

Lessons Learned in How to Generate a Complete, Correct and Usable Set of Requirements the First Time and Every Time

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ABSTRACT

From a quarter to one half of all projects that fail to meet their imperatives of cost, performance / quality or schedule are in some way associated with missing, poorly written or misunderstood requirements (1). This results in re-design, re-test and continual frustration to both the originator and the user of these requirements. Thus, a process for generating complete, consistent, unambiguous and verifiable requirements is essential to today's automotive development process which focuses on "fast to market" and "doing it right the first time."

Lessons learned from evaluating the customer, internal and supplier requirements specifications show that the following requirement deficiencies regularly occur –

- Hidden
- Incomplete or unclear
- Incorrect
- Ambiguous
- Missing
- Unknown
- Secret (competitive sensitive)
- Unknown Correlations.

This paper will review the purpose of requirements, characteristics of good requirements, and will provide examples of what did go wrong in two automotive

projects, what deficiencies / problems occurred, and how difficult it was to find and define some requirements.

INTRODUCTION – THE BASICS OF REQUIREMENTS

A requirement is defined as an unambiguous and verifiable statement of essential product or system characteristics. IEEE Standard 729 further defines a requirement in the following manner "A condition or capability needed by a user to solve a problem or achieve an objective. A condition or capability that must be met or possessed by a system to satisfy a contract, standard, specification, or other imposed document."

Specifications are those documents which record sets of requirements. A requirement typically has four essential parts:

1. A description of performance –
 - A function performed or a constraint on the design of the product
2. A negotiated value –
 - Defines the magnitude relative to a standard measure
 - Answers "the how much" and is usually numeric
 - May include tolerances

3. The conditions under which it applies –
 - Ambient conditions (e.g. temperature, humidity, vibration)
 - Operating conditions (e.g. moving, stationary, parked)
 - Pre-conditions (e.g. burnished brake pads)
4. The requirement verb indicating the degree of obligation
 - SHALL or MUST (European standard) - are used for contractually binding provisions that must be verified
 - SHOULD – denotes preference when specifying alternatives or desired conformance with objectives, standards or procedures
 - WILL – used to state requirements associated with the development of the product and not the product itself

Note that a defining characteristic of a requirement is that it must be verifiable. Typical means of verification are:

- TEST – collection and analysis of data from a controlled test
- DEMONSTRATION – verification that an event occurred as designed
- INSPECTION – a sensory examination is performed and compliance achieved
- ANALYSIS / SIMULATION – use of applicable data from previous programs, or an examination of data using engineering judgment or mathematical calculation

Verification is usually documented through means of a verification cross reference index (VCRI) or compliance matrix that is included within the specification. A personal observation is that no requirements specification should be issued without an accompanying VCRI. This ensures that the specification author has completely thought through the requirement by understanding its verification.

When writing a requirement, there are characteristics of a good requirement which should be considered (2).

- Verifiable – by test, demonstration, inspection or analysis
- Necessary – essential to complete its meaning
- Unambiguous – there is one and only one meaning
- Implementation Free – the requirement is written in such a manner that there is no preferred solution
- Complete – all parts of the requirement are present
- Concise – written succinctly
- Consistent - compatible with all other requirements
- Traceable – follows from other higher requirements
- Feasible –able to be implemented, practical.

BAD REQUIREMENTS - PROBLEMS AND IMPLICATIONS

An earlier SAE article (3) describes and illustrates the problems that result from requirements with deficiencies as listed and described in the Abstract above. In that article, four complex product projects were examined using the principles and processes of Six Sigma. Twenty-five percent of the “What went wrong” were associated in some way with requirements or their verification as described by the Systems Engineering (SE) process. These problems significantly impacted their respective project’s cost, schedule and performance. While many of these problems were associated with the initial Customer requirements statements, there were other problems which occurred throughout the project’s duration. Interestingly, each of these four projects independently listed “lack of understanding customer requirements” as a primary cause.

The content and purpose of the remainder of this paper is to present typical examples of requirement deficiencies found in two automotive projects as analyzed by their respective systems engineers. In the first case, Lori Runk presents her experience as she worked to understand customer requirements and the System Engineering (SE) tool she used to clarify and improve those requirements. In the latter example presented by James Waters, he found that hidden, unspoken, and unrecorded requirements had to be found by working closely and diligently with the customer and suppliers.

When both are considered together, the reader can see that the development of initial requirements was not sufficient. The total scope of a project must be carefully considered, such that all requirements are understood, fully identified and properly documented. In summary, the authors will offer lessons learned that the reader can use to generate a complete, correct and usable set of requirements. When applied to any process, this will result in requirements that are correct and usable the first time. This will save cost and time for corporations and projects. It will result in meeting or exceeding customer expectations.

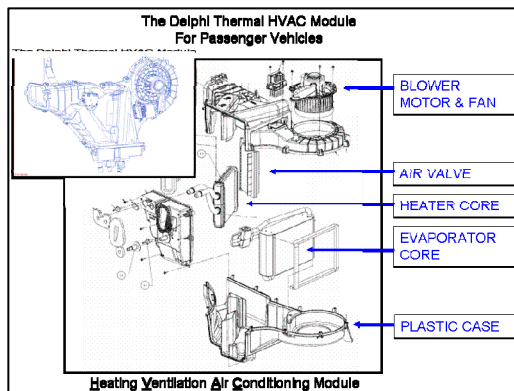
THE VALUE OF THE SYSTEMS ENGINEERING (SE) METHODOLOGY CAN BE SEEN IN A REAL WORLD EXAMPLE

The value of the SE methodology can be seen in a real world example. Delphi Thermal Systems designs, develops, validates and manufactures high quality HVAC (Heating, Ventilation and Air Conditioning) modules for many automotive manufacturers worldwide. In some cases they are design responsible for the whole

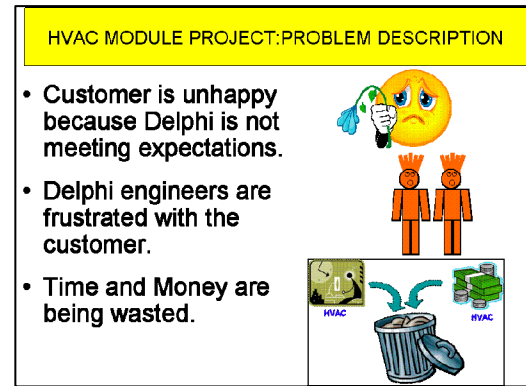
integrated HVAC subsystem in the vehicle. In other cases they are design responsible only for the HVAC module – one component of the vehicle's HVAC subsystem. The HVAC module is a package which generally consists of:

- plastic cases
- heater core
- evaporator core
- blower motor and fan
- valves which direct airflow
- electric actuators for the valves
- etc.

Customers provide Delphi with the requirements for the HVAC subsystem. Delphi experience and expertise is used to provide a product which meets and exceeds customer expectations. Delphi experience and expertise is also used to make sure they design, develop, validate and manufacture a product which meets Delphi Corp. business objectives. In other words, they are part of a business which is expected to make a profit!

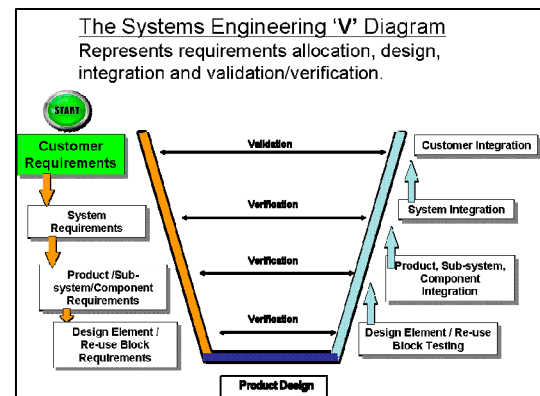


One of Delphi's recent HVAC module product development projects was not proceeding smoothly. The customer was getting frustrated because they did not feel Delphi was fully addressing their stated requirements. Delphi was getting frustrated because the customer seemed to be frequently changing design direction. Delphi was asked several times to rerun testing which had already been completed. In other words, Delphi had an unhappy customer. The profit numbers for the project were diminishing because of the redesign and rework activities occurring in engineering.



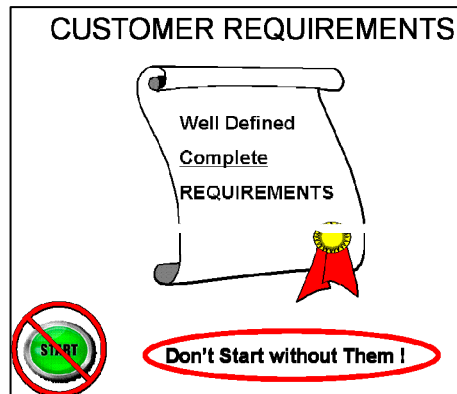
In order to address the problem, Delphi Thermal System's management assigned a temporary resource to clarify and come to a mutual understanding of the product design and validation requirements. In order to streamline the process, it was decided that they would approach this problem from a SE methodology perspective, using some of the Delphi SE common process tools.

If the SE "V Diagram" is reviewed, it can be seen that the starting point for the entire process begins with CUSTOMER REQUIREMENTS.



These requirements are defined, analyzed, developed, and allocated from system to subsystem to components. In addition, all of the work on the right side of the "V Diagram" deals with the validation and verification activities associated with meeting those requirements. The diagram shows that a successful project needs to start with good, clear complete requirements. In this way, those requirements can be correctly defined and allocated to lower level parts. Then valuable, meaningful

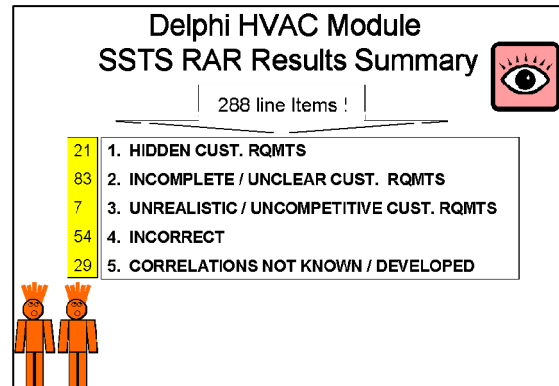
validation activities can produce a product which meets or exceeds those requirements. If this same information is viewed from a negative perspective, it can be seen that if a project does not start with good, clear complete requirements, there will not be valuable, meaningful validation activities. The end product will not make the customer happy. If a project does not begin with good, clear complete requirements, time and money will be wasted trying to develop and validate a product that in the end may or may not meet customer expectations.



Based upon the above information, Delphi Thermal System's engineers hypothesized that the source of the problems with the HVAC module development project was a misunderstanding of customer requirements. In order to determine if this was truly the source, it was decided to evaluate those requirements using a SE common process tool called a **Requirements Analysis Report** or RAR.

The RAR is a tool which provides the words, format and process for obtaining clear, reasonable requirements from the customer. It helps to identify deficiencies and problems as well as their associated risks, so that actions and mitigation planning can be initiated. Once the customer requirements have been defined, this tool can be used internally to evaluate product requirements before they are passed down to subcomponent suppliers.

The results of the RAR were eye-opening! Using the RAR tool Delphi identified a total of 288 customer requirement line items. The SSTS (**subsystem technical specification**) RAR results summary chart below lists the five common weaknesses discovered. These weaknesses were associated with 194 of the 288 line items. The chart also shows how many line items were associated with each of those weaknesses.



By working cooperatively with our customer to address the above deficiencies /issues, Delphi was able to bring the HVAC module development project back on track. This provided customer satisfaction and profitability for Delphi.

THE BASICS OF THE RAR TOOL

The RAR is a simple spreadsheet which is used to manage the work required to analyze customer requirements. The RAR is populated using the following steps:

1. LIST ALL CUSTOMER REQUIREMENTS:

- Every requirement paragraph from the **CRD (Customer Requirements Document)** is loaded onto the spreadsheet. The **"Requirement Number"** & **"Requirement Title"** are kept separate so they can easily be sorted. In this format, they can also be easily copied to a validation test planning document.
- The **"ORIGINAL WORDING"** of the requirement is copied into the spreadsheet cell. This is not a required field, but it can be a time saver because it :
 - prevents one from switching back and forth between the CRD and the RAR when discussing a certain technical requirement / paragraph.
 - prevents misinterpretation of a requirement based upon the "Requirement Title" alone.
- List any **ADDITIONAL CUSTOMER REQUIREMENTS** you have been given. These requirements are not found in the main CRD. They may have been communicated verbally in a customer meeting, or by e-mail, or through some other "Statement of Requirements" document received from the customer. Make sure **ALL KNOWN** product design related customer technical requirements are captured.

STEP #1 LIST ALL CUSTOMER REQUIREMENTS						
RAR TEMPLATE						
REQMT #	REQMT TITLE	ORIGINAL WORDING	INTERPRETATION	COMMENTS	COMPONENT APPLICABLE	UNAMBIGUOUS
					COMPLETE	VERIFIABLE
		Every Requirement Paragraph from the CUSTOMER REQUIREMENTS DOCUMENT is loaded into the Spreadsheet				
Requirement # & Requirement Title are kept separate so they can be easily sorted and/or copied to a validation test planning document.						

2. EVALUATE EACH CUSTOMER REQUIREMENT:

- After reading the ORIGINAL WORDING, judge the quality of the requirement. Make sure it is a good, clear complete requirement.
- Before setting up the spreadsheet, review the characteristics of a good requirement as listed above in "Introduction -The Basics of Requirements". Then pick the characteristics which are most critical to the project.

STEP #2 EVALUATE EACH CUSTOMER REQUIREMENT						
RAR TEMPLATE						
REQMT #	REQMT TITLE	ORIGINAL WORDING	INTERPRETATION	COMMENTS	COMPONENT APPLICABLE	UNAMBIGUOUS
					COMPLETE	VERIFIABLE
The ORIGINAL WORDING is reviewed to see if the requirement is:						
☐ Component Applicable ☐ Unambiguous ☐ Complete ☐ Verifiable						

- For the Delphi HVAC module, the "ORIGINAL WORDING" was reviewed to see if the requirement was:
 - HVAC Module Applicable (Component Applicable)** - is the requirement written in such a way that it applies to the part to be developed and validated and can it be verified at that part level? Delphi is responsible for the design of the HVAC module, but many of the requirements are specified at the HVAC subsystem level. In order to validate the HVAC module, requirements must be stated at the module level.
 - Unambiguous** - Is the requirement completely clear and cannot be

misunderstood? Can there be only one interpretation of the requirement?

- Complete** - Is the information stated with all of the details necessary to understand the requirement and / or to run the test? Requirements with "to be determined" are not complete.
- Verifiable** - Is the requirement stated clearly so it can be verified by defined subjective or objective measurements? Does the verification method and equipment exist within the company? Must and an outside resource be used? A requirement is NOT verifiable if the methods and/or equipment required are inaccessible due to cost, geographic location, or other limiting factors.

3. PROPOSE AN INTERPRETATION FOR EACH REQUIREMENT

- If a requirement meets all of the evaluation criteria, it should remain as stated in the original wording. An interpretation is not necessary.
- If a requirement does not meet the evaluation criteria, it needs to be interpreted (or restated) until it does meet the evaluation criteria.
- Consulting reference documents and subject matter experts within the organization and at the customer's organization may be required in order to develop a proposed interpretation.
- The RAR spreadsheet includes a "COMMENTS" section so any notes or references can be recorded which might be helpful when discussing the reasoning behind a proposed interpretation.

STEP #3 PROPOSE AN INTERPRETATION FOR EACH CUSTOMER REQUIREMENT						
RAR TEMPLATE						
REQMT #	REQMT TITLE	ORIGINAL WORDING	INTERPRETATION	COMMENTS	COMPONENT APPLICABLE	UNAMBIGUOUS
					COMPLETE	VERIFIABLE
Experts and reference documents are consulted, and a proposed INTERPRETATION is written.						
Comments are added to explain reasoning.						

4. FINALIZE AN INTERPRETATION FOR EACH REQUIREMENT

It is important to remember that all of the requirements must come from a customer. A proposed interpretation isn't valid unless the customer agrees with it.