19Dec2012 _ 12-50-28
7R_IVT_DB_TII_MASTER_SCRIPT _ 19Dec2012 _ 11-19-08
7R_IVT_DB_TII_MASTER_SCRIPT _ 18Dec2012 _ 17-10-59
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 11-15-54
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 11-36-28
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 14-08-37
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 14-37-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 14-49-25
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 15-31-57
7R_IVT_DB_TII_MASTER_SCRIPT _ 05Dec2012 _ 15-41-40
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 07-31-08
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 08-05-19
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 08-30-32
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 08-42-57
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 08-51-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 09-39-44
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 09-49-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 10-02-56
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 10-11-42
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 10-25-58
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 10-56-17
TII_MASTER_SCRIPT _ 06Dec2012 _ 07-25-31
7R_IVT_DB_TII_MASTER_SCRIPT _ 29Nov2012 _ 15-07-12
7R_IVT_DB_TII_MASTER_SCRIPT _ 17Dec2012 _ 16-45-32
7R_IVT_DB_TII_MASTER_SCRIPT _ 17Dec2012 _ 08-17-18
7R_IVT_DB_TII_MASTER_SCRIPT _ 13Dec2012 _ 16-42-25
7R_IVT_DB_TII_MASTER_SCRIPT _ 13Dec2012 _ 16-06-07
7R_IVT_DB_TII_MASTER_SCRIPT _ 13Dec2012 _ 11-02-49
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 17-43-03
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 17-32-09
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 16-43-18
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 15-48-07
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 14-52-13
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 14-43-53
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 11-36-11
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 14-48-47
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 10-00-21
7R_IVT_DB_TII_MASTER_SCRIPT _ 10Dec2012 _ 10-00-11
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 13-38-55
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 13-08-36
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 12-39-47
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 11-59-12
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 11-07-33
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 10-51-29
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 10-33-10
7R_IVT_DB_TII_MASTER_SCRIPT _ 07Dec2012 _ 07-14-23
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 15-47-20
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 14-59-59
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 13-00-27
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 12-45-03
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 12-23-40
7R_IVT_DB_TII_MASTER_SCRIPT _ 06Dec2012 _ 12-10-08
7R_IVT_DB_TII_MASTER_SCRIPT _ 29Nov2012 _ 15-01-04
VIN_Change_Test _ 06Nov2012 _ 16-04-18
VIN_Change_Test _ 06Nov2012 _ 15-58-09
VIN_Change_Test _ 06Nov2012 _ 15-48-34
VIN_Change_Test _ 06Nov2012 _ 15-45-37
VIN_Change_Test _ 06Nov2012 _ 15-43-53
BlankControlTable _ 06Nov2012 _ 07-09-21
7R_IVT_DB_TII_MASTER_SCRIPT _ 17Oct2012 _ 11-53-20
7R_IVT_DB_TII_MASTER_SCRIPT _ 16Oct2012 _ 07-03-48
7R_IVT_DB_TII_MASTER_SCRIPT _ 15Oct2012 _ 16-49-38
7R_IVT_DB_TII_MASTER_SCRIPT _ 15Oct2012 _ 09-54-15
7R_IVT_DB_TII_MASTER_SCRIPT _ 15Oct2012 _ 09-36-58
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 15-24-13
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 14-31-41
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 14-15-19
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 14-11-35
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 13-54-43
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 11-22-17
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 11-07-55
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Oct2012 _ 10-44-19
7R_IVT_DB_TII_MASTER_SCRIPT _ 09Oct2012 _ 15-46-13
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 14-41-10
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 14-19-10
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 14-09-43
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 13-48-10
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 12-57-56
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 12-53-16
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 12-47-20
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 12-43-18
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 12-37-34
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 11-12-10
7R_IVT_DB_TII_MASTER_SCRIPT _ 03Oct2012 _ 11-06-37
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 16-23-11
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 14-03-03
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 13-42-20
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 13-22-58
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 12-55-39
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 11-23-25
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 11-09-02
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 10-50-50
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 10-29-28
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 10-05-52
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 09-13-33
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 08-47-55
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 08-17-19
7R_IVT_DB_TII_MASTER_SCRIPT _ 26Sep2012 _ 07-54-52
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 15-37-12
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 14-27-34
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 13-33-44
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 13-15-12
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 10-40-43
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 10-30-17
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 10-19-11
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 10-14-53
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 10-10-00
7R_IVT_DB_TII_MASTER_SCRIPT _ 25Sep2012 _ 08-53-31
7R_IVT_DB_TII_MASTER_SCRIPT _ 24Sep2012 _ 17-32-48
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Sep2012 _ 15-24-25
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Sep2012 _ 15-16-23
7R_IVT_DB_TII_MASTER_SCRIPT _ 21Sep2012 _ 13-45-01
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Sep2012 _ 13-44-50
7R_IVT_DB_TII_MASTER_SCRIPT _ 12Sep2012 _ 09-59-49
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 14-07-05
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 13-25-27
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 13-10-50
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 12-57-33
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 11-08-35
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 10-50-36
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 10-34-34
7R_IVT_DB_TII_MASTER_SCRIPT _ 11Sep2012 _ 10-04-33
script _ 07Sep2012 _ 09-29-08
7R_IVT_DB_TII_MASTER_SCRIPT _ 23Aug2012 _ 13-59-32
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Aug2012 _ 15-29-30
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Aug2012 _ 11-00-27
7R_IVT_DB_TII_MASTER_SCRIPT _ 20Aug2012 _ 10-40-26
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 13-11-38
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 13-06-26
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 11-27-43
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 10-35-53
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 10-06-04
7R_IVT_DB_TII_MASTER_SCRIPT _ 14Aug2012 _ 09-32-03
```

Figure 17: A screen shot of Reports folder

<u>The Experiment Setup</u>

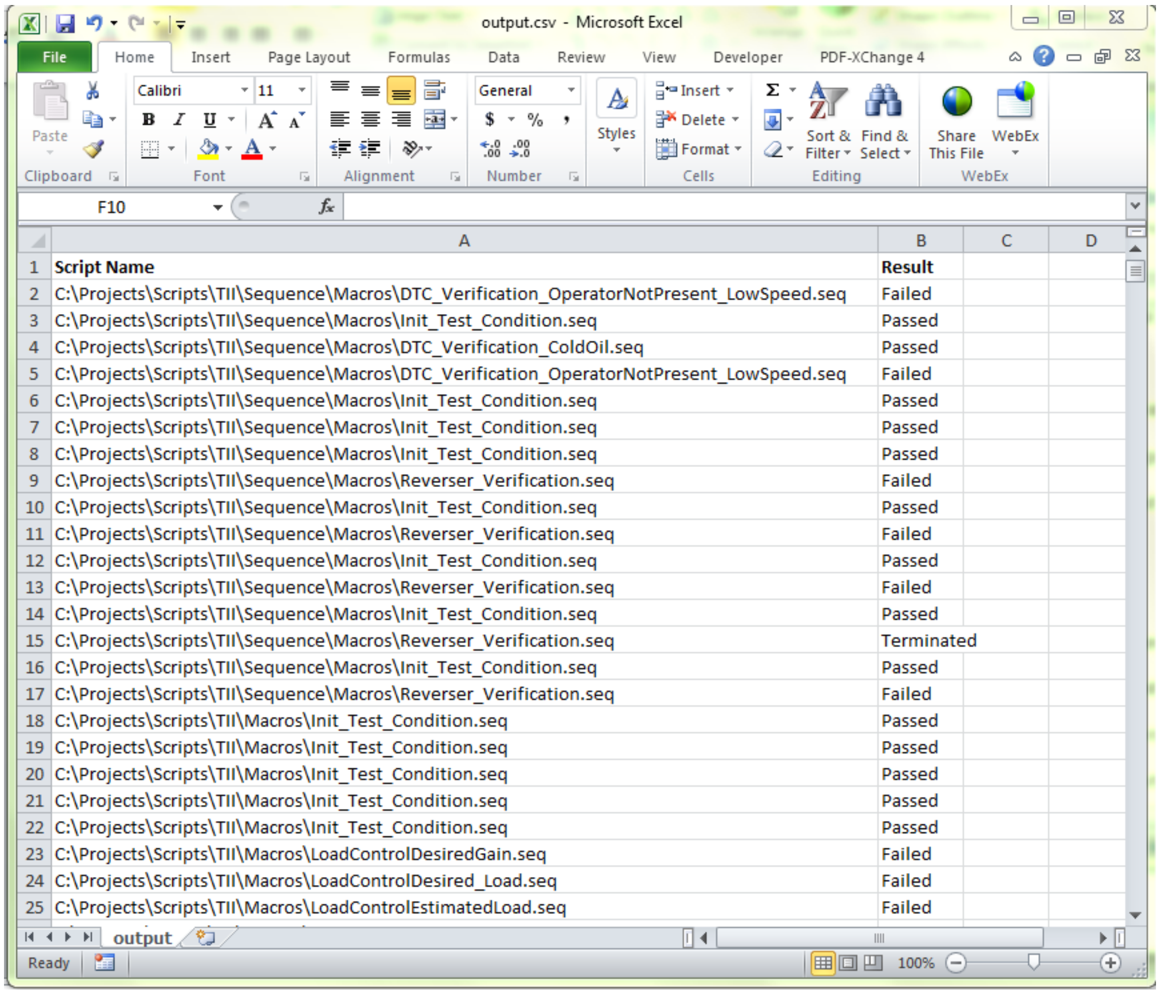
An experiment was designed to test and prove the effectiveness of an automated process for results reporting in a PV&V process. A study was conducted to search all the software development teams. It was found that there are 6 teams which utilize HIL simulators to test their software against limited hardware for functional testing. One of the software development teams in the organization which utilizes the HIL simulators for automated testing was randomly selected. 10 automated tests were chosen randomly from the total of approximately 151 automated TL scripts which were executed by the team for testing various features of their subsystem. These automated tests were executed by the team between the months of June 2012 to September 2013.

A simple prototype tool was designed and developed using the “PERL” scripting language. “PERL” scripting language was used because of its following features:

1. Perl is available for most of the platforms like Windows, UNIX, MS-DOS and Macintosh.
2. There is no cost associated with it.
3. Perl can be acquired from many sources.
4. Easy to use instruction set compared to other programming languages.

The tool would search through a reports folder path where all the reports generated at the end of automated script executions are stored. The tool would look for all the files with “.html” extension under the “subsequence” subfolder of “reports” folder. Once it finds a file with “.html” format, it further searches through each line of the source code for that particular file and looks for all the TL instructions. The tool then compares the results of each of the instructions found with “Passed,” “Failed” and “Terminated” strings until it reaches the end of line. It continues the search until it reaches end of the page. Once it reaches at the end of page, the control exits out of that file and starts searching for next “.html” file. It repeats the process until it is not able to find any further “.html” files.

Once done parsing the instructions and its associated results, the tool would generate a spread sheet as shown in the Figure 18 below with either ".xls" or ".csv" extension which can be further uploaded to the local company servers.



	A	B
1	**Script Name**	**Result**
2	C:\Projects\Scripts\TII\Sequence\Macros\DTC_Verification_OperatorNotPresent_LowSpeed.seq	Failed
3	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
4	C:\Projects\Scripts\TII\Sequence\Macros\DTC_Verification_ColdOil.seq	Passed
5	C:\Projects\Scripts\TII\Sequence\Macros\DTC_Verification_OperatorNotPresent_LowSpeed.seq	Failed
6	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
7	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
8	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
9	C:\Projects\Scripts\TII\Sequence\Macros\Reverser_Verification.seq	Failed
10	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
11	C:\Projects\Scripts\TII\Sequence\Macros\Reverser_Verification.seq	Failed
12	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
13	C:\Projects\Scripts\TII\Sequence\Macros\Reverser_Verification.seq	Failed
14	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
15	C:\Projects\Scripts\TII\Sequence\Macros\Reverser_Verification.seq	Terminated
16	C:\Projects\Scripts\TII\Sequence\Macros\Init_Test_Condition.seq	Passed
17	C:\Projects\Scripts\TII\Sequence\Macros\Reverser_Verification.seq	Failed
18	C:\Projects\Scripts\TII\Macros\Init_Test_Condition.seq	Passed
19	C:\Projects\Scripts\TII\Macros\Init_Test_Condition.seq	Passed
20	C:\Projects\Scripts\TII\Macros\Init_Test_Condition.seq	Passed
21	C:\Projects\Scripts\TII\Macros\Init_Test_Condition.seq	Passed
22	C:\Projects\Scripts\TII\Macros\Init_Test_Condition.seq	Passed
23	C:\Projects\Scripts\TII\Macros\LoadControlDesiredGain.seq	Failed
24	C:\Projects\Scripts\TII\Macros\LoadControlDesired_Load.seq	Failed
25	C:\Projects\Scripts\TII\Macros\LoadControlEstimatedLoad.seq	Failed

Figure 18: Sample output generated after executing the prototype tool.

<u>Experimental Procedure</u>

Ten automated test procedures scripted in TL were randomly selected from a list of 151 automated test procedures used by a single team utilizing one of the HIL simulators. One Engineer was selected randomly out of the six available engineers from the selected team. The Engineer was requested to search for exactly five reports generated for the selected automated tests from the “Reports” folder which contained hundreds of folders and subfolders with reports of various tests. Time taken by the engineer to search and manually update results for each automated test was recorded from a digital stop watch. An average of total time taken to search one report was calculated based on calculated average time taken to search each report.

To limit human error of recording times taken for searching results, the subject was requested to perform search at random work hours in the day like early morning, before lunch break, after lunch break and just before end of the working day. The different times of the day were chosen because the subject might be in different state of mind at different times of the day to resemble sometimes light and sometimes a little heavy work load. The number of searches was limited to maximum of 5 searches at one time to reduce fatigue.

The prototype tool developed to automate the reporting process was then executed on the same folder. Once the execution was complete, the excel file generated as a result of the tool execution was provided to the Test Engineer and requested to search for the result reports for the test procedures sample. The time taken for the Engineer to search the results was then recorded and average time was calculated. The calculated mean was then used to perform Hypothesis testing to prove the effectiveness of new process.

CHAPTER IV

FINDINGS AND DISCUSSION

Results and Discussion

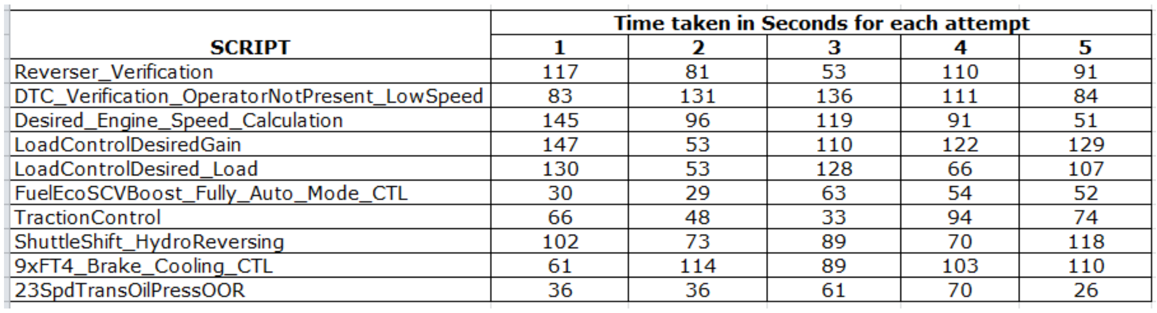
To validate the proposed automated results reporting in the process of PV&V at the organization of study, two series of experiments were conducted on 10 randomly selected automated test scripts. The sample of 10 scripts was collected using Random sampling method. All the scripts were numbered from 1 to 151. The "RANDBETWEEN" function of Excel spread sheet software was used to determine 10 random numbers between 1 and 151. The 10 scripts associated with the numbers were selected as sample.

In the first series of experiment, the Test Engineer was requested to search for exactly five reports generated for the selected automated tests from the "Reports" folder containing reports of various tests. The Engineer was asked to search the results at random times of working hours like early in the morning straight after the Engineer arrived at work, right before lunch, straight after lunch, right before end of the working hours and randomly in the middle of other work. Time taken by the engineer to search and manually update results for each automated test was recorded. In the second series, the prototyped tool was executed and the Test Engineer was requested to search for the same result reports from the newly generated spread sheet.

Before Implementing the Prototype Tool

Table 1 below shows the amount of time in “seconds,” the Test Engineer took to search five result reports for each of the script. For example, to search five result reports for the “Reverser_Verification” script took 117, 81, 53, 110 and 91 seconds respectively. The average time calculated to search one result report for this script came out to be 90.4 seconds.

Table 1: Time taken to search each report before implementing the tool.



SCRIPT	Time taken in Seconds for each attempt				
	1	2	3	4	5
Reverser_Verification	117	81	53	110	91
DTC_Verification_OperatorNotPresent_LowSpeed	83	131	136	111	84
Desired_Engine_Speed_Calculation	145	96	119	91	51
LoadControlDesiredGain	147	53	110	122	129
LoadControlDesired_Load	130	53	128	66	107
FuelEcoSCVBoost_Fully_Auto_Mode_CTL	30	29	63	54	52
TractionControl	66	48	33	94	74
ShuttleShift_HydroReversing	102	73	89	70	118
9xFT4_Brake_Cooling_CTL	61	114	89	103	110
23SpdTransOilPressOOR	36	36	61	70	26

Figure 19 below shows the data from Table 1 in graphical format. It suggests that variation from the amount of time taken to search results is large, the time taken is not consistent. There is no trend which can predict the amount of time it will take to search the next result.

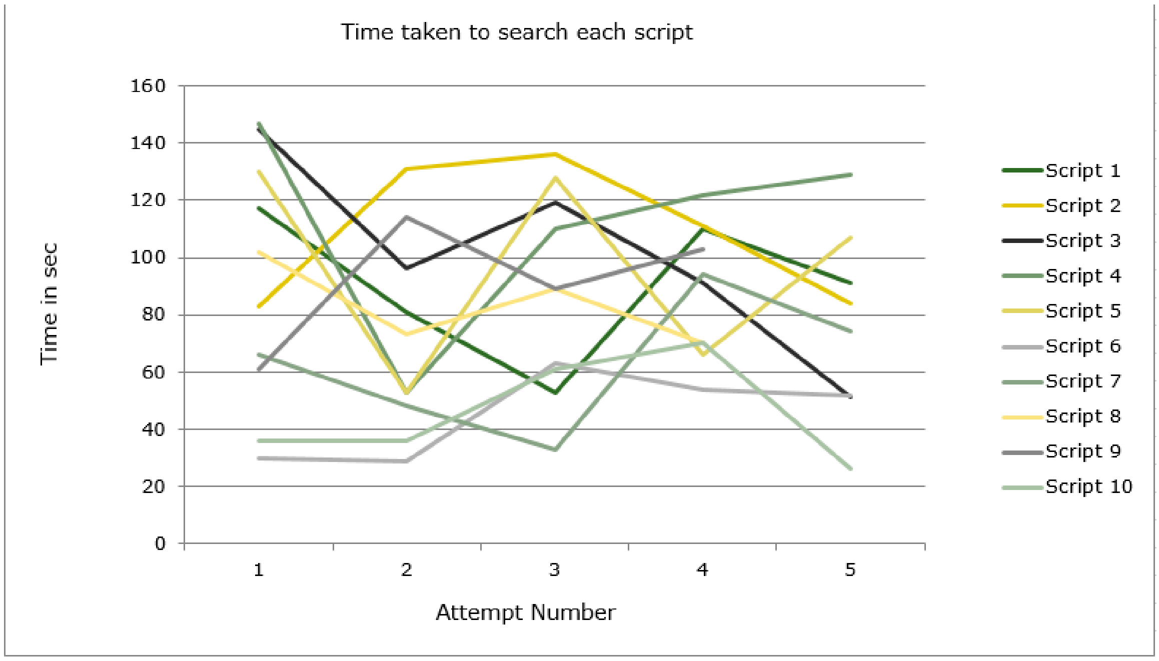
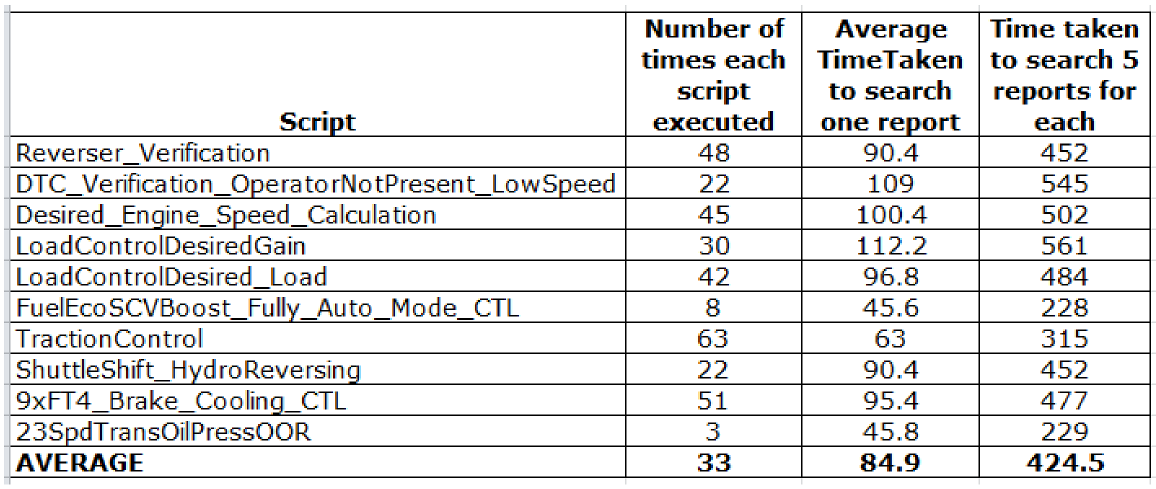


Figure 19: Chart displaying the trend in searching results before the implementation of automated results reporting tool prototype

As shown in the Table 2 below, each test script was executed many times at different dates between the month of February 2012 and December 2012 (10 months). Out of the total number of times the script was executed, the Test Engineer was asked to search only five reports of each automated scripts. For example, the “Reverser_Verification” script was executed 48 different times during the period. Average number of times each script was executed is rounded up to 33. Also, average time taken to search each report was calculated based on the data from the Table for each script was 84.9 seconds.

Table 2: Calculated Averages of current search method



Script	Number of times each script executed	Average TimeTaken to search one report	Time taken to search 5 reports for each
Reverser_Verification	48	90.4	452
DTC_Verification_OperatorNotPresent_LowSpeed	22	109	545
Desired_Engine_Speed_Calculation	45	100.4	502
LoadControlDesiredGain	30	112.2	561
LoadControlDesired_Load	42	96.8	484
FuelEcoSCVBoost_Fully_Auto_Mode_CTL	8	45.6	228
TractionControl	63	63	315
ShuttleShift_HydroReversing	22	90.4	452
9xFT4_Brake_Cooling_CTL	51	95.4	477
23SpdTransOilPressOOR	3	45.8	229
AVERAGE	**33**	**84.9**	**424.5**

Table 3 below shows the calculated numbers for all 151 scripts which the software team owns for testing their software features. According to this table, there will be 5043 total number of reports generated if all of the 151 scripts are executed 33 times which is the average number of times each of the selected scripts were executed. If all of the reports need to be searched for and update the results report, it will take a total of 120 hours to search through all the 5043 subsequence report folders generated after the execution.

According to “Indeed.com,” a job search website with more than 1 billion job searches per month, the average salary of Software Test Engineer salary stands at around $75,000 per year which can be broken down to around $37 - $40 per hour. As mentioned in the Table 3 below, considering hourly rate for the Software Test Engineer to be $37, the amount spent on searching reports would be $4,400.79 for one team. There are 9 known teams which utilizes automated test procedures to test their software. Thereby, the organization under study ends up spending close to $39,607.08 in just searching and organizing the result reports. (Software Test Engineer Salary, 2013)

Table 3: Generalized numbers for the population

Total number of reports generated if each of 151 scripts are executed 33 times	5043
Time taken to search all reports for each script from reports folders (in seconds)	428185
Total time in Hours	119
Cost in Dollars @ 37/hr.	$4,400.79
Total Cost for 9 teams in Dollars	$39,607.08

<u>After Implementing the Prototype Tool</u>

Table 4 below shows the amount of time taken after implementing the prototype tool for searching results. As displayed in the table, the amount of time taken to search each report has dropped significantly.

Table 4: Time taken to search results after implementing the tool.

	Time taken in Seconds for each attempt				
SCRIPT	**1**	**2**	**3**	**4**	**5**
Reverser_Verification	17	12	6	13	12
DTC_Verification_OperatorNotPresent_LowSpeed	14	13	13	8	8
Desired_Engine_Speed_Calculation	11	10	8	7	15
LoadControlDesiredGain	23	6	13	7	13
LoadControlDesired_Load	27	14	6	8	7
FuelEcoSCVBoost_Fully_Auto_Mode_CTL	13	6	10	8	14
TractionControl	24	12	6	6	15
ShuttleShift_HydroReversing	10	11	5	6	11
9xFT4_Brake_Cooling_CTL	12	8	14	5	12
23SpdTransOilPressOOR	23	12	5	11	13

A line chart is developed in Figure 21 using the data from the Table 4 to investigate a trend in the time taken for each search. As seen in Figure 18 below, the amount of time taken to search the first result of each script is higher than the time taken to search the next 4 results for the same script. This is because of the initial time taken by the Engineer to filter the results by the name of the script. Once the results are filtered, the time taken to search the next result for the same script is very less because all the results for that script are populated in the spreadsheet therefore there is no need to manually search the reports folder again.

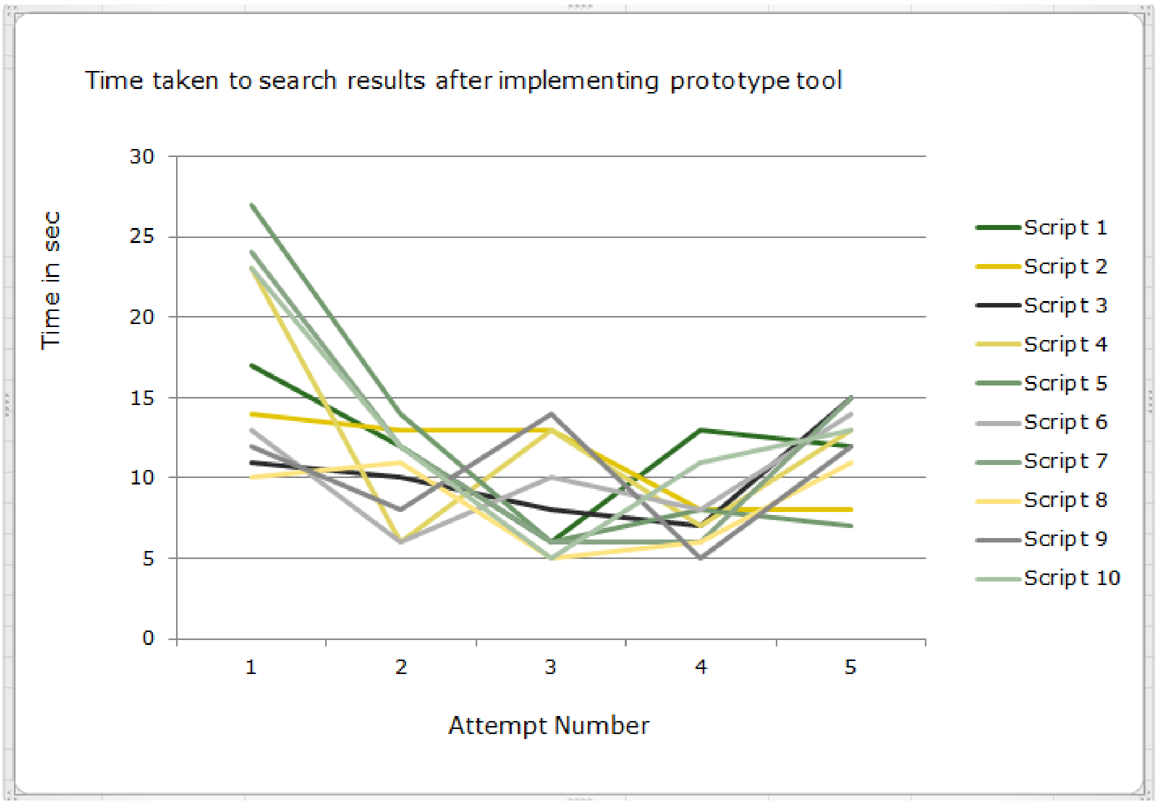


Figure 20: Chart displaying the trend in searching results after the implementation of automated results reporting tool.

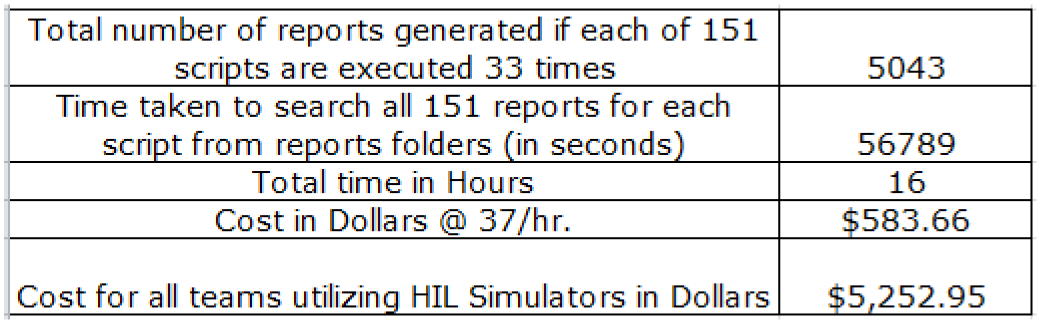
Table 5 below shows the calculated averages for time taken to search results report for each script after the implementation the prototype tool. Out of the total number of times the script was executed, the Engineer was again asked to search only five results for sampled automated scripts. Taking the example of “Reverser_Verification” script again, this was executed 48 different times in all. Average number of times each script executed is same as before which is 33. Also, average time taken to search each report was calculated based on the data from the table 4 for each script is 11.64 seconds which is significantly less than the average time before implementing the tool.

Table 5: Calculated averages after implementing the tool.

Script	Number of times each script executed	TimeTaken to search one report for each script (in Seconds)	Time taken to search 5 reports for each script(in Seconds)
Reverser_Verification	48	12	60
DTC_Verification_OperatorNotPresent_LowSpeed	22	11.2	56
Desired_Engine_Speed_Calculation	45	10.2	51
LoadControlDesiredGain	30	12.4	62
LoadControlDesired_Load	42	12.4	62
FuelEcoSCVBoost_Fully_Auto_Mode_CTL	8	10.2	51
TractionControl	63	12.6	63
ShuttleShift_HydroReversing	22	8.6	43
9xFT4_Brake_Cooling_CTL	51	10.2	51
23SpdTransOilPressOOR	3	12.8	64
AVERAGE	**33**	**11.26**	**56.3**

When generalizing the averages found in Table 5, there is a clear difference in numbers when compared with the generalized numbers calculated before the implementation of the tool. Table 6 below shows that the total time taken in hours is reduced to 16 hours. Again, assuming $37 per hour as minimum salary for a Test Engineer, amount spent for 16 hours would be $583.66. For 9 teams utilizing automated scripts, the organization would end up spending $5252.95, which is significantly less than amount spent before implementing the tool.

Table 6: Generalized numbers after implementing the tool.



Total number of reports generated if each of 151 scripts are executed 33 times	5043
Time taken to search all 151 reports for each script from reports folders (in seconds)	56789
Total time in Hours	16
Cost in Dollars @ 37/hr.	$583.66
Cost for all teams utilizing HIL Simulators in Dollars	$5,252.95

Figure 21 below paints a clear picture of the difference between the amounts of time taken to search results for each sample TL script. The amount of time taken to search results for each script is significantly lower after implementing the reporting tool. Not only the amount of time taken is less compared to current reporting process, it also has an expected consistency.

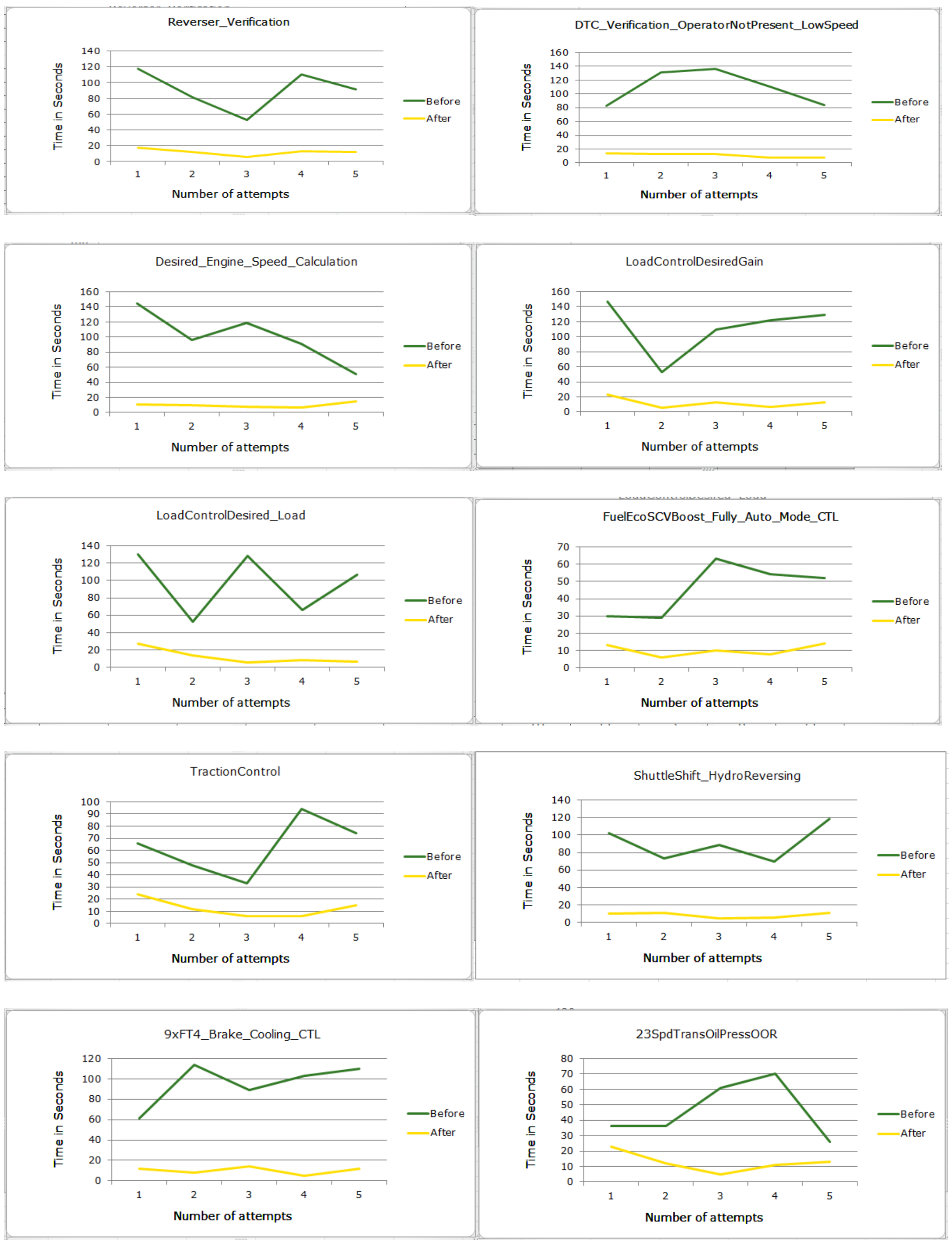


Figure 21: A broken down view of time taken to search results before and after implementing reporting tool for each script.

Hypothesis Testing

To prove that the results reporting process after the implementation of the prototype tool takes less time than the calculated average time of the current process, a hypothesis testing was performed. The mean time taken to search results report for each script by current process is 84.90 seconds. The Null Hypothesis was developed assuming that there is no difference in the mean time before and after the implementation of new tool with a confidence level of 95% and margin of error (α) of 0.05.

For this test, the Null Hypothesis: H_0 is that there is no difference between the mean time taken to search results report for a particular script before and after the implementation of prototype tool.

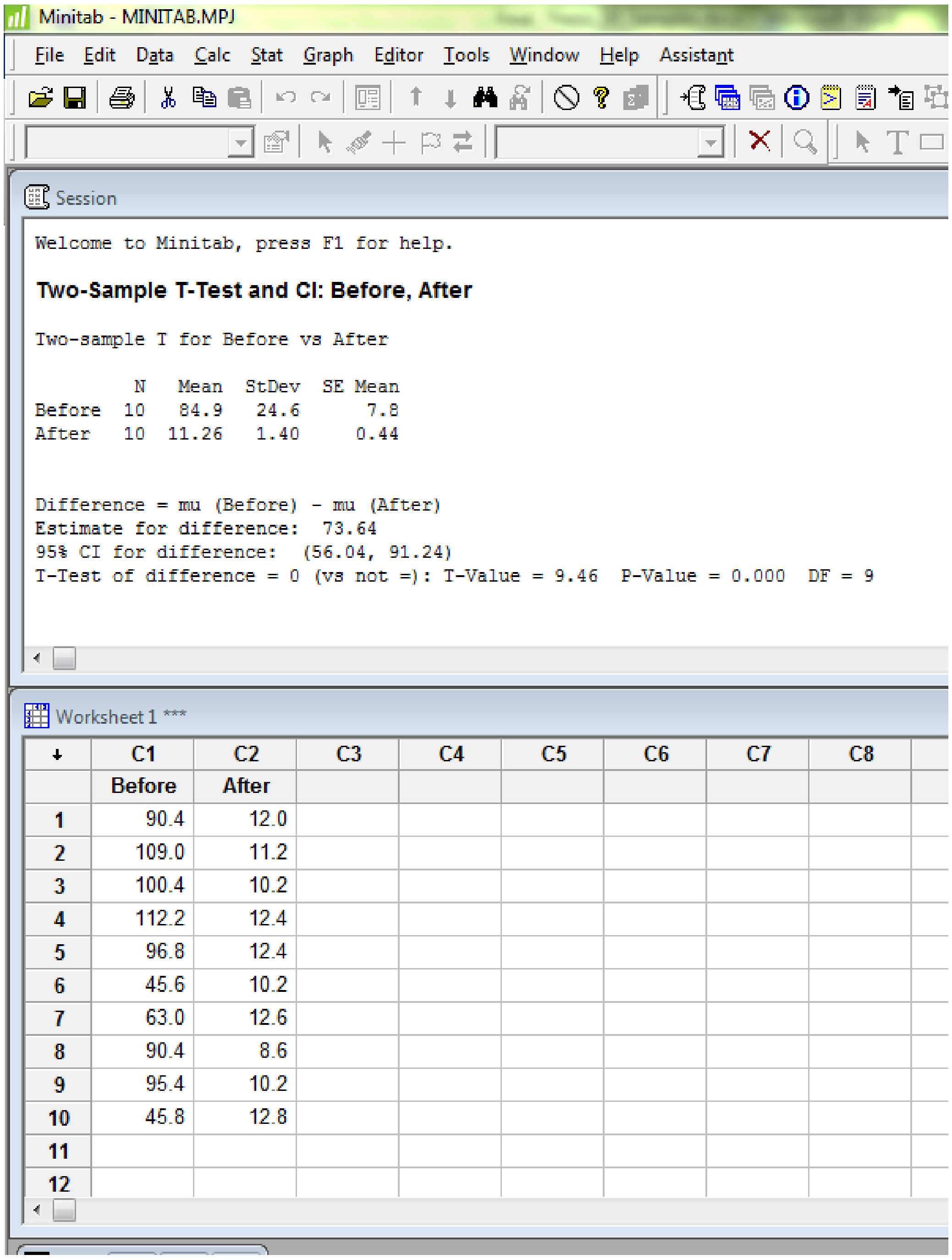
$$\mu_{Before} = \mu_{After}$$

The Alternate Hypothesis: H_A is that the mean time taken to search results report for a particular script after the implementation of the prototype tool is less than the amount of time taken to search before the implementation of prototype tool.

$$\mu_{Before} < \mu_{After}$$

Figure 22 below shows the output generated from the student version of Minitab 16.0 statistical software used to perform two sample T-test. Two sets of data termed as “Before” which is the average time it took for the Test Engineer to search result report for each script and “After” which is the average time it took for the Test Engineer to search results for each script after the implementation of the experimental tool, were entered in the data sheet. A two-sample T-test was performed using the Minitab "2-Sample t…" function with Confidence Interval set at 95% and assuming the two sets of data have equal variances.

Looking at the output of Minitab in the Figure 22 below, there is a mean difference of 73.64 seconds is an estimate of difference between the population means which is significantly large. The confidence interval for the difference is based on this estimate and the variability within the samples. We can be 95% sure that the difference between the mean time to search results is between 56.04 and 91.24 seconds higher before the implementation of the experimental tool than after the proposed change. The t-value for the test is 9.46 and is associated with a very low p-value rounded off by Minitab to 0.00. Since, the p-value is very low, we can reject the Null Hypothesis at $\alpha = 0.05$ and conclude that there is a statistically significant difference between the two means. In fact, the time taken to search the result report for each script is much larger than the time taken after the implementation of the prototype tool.


Minitab - MINITAB.MPJ
File Edit Data Calc Stat Graph Editor Tools Window Help Assistant
Session
Worksheet 1 ***

```
Welcome to Minitab, press F1 for help.
```

Two-Sample T-Test and CI: Before, After

```
Two-sample T for Before vs After

         N   Mean  StDev  SE Mean
Before  10   84.9   24.6      7.8
After   10  11.26   1.40     0.44


Difference = mu (Before) - mu (After)
Estimate for difference:  73.64
95% CI for difference:  (56.04, 91.24)
T-Test of difference = 0 (vs not =): T-Value = 9.46  P-Value = 0.000  DF = 9
```

↓	C1	C2	C3	C4	C5	C6	C7	C8
	Before	After						
1	90.4	12.0						
2	109.0	11.2						
3	100.4	10.2						
4	112.2	12.4						
5	96.8	12.4						
6	45.6	10.2						
7	63.0	12.6						
8	90.4	8.6						
9	95.4	10.2						
10	45.8	12.8						
11								
12								

Figure 22: Two sample t-test output from Minitab

CHAPTER V

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Summary

The research presented in this thesis laid the foundation for implementing Automated and Centralized Reporting System (ACRS) for the organization under study. ACRS system used a small prototype of automation tool to effectively report and manage large amount of reports generated at the end of embedded software testing cycle in a large off-road vehicle manufacturing organization. The current systems in place are laborious, less effective and utilize lot of resources thereby costing the organization a lot of money and usually get unnoticed. As further developments happen in the field of software testing using HIL, SIL and MIL based tools, having a common automated reporting tool would help organizing and reporting of test results more effective and efficient.

Chapter II described the extensive background on embedded software, its development cycle and importance of testing. It also informed the importance of thoroughly testing embedded software intended to be used in off road vehicles. This chapter also detailed the observed process of testing and its results reporting at the organization under study. Although most of the organization under study had focus on thoroughly testing the software to be used on the vehicles and defects resolution, there is not enough attention provided to the area of implementing common reporting systems to streamline results generated from various types of testing tools. There are tools available on every testing platform to generate reports in one form or the other, but there is no option to convert the reports of various formats into one common and easily available report.

Chapter III introduced the Hardware-in-loop simulation platforms also called as HIL system and their architecture under study. This chapter mainly focused on the methodology of the experiment which included the test automation language called TL. It explained the complete architecture, folder structure used, basic syntax and highlighted on the test case generation tool which is used for automatically generate possible test cases for a feature. It explained the functioning of the TL scripts and macros which generate ".html" type of files for the results reports.

This chapter concluded with explaining the experimental procedure which was performed to conduct the research. In this experiment, the Test Engineers were asked to search results of 5 randomly selected scripts out of a total of 151 scripts available in the folder containing large amounts of reports. Time taken to search each report was recorded for analysis. Then, a prototype tool depicting as a new step in the results reporting process was developed using PERL scripting language and executed on the same folder containing large amounts of reports and the data was recorded for further analysis.

Chapter IV was mainly focused on analysis of the data collected during the experiment. Averages were calculated from the set of data collected before and after the implementation of the tool for 5 scripts. After performing the data analysis, it was revealed that the amount spent on just searching the results from the reports generated before implementing the prototype tool is around $175,000.00. The amount spent to perform the same action after implementing automated tools can be reduced to around $16,760.00 which is almost 10 times less than the current amount being spent.

Answers to Research Questions

This section will try to answer some of the research questions which were provided earlier:

1. Will implementing the recommended reporting process changes improve the complete process of PV&V?

   As seen from the data analysis, there is a huge potential for the organization under study to save a lot of precious Engineering time and cost which eventually can be saved by utilizing automated tools to improve on results reporting process which is a very important but neglected part of the PV&V process. The experiment performed during the study certainly revealed the area of results reporting which is not efficient currently and improving the way results are stored and reported can make the process more efficient.

2. How much average time does an engineer consumes on results reporting process before and after the implementation of the proposed improvement?

    According to the data analysis performed in the study, on average a Test Engineer will spend approximately 120 hours for just searching results. If automated tools like the ACRS are implemented, the same Engineer will spend around 16 hours on the process which is significantly less than number of hours spent currently.

3. How do the recommended improvements improve the security of the testing assets?

    At this point of time, all the results are stored on the local hard drive of the simulator machines. These hard drives also contain very critical data like vehicle configurations, simulation models and various databases used for the functioning of the simulator. To collect the results from remote machines, the local hard drive is shared on the network thereby making it available to non-users of the simulator who can potentially damage the critical files and information knowingly or unknowingly. With the implementation of the ACRS, the results can be directly exported to the local servers which are more secure and have dedicated maintenance resources. Hence, only the users with proper credentials can access the data from any location without compromising the simulators security.

4. How much time and engineering costs the company would save if the recommended improvements are implemented?

   According to the study performed, the current process of results reporting cost $39,607.08 to the organization. As per the data collected after the experiment, the total cost of results reporting only came out to $5252.95 which is significantly less than the current costs. If the company decides to utilize automated tools like the prototype used in the study, it can accomplish the task of results reporting for far less than current costs.

Conclusions

This study has introduced a simple but very powerful prototype tool called ACRS (Automated Central Reporting System) which if implemented properly can reduce the amount of time and money spent on usually unnoticed task of searching results from a large pool of automated test results. The research highlighted the unnoticed area of results reporting process in the organization which if looked closely is still not efficient, thereby making the complete process of PV&V in the organization less efficient. The study proved that there is a lot of room for improvement in the current results reporting process if the organization looks to implement automated tools for reporting results from automated tests.

Recommendations for Further Study

With the increase in competition and economic downturn, organizations are looking for ways to save their operating costs in any possible way without compromising the processes which are critical to quality of the final product. PV&V is one of the most important processes which if not performed properly, can lead to products with defects. Defective products lead to even higher costs for the organization in terms of warranty or repairs. Therefore it is very important for the companies to produce quality products but keeping their development cost down to be competitive.

This study conducted for process improvement applied to the 9 teams which operate from one of the engineering centers of the organization in Midwest which are responsible for developing one product. The organization manufactures various off-road, utility vehicles and other agricultural equipment at various locations which are not included in this study. Further studies can be performed to search for similar processes in other units of the organization which develop other products.

Further studies can be conducted to find other processes in the organization which have reporting process that are inefficient and which can be automated to make them cost effective. Therefore the potential for the company to improve processes across all units is wider than the current study.

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