Comparing Reliability Predictions to Field Data for Plastic Parts in a Military, Airborne Environment

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Key Words: Reliability prediction, Field data, Mil-Hdbk-217, PRISM®, Plastic Encapsulated Microcircuit (PEM), Lessons learned

SUMMARY & CONCLUSIONS

This paper examines two popular prediction methods and compares the results to field data collected on Plastic Encapsulated Microcircuits (PEMs) operating in a military, airborne environment. The comparison study focused on three digital Circuit Card Assemblies (CCAs) designed primarily with plastic, surface mount parts. Predictions were completed using MIL-HDBK-217 models and PRISM®, the latest software tool developed by the Reliability Analysis Center (RAC). The MIL-HDBK-217 predictions which correlated best to the field data were based on quality levels (π_Q) of 2 and 3, rather than the typical π_Q values of 5 or higher, traditionally assigned per the handbook's screening classifications for commercial, plastic parts. The initial findings from the PRISM® tool revealed the predictions were optimistic in comparison to the observed field performance, meaning the predictions yielded higher Mean Time To Failure (MTTF) values than demonstrated. Further evaluation of the PRISM® models showed how modifying default values could improve the prediction accuracy. The impact of the System Level Multiplier was also determined to be a major contributor to the difference between PRISM® predictions and field data. Finally, experience data proved valuable in refining the prediction results. The findings from this study provide justification to modify specific modeling factors to improve the predictions for PEMs, and also serve as a baseline to evaluate future alternative prediction methods.

1.0 INTRODUCTION

The work described in this paper was funded under the Electronic Parts Obsolescence Initiative (EPOI), a cost share, five-year program managed by the Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson AFB. Eight contracts have been awarded to a diverse group of participants, including commercial companies, military aerospace, small businesses, and universities. The objective of the EPOI is to improve parts obsolescence management to ensure mission readiness and increase the fielded life of weapons systems at an affordable cost.

The widespread usage of plastic parts in today's military systems is of particular interest to the reliability community. Much of the existing field reliability data represents older systems, designed with military-screened components. Very little field data has been collected for commercial (plastic) parts operating in military systems. The purpose of this study was to compare predicted reliability to field data for PEMs operating in military, airborne environments. Findings from the comparison study would then be used to refine the reliability prediction techniques, ultimately leading to more accurate failure rate data for life cycle cost analyses as well as parts obsolescence decisions and management tools. Lessons learned are summarized as a reference for the practicing reliability engineer.

2.0 ABBREVIATIONS AND ACRONYMS

CCA - Circuit Card Assembly
EPOI - Electronic Parts Obsolescence Initiative
FPMH - Failures Per Million Hours
LRM - Line Replaceable Module
MODAR - Modular Airborne Radar
MTTF - Mean Time To Failure
NHA - Next Higher Assembly
PEM - Plastic Encapsulated Microcircuit
PLCC - Plastic Leaded Chip Carrier
RAC - Reliability Analysis Center
RTOK - Retest Okay
SOP - Small Outline Package
SSOP - Shrink Small Outline Package

3.0 BACKGROUND

Historically, reliability predictions have been a source of controversy, but have become even more so with the onset of commercial parts in military systems.

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One traditional approach is MIL-HDBK-217, which is still used today. However, the last update to this document was in February 1995 with no planned updates in the future. The major problem with the handbook occurs when applying the models to newer technologies and plastic parts. These outdated models severely penalize commercial (plastic) parts when compared to equivalent, military-screened, ceramic parts. Consequently, the Mean Time To Failure (MTTF) results appear too pessimistic.

In spite of the obsolescence of MIL-HDBK-217, viable alternative models have been few. The latest prediction methodology from RAC is entitled PRISM®, released in January 2000. PRISM® is a software tool developed to overcome the limitations of MIL-HDBK-217. These two popular reliability prediction methods were chosen for the study. The major steps in the comparison process are outlined as follows:

- Select Candidate Designs
- Compile Initial Predictions using MIL-HDBK-217FN2 and RAC PRISM® Methods
- Compute Field Reliability
- Compare Initial Predictions to Field Reliability
- Refine Predictions with Adjusted Modeling Factors
- Summarize Final Results

4.0 ANALYSIS

4.1 Select Candidate Designs

The first step in the prediction comparison study was to identify a program with sufficient field data. The Modular Airborne Radar (MODAR) program, military designation AN/APN-241, was selected for several reasons. First, the majority of microcircuits are commercial (plastic), as opposed to hermetic, fully screened parts in many of our legacy, fielded systems. Second, a significant amount of quantifiable field data has been collected on this program. As shown in Figure 1, more than 300,000 operating hours have been accumulated in the field. This translated into a substantial amount of device hours for our study. Third, the field data is reviewed on a monthly basis by the U.S. Air Force, ensuring both accuracy and credibility. Lastly, Northrop Grumman Electronic Systems performs all depot repairs for the U.S. Air Force, allowing direct access to the repair records. This enabled the determination of whether a field removal was a confirmed failure or a Retest Okay (RTOK), thus eliminating false removals in our data.

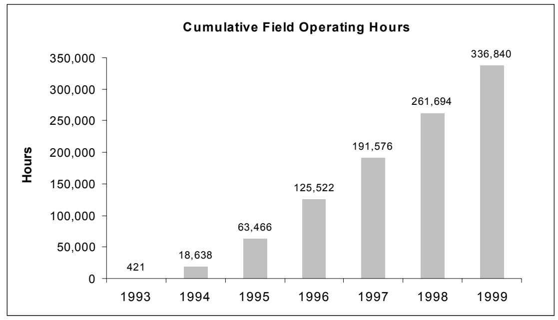

Figure 1: Field Data Represents > 300,000 Operating Hours

As with all field reliability studies, there are limitations associated with the data. The fielded systems are comprised of component packages and technologies that lag what is currently available in today's commercial marketplace. Another problem is the lack of visibility at the component level. Failure analyses conducted on piece parts are rare to non-existent. Despite these shortcomings, the MODAR field data offered a unique opportunity to examine how well the different prediction models tracked actual experience, and provided a method to refine the prediction modeling assumptions.

After a thorough review of the radar configuration, three digital CCAs designed primarily with plastic, surface mount parts, were selected for the predictions. This mix of parts best suits the designs of today that rely almost exclusively on surface mount parts for military, avionics applications. The digital CCAs were grouped together to collect statistics on the various package styles (plastic vs. ceramic) represented in the study. Over 96% of the microcircuits were plastic, as opposed to hermetic packages. The components were further classified according to whether they were surface mount or thru-hole package styles. The majority of plastic microcircuits were surface mount, 87%, verses thru-hole, 13%. As illustrated in Figure 2, approximately 90% of the plastic, surface mount packages were Plastic Leaded Chip Carrier (PLCC), Small Outline Package (SOP) or Shrink Small Outline Package (SSOP) styles.

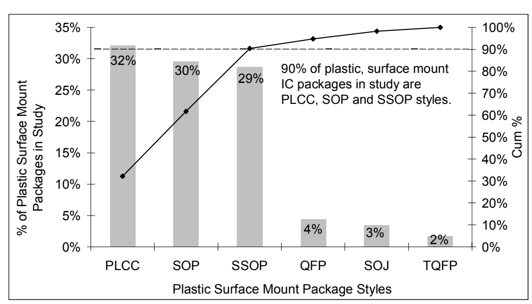

Figure 2: Package Styles in Reliability Prediction Comparison Study

4.2 Compile Initial Predictions using MIL-HDBK-217 and RAC PRISM® Methods

The first set of predictions was generated using MIL-HDBK-217FN2, Revision F, Notice 2, dated February 28, 1995 (referred to as MIL-HDBK-217FN2). The "parts stress analysis" method was implemented. Multiple iterations of the predictions were compiled with quality factors (π_Q) ranging from commercial grade (π_Q = 10), up to the highest quality level; that is, parts screened to MIL-M-38510 Class S requirements (π_Q = 0.25). This approach offered multiple data points to compare the predicted reliability to the field reliability.

The second set of predictions was performed using the RAC PRISM® tool. Two different approaches were implemented. The first method was similar to MIL-HDBK-217FN2. The total failure rate for each CCA was determined by the summation of the individual component failure rates, incorporating the same stress data used in the MIL-HDBK-217FN2 models. The second method introduced a new factor featured in the PRISM® tool, the System Level Multiplier. The purpose of the System Level Multiplier is to account for failure occurrences in the field due to reasons other than the components themselves. A series of questions are answered by the user, covering a variety of topics such as design, manufacturing, parts quality, system management, induced, wear-out, growth and infant mortality. The user may opt to answer only the required questions for each Process Grade Factor, or answer all of the questions to yield a more accurate score. In this study, only the required questions were answered due to limited information available on the designs manufactured over six years ago. The answers were then converted into scores, corresponding to Pi factors for each Process Grade category. The System Level Multiplier is determined from the composite value of the Process Grade Factors and multiplied by the total hardware component failure rate to achieve an overall system failure rate. This final step produces a prediction that quantifies the effects of a manufacturer's process variability relative to each of the failure cause categories.

Table 1 lists the prediction results for each of the three CCAs. The last two entries in the table represent the results from the PRISM® prediction methods. It is important to note the PRISM® failure rates must be converted to failures per million operating hours for a direct comparison to the MIL-HDBK-217FN2 predictions. The conversion is made by dividing the PRISM® failure rates (in failures per million calendar hours) by the operational profile duty cycle (%). The PRISM® default value of 25% duty cycle for military aircraft was used for the initial predictions. As evident in this table, the PRISM® methodology produced lower failure rates than the MIL-HDBK-217FN2 predictions.

Table 1: Initial Prediction Results: MIL-HDBK-217FN2 and RAC PRISM®

		Predicted Failure Rates (fpmh)		
Prediction Method	**Modeling Assumptions**	**CCA # 1**	**CCA # 2**	**CCA # 3**
MIL-HDBK-217FN2	Microcircuits Pi Q = 10	90.05	61.19	18.85
MIL-HDBK-217FN2	Microcircuits Pi Q = 5	46.47	33.93	12.18
MIL-HDBK-217FN2	Microcircuits Pi Q = 4	37.76	28.48	10.84
MIL-HDBK-217FN2	Microcircuits Pi Q = 3	29.04	23.03	9.51
MIL-HDBK-217FN2	Microcircuits Pi Q = 2	20.32	17.57	8.17
MIL-HDBK-217FN2	Microcircuits Pi Q = 1	11.61	12.12	6.84
MIL-HDBK-217FN2	Microcircuits Pi Q = .25	5.07	8.03	5.83
RAC PRISM®	Hardware Only (without "System Level Multiplier")	4.50	4.41	5.78
RAC PRISM®	Process Grade Factors Included (with "System Level Multiplier")	3.52	3.45	4.52

Failure Rates measured in failures per million (operating) hours

4.3 Compute Field Reliability

An extensive database of depot repair information served as the primary source of field failure data. Each field return inducted into the Northrop Grumman depot is documented and tracked for the MODAR program. The database structure included fields such as:

- RMR # (unique identification number assigned for each induction)
- Air Force Command, Aircraft Number (where unit was returned from in the field)
- Date Received, Failure Date, Return Date (dates for tracking purposes)
- Part Number, Description, Serial Number (used to sort database and select records)
- Test Results, Repair Action, Part Removed, Engineering Evaluation (reliability information)

The starting point was to query the database and extract the relevant records. This was straightforward, with the exception of one CCA style in the study. In this case, the Next Higher Assembly (NHA) was the Line Replaceable Module (LRM), not the CCA itself. Each repair record for the NHA had to be reviewed to determine whether any of the repairs involved the replacement of the subject CCA. Once the appropriate database records were identified, the results were imported into an Excel spreadsheet and sorted by part number for this initial assessment.

The data was then refined to exclude hardware returns from sites where operating hours were not accumulated. The majority of these returns were from aircraft, system-level integration and test. These records were identified for potential trend analyses and removed from the data set. For the remaining records, the repair descriptions were reviewed to determine the appropriate failure classifications. Inductions for verified failures with repair information were categorized as "Relevant", to be included in the field MTTF calculation. RTOKs were not included, as well as non-relevant failures, such as returns for configuration updates or software upgrades, not representative of actual field failures.

Operating hours were then calculated for the 1995 through 1999 time frame, correlating to the available depot repair information. The field MTTF was determined by dividing the operating hours by the number of relevant failures for each of the CCAs and is summarized in Table 2.

Table 2: Field Reliability Results (1995 - 1999)

Field Reliability Calculations	**CCA # 1**	**CCA # 2**	**CCA # 3**
Field MTTF (Total Operating Hours / Relevant Failures)	45,458 hrs	39,775 hrs	159,102 hrs
Field Failure Rate (fpmh) Point Estimate	22.00 fpmh	25.14 fpmh	6.29 fpmh

Mean Time To Failure (MTTF) measured in hours
Failure Rates measured in failures per million (operating) hours

4.4 Compare Initial Predictions to Field Reliability

The next step was to compare the predictions to the field reliability results for each of the CCAs. Figures 3 through 5 illustrate the comparison findings. The PRISM® prediction results were considerably more optimistic (i.e. lower failure rates) than the field data had indicated for CCAs #1 and #2. However, the PRISM® results were more in line with the field data observed for CCA #3.

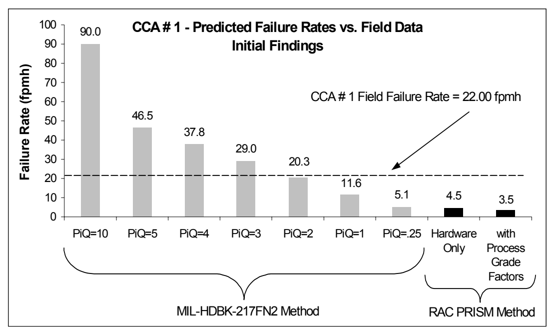

Figure 3: Initial Predictions vs. Field Reliability for CCA # 1

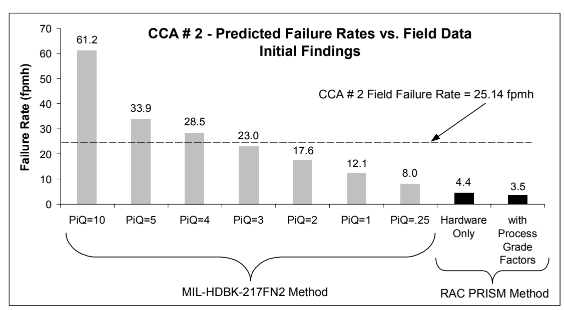

Figure 4: Initial Predictions vs. Field Reliability for CCA # 2

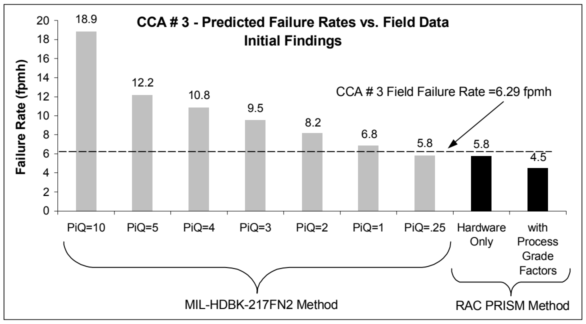

Figure 5: Initial Predictions vs. Field Reliability for CCA # 3

4.5 Refine Predictions with Adjusted Modeling Factors

A more thorough evaluation of the PRISM® prediction models was necessary to identify the factors which may have contributed to differences between predicted and field reliability. The focus was on the PRISM® default values assigned for the operating profile, namely Duty Cycle and Cycling Rate. Both factors have a major impact on the prediction results if the values differ substantially from the PRISM® defaults. After reviewing the field data, it became apparent sufficient information existed to refine the PRISM® default values for Duty Cycle and Cycling Rate to more accurately reflect the field operating conditions for the CCAs in the study.

Duty Cycle is defined as the percentage of calendar time the system is in operation. The field data was reviewed to identify the number of aircraft and the total operating hours on a yearly basis. The operating hours were divided by the number of aircraft to obtain an average number of hours per aircraft (per year). The average operating time over a five-year period was then divided by calendar hours to determine the average duty cycle of 7%.

Cycling Rate was computed based on the number of on-off cycles per year. Since flight operation differs from ground checkout practices, on-off cycles were computed separately for each environment, and then added together for the total cycling rate of 396 cycles per year. The PRISM® defaults and updated values for the operating profile (7% Duty Cycle, 396 Cycles/Year) are listed in Table 3.

Table 3: PRISM® Operating Profile Defaults and User Defined Values

Parameter Fields	RAC PRISM® Defaults	Modified Values (Based on Field Conditions)
Duty Cycle (%)	25.0	7.0
Cycling Rate (Cycles/Year)	1008	396

The updated user-defined values were entered into the PRISM® tool and the predictions were recompiled. A comparison of the initial predictions and the updated predictions are shown in Figures 6 through 8. By incorporating the actual field operating profile factors, the prediction results for the CCA #1 and CCA #2 were closer to the actual field data than the initial PRISM® prediction results had originally indicated.

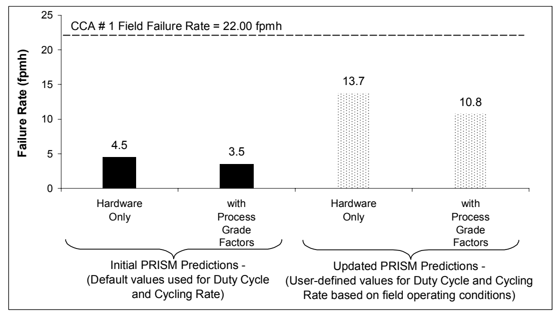

Figure 6: CCA #1 Initial and Updated PRISM® Predictions vs. Field Data

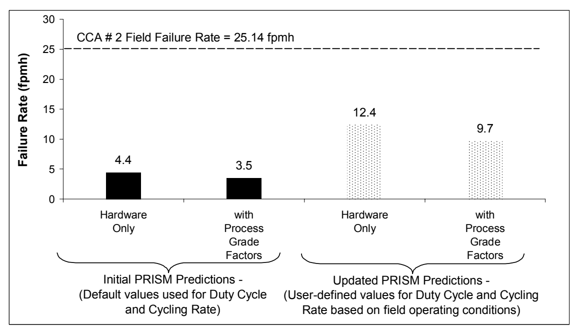

Figure 7: CCA # 2 Initial and Updated PRISM® Predictions vs. Field Data

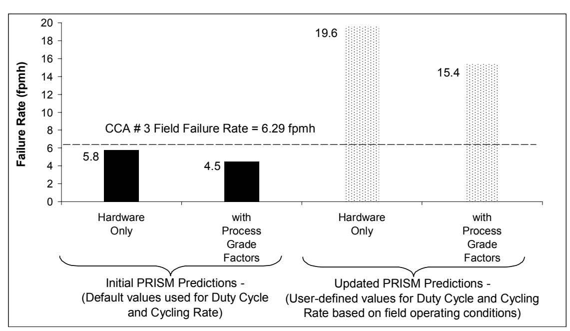

Figure 8: CCA #3 Initial and Updated PRISM® Predictions vs. Field Data

Unlike the other two CCAs, the predicted failure rate for CCA #3 was much higher than the field reliability, meaning the prediction was overly pessimistic when the field operating parameters were used. The detailed prediction was reviewed to identify the top contributors to the overall failure rate. Three filters accounted for approximately 50% of the total failure rate. These filters were not used on the other two board styles in our study. Since a RACRates© model does not exist for filters, the failure rate was obtained from the RAC database (embedded in the PRISM® tool). A review of the field repair data revealed there were no documented failures of the filters. The prediction file was modified to remove the three filters to determine the impact on the overall failure rate. The modified prediction was much closer to the field reliability as shown in Figure 9.

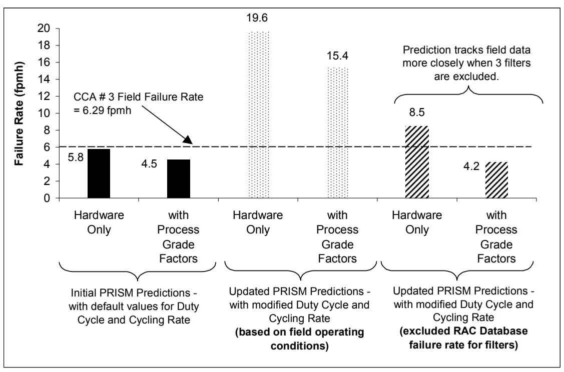

Figure 9: CCA #3 Initial and Updated PRISM® Predictions vs. Field Data

4.6 Summarize Final Results

Table 4 includes a summary of the MIL-HDBK-217FN2 and updated PRISM® predictions, along with the corresponding field failure rates. The predicted values that correlate best to the field data are highlighted in the table.

5.0 LESSONS LEARNED

The following is a summary of the lessons learned pertaining to the prediction methods and the observations from this study.

MIL-HDBK-217FN2:

The predictions which correlated best to the field data were generated using π_Q values of 2 or 3 rather than the traditional π_Q values of 5 through 10 per the handbook's screening classifications. Since the quality factor is a direct multiplier in the prediction models, the impact of changing π_Q was significant. The predictions with modified π_Q factors of 2 or 3 were within 10% of the demonstrated field reliability for the three CCAs in the study.

PRISM®:

A significant observation was made regarding the environmental assumptions used in the PRISM® models. When the duty cycle and cycling rate default values were modified to more closely represent the field operating conditions, the accuracy of the predictions improved. On average, the predictions were twenty to forty percent closer to the field data compared to the initial predictions based on the PRISM® default values.

Table 4: Final Predictions vs. Field Data

		Predicted Failure Rates (fpmh)		
Prediction Method	**Modeling Assumptions**	**CCA # 1**	**CCA # 2**	**CCA #3** (w/o filters)
MIL-HDBK-217FN2	Microcircuits Pi Q = 10	90.05	61.19	16.75
MIL-HDBK-217FN2	Microcircuits Pi Q = 5	46.47	33.93	10.07
MIL-HDBK-217FN2	Microcircuits Pi Q = 4	37.76	28.48	8.74
MIL-HDBK-217FN2	Microcircuits Pi Q = 3	29.04	**23.03**	7.40
MIL-HDBK-217FN2	Microcircuits Pi Q = 2	**20.32**	17.57	**6.07**
MIL-HDBK-217FN2	Microcircuits Pi Q = 1	11.61	12.12	4.73
MIL-HDBK-217FN2	Microcircuits Pi Q = .25	5.07	8.03	3.73
RAC PRISM®	Hardware Only (without "System Level Multiplier") 7% Duty Cycle, 396 Cycles/Year	13.73	12.36	8.48
RAC PRISM®	Process Grade Factors Included (with "System Level Multiplier") 7% Duty Cycle, 396 Cycles/Year	10.75	9.68	4.21
	Field Failure Rate (fpmh)	22.00	25.14	6.29

Failure Rates measured in failures per million (operating) hours

RACRates© models embedded in the PRISM® tool should be used to the maximum extent possible. In cases where RACRates© models do not exist for a particular component type, the user has to assign a failure rate or select one from the RAC database (included in the PRISM® tool). The predictions for two of the CCAs in this study were primarily based on RACRates© models. Both of these predictions tracked the field data better than the third CCA with failure rates incorporated from the RAC database.

The System Level Multiplier produced overly optimistic results when accounted for in the PRISM® predictions. The recommendation is to generate predictions with and without the multiplier, yet refrain from formally utilizing it until field data is available to substantiate the improvement factor. Specific knowledge of the program's design, manufacturing, quality and management practices is required for an accurate assessment.

Experience Data:

Field data proved valuable for one of the CCAs in the study where a component failure rate skewed the overall prediction results. Once the failure rate contribution was removed from the prediction, the results were much closer to the field data.

In summary, the prediction comparison study funded under the EPOI program offered a unique opportunity to independently evaluate various prediction methods and compare the results to actual field data collected on plastic parts in a military environment. Findings from this study provide justification to modify specific modeling factors to improve the predictions for PEMs, and also serve as a baseline to evaluate future alternative prediction methods.

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