IPN Progress Report 42-187 • November 15, 2011

The DSN Asset Management/Maintenance Improvement Initiative

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ABSTRACT. — This article describes the Asset Management/Maintenance Improvement (AMMI) initiative: the first focused Deep Space Network (DSN) initiative intended to improve the efficiency and efficacy of maintenance, support improvement in equipment reliability, and provide metrics for use in understanding equipment reliability and the use of maintenance resources. The initiative has resulted in the introduction of many new processes and procedures including the global use of a computerized maintenance management system (CMMS) and Reliability-Centered Maintenance (RCM) concepts. The work performed as part of the AMMI initiative represents significant changes to the DSN maintenance culture that has been in place for over 40 years.

I. Introduction

Maintenance of the Deep Space Network (DSN) for most of its history has been based largely on local interpretations of design information, local facilities demands, and local self-imposed requirements. Maintenance was scheduled based on calendar rather than on need, resulting in frequent conflicts with tracking requirements and reduced equipment availability. Metric information regarding maintenance was largely lacking. The DSN maintenance strategy was highly reactive, responding to equipment failures rather than trying to prevent them. Because support requirements were apparently being met, little attention was paid to the maintenance situation even though equipment availability was degrading and more heroics were necessary to meet the support requirements. The Asset Management/Maintenance Improvement (AMMI) initiative was begun in 2006 under the "Green Plan" umbrella to address the state of DSN maintenance. This ongoing initiative is attempting to address the DSN maintenance culture by globalizing maintenance practices and reporting, introducing maintenance metrics and beginning the process of Reliability-Centered Maintenance (RCM). Subsequent sections of this article will discuss how this is being done and provide a few lessons learned.

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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

II. The Green Plan Opportunity

In late 2005, National Aeronautics and Space Administration (NASA) Headquarters directed the Jet Propulsion Laboratory (JPL) to develop a plan for achieving and keeping a "green (or fully operational)" state for the DSN. This was done because of the continuing and worsening budget constraints and in recognition that much equipment in the network was old and reaching its end of life. The network had been deemed by NASA to be "fragile." The Green Plan, as it came to be known colloquially, was published in early 2006 and addressed various aspects of maintaining readiness including implementation requirements, asset management, and program management.

In the plan document, asset management was defined as "…the plans, processes and procedures used to maintain and sustain all DSN assets…" Under this umbrella, the plan specified the implementation of RCM and maintenance metrics amongst other related actions. Work on the asset management activities of the Asset Management/Maintenance Improvement Initiative (AMMI) began almost immediately. ITT personnel and each of the Deep Space Communications Complexes (DSCCs) were requested to provide support. Equipment Links, Inc. (EQL), a maintenance consulting corporation that had previously been used at the Goldstone DSCC and other NASA facilities, was contracted to lead the implementation of modern asset management strategies including RCM, metrics, and the Computerized Maintenance Management System (CMMS) tools required to enable them. It should be noted that NASA had specified that RCM methodology be used to maintain its assets many years before the development of the Green Plan. The DSN had not implemented any RCM-related processes in response to that directive.

III. The DSN Maintenance Environment

At the very first meeting with DSN maintenance personnel to begin the process of informing them of the upcoming AMMI initiative and its goals, the presenters were greeted with the rejoinder that maintenance had been done effectively in the DSN for 40 years and no improvement initiative was required. The DSN maintenance culture is a result of the network's geographic diversity. Prior to the AMMI globalization efforts, each DSCC performed maintenance in its unique way, reflecting the local maintenance organization, its skill set, and training even on common equipment. This led to obvious questions regarding efficiency and efficacy of maintenance and was reflected in the varying staffing levels and reliability at each DSCC.

IV. AMMI Future Vision and Strategy Development

The DSN vision was to maintain, as much as possible, the cultural basis of the three DSCCs and to encourage the operators and maintainers of the equipment to implement new and improved processes. The plan was to identify or define best practices and to educate DSCC personnel on the important characteristics associated with maintaining equipment reliability through a highly interactive program involving key personnel from each DSCC; then to implement these best practices as consistently as possible so that any data or information associated with work and performance history would benefit all three DSCCs. In order to be able to develop a strategy for meeting the end goal, it was first necessary to assess the current state of behaviors at each of the DSCCs.

The authors (in particular, Mr. Dundics) performed a comprehensive assessment in 2006 at each of the DSCCs. The assessment investigated all of the behaviors associated with asset management, and compared the behaviors to established industry baselines. What we found was that:

- None of the sites used a computerized maintenance management system (CMMS) work order tool consistently or widely.
- None of the sites had comprehensive maintenance metrics to track equipment reliability or work force usage.
- There was no use of RCM maintenance strategies.
- There were no underlying processes for performing maintenance, using work orders, or generating metrics.
- There was no improvement process.
- There was no consistency across the DSCCs.
- Key information required to globalize maintenance such as an asset hierarchy, standardized job plans, or work order content was nonexistent.

This, quite obviously, did not represent where the DSN wanted to be in light of NASA Headquarters scrutiny, the Green Plan, and limited and shrinking budgets. Thus, the AMMI began in earnest to develop a roadmap to address these issues.

While the assessments identified a wide range of behaviors that were inconsistent and needed improvement, the ultimate strategy only targeted those behaviors where it was believed that there could be maximum return on investment. The target areas needed to have a focus to ensure that the “right maintenance” was being performed, and also that the maintenance was being performed “efficiently.” The specific target areas that would help achieve these desires were categorized into four key areas:

- RCM — Activities for determining the best maintenance program for achieving the desired reliability of the antennas.
- Maximo — The CMMS (a commercial software product owned by IBM) that would contain the data associated with work and equipment performance history. This is data from which all reliability analyses would be made, and therefore it must be set up to contain all of the information that a reliability engineer would need.
- Metrics — The data from which decisions would be made. The data must represent the true situation and behaviors of the organization, and therefore must be accurate.
- Processes — The manner in which work is executed and data is stored and extracted. Adherence to processes will ensure accuracy and consistency of data, regardless of the DSCC performing and documenting the work.

V. AMMI Goals and Approach for Implementation

Using the insights gained from the assessment and directions from the Green Plan, the initial AMMI Steering Group set about defining the goals and objectives of the AMMI Initiative. There were four strategic objectives for the AMMI to address. These were:

- Ensure the effective and efficient use of limited DSCC maintenance resources.
- Provide useful metrics.
- Support programmatic decision-making.
- Drive implementation of more reliable designs in both hardware and software.

The approach to satisfying the objectives was to embark on a series of initiatives under the AMMI umbrella. These were to introduce RCM methodologies into the DSN; implement reporting using the Maximo CMMS; improve and standardize maintenance-related processes; and address the opportunities identified in the maintenance assessment previously discussed.

RCM. RCM was developed several decades ago to address the growing and unsupportable requirements for aircraft maintenance. This type of maintenance is more efficient than traditional maintenance techniques in that equipment criticality determines the level of maintenance support instead of applying maintenance equally to all assets. The DSN had long claimed to use RCM but it indeed was not. This represented a fertile area for DSN improvements. The benefits of implementing RCM include improving the efficiency of the use of maintenance resources, improving the reliability of DSN equipment, extending the life of existing assets, and helping to improve the design for maintenance of future hardware.

Metrics. These are key to all the AMMI objectives, as well as being one of the key goals. Metrics are necessary to understand:

- The use of and demands on the maintenance work force. This is important for understanding and controlling personnel costs.

- The reliability-maintainability-availability–related performance of the DSN assets. This is important to understanding the performance of the DSN, the demands on and performance of the maintenance work force, the efficiency of maintenance, for improving the design of future hardware and software, and for support decisions regarding equipment replacement and upgrades.

Maximo/CMMS. Maximo had been in use for many years in an ad hoc manner. That is, there was no standardization of parameters required to describe work requirements or reporting requirements. Each site used Maximo differently and to differing extents. At any DSCC, one could find some groups using Maximo and some using note cards to specify work requirements. The goal was to define Maximo data requirements for a universal implementation that was intended to improve the efficiency of maintenance and to provide common data for the generation of metrics.

Processes. Even though maintenance had been done regularly, there were almost no defined maintenance processes. There was not even an overarching process for doing maintenance (e.g., identifying the need for maintenance work, defining the work and doing the work). All had been pretty much left up to a "we've always done it that way" methodology based on past experiences. The goal was to improve efficiency by defining standardized processes to the extent that a maintenance technician could do his job at any of the sites. Other benefits include improved asset reliability and availability and a life extension of aging equipment.

All of these areas had a measure of dependence and all were essential to improving the general health and status of DSN maintenance and the network itself. Specifically, it was hoped that the AMMI actions would result in improved availability and reliability of DSN assets, a reduction in high risk and high-cost failures of moving equipment, a reduction of repeat failures, better documentation of work activities related to maintenance and repair, more consistent maintenance around the DSN, more and improved insight into asset status and maintenance requirements, and a better focus on reliability and maintainability in the design process and the development of new hardware products.

In order to achieve the AMMI initiative, Working Groups (WGs) were established for each of the key behavioral improvement areas (Process, Maximo, RCM, and Metrics), led by a Steering Group (SG). The entire program had an Oversight Committee, which had the responsibility for ensuring that the program was progressing in a manner that met the DSN's goals and established milestones.

The SG, consisting of key individuals from JPL, ITT, and EQL, was responsible for implementing the program. The SG met regularly and was in almost constant communication regarding program issues. Each of the WGs was led by a designated individual from the SG, and consisted of key individuals from each of the DSCCs who were responsible for local implementation of the program. The WGs met periodically (6 to 12 months) in face-to-face conferences, and were also in constant communication via email regarding program issues. WG members usually had to balance their workloads with their other local assignments, so their time available for AMMI issues was often limited.

VI. Initial Actions — RCM

While RCM had been required by NASA policy directive[1] for many years, it had not been effectively implemented in the DSN. The implementation of RCM became the primary focus of the AMMI group and specifically of EQL personnel. At the direction of DSN Project Office management and in compliance with the Green Plan, EQL focused on DSS-14 for performing a pilot implementation. An RCM analysis of equipment typically consists of identifying and ranking the critical assets; clearly identifying the asset's equipment, its interfaces and its boundaries; analyzing the failure history of the asset; performing a failure modes and effects analysis (FMEA) analyzing current maintenance requirements; proposing

[1] *Maintenance and Operations of Institutional and Program Facilities and Related Equipment*, NASA Policy Directive 8831.1E, June 19, 2003.

changes to the maintenance of the equipment resulting from the previous analytical activities; documenting all of these; and, most importantly, securing agreement from the DSCC personnel. The changes to the equipment maintenance could range from doing nothing (known as Run to Fail), adding or deleting preventive maintenance (PM) actions, or changing PM frequencies.

Many DSN-unique issues complicated the pilot project. Every RCM analysis at any level was hampered by difficult to locate, nonexisting, or poor quality documentation. There was frequently the need to generate piping and instrumentation diagrams (P&IDs) in order to properly understand the configuration of the asset. Often, asset boundaries seemed to be arbitrarily defined more according to management considerations than functionality, complicating the criticality and FMEA analyses. The final DSN step of the RCM analysis process was to secure agreement from the representatives from each DSCC. Local resource issues complicated even this step. The initial process required the RCM personnel to provide technical agreement to the RCM analysis (that is, agree that the resultant maintenance plan represented the best possible maintenance approach) and to adopt it (that is, to agree to actually do the maintenance). The DSCC could generally agree that the proposed maintenance was acceptable but often they would not agree to adopt a plan because of insufficient resources to perform it. Typically, the frequency of a PM was onerous due to availability of personnel but was understood to be the right maintenance to do. The AMMI SG initially proposed to try to resolve these issues, but as more RCM analyses were performed it became too daunting and typically unresolvable. The SG modified the process to seek agreement for the plan but to leave the resolution of resource issues (the adoption part) to DSCC and DSN management. Even though the process required review by designated RCM personnel at each DSCC, it became apparent that not everyone reviewing the document had sufficient background in RCM to contribute effectively to the review process. As a result of this, the AMMI SG sponsored RCM training at each DSCC and at the ITT facility in Monrovia, California.

The pilot project at DSS-14 resulted in five major RCM analyses being performed, including the servo hydraulic, hydrostatic bearing, and 20-kW transmitter assemblies. The analyses resulted in a total of 84 suggested maintenance actions. Upon completion, a final report was issued.[2] The AMMI oversight group then directed the AMMI Steering Group to begin working on RCM implementation at the 34-m beam-waveguide subnet in order to provide support for the upcoming implementation of the new antennas at Canberra DSCC.

VI. Initial Actions — Maximo

One of the observations of the initial assessment was that none of the DSCCs were taking full advantage of the features and benefits associated with the Maximo computerized maintenance management system. The data that was entered was often inconsistent and incomplete and did not promote an accurate analysis of the true condition or the true maintenance behaviors of the organization. Not all work was being documented, and much

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[2] *DSS-14 Pilot Project Final Report*, JPL D-50671, 818-309 (internal document), Jet Propulsion Laboratory, Pasadena, California, April 10, 2008.

of the work that was documented was not entered in a manner that was easily analyzed. A significant effort was initiated by AMMI and led by ITT to help promote consistent data between all three DSCCs so that data could be shared and also so that equipment-related practices discovered at one DSCC could benefit the practices of the others. In order to achieve this consistent behavior, the structure of the Maximo databases for all three DSCCs needed to be as similar as possible, and all three DSCCs needed to follow the same processes and practices for entering the data into Maximo.

The first challenge was to develop an asset hierarchy structure that promoted a roll-up of work history and work costs using a modified version of the DSN equipment hierarchical structure used by engineering and other personnel. It was perceived as being the structure that could best integrate information between operations, engineering, and maintenance groups. The resultant asset hierarchy (AH) that was developed conforms to the existing numbering format defined in the 820-061 Numerical Configuration Item Report (August 7, 2009) and is in conformance with Machinery Information Management Open System Alliance (MIMOSA) equipment specification standards.[3] Using this structure, each work order has the ability to identify the assembly against which the work is being performed. To implement this structure, the Maximo database needed to be modified in order to allow data entry of the following information:

- DSCC (example: GDSCC)
- Antenna (example: Deep Space Station 24 [DSS-24])
- Subsystem (example: 101)
- Major Assembly (example: 1)
- Assembly (example: 01)

Additionally, another layer of indenture was added to allow the entry of maintainable equipment components. Thus,

- Component (example: 001)

When completely assembled, the new AH field within Maximo would have the following format:

DSS24; 101.101.00

Because each site maintains separate databases, it was not necessary for each site to enter their DSCC location. Whenever the sites would download their data to a common DSN data for metrics purposes, the interface application would automatically add the appropriate DSCC designator.

Another challenge was to be able to accurately assess the proactive or reactive maintenance behavior of each DSCC, and to ensure that work information and history was only being

[3] *Glossary of DSN Terms and Activities for Maintenance and RMA*, JPL D-51467, 818-002 (internal document), Jet Propulsion Laboratory, Pasadena, California, July 18, 2011.

analyzed for equipment that was of primary concern to the analysts. One of the metrics used to evaluate this maintenance behavior is the "maintenance ratio." The metric was producing inaccurate results because of inconsistent use and unclear definitions of the "work order type" field utilized in Maximo. Correct use of this information would help analysts to exclude work orders that were not of primary maintenance concern (such as janitorial, landscaping, operations support and test, administration, capital projects, and engineering changes), and the remaining work could be separating into activities that were either reactive (corrective maintenance) or proactive (preventive maintenance, predictive maintenance, and calibrations).

Even after the above two configuration changes were made to Maximo, we discovered that the work order data was still incomplete and generating inaccurate results. The configuration was further modified to provide a drop-down list of assembly information so that users could pick from a list rather than manually enter the data, and a validation requirement was added that would prevent the user from closing the work order if the asset hierarchy field was not entered. There was also considerable user training required and enforcement of data entry by the supervisors. A quality checklist was implemented to provide a standardized check of the data to help identify problem areas associated with data entry. The work order requirements were published in a comprehensive requirements document reviewed by the AMMI participants. It was hoped that a focus on those problem areas would result in continuous improvement of the data.

A different but equally significant challenge was standardizing the Maximo job plans. A job plan describes in detail the work to be performed when a work order is executed, primarily for preventive maintenance actions. Prior to the AMMI initiative, job plans consisted of simple work instructions developed at each DSCC. Many of these used the Maximo capability consisting of six lines of textual data. The AMMI working group agreed to a formalized process for developing the job plans and to a fixed format and content for them (published in the DSN 866 series of internal documents). The DSCC personnel also agreed to write the job plans for already existing maintenance activities and for new maintenance actions identified in the RCM analyses. In addition, the Services Capabilities Development (SCD) process was modified to require job plans to be provided as part of the delivery process for new implementation.

VIII. Initial Activities — Metrics

The AMMI Metrics activity was dedicated to providing a comprehensive set of metrics that could be used to support management decision-making in the areas of resources, scheduling, and equipment replacement. The fundamental goals of the metrics are to determine the reliability of the DSN at DSCC, DSS, and Major Assembly levels; generate information on the use of maintenance resources; and report on the current state of the maintenance program.

The metrics were to be generated primarily using data from Maximo, the Discrepancy Report Management System (DRMS), and the schedule database of the Service Quality Assessment (SQA) Assembly. The Metrics WG was tasked with identifying metrics requirements, developing an implementation plan, generating the metrics, and providing them to DSN management on a regular basis. The initial metrics pilot was begun once the requirements were defined. This pilot used Maximo data to observe the amount of preventive and corrective maintenance (both in terms of numbers of jobs and associated work hours) being done. The metrics generated during this pilot were generated from hand-derived data using Excel spreadsheets. After about 6 months, the DSCC personnel became concerned about the effect of the quality of the data input on the metrics and the resulting unclear and inconsistent message sent to management. The AMMI SG shared the concern about work order quality, as discussed in the previous section, so the pilot was terminated.

A follow-on set of metrics to monitor work order data quality exclusively began. This metrics set was identified as the WONUM (for Work Order Numbers) and was used to keep track of the completion of required fields in the work orders. WONUM was highly useful in motivating the DSCCs to correctly complete the work orders, an important first step in the successful generation of metrics. An example of the WONUM metrics report is shown in Figure 1.

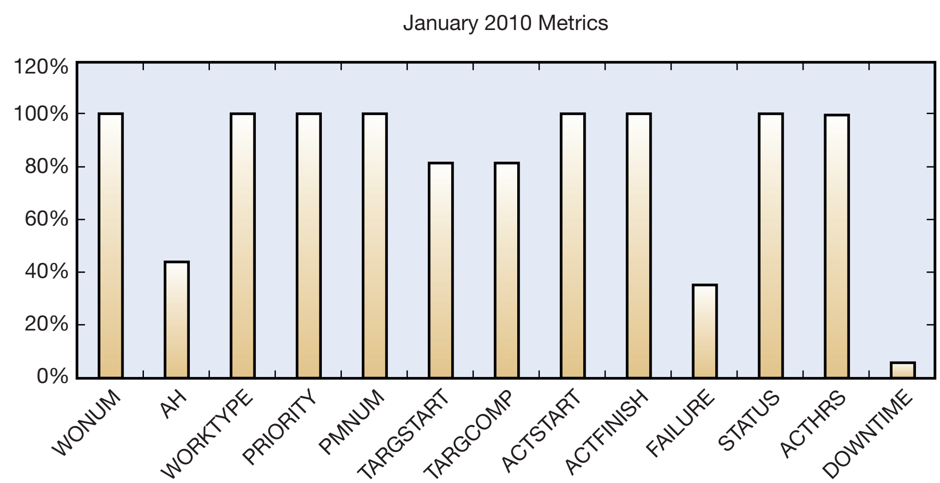

Figure 1. WONUM metrics.

While the AMMI group was busy pursuing maintenance metrics, others were beginning the implementation of the SQA assembly. SQA was (and is) intended to be a central warehouse of status information such as schedules, DR metadata, and (now) work order metadata that can be used in different ways to produce a broad set of metrics. The metrics software makes use of a commercial tool to mine the SQA (and other) databases and compute the maintenance metrics. Two implementations of SQA metrics were completed with varying levels of success. The initial implementation adopted the pilot approach and was limited in scope. The second implementation that remains in use was more successful and included a larger suite of metrics. The AMMI metrics include several estimates of Availability, Maintenance Ratio (ratio of preventive maintenance to corrective maintenance), work hours per maintenance action, Break-in Maintenance (amount of unplanned maintenance), Mean Time Between Corrective Maintenance (MTBC, a set of metrics normalized by antenna type and number), maintenance backlog, and measure of each type of work order. A few examples may be found in Figures 2 and 3.

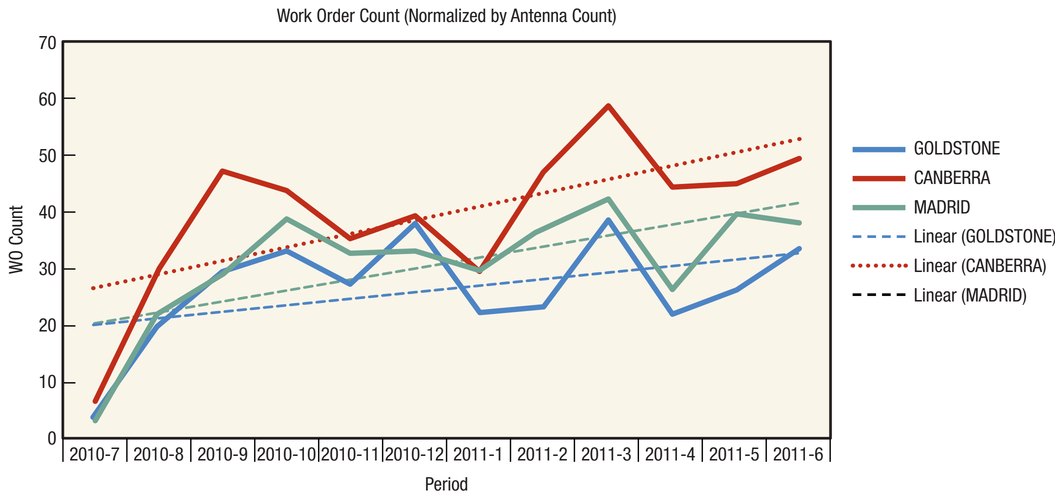

Figure 2. Work order count.

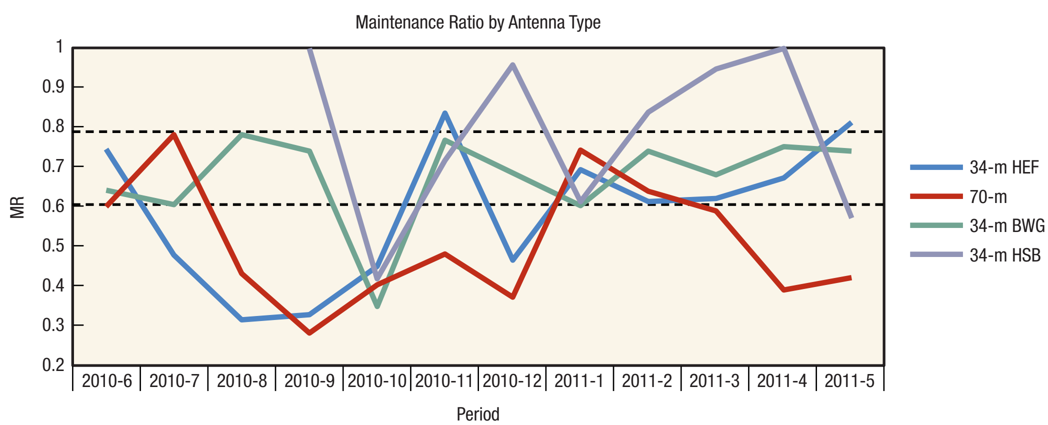

Figure 3. Maintenance ratio. (HEF = high-efficiency antenna; BWG = beam-waveguide antenna; HSB = high-speed BWG antenna)

These metrics were developed based on a set of functional requirements that arose from the maintenance assessment discussed in a previous section and the availability of parameters required for their computation. They are intended to provide a look by DSCC, DSS, and Major Assembly of the maintainability and reliability of the DSN as well as the usage of the work force and maintenance resources. The metrics are published approximately monthly to a wide distribution of JPL and ITT managers and engineers.

XIX. Initial Actions — Processes

Near the beginning of the AMMI initiative, the team determined the need for an underlying framework for maintenance activities. The general maintenance process was understood but had never been formalized. The AMMI SG began developing the basic maintenance process and workflow (i.e., Identify and Initiate Work; Plan and Schedule Work; Execute Work; Review and Close Work) based on industry best practices. The intent of this activity was to identify gaps between what the AMMI SG saw as the ultimate goal and the then-current state of maintenance and then, equally important, to use the process as guidance for the future AMMI developments. The basic process[4] was used to focus AMMI implementation activities, particularly in the area of work order development since the identification of an ideal but industry-based process clearly exposed the need for work orders and defined their content. Currently, AMMI has documented (for the first time in most cases) processes ranging from the basic maintenance process to defining the RCM process to the generation of metrics data inputs to changing the frequency of a preventive maintenance task. This has the effect of providing a sound basis to maintenance-related activities and instilling standardization around the network. A typical process is the generation of a Preventive Maintenance Plan following completion of an RCM analysis. This process is illustrated in Figure 4.

X. Foundation for the Future

In 2010, the SG recognized that the initial establishment phase of the initiative would likely be coming to a conclusion in fiscal year 2011. This conclusion would be marked by the departure of EQL and the need for DSN personnel to assume the lead role in the key RCM activities. The group worked with JPL and ITT program management and with EQL management to develop a plan to transition responsibilities from EQL to ITT that would result in a firm foundation for continued activities. This plan established a new role — DSN RCM Facilitator — who would assume the lead responsibilities for doing the required RCM analyses, developing documentation of the results, maintaining related databases, and providing training for future RCM analysts. After executing the transition plan, ITT assumed the lead in June 2011 and soon thereafter, EQL personnel were released, thus ending the initial AMMI implementation phase.

XI. Lessons Learned

Though AMMI is an ongoing activity, there have been many lessons learned to date. The authors present a few of them in this section.

Vision and Mission. There is a wide diversity of personnel involved in maintenance and maintenance related activities, from managers to maintenance technicians to administrative aids. All must be made aware of the goals, vision, and plans in order to facilitate changes to the existing state. Even though the AMMI SG published the AMMI goals and mission early on and tried to rationalize the actions being taken, they were not effectively communicated to everyone affected. This led to confusion as to why directions were being taken and why decisions were made (and unmade). So it is important get a good in-depth baseline to understand exactly where you are starting from and establish a roadmap to

[4] *DSN Maintenance Process and Workflow*, JPL D-50858, 818-001 (internal document), Jet Propulsion Laboratory, Pasadena, California, February 18, 2011.

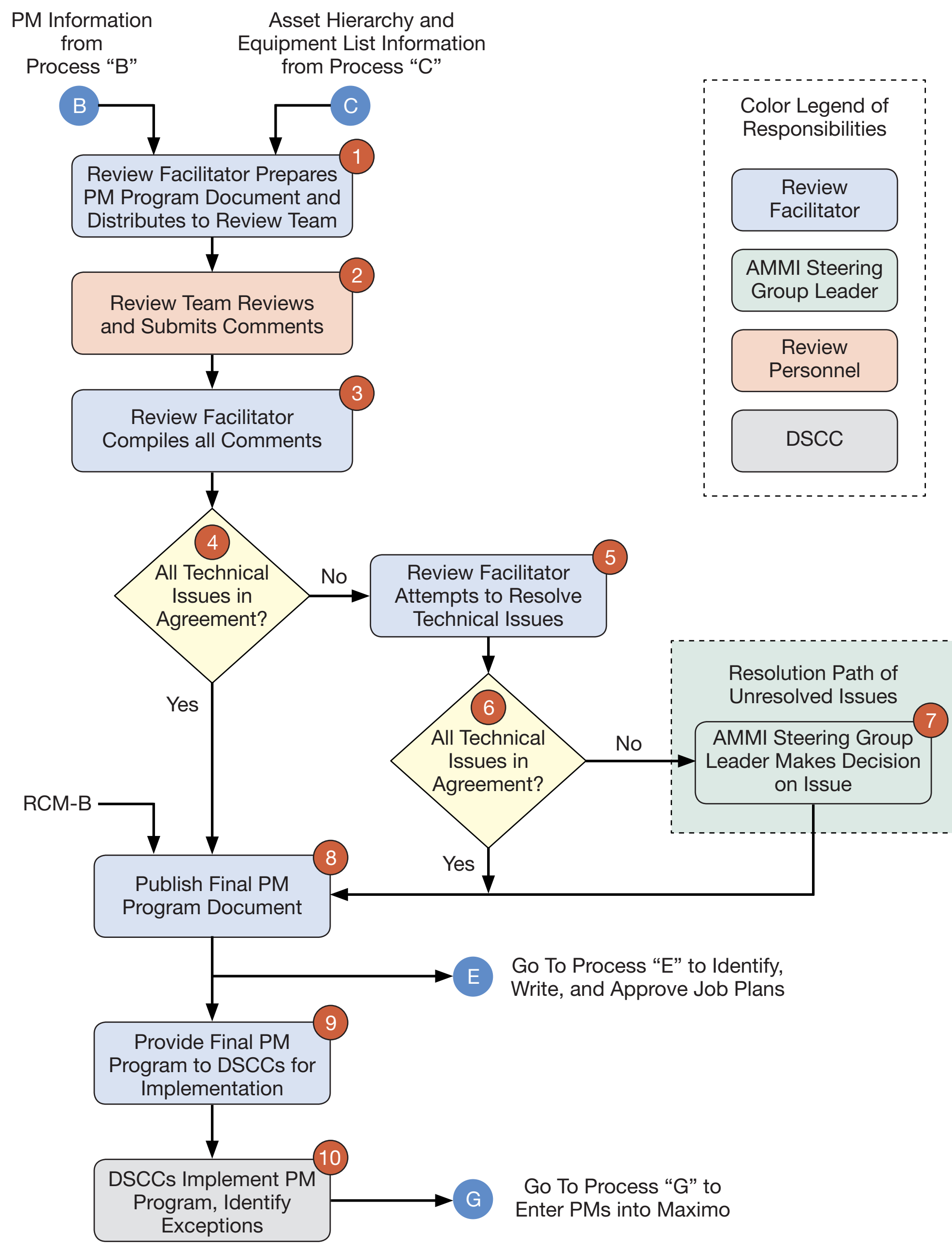

Figure 4. PM Plan generation process. From *DSN Asset Management/Maintenance Improvement Processes*, 818-104 (internal document), Jet Propulsion Laboratory, Pasadena, California, November 15, 2010.

know where you are going and why. It is essential to effectively communicate this information to all levels of affected personnel. It's mandatory to establish criteria for measuring progress and for success.

Management. To be successful in a task of this sort, management must agree to and share the goals and vision. This agreement must also include a direct, firm commitment of resources. In addition, management and the task leaders must have common expectations. AMMI received minimal direct management support and the expectations of management (beyond sharing the four goals) were never clearly communicated to the AMMI team. A continuous message of support must be forthcoming from management; infrequent or periodic interest and comment will not work.

Resources. Obvious — have a staff and funds sufficient to enable realization of the goals of the initiative. An initiative of this sort requires full-time, undivided support by engaged individuals. It also requires a stable budget with sufficient funding to allow for implementation of tools and capabilities required to meet its goals. AMMI always had minimal funds and no dedicated staff. DSCC participants in particular were dedicated to other, mostly higher priority, tasks. The initial phase of AMMI was, in fact, cut short by the zeroing out of required funds.

Processes. Define the underlying processes early and in some detail. This aids in the understanding of the initiative and in the decisions being made. AMMI did this, we believe, successfully. It helped in the establishment of standardization of maintenance processes and in defining areas that need to be focused on (such as work orders).

Documentation. The AMMI group decided early on to establish an extensive documentation tree within the DSN documentation system. This was important not only as a matter of good system engineering but also to allow wide document review and to establish a context for current and future activities.

Culture. The diversity of the cultures (both in a national sense and in the way business is done) was a unique stumbling block to AMMI. It remains almost impossible to achieve consensus. It is extremely important early on to shape (or reshape) the attitudes of the involved personnel via careful indoctrination of the importance of the action on the continued health of the DSN and as to the direct benefit of the initiative to them. If this is not done, it will be very difficult, if not impossible, to overcome the existing culture. An ironclad mandate from management is also essential.

XII. Summary

The AMMI initiative has succeeded in introducing the DSN to RCM methodologies. It was able to establish basic maintenance processes, develop a useful set of metrics, and implement a common CMMS/Maximo baseline with at least common required parameters and definitions. Work remains to be done in transitioning more responsibilities to the DSCCs and more firmly embedding a global maintenance philosophy into the DSN. The strategic visions enumerated here are still valid and well within reach.

Acknowledgments

The authors wish to acknowledge Chris Owen for his careful review of this article, Al Bhanji for his support of the initiative, and the members of the AMMI Steering and Working Groups, past and present, for their continuing support and hard work in bringing the initiative to fruition.