THE CONCEPT OF REMOTE MAINTENANCE MONITORING AND ITS' COMPUTER ARCHITECTURE

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Abstract

The Concept of Remote Maintenance Monitoring (RMM) was developed and introduced in industrial engineering as a means to measure performance. This concept has been studied, evaluated, implemented and deployed by the Federal Aviation Administration (FAA).[1] The application of RMM has improved the maintenance and performance of ground-based navigational aids, weather-related systems, RADAR surveillance and environmental control systems. Hundreds of FAA Air Traffic Control (ATC) facilities, airports and remote monitoring stations throughout the country employ some sort of RMM. Reliability, suitability, and longevity of navigational aids, weather processors, and surveillance systems has improved due to the functionalities RMM systems provide. Site-specific needs of some of these ATC facilities are due to geographical location and the surrounding environment.

RMM Computer Architecture and Computer Communication methods will be discussed and analyzed. This discussion will center on a successfully deployed RMM sub-system for a weather-related system, an environmentally controlled monitoring system and a ground-based surveillance system. In the end, a sincere attempt will be made to demonstrate the success of RMM technology implementation, showcase the benefits and progress towards a versatile open systems approach and present the economic feasibility of this technology with a view towards the future.

[1] This paper was written as a result of the experiences gained from the Operational Test and Evaluation (OT&E) of twenty-three Remote Maintenance Monitoring Systems (RMMS) for ground-based navigational aids, weather-related processors and secondary surveillance systems. No new concepts or proprietary information is discussed except to provide the reader with technical reasons for the benefits of this technology.

The Remote Maintenance Monitoring Concept

For an industrial or manufacturing plant with command and control capabilities to function efficiently and productively, an external sub-system that monitors overall system performance should be integrated within the facility. Utility companies that produce electricity for power generation, water and hazardous waste treatment plants that separate contaminants, oil refineries that process crude oil into useful petroleum products and pharmaceutical companies concerned with quality control have all adopted some form of remote maintenance or performance monitoring.

Since electric utilities have been deregulated, demands for increased efficiencies have increased at each level of operation. [1] These demands have been met by using remote maintenance monitoring and control systems for power distribution. Remote monitoring apparatus and control software has successfully measured the performance of turbines, boilers, natural gas and air compressors, cooling towers, vibration monitors, and switching gears. Maintenance costs, subsystem downtimes, and operational expenses are reduced when RMM apparatus and control software are fully integrated into utility plant functions.[2]

Water and hazardous waste treatment plants need to monitor water levels on distant reservoirs and lakes. Plant operators require feedback on chemical treatments and flow rates that are controlled in multiple tanks and lagoons. Information on pumps operating at different lift stations must be relayed to control centers that are located a distance away. The benefits that water and waste treatment plants derive from remote monitoring apparatus include centralized water and

[2] In industrial and commercial circles the term "RMM" isn't necessarily standard. What was being adopted was the use of Feedback Control Systems because the output is measured and compared with a standard representing the accepted range.

waste treatment control, improved automated treatment processes and reduced costs [2].

Oil refineries perform numerous complex tasks during the processing of crude oil. Some tasks involve processes that require constant monitoring. During fractional distillation different components are separated. The components called "fractions" undergo chemical processing to develop other components in a process referred to as *conversion*. After impurities are removed from these components a process of *combining* produces the desired petroleum products [3]. In order for these tasks to be successfully executed, tank gauging, leak detection and environmental monitoring must be recorded and controlled. When remote maintenance monitoring devices are used, cost-efficiency improves, productivity increases, and inventory management is made easier.

Pharmaceutical companies have concerns with every stage of the drug development process including quality control. Once a drug becomes marketable, all process data such as temperatures, heating, cooling cycles and drug compositions are monitored on a continuing basis. The ability to monitor and measure these process parameters from remote locations has enabled companies to save thousands of dollars for overtime, improve quality control, and increase productivity [4].

Successful RMM implementations can be applied in many industries. A well-known appliance manufacturer a few years ago installed and integrated a power monitoring system interfaced to a communications network. Smart metering devices, protective relays, circuit breaker units and motor starters were included on the network. In addition to monitoring the power consumption of two manufacturing plants in Ohio, this appliance manufacturer tracked and metered power usage using dial-up telephone modems at plants in Texas and New Mexico [5]. Using this communications network, equipment reliabilities were determined by measuring certain parameters. Data was recorded at one central location and exchanged with multiple sites, enabling plant equipment to operate properly; saving monitors hundreds of miles of travel per day.

Engineers at pharmaceutical company SmithKline Beecham installed a Personal Computer (PC) based Supervisory Control and Data Acquisition (SCADA) system to solve quality control and production-related problems [4].[3] This system provided real-time monitoring, alarming and data acquisition of reaction parameters, and plant utilities. The software and hardware that was used enabled authorized personnel to track and record numerous control processes. The PC-based monitoring component of the SCADA system consisted of five PCs, two programmable logic controllers (PLCS) with communications software, human-machine interface (HMI) software, software to operate the PCs remotely, modems, alphanumeric pagers for supervisors, and software to send messages to the pagers. The data acquisition software shares records utilizing commercially available software programs, such as spreadsheets and application programs. The system is programmed to monitor reactor process temperature with high and low alarms, jacket temperature with high and low alarms, agitator current, process drying equipment pressure and temperature, fume scrubber data, vacuum pump pressure, tank levels, and plant utility data.

To increase the reliability and dependability of ground-based navigational aids, and other ATC FAA terminal and enroute systems, an RMM requirement was mandated. This requirement was included in all development contracts for ground-based navaids, terminal, and enroute systems. The size and complexity of the RMM subsystem component depended on various factors. Most important among these factors were the functionality and complexity of the system to be monitored. Data information on the operational performance of a system is forwarded in the format of software datapoints. The Remote Maintenance Subsystem (RMS) can be located at an ATC facility, an outdoor remote monitoring shelter near one of the airport runways, or a remotely-located site hundreds of miles from the actual system or airport. An FAA proprietary or non-standard computer communication protocol is used to forward and exchange information from the RMS to a central collection location called the Air Route Traffic Control Center (ARTCC). Operational,

[3] This is a system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station).

performance, and maintenance information from numerous types of navigational, weather and surveillance systems are forwarded to twenty-three ARTCCs every day throughout the country.

The demand by industry and manufacturing companies for specialized and specific remote monitoring services has created a new market. New RMS service-rendering companies have surfaced for these manufacturing companies. These new companies are prepared to provide specialized and specific remote monitoring services to automobile manufacturing plants, industrial plants, oil refineries and computer or security firms in the high-tech world.

The Remote Monitoring Environment

The Remote Monitoring environment can be complex or basic. This depends on the requirements of the system to be monitored, and the technology used. An industrial environment RMM system might consist of a combination of switch boxes, sensors, measuring equipment and communication devices, which relay performance information to a central location either 50 feet or 50 miles away. A simple PC could be the device that receives this information.

A computer automated SCADA system, similar to that installed by the pharmaceutical company SmithKline Beecham, would consist of conventional control systems and innovative software and hardware combinations. These combinations would allow authorized personnel to monitor processes remotely. The system's software notifies on-call personnel using a paging system of any deviations from the process and plant parameters. Once the alarm is received, the on-call person contacts the host computer monitoring system via a laptop or remote PC. The supervisor views the active alarms on the screen and notes the flashing icon. Clicking the icon with a mouse brings the alarm history to the screen [4]. At any time, all personnel so empowered have the ability to contact the host computer and observe plant activities via a phone-based datalink.

Another Remote Monitoring environment feature involves computer automation. When the system to be monitored is complex, advanced technology may be used to satisfy complicated requirements. One prototype RMM system introduced by the FAA in the Southwest Region was the MCI (MicroCircuits Incorporated) Smart Circuits ALERT Program. This was an Environmental Remote Monitoring Subsystem (ERMS) Program that was proposed as one alternative within the ERMS program.

The MCI Smart Circuits ALERT[4] package consisted of the (1) Smart Circuits ALERT Box, (2) the Demarcation or SOTAS[5] Box, and the Environmental Remote System (ERS), which was a Sun Microsystems Workstation using HP Openview Software. (The ERMS components included the Smart Circuits ALERT Box and the Demarc or SOTAS Box) The HP Openview Software utilized the Simple Network Management Protocol (SNMP). The EMS and the ERMS communicated via an MCI telephone leased–line and modem configuration. Operational Technology Services and Stanford Telecommunications constructed and assembled the SUN Workstation used as a platform for the EMS. The monitor for the Sun Workstation used different colored coded logos for each parameter or data point. All engine generator and sensor inputs were directed to the ERMS. Consistent with SNMP, the EMS used a Smart Circuit Management Information Base (MIB) that partitioned all sensor inputs into thirteen groups. All requirements to be satisfied were represented and included in a System Requirements Document (SRD) [6].

Once the complexity of the Remote Monitoring environment increases, the difficulty in understanding this environment also increases. The Test and Evaluation of the operational performance of this environment can only be possible if the environment is thoroughly understood. As in physics an idealized model is sometimes helpful and necessary in understanding a complicated Remote Monitoring (RM) environment. Figure 1

[4] The complete name of the program was "The Micro Circuits Incorporated (MCI) Automated Leased Interfacility National Airspace Communication System (LINCS) Environmental Remote Resource Tool (ALERT) Environmental Remote Monitoring Subsystem (ERMS).

[5] SOTAS is a trademark name. The SOTAS box contains the SmartCircuits SNMP Agent and provides communication ports for the system management and Test interfaces.

represents an example of an idealized operational model RM environment configured by the FAA [7].

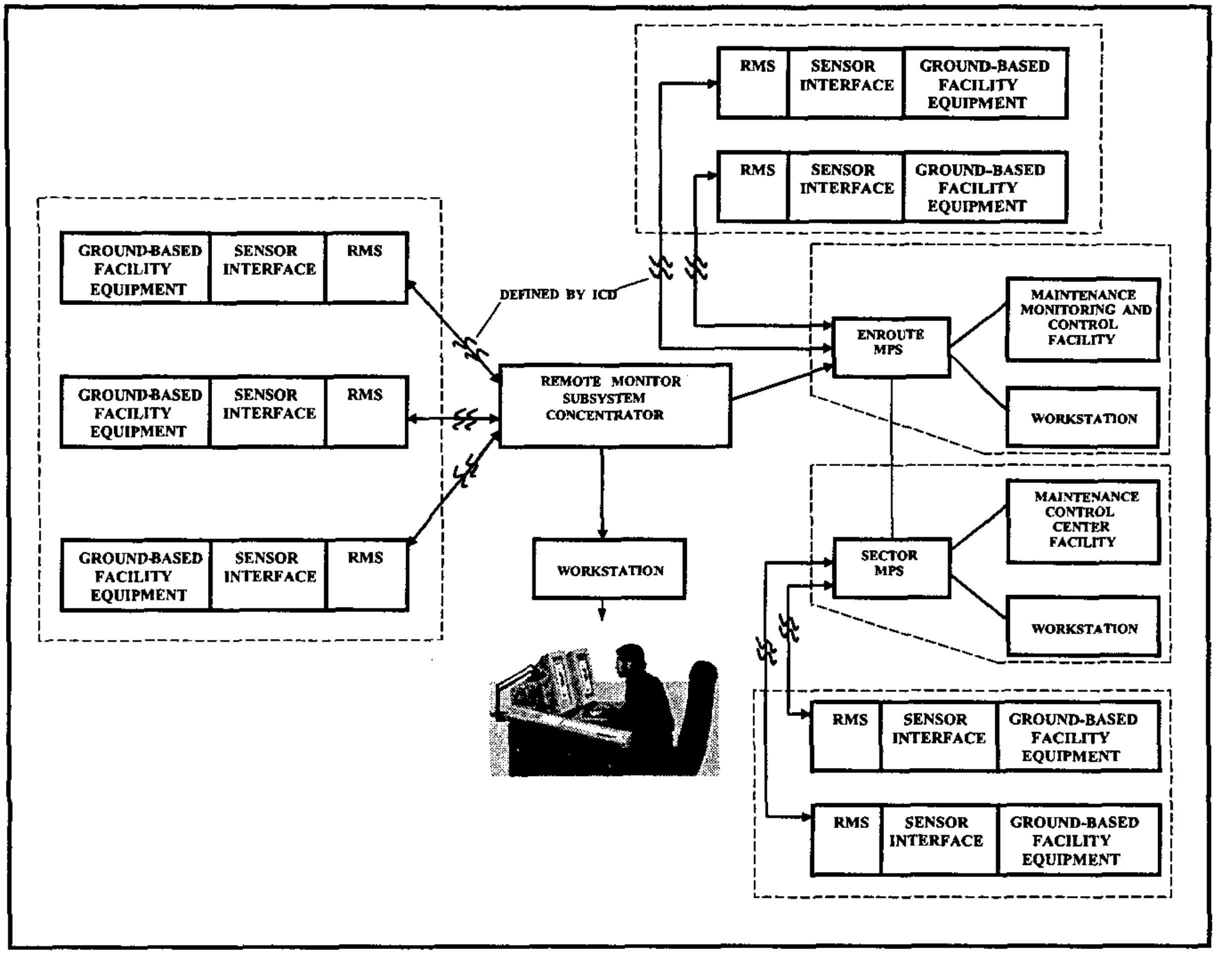

Figure 1. An Idealized Model of an Operational RM Environment Configured by the FAA
Central and Remote Elements Typically Representative of a Ground-based Deployment are Shown.

The figure can be representative of any computer automated RM environment that monitors alarm conditions and status changes for ground-based navigational aids, weather-related processors and RADAR surveillance systems. A workstation can be located at the ARTCC, at the RMS shelter, (which is a distance from the ARTCC) at the Maintenance Monitoring and Control (MMC) facility and at the Maintenance Control Center (MCC).

The Enroute and Sector Maintenance Processor Subsystems (MPS) are two different types of MPSs that were proposed at one time. They are separate from the host MPS and are located a distance from the ARTCC.[6] All data information is forwarded to a Remote Monitor Subsystem Concentrator (RMSC). The function of the RMSC is to consolidate all alarm and status information inside the facilities of a small geographical area and interface these facilities to the MPS [7]. The facility equipment and RMS system located and protected

[6] The MPS is the central processor for a given geographical area and will act as a control point to collect, record, and analyze monitored data and Issue commands. The MPS is also responsible for the display of monitored data and the maintenance of historical records of reported data [7].

inside a shelter are connected and interfaced to sensor devices. These shelters are sometimes near the airport runway or at some distant location. An Interface Control Document (ICD) defines the required command and data structures to establish computer communications and connectivity between the RMS and MPS.

The Industrial RM Environment

The industrial production lines in manufacturing were possibly the first to recognize the need and utilize the benefits derived from remote maintenance and performance monitoring. The first RM devices added to industrial equipment and machinery consisted of a combination of switch boxes and communication devices that relayed performance information to a central location. Today computerized networks and advanced technology are used in industrial engineering environments.

For example, the Voith Paper Technology Center in Appleton, Wisconsin has adopted new automation technologies into its papermaking facility. Their remote monitoring system has incorporated Microsoft software, the Internet and wireless communication standards. New control technology is used to remotely monitor the progress in Voith's papermaking plants all over the world. An RMS could have been constructed independently from the pilot plant's PCS (Process Control System), however the new control technologies presented advantages in coupled monitoring and control, and customer tracking. Some of these advantages include having a global database and a built-in historical record. Another advantage of this new technology is the ability to integrate additional PCs and have third party software packages gather, store, integrate, manipulate and analyze the data collected from pilot plant or customer and laboratory equipment. Coupling remote monitoring to the PCS has allowed the papermaker to refine monitoring procedures in-house before offering them to customers. For maintenance monitoring, the papermaker uses Internet technologies to view its' machinery in distant plants. Operating parameters such as downtimes and uptimes are tracked and customers can be advised when components such as bearings and motors need to be changed. In performance monitoring sensors are installed on customer equipment to indicate how well the equipment is operating, when it needs attention, and how to make it run more efficiently. New open platform sensors and sensor systems used by the Paper Company contribute to improved performance monitoring [8].

New types of businesses have surfaced which will provide RMM services to industrial plants and manufacturing areas. Many new providers of RMM services have targeted and competed for the business of numerous manufacturing elements. Industrial concerns about profits, productivity, pollution and quality control have increased the desire to use RMM technologies. Therefore the ability to use RMM measurement techniques to forecast and improve industrial output will remain popular.

The Computer Security RM Environment

Computer security is an important concern and creates another kind of RM environment. Computer systems, networks, and workstations used in business, government offices, and manufacturing have all adopted some form of security apparatus using remote monitoring techniques. These RM techniques can be designed to prevent intruders from entering a computer network or alerting a maintenance operator if someone penetrated into a secure network. The need for a computer system to be secure involves protecting databases, applicatons programs, and computer communications regardless of operating system or platform used. Monitoring work activity and employee communications may be another desired feature of RM used in secure computer environments.

In all non-Internet based business transactions the main focus is network security. Large and small corporations will use RM and other diagnostic services to verify that only authorized parties pass firewalls and that data is secure from hackers. Before implementing an RM package that contains a security apparatus an evaluation should be taken to ensure proper security preparations are employed and suited to the computer environment. The complete RM and security service provider will use a device or package that has a secure connectivity infrastructure and a strong identification element.

Other important elements in the package will be software that dynamically filters, separates and ensures data integrity [9].

New software tools and products have been introduced by software security companies. Avaya Integrated Management platform developed by the Converged Enterprise Technology Networks (CETNetworks) is a Secure Remote Maintenance Monitoring (SRMM) package that provides 24-hour service support. The package can be used on Linux, UNIX, and Windows Operating systems [10]. Another RM security Software Company offers comprehensive database monitoring, data encryption and management solutions to maintain Oracle databases. The efforts to protect computer communications, software applications and databases will never end since the threat from outside sources will always be there.

The Computer Architecture Description

Remote Maintenance Monitoring Components

The design of a specific Computer Architecture will vary according to the desired function and proposed requirements of the remote maintenance monitoring system. The method of data information collection, measurement, analysis, storage and exchange with other plants, sites and facilities will determine the design of the computer architecture. In some cases site specific needs and different site configurations will suggest certain computer architectures be used. The FAA's RMM network has selected computer architectures tailored to fit the needs of the National Airspace System (NAS). Ground-based navigational aides, surveillance, environmental systems and weather-related processors depend on these RMM systems to ensure their reliability, dependability and increase longevity.

The RMM components and architecture composed and constructed by the FAA have been successfully tested and deployed throughout the country. Because many of these components have passed reliability and dependability tests, they are discussed here. The main components of the RMM architecture include the MPS, the RMS, the RMSC, the Interfacility Communications System, the Maintenance Data Terminal (MDT) and the Maintenance Monitoring Console (MMC).

The MPS located at each ARTCC represents the main Central Processing Unit (CPU) for a geographical area. The collection, control and distribution of monitored data are performed by the MPS. Processing, storage, retrieval of historical information, and communication interfacing are also performed by the MPS. Two software packages supporting the MPS in this task are the Monitoring and Control Software (MCS) and the Maintenance Management Subsystem (MMS). The MCS creates a central monitoring and control capability. This capability facilitates equipment performance monitoring, remote control and adjustment, alarm notification and the collection of equipment certification data from centralized work centers. The MMS facilitates all administrative and maintenance-related-functions [11].

The RMS collects performance measurement and maintenance data from remotely located equipment and identifies alarm and status conditions. Diagnostic tests using the resident RMS software are performed, during operational testing and system troubleshooting. When these diagnostics are performed the alarm, status, and certification reports can be transferred to a portable MDT or forwarded to an MPS through an RMSC. The RMS can be retrofitted to an existing system, or be an embedded agent or device of a new system [11]. In certain areas, there are numerous RMS equipped facilities such as airports, Automated Flight Service Stations (AFSSs), Air Traffic Control Towers (ATCTs), and Terminal RADAR Approach Control Facilities (TRACONs). For these areas concentrators can be used to consolidate the data and messages being transmitted from these facilities. The RMSC can reduce the number of communication links and simplify the communication interface between the MPS and the monitored facilities (See Figure 1).

Each FAA facility has an existing ground-based communication infrastructure. This existing communication infrastructure is used in the data and message exchange of RMS elements. On occasion new data communication networks have been built, and dedicated TELCO or telephone lines have been installed to insure RMS computer communications. Whenever possible the existing communication infrastructure will be used or modified to accommodate the RMS computer architecture.

The MDT can be a portable laptop or fixed device. Commands exercised from the MDT include requests for data, the displays or responses to system messages, and system status. The fixed MDT interfaces with an RMS or selected RMSCs. Portable MDTs can communicate with an MPS, RMS or other MDTs while the system operator is at a remote location.

The MMCs or workstations will be considered the central monitoring and control points (See Figure 1). These consoles located at the MCCs provide an access to the RMS system and display acknowledgements when desired [11].

The Management of Computer Communications and Application Programs

The Computer Communications and data information monitored between the RMS and MPS is possible because of the operational interface of the application programs. Many of these application programs are transparent to the technician at the ARTCC or operator at the RMS site. However, each RMS interface is tested using many of these application programs prior to operational integration within the NAS. The FAA has successfully used a proprietary or non-standardized communication protocol defined via NAS-MD-790 to forward and exchange data information with the RMS. Data formatting, signal levels for data and control, sychronization and appropriate sequencing are provided by any protocol [13]. When exchanging messages with the MPS this protocol defines the necessary electrical, mechanical, and data link control elements. Recently the FAA has started to utilize other types of communication protocols with the same architecture or modified architecture. NAS-MD-790A and the Simple Asynchronous Interface[7] (SAI) are examples. In an effort to improve the technology and have open systems architecture the FAA has started using the commercial standard SNMP. With SNMP, other software applications compatible with Transmission Control Protocol / Internet Protocol (TCP/IP) are used at the MPS. These items are modular in design and well suited to Commercial-Off-the-Shelf (COTS) products.

The maintenance data and status information that the MPS receives from surveillance, navigation / landing and weather systems is periodically updated. Technicians and operators at the ARTCC then forward this information to maintenance control specialists at the MCCs. The application software programs resident on the MPS are used to perform this task, which includes data transmission exchanges, data acquisition management and data display updates. Maintenance Automation System Software (MASS) and Direct Monitor and Control Software (DMCS) are two application software programs assigned to perform this task [12].

Since MASS has been designated to replace DMCS, it can operate simultaneously with DMCS. It has a windows-based user interface with capabilities based on a client-server technology. MASS has created an environment where real-time monitoring, control, and alarm routing for most RMSs is possible. The MASS environment includes the standard Tandem system software, third party vendor software, and custom developed MASS software. DMCS provides the Graphical Unit Interface (GUI) and has been modified to accommodate the implemention of MASS software. These modifications include the introduction of Structured Query Language (SQL) data structures and decoders.[8]

MASS operates in a combined mainframe and workstation configuration. The mainframe portion is co-located with DMCS on the MPS within the RMS platform environment. The MPS mainframe is a Tandem Non-Stop CLX 200 Reduced Instruction Set Computer (RISC), executing the Guardian Operating System. The user and administrative workstations have IBM-compatible PCs running Windows equipped with terminal emulation software. The terminal emulation software is composed of OutsideView for Windows with

[7] Data collected during the Operational Test and Evaluation (OT&E) of the RMS / MPS interface is easier to analyze when the SAI protocol is used.

[8] Structured Query Language (SQL) is a query language designed for accessing data and performing queries on relational databases. It is standardized by ASC X3, which is a standards committee accredited by the American National Standards Institute.

Tandem terminal emulators; client/ server transport layer communications (Tandem Remote Server Call); and database access software by Cornerstone DynaAccess) [12].

The MDTs are part of the RMS platform environment and are connected to the Tandem Computer through Multi-LAN Communication devices or standard asynchronous telephone dial-ups or TCP/IP. An MPS Functional Area Description Diagram is illustrated in Figure 2 [12].

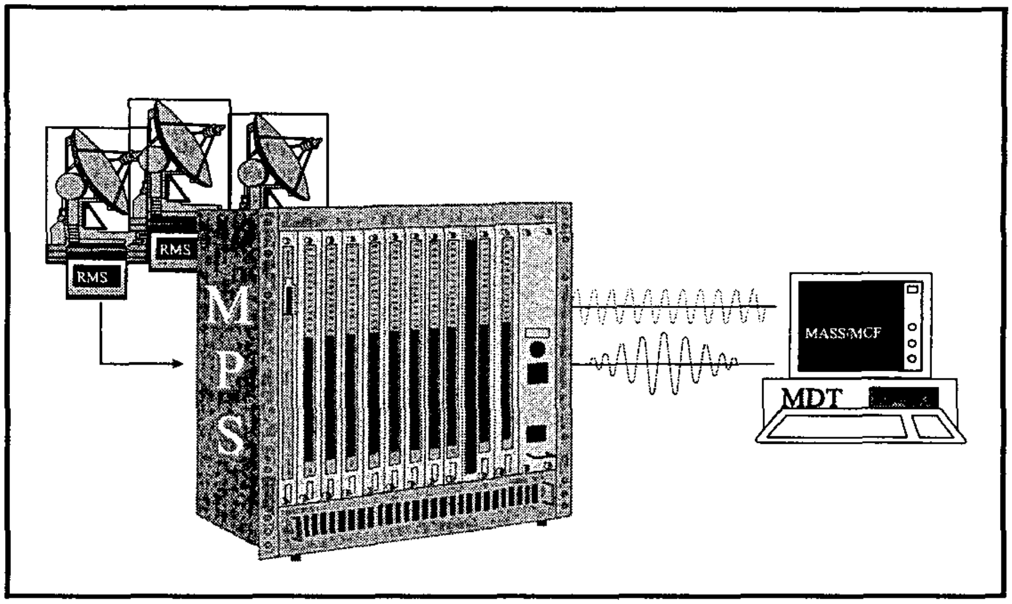

Figure 2. An MPS Functional Area Description with an RMS and MDT Interface

The Monitoring Control Function (MCF) application software as part of MASS enables connectivity between the MPS and the RMS or the MPS and MDT so real-time monitoring information can be displayed. Terminal emulation can operate over the three connection methods identified above. However, MASS will only operate when connected by asynchronous or TCP/ IP methods. When connected using TCP/IP, both MASS and terminal emulation can run concurrently on the same PC. Given the asynchronous connection method, a PC can run MASS or terminal emulation, but not both at the same time.

Computer peripherals such as terminals and printers in the laboratory are directly connected to the Tandem mainframe. Off-site devices such as remote terminals and printers are interfaced via the Federal Aviation Administration / Telecommunication (FAA/ TELCO) System. In most cases the Tandem computer hardware resides in sector headquarters, and communication with other sector computers is achieved through the standard FAA/ TELCO network. Expansion to MCC facilities is possible using Multi-LAN Communication devices for terminal emulation and TCP/IP for terminal emulation and MASS.

Computer Communication Methodologies and RMM Deployments

The Integrated Terminal Weather System (ITWS)

The ITWS is a weather system processor developed by the Raytheon Corporation for the FAA. It is an automated and integrated terminal weather information system that will improve the safety, efficiency, and capacity of terminal aviation operations. The system collects data from National

Weather Service (NWS) sensors and from aircraft in-flight over the terminal area. Other aviation-related weather products are collected and without additional meteorological interpretation used by ATC Technicians. Some of these products give descriptions of terminal weather conditions and short-term predictions of local weather phenomena. ITWS is able to provide this information because certain software and hardware elements are integrated in the system design. These elements are comprised of a weather data processing algorithm, the computer processing itself, and the hardware with interconnecting links. Besides these elements the system has connections to external data sources [12].

The ITWS components include the Product Generator (PG), the multiple Situation Displays (SDs), and the associated Ribbon Display Terminals (RBDT). Specific data sets from the NWS are obtained at one designated system location and transmitted to other Product Generator sites via TELCO lines. Interfacility communications are provided via the National Airspace Data Interchange Network II (NADIN-II), a national packet switching network (PSN), or over point-to-point terrestial communication lines. The connection to the NWS is provided via the FAA Bulk Weather Telecommunications Gateway (FBWTG) service to the NWS Filter Unit (NFU). Portions of the NWS are extracted by the NFU for each ITWS.

The embedded RMS monitors and reports maintenance alerts, alarms and executes fault processing. It is the entry point for maintenance commands, system control, and for entering site adaptable data. Maintenance-related data and control functions are forwarded to maintenance specialists using the non-standard NAS-MD-790 protocol. The decoder module, which has the ITWS database, will be tested and verified once loaded on the MPS. The MASS and DMCS application programs previously discussed will be used to perform this task. The developer will install the decoder module for initial testing at the Technical Center, at the Houston ARTCC for Delta operational testing (OT), and at the Kansas City Olathe ARTCC, for regression OT. (Delta testing is required when an RMS has specific system functionalities located at a particular site, while regression testing involves retesting the same functionalities that previously failed.)

The majority of OT occurred at the Technical Center. Delta and regression OT was planned to be conducted in operational settings at the Airport Surveillance RADAR (ASR) facility in Houston, Texas and Olathe, Kansas. The system was remotely monitored and controlled at the Houston and Olathe Center ARTCC. Figure 3 illustrates the Houston or Kansas City TRACON and ATCT Equipment Room Layout & Communication Link Test Configuration for the ITWS RMS [12].

The facility environment to test the ITWS RMS interface included the Tandem Computer, accessed through any available MPS terminal at the ARTCC or the Technical Center and the appropriate modems. The System Control & Support (SCS) Software will communicate with the MPS using the 790-decoder module. The DMCS resident on the Tandem will provide the GUI to the MPS. The MASS program may also be running, which will be properly configured for the sub-system under test.

The testing configuration will include a Network Sniffer located at the ARTCC and a Toshiba Tecra with a *Pocket Scope.* The sniffer can be used to capture NAS-MD-790 formatted data or used as a protocol analyzer during testing at the MPS. The Toshiba Tecra with the Pocket Scope can also be configured as a protocol analyzer and collect NAS-MD-790 formatted data using a special data collection program. An additional laptop running *HyperTerminal,* or an equivalent terminal emulation program, can be used as a local interface or MDT connected to the RMS or SCS function. The ITWS RMS was successfully deployed after the completion of OT and the resolution of all communication and interface related problems.

The Environmental Remote Monitoring System (ERMS)

The ERMS is an environmental or climatic monitoring system developed predominantly by the FAA. It is unique since the complete system is a remote monitoring device as opposed to being a component of a larger system. The system is based on a network of intelligent and independent processors, which are operating in a multitasking, multiuser environment. This RMM device is comprised of hardware and software suitable for installation into a NAS facility to monitor and control the environmental equipment within the facility. The environmental equipment consists of electrical power systems, environmental conditioning systems, smoke and fire detection systems, fuel tank monitoring systems, uninterruptable power systems, and computer network security and safety systems [14]. Some ERMS will have different configurations or functionalities depending on the kind and type of equipment at each site.

The OPTO-22 is one of several ERMS proposals and alternatives to monitor and report on the indoor conditions of any remote FAA facility. Each alternative is distinguished by the type of requirements it has to satisfy, the computer architecture of the interface, and the computer communication protocol used. Different protocols require different software application programs resident on the MPS. Also modifications in the computer architecture are sometimes necessary.

The OPTO-22 is a COTS product and system which scans sensors and other remote control devices for information. The data collected is formatted for storage and transmission. Before this occurs, parameter values are compared against established alarm and alert thresholds. If these parameters are outside the established threshold limits, an alarm or alert message is prepared. An MDT is located with the RMM at the site. While the ERMS provides this data to the MDT, this same data is then transferred for further processing, storage or display to the MPS. The OPTO-22 is supported by GFE data communication circuits, modems, and MDTs where possible. An auto-dial/auto-answer (A/A) modem configuration is employed to facilitate communications with the MPS [15].

This RMM system has two control modes *Operate* and *Maintenance*. The Operate mode is the normal operational mode, while the Maintenance mode removes power for engine generator functions. In the Operate mode the system provides full operational monitoring capabilities. When the Maintenance mode is selected via a front panel switch, the site technician is able to monitor environmental data points at the remote NAS site [15].

The OPTO-22 utilizes the SAI protocol. SAI software templates are installed on the MPS and supported by the DMCS at the ARTCC. The communications between the MPS and OPTO-22 ERMS are facilitated in a send-and-wait automatic repeat request manner. The FAA developed the software required for this protocol, and integrated the commercial OPTO-22 and FAA hardware/ software components.

The Air Traffic Control Beacon Interrogator Model 6 (ATCBI-6)

The ATCBI-6 is a replacement surveillance system with newly designed hardware and configured software. This replacement is necessary because existing systems are currently susceptible to distortion when common types of interference interrupt a steady stream of replies. The function of this system is to assist ATC by providing aircraft position and identification information for aircraft equipped with the proper transponders. Range requirements must be satisfied. This is accomplished by transmitting interrogation signals from the ATCBI-6 and decoding and correlating the replies received from properly equipped aircraft. Range and azimuth are determined by the time measured to receive a reply and the azimuth of the received signal. Data information with identification and height are derived from the information embedded in the replies.

The System Control and Monitoring (SCM) ability of the system provides a user interface. These users are the controllers at the ATC facilities and /or the Airways Facilities (AF) technicians at the radar site. This RMM system has control functions that provide real-time system management actions. Manual control is allowed from the following three access points, (1) the Remote System Control Terminal (RSCT) located at the ARTCC, (2) the Local Maintenance Terminal (LMT) located at the radar site, and (3) the embedded RMS agent or MDT located at the Junction Box [16].

Operational Test (OT) will verify the requirements relating to the radar maintenance and SCM function of the ATCBI-6 either remotely or locally through the RMS port. These tests will also verify that all RMM interfaces are fully functional and that all control, monitor, and radar maintenance functions are available [16].

The testing configuration of this system is simliar to the OPTO-22 since the same communication protocol is used. The System Monitoring Function will include the MPS, which can be accessed through any available Tandem terminal at the ARTCC. The system monitoring function software located at the Junction Box of the ATCBI-6 will communicate with the MPS using the SAI software templates. DMCS resident on the Tandem will provide the GUI to the MPS. The MASS program may also be running, and will be properly configured for the sub-system under test.

The Economic Feasibility and Beneficial Necessity

Cost Analysis of a Remote Maintenance Monitoring System

The beneficial aspects to measure performance, productivity, and system health using remote maintenance monitoring have far outweighed the cost of implementing or maintaining an RMM system. Industrial plants, manufacturing companies, the government, and the banking community have sought an easier way of maintaining factory equipment, checking the performance of a ground-based navigational aid and advising of an intruder in a computer banking system.

Industrial corporations and manufacturing companies have discovered that to successfully compete in the marketplace now and in the future, productivities must increase, costs must be reduced, and capital investments must be preserved. To reduce costs, various industrial plants and manufacturing environments have adopted RMM systems. The SCADA solution has succeeded in significantly reducing operating and maintenance costs. A centralized SCADA system minimizes resource and maintenance expenditures by requiring fewer personnel to monitor machinery and equipment. When multiple pieces of monitoring and control equipment are replaced with a single system, expenses for parts are reduced. The cost of training personnel also decreases when fewer systems are used.

A manufacturing facility, a water treatment plant, a pharmaceutical company, or an oil refinery will spend money for investment to increase their business longevity and improve their competitive edge. Citect, a leader in water and waste treatment, uses an open system design in its centralized SCADA system. The Windows-based CitectSCADA has the flexibility to operate with standard open protocols which are supported by multiple hardware and software vendors. The opened migration paths will improve technology and performance without costs of a total system replacement.

Cost savings are created for the FAA when remote maintenance monitoring enables a transition to solid state equipment. Additional savings occur when visits to remote sites are reduced, and work centers are consolidated. Consolidating the work centers efficiently mobilizes the work force and energy resources. Other benefits derived from RMM deployments include easy access to records, equipment histories and technical help from the national level [11].

While cost savings vary for each type of business or manufacturer, there is a commonality in the cost advantages derived. Whether in the private or public sector, RMM provides cost advantages in protecting materials, equipment and systems; reducing labor costs and lowering infrastructure expenses.

Cost Effectiveness with RMM Management

Cost effectiveness can sometimes be measured by accident. In some industries these accidents can prove to be extremely costly. Only when these costly events are prevented are the advantages demonstrated and realized.

Systems Electrical Services Corporation (SESC*)* provides electronic monitoring services of critical laboratory conditions for hospitals, universities, and pharmaceutical companies. A customer requested SESC to design and install an RMM management system. To ensure all designed functionalities and requirements were adhered to, SESC employed Sensaphone, Incorporated of Aston, PA. As a manufacturer of high-performance monitoring, control and alarm systems, the system Sensaphone designed was comprised of autodialing capabilities, Web-enabling software, wireless communications, and data logging. The unit was to remotely monitor and report on conditions that included indoor/ outdoor temperatures, humidity, tank levels, tank pressure, HVAC controllers and flow rate. Using the Sensaphone equipment, SESC monitored a medical laboratory's liquid nitrogen level in several cryogenic freezers. In some freezers, a sensor monitored the actual level of the liquid and in others a differential pressure. In one incident, someone had left the freezer door open on Friday. This would have been a major disaster since no one would have been back in the lab until Monday. The change in temperature was fortunately detected by the system and using the autodialing technology called 48 pre-programmed numbers to alert SESC's facility operators and laboratory technicians to the situation. Personalized, digitized voice messages were delivered and reaction was swift. When the temperature reached the 5-degree Fahrenheit alarm point, the system immediately dialed-out to the pre-programmed numbers and the drugs under test were saved. It was estimated the RMM Management system saved the lab between $30 to $50 thousand dollars.

More companies are transitioning from high-maintenance monitoring systems that require off-site visits. In many industries temporary employees are no longer needed to manually monitor systems from a centralized location on a 24-hour basis. Instead, remote systems utilizing control programming and wireless autodialing capabilities have helped to free valuable manpower hours.

PAS Technologies of San Juan, Puerto Rico recommended a Web-based RMM management system to the Water Company. Another product created by Sensaphone was the SCADA 300 advanced remote monitoring system, which replaced the water company's 70-plus existing remote terminal units (RTUs). The SCADA 300 featured a 32-bit software program with built-in amenities, including real-time screen building, program editors, alarm functions, and a communications manager. It can automatically build a Web page reporting all critical functions that can be viewed over the Internet at any time anywhere in the world. Once operable, the powerful new monitoring management system saved the company thousands of dollars in annual maintenance and manpower costs.

Reduced infrastructure expense is another area where cost effectiveness can be demonstrated. The introduction of wireless capabilities through radio telemetry has altered the monitoring and control industry forever. Wireless technologies free users from the costly and disruptive installation of an infrastructure system (i.e. Telephone lines).

As an example, a municipality may require intelligent control and monitoring at multiple wells and pumping stations within a radius of several miles. The control logic at one location may depend on the level or flow conditions at facilities several miles away. Using wireless radio telemetry at each location and a host computer, the municipality can centralize the control and monitoring process to achieve its goals.

A telephone connected to the host computer provides alarm dial-out capability. In addition, the host computer can be configured to produce web pages that display the status of each unit. By simply checking a few web pages, plant managers can obtain the current status of each location and be assured that everything is operating correctly. The combined effect is translated into reduced infrastructure–related costs [17].

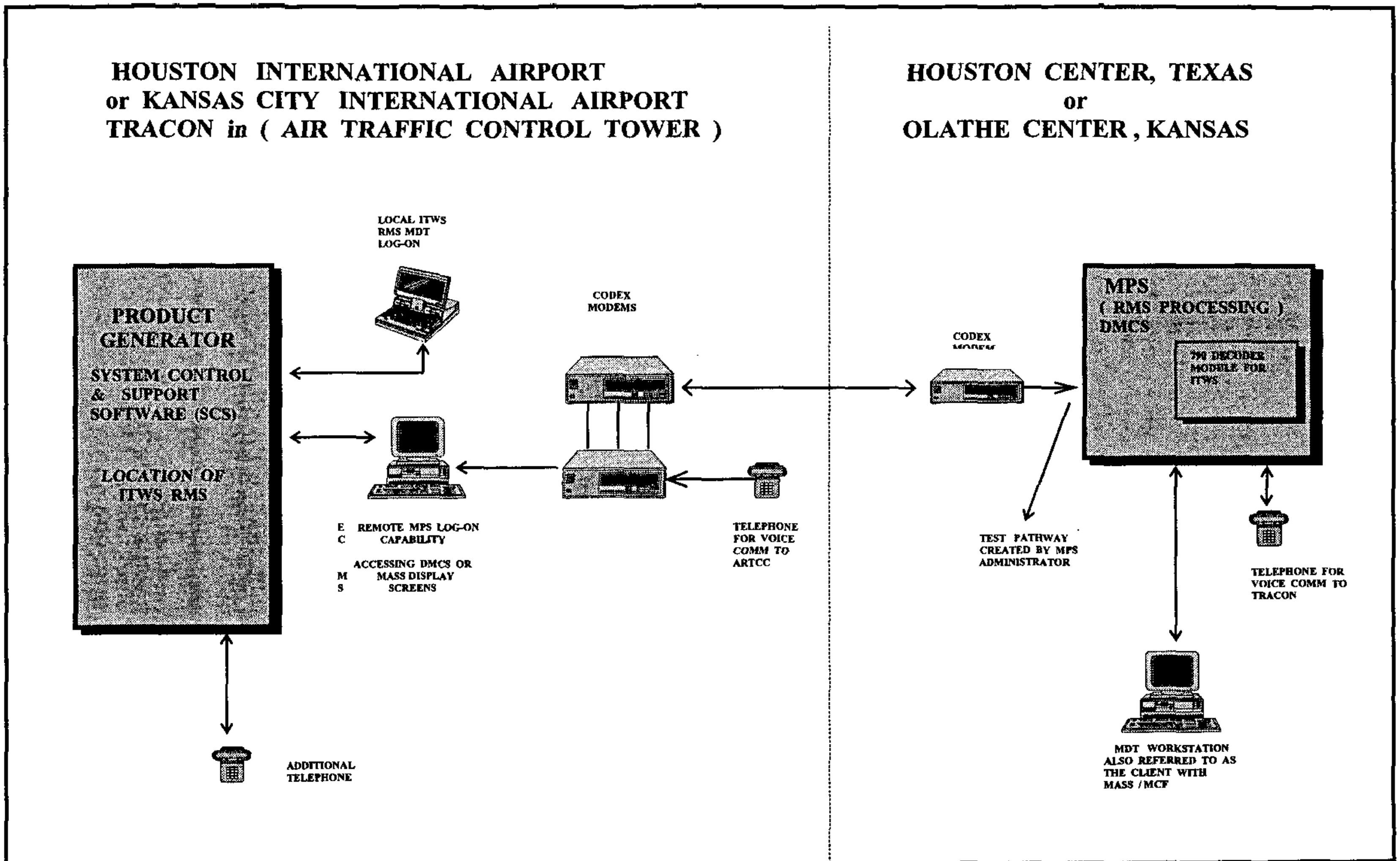

Figure 3. Houston or Kansas City TRACON Equipment Room Layout & Communication Link Test Configuration for ITWS RMS

Conclusion

The successes and widespread use of RMM technology has been discussed. Industrial plants and manufacturing companies have discovered adopting remote maintenance monitoring techniques will improve productivities and increase efficiencies. Oil refineries, power utilities, water treatment plants, pharmaceutical companies, the government sector, and the banking industry have all introduced some form of remote maintenance monitoring method or technology. Public and private sector elements have sought technologies, which are modular in design and flexible in implementation.

Remote monitoring environments vary according to the application, requirements, and technology used. In an industrial or manufacturing environment the computer automated SCADA system has been used to measure equipment or machinery performance, collect quality control data and solve production-related problems. In the FAA remote maintenance monitoring systems have improved the maintenance and performance of ground-based navigational aids, weather-related systems, and surveillance systems. In the banking industry computer security has been a concern so remote monitoring can be used to create an environment secure from intruders and outside threats.

The Computer Architecture for a remote monitoring system will depend on the desired function and proposed requirements for the RMM system. The reliability and dependability of the FAA's ground-based navaids, weather and surveillance systems are a result of the efficient FAA network of RMM integrated into the NAS. The Computer Architecture designed for the RMM is compatible with the desired functionality and integration into the NAS. The management of computer communications and the application programs used are important elements in the mosaic of the NAS. The weather system called ITWS, the environmental monitoring system ERMS, and the replacement surveillance system, ATCBI-6 have RMM systems that have or will be successfully tested.

RMM technologies have proven to be econmically feasible, beneficial and a necessity. The necessity aspect is apparent when companies realize that in order to compete in the marketplace productivities must increase, costs must be reduced and capital investments must be preserved. Whether in the public or private sector RMM generates advantages in protecting materials or equipment, reducing labor costs and lowering infrastructure expenses.

This technology demonstrates versatility as an open system architecture, which is valuable in the marketplace. In the end it will be the needs of leading-edge businesses, which will create the spawning grounds for the uses of advanced remote maintenance monitoring.

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