Electromagnetic Environmental Effects (E^3) Technical Performance Measures (TPMs)

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Abstract

A way of communicating Electromagnetic Environmental Effects (E^3) concepts to project/program management is discussed in this paper. Called "Technical Performance Measures" (TPMs), it is a method for evaluating performance attributes using consistent judgment criteria. Attributes of subsystems may be evaluated and combined together to form system-level TPMs. While calculating system performance, weighting factors can be assigned to stress the importance of some subsystem attributes. Once the attributes are defined, judgment criteria established, and weighting factors determined, it only takes a minimal amount of time to update the TPMs periodically using a common tool such as Microsoft ™ Excel. This paper describes how TPMs can be constructed for E^3, but the same concept can easily be extended to other engineering disciplines.

Introduction

As leaders of E^3 teams working on large and complex aircraft development programs, we have historically struggled with communicating our technical concerns to our management in effective manner. We would try to discuss CS101 and RS103 for example, but our management would just look at us with a confused glaze in their eyes – a deer in the headlights look, so to speak. We realized that we needed to establish a common ground for communications, in order to make it easier for them to understand our concerns and the technical basis for those concerns. We recognized that we needed a more consistent methodology for expressing our engineering judgments to management. It was also necessary to develop a tool whose data could be updated quickly and easily so that the tool was not a burden to use.

E^3 TPM Concept

Risk management techniques were chosen as an easy method to communicate with management using familiar concepts and red, yellow, green colors to form stoplight charts. Starting with the subsystem components of a complex system, the E^3 requirements are broken down to their lowest level. These can commonly be found in the "shall" statements in subsystem requirement documents. Each "shall" attribute is evaluated based on the confidence of compliance with the requirement. Each requirement is then assessed for your confidence that the subsystem does (or will) comply with it. The challenge is to decide at what complexity level it is practical to do requirement compliance evaluation (major subsystems only, all subordinate subsystems, or some of both). Usually, the assessments are done most easily at the level that will be tested for specification compliance, such as the subsystems which will be tested individually for RTCA DO-160 compliance.

All these attributes ratings can be combined with other subsystem attribute ratings to form a single system score. System scores can be grouped together for successive higher-level systems ratings to come up with one rating for the entire system.

In the end, you will have an overall E^3 rating for a highly complex system that you can present to your management in a way that they can understand. When a problem is indicated, you have a tool to drill down to identify exactly what the problem is, which subsystem has the difficulty, and how serious the problem is to the overall system.

Rating Criteria

Establishing ground rules for rating criteria is a very important step in setting up the tool. A standardized set of evaluation criteria that is applied across the entire system is essential. We found it helpful to assign numeric ranges to the stoplight colors. If numeric ranges are utilized, you'll need to determine a scale (i.e. 1-5, 1-10, 1-100) and decide whether larger numbers indicate a good rating or a bad rating.

When creating a rating system, it is important to understand that the definitions of the ratings will change as the maturity of the system develops. The early days of a development program are dominated by design reviews and proposal evaluation activities. For that phase of the program, a red rating would indicate an insufficient design to meet the requirements; a yellow would mean that some uncertainty exists that the design would meet the requirement; and a green would show that you have confidence that the design will meet the requirements.

It is much easier later in a development program to determine ratings as verification testing is taking place and test data is available. During that phase, a red rating would indicate that there was a failure to meet the requirement, with no variance to the requirement anticipated; a yellow score might indicate that the requirement was nearly met and a variance is expected; and a green rating would indicate that the requirement was met by test. New TPMs can and should be defined as necessary. Rating criteria should be adjusted as a project/program matures.

Weighting Factors

Some E^3 attributes of a subsystem may be more important than others to overall system performance or safety. Weighting factors can be applied to the E^3 attribute itself to relate it to the system-level consequences if a particular E^3 requirement is not met. For example, a transient susceptibility of a particular subsystem may be deemed to be of more concern than radiated emissions. Different weighting factors can be assigned as the ratings are rolled up from the subsystem level and combined to a system level rating. i.e. Interference to a radio receiver may not be as important as interference to a flight control computer.

Subsystem E^3 performance can also be affected by integration E^3 attributes, such as electrical bonding, signal routing, and shield terminations. These attributes are usually found in integration or interface control documents, and are not as easily identified as a “shall” in a subsystem requirements document.

We found it very difficult to determine the values of the weighting factors in the beginning, and we spent a great deal of time doing that the first few times we used this tool. We recommend that you not worry too much about the values that you assign to your weighting factors, at first. Use your experience and just make a decision. Then you can use the tool and see how it works out. You can and should adjust the weighting factors to incorporate common sense and lessons learned. Manual corrections to the calculated roll-up values may be necessary to represent reality more accurately. Don’t be afraid to change things during the first few rating cycles. Remember, this is your tool to help you communicate issues to your management. Let the tool work for you.

Generic Example of E^3 TPMs

The numerical range of Confidence Scores is chosen to be between 0 and 5, with 5 representing the highest confidence level. There are four Confidence Rating colors selected for this example: red, yellow, green, and gray. The numerical ranges for each color are established as 0.01 to 1.66 for red (low), 1.67 to 3.33 for yellow (moderate), 3.34 to 5.0 for green (high), and 0.0 for gray to indicate a not-applicable (N/A) condition. The combination of stoplight colors and numeric values makes it easy for the audience to understand the system status at a glance.

The next two figures illustrate different ways to display the TPM status of the system and subsystems. Figure 1 is a bar chart that shows the percentages of subsystems that are categorized in each of the Confidence Rating colors. The three bars pro-

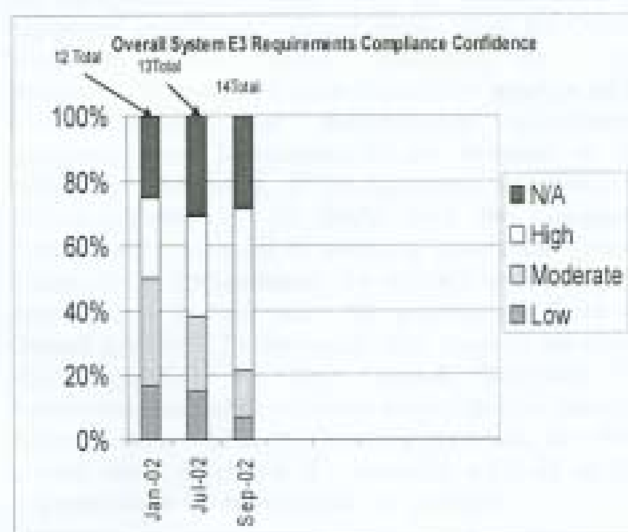

Figure 1 - Overall System E^3 Compliance Confidence History

vide the data from September 2002 as well as two previous assessments, so that the audience can understand the trends of the ratings changes. The total number of subsystems that were assessed is shown at the top of each bar. The number can change as subsystem designs become mature enough to evaluate, or when it makes sense to break down subsystems into their subordinate subsystems and assess those individually. In a well-run project, the confidence ratings would be expected to progress to high as the product design matures and completes its requirements verification testing.

Figure 2 demonstrates a different approach for displaying system status. It is also a bar chart, but this one provides the confidence rating for each subsystem for the latest assessment. This snapshot in time allows for a comprehensive display of the status for all the subsystems.

Table 1 is an example Excel spreadsheet that represents a system that includes four major subsystems (A, B, C, D) and their subordinate subsystems. The top row names all possible E^3 requirements or attributes that could be applied to any of these subsystems, and there is a row for each subsystem. The bottom five rows provide roll-up data for each attribute for each major subsystem, as well as for the total system. The first three columns provide identification data for each subsystem. The columns entitled “CE102”, “CE106/RE103”, and RE102” address emissions requirements. Columns “CS101” through “Lightning Indirect Effects” cover susceptibility attributes. System-level requirements for interfaces and equipment installation are addressed by

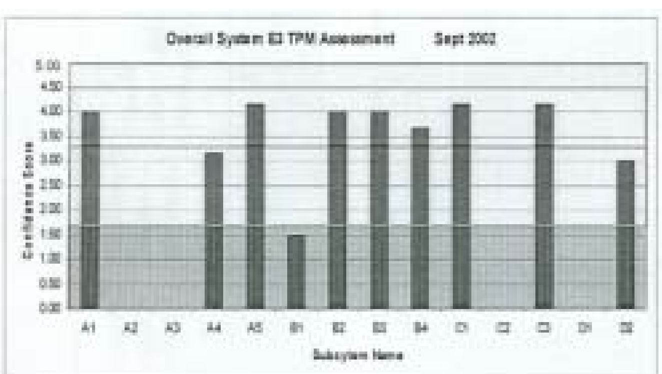

Figure 2 - Overall System E^3 Compliance Confidence Snapshot in Time

columns “TPDs” through “Installation.” The “Performance Criticality” column is not a requirement, but we needed to keep track of this designation, and found it useful in the weighting calculations and for data sorting purposes. The “Subsystem E^3 Susceptibility Performance Value” column shows the combined susceptibility requirement compliance assessment for the subsystem. The “Subsystem E^3 Emissions Performance Value” column consolidates the emissions evaluations for each subsystem. The “Overall Subsystem E^3 Performance” column shows the results of roll-up calculations from the installation, susceptibility, and emissions assessments for each subsystem. Each populated cell in a row displays a number and a color for the evaluation of that particular requirement or attribute. There is a “Notes” option available in Excel that allows you to record comments or brief explanations about why the rating was chosen, or reminders to check on particular details during future reviews.

We recommend creating the weighting formulas by starting with top-level logic statements for each subsystem in words, before going into details of the formula itself.

For the example in this paper, the initial logic statements are as follows:

• Experience with these types of systems indicates that the susceptibility and the emissions characteristics are of equal concern.

• Poor or inadequate equipment electrical bonding has resulted in unsuccessful subsystem EMI qualification testing or EMI problems on the system in the field.

The resulting logic sentence for the subsystem row therefore concludes that the “Overall Subsystem E^3 Performance” equals the average of its own Emissions and Susceptibility performance parameters, AND the subsystem “Installation” configuration can be Acceptable or Not. The consequences of the “Installation” are then defined in more detail. We wanted to indicate that an inadequate Installation can have serious adverse effects on subsystem E^3 performance, so we decided that the Installation attribute value can be either 1 for “good” or 0 or “bad.” This is consistent with the rest of the ratings in this example, for which bigger values are better. So, if the Installation is Acceptable (1 for Good), then the equipment installation will not detract from the Overall Subsystem E[3] Performance. The Overall System E[3] Performance value equals the Average of its own Emissions and Susceptibility performance parameters, and Installation in not included in the calculation. However, if the subsystem Installation is Not Acceptable (0 for Bad), then the equipment installation is expected to seriously reduce the Overall Subsystem E[3] Performance. To indicate how severe the impact could be, the value 2.0 is subtracted from the Overall System E[3] Performance. The range of calculated values possible for the Overall Subsystem E[3] Performance should be explored ensure that the resulting values remain within the boundaries set in the TPM ground rules, which for this example are 0.01 to 5.0. Adjustments to the formula may be necessary.

The final version of weighting logic formula for a particular subsystem row is:

IF [AVG (Susceptibility & Emissions) + (Installation)] is <0, then the Overall System E[3] Performance is 0.01,

ELSE Overall System E[3] Performance = AVG (Susceptibility & Emissions).

The roll-up formula for the subsystem columns can be derived in the same way, or could be chosen as the average, minimum, or maximum of the cells in each column, as appropriate.

TPM Usage Caveats

These TPMs are intended to provide insight into only the technical performance of the system and subsystem equipment. They are not intended to be used as an "earned-value" cost/schedule management tool, or as metrics for management of costs or sched-

Subsystem	Supplier Company	Configuration	CE102	CE106 / RE103	RE102	CS101	CS116	RS103	Ground Reference Plane Noise	Lightning Indirect Effects	TPD's	Cable Shields	Electrical Bonding	Installation	Performance Criticality	Subsystem E3 Susceptibility Performance Value	Subsystem E3 Emission Performance Value	Overall Subsystem E3 Performance
A1	AAA	1.0	5		5	5	5	4	5	5	5	5	4	1	1	4.00	5.00	4.50
A2	AAA	1A													2			
A3	[illegible]	1.0													1			
A4	RST	1A	4		4	5	5	4	5	4	5	3	5	1	1	4.00	4.00	4.00
A5	AAA	1.0	4		4	5	5	5	5	5	5	5	5	1	1	5.00	4.00	4.50
B1	SSS	1.0	5		5	5	5	4	5	2	4	5	5	0	2	3.00	5.00	2.00
B2	RST	1.0	5		5	5	5	4	5	3	5	5	5	1	1	3.00	5.00	4.00
B3	RST	1.0	5		5	5	5	4	5	3	5	5	5	1	1	3.00	5.00	4.00
B4	SSS	1.0	4		4	5	5	4	5	3	5	4	5	1	2	3.00	4.00	3.50
C1	TTT	2.0	4		4	5	5	5	5	5	5	5	4	1	2	5.00	4.00	4.50
C2	TTT	1.0													2			
C3	TTT	1.0	4		4	5	5	4	5	4	5	5	4	1	3	4.00	4.00	4.00
D1	RST	1.0													2			
D2	RST	1A			5	5	5	5	5	5	5	5	5	0	1	5.00	5.00	3.00
		Sum Subsystem "A" Rqmt Performance	4.00		4.00	5.00	5.00	4.33	5.00	4.67	5.00	4.33	4.67			4.00	4.00	4.33
		Sum Subsystem "B" Rqmt Performance	4.00		4.00	5.00	5.00	4.00	5.00	3.00	4.75	4.75	5.00			3.00	4.00	3.38
		Sum Subsystem "C" Rqmt Performance	4.00		4.00	5.00	5.00	4.50	5.00	4.50	5.00	5.00	4.00			4.00	4.00	4.25
		Sum Subsystem "D" Rqmt Performance			5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00			5.00	5.00	3.00
		Sum Total Subsystem Rqmt Performance Value	4.00		4.00	5.00	5.00	4.45	5.00	4.29	4.94	4.77	4.67			3.50	4.00	3.80

Table 1 - Example E[3] TPM Spreadsheet

ule or critical path activities. There is no actual or implied relationship between E^3 engineering personnel performance and equipment technical performance. Good E^3 engineering advice can be overridden or ignored by project and/or program management, when technical performance is balanced against product cost, weight, schedule, reliability and other valid requirements or constraints. TPMs are not intended to take the place of risk evaluations, even though they are based on risk assessment techniques. Risks should continue to be identified, assessed, and mitigation plans developed for requirements compliance or system integration issues.

Conclusion

This E^3 TPM tool has successfully been used at Lockheed Martin and has proven to be useful for communicating E^3 concerns and status to program management. It is fast and easy to use because it is based on a readily-available spreadsheet application, and uses familiar project risk assessment techniques. It provides multiple layers of performance evaluation that enable justification of complex technical assessments. Although this spreadsheet is intended for use primarily by the E^3 specialists, it can be useful to share the detailed assessment data with project/program management. They seldom want or need all the minutiae supporting the top-level system E^3 performance confidence assessment, but are often reassured to know that it exists and can be produced if necessary. E^3 TPM evaluations can easily be defended when they are based on supplier qualification test data or very detailed assessments by subject matter experts.

This E^3 TPM approach provides a consistent methodology for assessing, predicting and tracking E^3 performance by allowing for archiving assessments to give a way to track the history of system and subsystem performance and the historical performance can be used with trend analysis for predictions for future similar equipment. This tool also provides technical assessments with little time invested. The most recent evaluation update required only three man-hours of labor for more than 45 subsystems on a current Lockheed Martin program. It is expected these TPMs will evolve further, as we refine our tools for effective communications with our program and technical managers.

February 2006 Reflector Submission from the Reliability Chapter

CENTER SECTION
Reliability – 6:00 PM, Wednesday, February 8
Impact of the ESD Trend Toward Ultra-sensitive Components

Terry L. Welsher and G. Theodore Dangelmayer

The IEEE Reliability Chapter held a joint meeting with the ESD (Electro Static Discharge) Society. This meeting focused on proactive measures to deal with the challenges of unexpected ESD failures in new locations in the manufacturing process due to the industry wide trend towards ultra-sensitive (ESD Class 0) components. The interactive discussion stressed countermeasures including both manufacturing and design enhancements.

The meeting was held at RSA Security in Bedford, MA. Visit the IEEE Boston Reliability Chapter website: http://www.ieee.org/bostonrel.

ARTICLE

Reliability Society – 6:00 PM, Wednesday, February 8

Impact of the ESD Trend
Toward Ultra-sensitive Components

Terry L. Welsher and G. Theodore Dangelmayer

ESD failures are occurring with increasing frequency, in unexpected ways and at new locations in the manufacturing process due to the industry wide trend towards ultra-sensitive (ESD Class 0) components. Even wafers are now failing due to ESD damage and mathematical models indicate these failures will increase with the scaling trends. Device design experts are experiencing increasing difficulties designing-in adequate ESD protection. The SEMETECH and ESD Association technology roadmaps are projecting sensitivities below 100 volts for all three simula-