Field Data is Reliability Information: Implementing an Automated Data Acquisition and Analysis System

James Jauw ◆ Amway Corporation ◆ Ada
Pantelis Vassiliou ◆ ReliaSoft Corporation ◆ Tucson

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SUMMARY & CONCLUSIONS

This document describes the conception and development of the Amway Product Quality Tracking System (PQTS). The PQTS is an integrated product quality tracking system that allows the organization to 1) Capture product quality, reliability and warranty data from disparate data sources and incorporate that data into a single centralized database that can support powerful data analysis. 2) Carry out sophisticated data analysis routines that transform data into information that can be used for decision-making. 3) Present analyzed reports and graphs in a graphically rich, multi-faceted and carefully organized presentation interface accessible via Intranet or Internet to support the decision-making of key organizational personnel. Development of this system began with an attempt to improve on labor-intensive manual methods of report creation and proceeded to the development of the fully automated system available to Amway today. A general description of the development process, an analysis of the lessons learned during system implementation and benefits to the corporation are presented.

1. INTRODUCTION

The most challenging aspect of product quality and reliability data analysis is often the acquisition and management of the data itself. Many organizations are unable to take advantage of valuable field product-failure or field performance data because data is not collected, the data lacks uniformity or sufficient granularity and/or the data is inaccurate or lacks validity. If data is collected at all, it is often stored in a variety of locations (manufacturing sites, repair centers, in-house testing facilities, telephone call centers, etc.) with little or no integration among data sources or uniformity in format. These deficiencies in the data infrastructure make coherent analysis difficult or impossible. An integrated approach, focused first on assuring that data is properly collected, stored, correctly analyzed and properly presented, is therefore desired. Such an approach will lead to a complete Product Quality, Reliability Analysis and Reporting System that allows an organization to turn real-time data into information, and information into decisions for rapid continuous improvement.

Over the last three years, the adoption of this reliability philosophy for business has led Amway Corporation, working with ReliaSoft, to develop and implement an automated system for tracking product field reliability and "Quality." The creation of such a system for Amway, the Amway "Product Quality Tracking System" (PQTS), involved the modification and integration of many individual systems and disparate data sources. The PQTS is a comprehensive and automated system that incorporates all facets of data acquisition, coupled with advanced reliability analysis engines to provide real-time data and reliability predictions for Amway products worldwide, in a comprehensive and easy-to-use graphical format. The early success of this implementation has already provided Amway with an early warning system to apprise management of significant changes in typical defect levels, a reduction in time required for problem analysis and overall product design improvements that significantly increase product quality and reliability. To our knowledge, this is the first such system implemented for a manufacturer of household products. This paper presents the outcome of this effort, an overview of the process as well as discussion of the pitfalls and lessons learned in implementing this system.

2. HISTORICAL AND BACKGROUND INFORMATION

The internationally recognized business model of Amway Network Marketing is the subject of books, occasional jokes (as featured on "The Tonight Show") and many personal success stories. It is a closed system of distributors and service providers in which no independent third-party distributor or repair company exists. All products are sold and serviced through company authorized providers. This system is very much like automobile sales where warranty service is the exclusive domain of the dealerships.

Amway Corporation began down the path of Reliability Engineering when they started to design, manufacture and sell market-leading home appliances for the Japanese market. Prior experiences with similar products in the United States and Asia showed Amway that better design testing and analysis of reliability data (from in-house reliability testing, field data from both repairs and telephone hotline calls) was essential to rapid risk management and superior customer service. Key to this success was the need to answer reliability-related questions appropriate to the various levels of management and areas of business function. Initial management needs focused around the central questions of "What is my current defect rate for these units in the field?" and "How many in-warranty failures are we expecting during this time period?" which translated into the question of "What is the failure rate of units in the field currently in warranty?" Although the questions seem deceptively simple, they are considerably more complex when one considers rolling populations (i.e., population of units under warranty changes continuously), variable sales (i.e., sales change monthly) and that the units under warranty are of various ages.

Starting in 1995, Amway began collecting data for the required analysis from a variety of sources. The analysis of this data resulted in in-depth printed reports that included some answers to the previously posed questions, along with further analysis based on subassemblies and components for the product under consideration. Despite some shortcomings in the data available and the necessity of relying on some assumptions in analysis, these first attempts provided impressive results. Amway R&D engineers were able to characterize failure modes from field data and correlate them to in-house testing as well as accelerated test results. This data gathering and analysis process began with engineering knowledge of the product and was coupled with codified symptoms from the Customer Service Telephone Hotline (THL), codified repair information from the product repair center and sales and manufacturing data. The data came from different locations around the world and resided in different computer systems (which varied in type, size, operating system and applications).

This initial method, though commendable, was extremely time-consuming. Hundreds of hours were required to set up the queries, create the spreadsheet and related graphs. This adversely affected the timeliness of reports, so that an acute problem in the field could surface without being detected in a timely manner. In 1996, with the help of ReliaSoft Corporation, Amway began a project that would: Automate and improve the data-collection and report-preparation process; validate and solidify the mathematics used for computations and predictions; and develop a system that would transform the data into instant information for use by managers and engineers alike. In time, this project became the Amway Product Quality Tracking System (PQTS).

3. DESIGNING THE PQTS

3.1 Determining the Required Data

The first step in designing the PQTS system was to determine the data required for current and future analysis. To determine the required data we first identified the kind of reports and analysis that the system customers (i.e., Amway managers and engineers) would require. Using the current reports as a starting point, several days were spent with managers and engineers to discuss their reporting and analysis needs. The next step was to define the data that would be required to create the reports and analyses designed in that manner. The required data identified in this manner was divided into four major categories: Manufacturing Data, Sales Data, Failure/Repair Data and Telephone Hotline (THL) Data. Figure 1 provides an overview of the required data flow in the PQTS system.

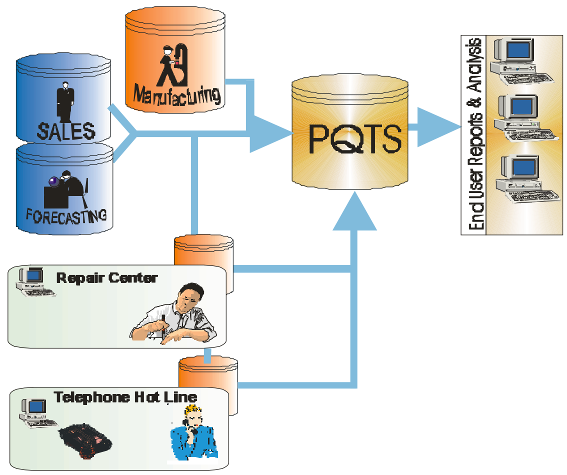

Figure 1: PQTS System Data and Report Flow.

Each of the data sites identified in Figure 1 provided a piece of the puzzle that would eventually make up PQTS. Data from manufacturing provided the serial number and date of manufacture of each unit along with the serial numbers (or lot numbers) of the subassemblies. Sales data provided the number of units sold per time period and income derived, while repair data provided the serial numbers of the failed units along with the component that failed and the reason(s) for failure. Telephone hotline data provided the symptoms experienced by the consumer along with a preliminary diagnosis and resolution.

3.2 Establishing the Data Infrastructure

Once the required data was determined and the data sources were identified, we embarked upon a thorough examination of the current data infrastructure. Like Fortune 500 companies, Amway has a long-standing commitment to automation at every part of the business model. A basic infrastructure already existed, i.e., there was a computer of some type to capture the data at each source and a wire to transmit the data and applications developed for the specific task(s) at hand were residing on each of these machines. These "point of use" computers were connected by many types of connections either to a Mainframe Computer or via Local Area Network (LAN). These local systems connected to the corporate system and comprised the evolving Global Information Network of Amway.

The internal challenge was to optimize existing tools and people. The external challenge was to automate and integrate data from two non-Amway entities, our product supplier and repair service provider. To meet these challenges, a decision was made to design our processes to conform as much as possible to the existing processes of these data suppliers. Changing the processes at any of the sites would have been much more complex and would have been met with severe

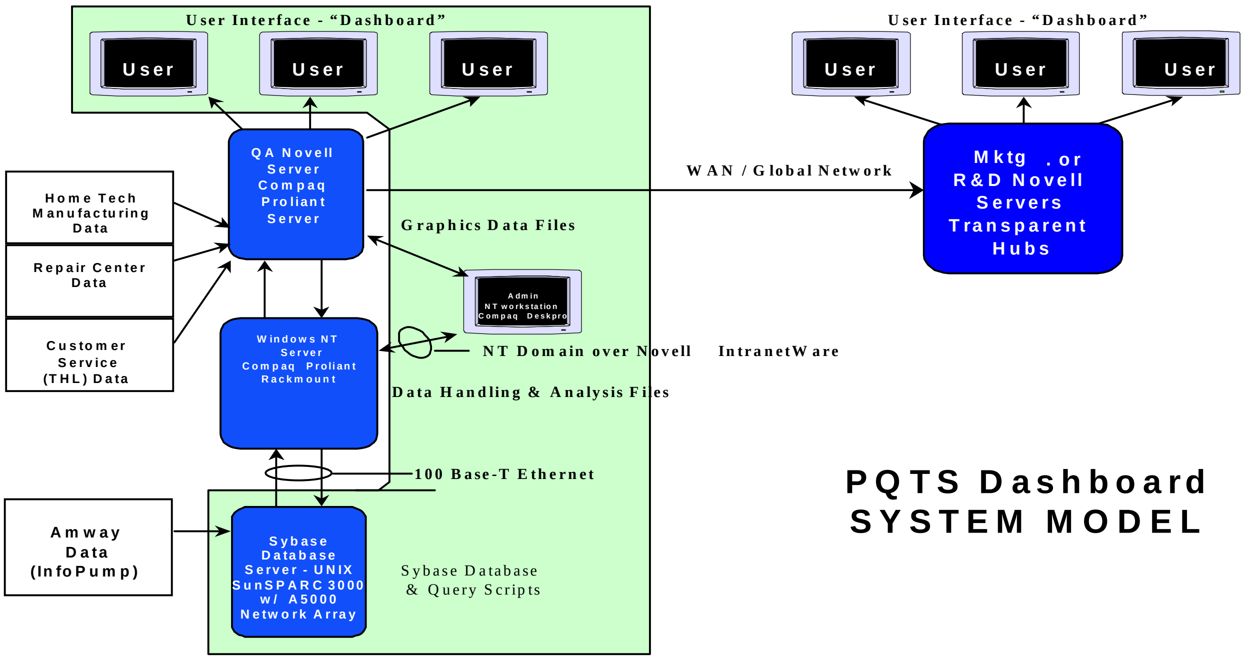

Figure 2: PQTS System Architecture Diagram

objections and obstacles that might have halted the project well before it began. The end result was walking the thin line of accomplishing our objective in such a way that it was transparent to the data providers and, where transparency was impossible, implementing changes in such a way that it minimized the additional burden on these providers.

To further complicate matters, the data was stored in disparate locations around the world and housed in a variety of configurations. Although each different configuration was appropriate for the local application, the differences in machines and databases posed challenges of data transportation, translation and importation into PQTS. To acquire and transport the data, an array of automated software tools were created specifically for each site to automatically extract the required data, package it and transport it to a centralized PQTS database. Since different sources had different connections and security concerns, multiple data transfer methods were used including simple Modem transport to ISDN connections and Corporate T1/T2 lines. Figure 2 shows an overview of the different systems, locations and connections that comprised PQTS.

Concurrent with this coordination of data capture and transport, the PQTS relational data model was designed and the necessary hardware infrastructure to support PQTS functionality was put into place.

3.3 The Reports and User Interface

Knowing full well that all the data in the world is useles unless properly reported and presented, many hours were spent in determining what the reports should look like and how they should be accessed. After many brainstorming sessions, and with the knowledge that the final customer (or the most important customer) was management, our final decision was to present the data in a "Dashboard" format that would present the data as information that can be viewed at a glance. The first level of the PQTS Dashboard contained what was deemed by Amway to be the most important issues regarding the product and arranged them as shown in Figure 3.

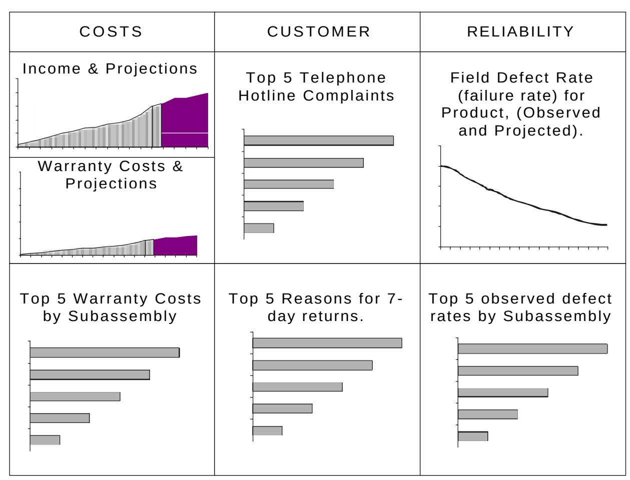

Figure 3: PQTS Dashboard Presentation of Product Data.

The top-level Dashboard was designed to provide three important categories of information divided into three columns: Costs, Customer and Reliability. The information was presented in a rich graphical format (much like a "USA

Today" snapshot for the product's health). At this top-level, one could (with a simple mouse-click) drill down on each item for more detailed graphs and analysis. The PQTS top-level Dashboard design, a design that can be utilized by most product manufacturers, contained the following analysis presentations.

3.3.1 Cost Column **-** The Cost column was designed to present Financial issues and was comprised of three panels. The top panel contained Revenues for the product, which were presented based on a simple rolling average[1] for the last 18 months and forecasted out for the next four months. This data was obtained monthly from existing sales and forecasting databases, maintained by the financial departments at Amway. The second panel presented the warranty costs for the overall product, based on data obtained from THL and the repair center and again projected out for the next four months (with projections based on projected defect rates and projected sales). The last panel presented the warranty costs by subsassembly, again based on data obtained from THL and the repair center.

3.3.2 The Customer Column **-** The middle column of the PQTS Dashboard was designed to provide information on Customer issues and was comprised of two panels. The first panel showed the top 5 issues at THL. These issues represent what the customers experienced when they called the call center. They provide an early warning system as to symptoms experienced in the field. The second panel in the customer column presented the top 5 reasons for product "Seven-Day Returns," or reasons a product was returned or failed only seven days after purchase. This was deemed critical to customer satisfaction and of high priority, since a customer that returned a product only seven days after purchase was more than likely to be dissastisfied and their loyalty perhaps lost.

3.3.3 The Reliability Column **-** Much thought went into the reliability column and the results shown. Again, in our effort to cater to the manager's perspective, we decided to use familiar terminology such as "defect rates" (percent failed under warranty). The top panel in this column showed rolling defect rates for the entire unit, and is a composite computation based on the defect rates of the subassemblies. The projections were also computed based on reliability predictions of the subassemblies (i.e., the percent expected to fail under warranty for each subcomponent) and then combined using system reliability methods and principles. When dealing with subassemblies and depending on the component, data granularity varied. In cases where the unit was sent to the repair center, serial numbers were availaible, which allowed the system to determine how long the component was in that particular product and, in effect, obtain a time-to-failure for that component. Once times-to-failure for the components were obtained, analysis and prediction could be easily performed using standard life data analysis techniques (i.e., parametric techniques) with statistical distribution fits to the data, such as the Weibull distribution, and from there perform the necessary calculations and predictions. These methods are well documented and there is a wide variety of software availaible to perform such analyses, including market leading software and engines from ReliaSoft Corporation.

Obviously, when times-to-failure data along with time-in-operation data was available, the analysis task was trivial. The difficulty arose when dealing with certain subassemblies of the product where minimal data was availaible. This occured for subassemblies of the product that were sent out by THL after the customer called the center. In most cases, no serial number for the unit was available or recorded, thus it was impossible to ascertain the age of the component. The only data we could obtain were the number of the assemblies that entered the per-time period and the number of reported failures under warranty per-time period. Our approach was to use a non-parametric (sales-invariant) approach to compute the defect rate. This simple non-parametric approach is given in the Appendix of this paper.

The next figure, Figure 4, shows an actual screen shot of the PQTS Dashboard (with fictional data) as originally implemented at Amway (utilizing a client-server approach), along with an illustration of the drill down graphs that the user can invoke from the top-level. The Dashboard is updated through the PQTS system automatically. For this implementation, we chose weekly updates to the Dashboard.

4. TURNING ON THE PQTS

Once all of the pieces of the system were designed, the next task was to turn the system on. To meet the computational requirements, all existing historical data was required by the system, so the first step was to load historical data into the PQTS database. During this process, many hours were spent cleaning polluted data that already existed. Once the database was populated with historical data, the system was turned on and we performed a historical analysis using the established analysis routines to see how the system performed and to validate our predictions against known history. During this debugging phase, we accounted for anomalies of program behavior and analysis results. Once adjustments were made to correct the anomalies, the program was backed up, reloaded and run again. Heavy emphasis was placed on thorough validation of every routine in the system, because we anticipated that management may take action, based on the results presented, the minute the system was made available. We spent weeks repeating each calculation (either manually or with other software) and verifying the results for the hundreds of reports the system created.

The types of analysis that this system enabled exceeded the original design intent. Aside from the automated non-

[1] Other methods such as an EWMA can also be utilized. In most cases we chose methods that most people are familiar with.

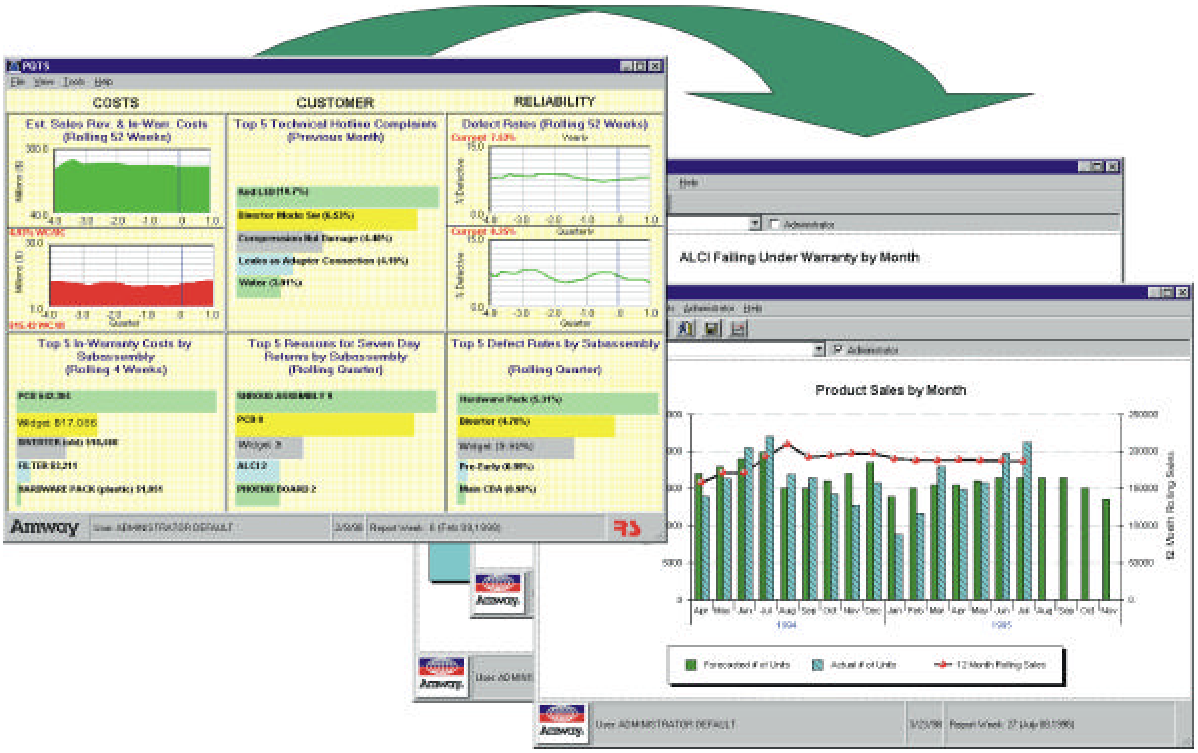

Figure 4: PQTS Dashboard Screen Display with Fictional Data.

parametric analysis, a new realm of automated and ad hoc parametric analysis was fostered. For example, Service and Warranty cost estimates are now provided for new products, prior to product launch into a market. We have been able to provide good estimates because they are based on the statistical history of similar products in conjunction with mathematical knowledge of the mechanics of each market where Amway Corporation conducts business.

5. PITFALLS & LESSONS LEARNED

During the design and development of the PQTS system, we experienced and overcame a number of pitfalls and learned valuable lessons that contribute to the successful implementation of a project of this scope. Some of these managerial, theoretical/conceptual, technological and project management lessons are presented next.

5.1 Managerial Lessons

5.1.1 Managing Changing Management - Just when you thought you had "trained your boss," he/she "moves on." These days, it is rare that your next boss will come ready-equipped with a full understanding of the jargon and project nuances. New managerial staff changes in another department can also cause interruptions, especially if your project touches his/her budget. So long as our project made business-sense, we continued the education and marketing process.

5.1.2 *Inspiring the Right Type of Confidence* - The overall project has experienced its share of setbacks caused by an ill-turned phrase tossed in the wrong direction. Because all cooperative ventures depend on team members who will listen, and hopefully act in your favor, the right climate of trust and confidence must be maintained.

5.1.3 Budget Wars - Almost every enterprise-wide project will depend upon more than one budget and this project was no exception. PQTS continues to exist based on the generosity of many Information Services (IS), Manufacturing, Operations Engineering, Distribution and Service divisions, and the respectively similar divisions of our affiliates and suppliers. One key to achieving the necessary budgetary support was our effort to make our project tools as transparent as possible, such that they required very little maintenance and administration. We tried to make all resource-intensive costs a one-time charge during installation of the various modules and to piggy-back our project modules onto any similar project from another area to leverage value for the company.

5.2 Theoretical/Conceptual Lessons

5.2.1 Managing Mathematics - Discussions over numbers related to money inspire passionate involvement from almost everyone in a company. Often though, these people do not tend to bring the same enthusiasm to discussions of measurement tools based on statistics and other forms of higher math. These discussions are necessary, however, as they do relate to and impact the corporate "bottom line." In PQTS development, explanation of mathematical algorithms were graphically illustrated to quickly display the relevant issues and the impact on other parts of the business. At the same time, we must caution against underestimating your audience and patronizing them by "dumming down" your presentation. Keep your formulae, expressions and notation accurate. The work must appear credible, be reproducible and have integrity independent of the analyst.

5.2.2 Design Complexity - *Schematic and Other Diagrams:* Thorough documentation of each phase of a complex project produced a myriad of charts and diagrams, essential for understanding by people within a discipline. We had complete written plans for implementation, along with cross-functional process maps, entity relationship diagrams, schematic diagrams, program flowcharts, data dictionaries, wiring specifications and more. However, showing someone these types of charts or diagrams may not give that person an instant understanding of a given situation. Patience, analogy and alternate verbal explanations are sometimes necessary to help clarify clouded situations.

5.3 Technological Lessons

5.3.1 Letting Technology Catch Up To You - When we began our project, some of the solutions we put forth for secure international data transportation were "ahead of their time." That is, those in a position to approve their use were unfamiliar with their reliability and security. Although most of this technology, encryption/decryption, modem recognition of authorized machines, etc., is used in most every corporate system today, we were initially denied the use of these tools in 1996 when we began the project. In this instance, we had no choice but to modify our system for the tools allowed at the time, even though we experienced an adverse impact on performance.

5.3.2 Navigating the IS/IT Seas - Whose job is it? For large companies, information systems tasks are divided by area of specialty, each department having its own management, technical staff and budget to deal with. Our project had to enlist the help of experts in such IS departments as Server Technologies, PC Technologies, Telecommunications, LAN Applications, Mainframe Programming, Database Design, Database Administration, Data Security and Global IS. There was no "one-stop shopping guide" to help us through this sea of people. In a sense, we built PQTS like a modern aircraft or car, with specialty departments building their respective subassembly without major knowledge or regard for each other.

5.4 Project Management Lessons

5.4.1 Assumptions (research your business) - We assumed that this project was going to be very expensive (millions of dollars in hard costs): we were wrong. When we conducted our needs assessment, however, we found that many of the computers and software were already in place serving other functions and monetarily supported by existing budgets. Our costs were directed toward modification, optimization and integration of the existing systems. Reality will often surprise you.

5.4.2 Complex Project Management - A project of this size and scope requires the cooperation of people from many different companies, departments and disciplines (including the legal profession). Concurrent engineering and development is essential to delivering the final product on time and within budget. The success at all phases of the project depends on a lot of good communication, a smattering of patience, a dose of understanding people and a good helping of faith. Selection of the internal team members isn't always in the project manager's control, but the selection of trusted and competent consultants and solution providers is. Researching your outside players and developing solid partnerships is essential, especially when times are tough and the project isn't progressing as planned.

5.4.3 Intimidation of Scale and Scope - Nobody ever told us that this project was impossible, so we moved ahead never letting the enormity of the project get in the way of achieving our goals. In this respect, ignorance is truly bliss.

5.4.4 "Murphy" still rules, but he is manageable - Unexpected challenges are a part of this type of business, but there is another saying that equally applies: "if it were easy, everybody would be doing it." Because all systems depend on consistent performance of all their parts, any disaster that befalls these parts is cause for pause. The dynamic nature of business forced the PQTS to be dynamic in order to remain viable.

5.4.5 Management Support and Vision - There are many details of this project that are specific to a discipline and that may be outside the understanding of a manager who controls needed resources. Communicating the relevance of the project to the business (in terms of time, resources, monetary benefits and long-term customer benefits) is a never-ending job. Management must maintain the "vision" in order to continue support. Ultimately, it is their understanding and trust that gives management the confidence to let you, the project manager, manage their resources. We are happy that this vision continues at Amway and ReliaSoft.

6. BENEFITS

Amway Corporation has already experienced a direct return on this investment. For a crisis in the field, PQTS allowed us to rapidly characterize the quantity, timing and cost of corrective action. To the customer, this process was transparent and just as rapid, thus fortifying their loyalty and our reputation. For existing products, PQTS gave us rapid assessment of the impact of design improvements in the field and a significant reduction of the corrective action cycle time. The company now focuses the right resources to product improvement and problem solving based on measurement results, instead of stories and intuition. Some "next generation" products derive feature and performance improvements based on the data gathered by PQTS. PQTS helped change the way we deliver service for the appliances we make, thus helping Amway Corporation stay on the leading edge of the home appliance industry. By ensuring products made with the best reliability, based on the best science, we work to help Amway be "the best business opportunity in the world."

7. ACKNOWLEDGEMENTS

A project of this magnitude could have never been completed without the involvement and support of many people. We express thanks to Mr. Barth Wilson, who helped champion this project and formulate the original Dashboard idea along with the information that should be presented on it. Additional thanks go to Mr. Ron Markham and Mr. Simon Vance for their various contributions to the analysis methodologies. Recognition is also given to Mr. Rick Jones and Mr. Richard Joyce for their unwavering support. A special thanks goes to the staff of ReliaSoft Corporation who made this project possible. Last, but not least, we acknowledge the many technical contributions from the R&D, QA, IS/IT, Customer Service, Marketing, Logistics/Support, and Legal staffs of Amway Corporation and Amway (Japan), Ltd.

8. APPENDIX

In determining the average defect rate under warranty for a product, when the only information available is the Number of Units/Components sold per unit time period (i.e. per month), and the number of Units/Components failing under warranty for each time unit period, the following formulation was used,

$$DR_T = \sum_{j=T-(U-1)}^{T} \left(\frac{R_j}{\sum_{i=j-(U-1)}^{j} N_i} \right)$$

where T is the current time period (week or month), U is the warranty period, R is the number of under warranty failures reported that time period, and N is the number that entered the warranty population during that time period. This formulation is invariant of sales and truly accounts for the at-risk population.

Quick Example

The following are hypothetical sales and returns for component per time period or for time period U denoted as (Sales, Failures)$_U$

$(1,000; 10)_1$, $(10,000;110)_2$, $(120,000;1,310)_3$, $(5,000;1,360)_4$,$(100;1,351)_5$; $(580;1.257)_6$, $(5,600;113)_7$, $(40,000; 463)_8$

If we assume a 4 month warranty period or U=4, at the 7th month our under warranty defect rate will be,

$$DR_7 = \sum_{j=4}^{7} \left(\frac{R_j}{\sum_{i=j-3}^{j} N_i} \right)$$

$$= \frac{1,360}{1,000 + 10,000 + 120,000 + 5,000}$$
$$+ \frac{1,351}{10,000 + 120,000 + 5,000 + 100}$$
$$+ \frac{1,257}{120,000 + 5,000 + 100 + 580}$$
$$+ \frac{113}{5,000 + 100 + 580 + 5,600}$$
$$= 0.04$$
$$= 4\%$$

9. BIOGRAPHIES

James Jauw
Amway Corporation
Mail code 26-2C
7575 Fulton Street East
Ada, MI, 49355-0001, USA
Work Phone: 616-787-7648
Fax: 616-787-4976

Email: Jim_Jauw@Amway.com

Mr. Jauw is a Quality Engineer for the Home Tech Quality Services department of Amway Corporation and is the Project Coordinator for the “Product Quality Tracking System” (PQTS), their field data Reliability Analysis tool for Home Tech appliances. He oversees PQTS development, implementation and validation, working with programmers, system analysts, designers, administrators, engineers and managers from the U.S. and Asia (he still manages to occasionally debug and write code). Mr. Jauw works directly with Amway’s Reliability Engineering program, providing risk analysis reports, Weibull and Non-parametric, for new and existing products. He is a member of the American Society for Quality (ASQ) and an ASQ-Certified Quality Engineer.

Pantelis Vassiliou
ReliaSoft Corporation
Corporate R&D, Suite 103
115 S. Sherwood Village Dr.
Tucson, AZ, 85710, USA
Work Phone: 520-886-0366
Fax: 520-886-0399

Email: Pantelis@ReliaSoft.com

Mr. Vassiliou is the President of ReliaSoft Corporation, a research and development organization comprised of reliability engineers, statisticians and computer scientists, and dedicated to providing reliability engineering solutions. For the past seven years, Mr. Vassiliou has managed and coordinated ReliaSoft’s R&D efforts to deliver state-of-the-art custom systems such as the one discussed in this paper, along with commercial software tools and reference books for applying reliability engineering concepts and methodologies including the following: ReliaSoft’s Weibull++ and “ReliaSoft’s Life Data Analysis Reference” for life data analysis; ReliaSoft’s RG and “ReliaSoft’s Reliability Growth Reference” for reliability growth analysis; ReliaSoft’s BlockSim and “ReliaSoft’s System Reliability Reference” for reliability, maintainability and availability analysis of complex systems; and ReliaSoft’s ALTA and “ReliaSoft’s Accelerated Testing Reference,” the first commercial software package specifically designed for analyzing accelerated life data. He holds a Masters degree from the University of Arizona in Reliability Engineering.