

An Approach to Automating Mission Operations Telemetry and Ranging Contacts with the MESSENGER Spacecraft

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As part of its commitment to the use of efficient operations approaches to reduce risk and cost, the MERcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) team has designed and implemented a process for the automation of telemetry, ranging, and delta differential one-way ranging contacts with the spacecraft. The operations team, located at The Johns Hopkins University Applied Physics Laboratory (JHU/APL), has the ability to automate the routine monitoring and verification of spacecraft telemetry and ground system status during contact with the Deep Space Network (DSN) using custom scripts and tables. This automation also provides remote notification to responsible personnel in the event of unexpected telemetry-limit violations or contingency conditions involving the DSN. Automating selected telemetry and ranging contacts, especially those that are off-hour or require quick turnaround, reduces the real-time support requirements for the flight controllers during the more active portions of the cruise phase of the mission. This action allows the mission operations team to focus their efforts on other critical activities and reduces operator fatigue and stress points in the staffing schedules. Automation may also enable orbit-phase operations to be conducted with a staff of flight controllers that is smaller than originally planned before launch, thereby reducing cost. The automation is designed to work with three different types of contacts with the spacecraft. The first type of contact provides telemetry from the spacecraft and is typically accompanied by two-way, or coherent, ranging. The second and third types of contact involve one-way ranging support without spacecraft telemetry, with carrier or beacon signal only. This paper describes the three types of contacts and details the automation scheme that is applied to each. It also provides an overview of the key components of the overall automation system.

Nomenclature

<i>APID</i>	= Application ID (for telemetry)
<i>BOT</i>	= Beginning of (DSN) track
<i>bps</i>	= bits per second; <i>kbps</i> is kilobits per second
<i>DCC</i>	= Downlink Control Channel
<i>DOR</i>	= Differential One-way Ranging
<i>DSN</i>	= Deep Space Network
<i>EOT</i>	= End of (DSN) Track
<i>HK</i>	= Housekeeping Telemetry
<i>ISI</i>	= Integral Systems, Inc.

MOC = Mission Operations Center
RF = Radio Frequency
RTL = Round-Trip Light Time
S/C = Spacecraft
SOA = Start of Allocation/Activity (for a DSN track), typically 1 hour before BOT
SSR = Solid-State Recorder
STAMP = STOL Automated Monitoring Procedure
STOL = Satellite Test and Operations Language
TD = Turbo Decoder

I. Introduction

To meet the objective of low-cost, efficient, risk-reducing operations, the MErcury Surface, Space ENvironment, GEOchemistry, and Ranging (MESSENGER) operations team at The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has developed a process to automate real-time monitoring of telemetry, ranging, carrier, and delta differential one-way ranging (Delta DOR) spacecraft tracking activities. Central to the MESSENGER concept of operations for this automated support is the ability to supplement real-time operator monitoring with software that recognizes telemetry-limit violations or off-nominal Deep Space Network (DSN) conditions and can alert operators and analysts for proper response. Two scripts are used to implement MESSENGER automation's core functionalities. The first is a monitor script written in EPOCH 2000 Satellite Test and Operations Language (STOL) from Integral Systems, Inc. (ISI), and the second is a simple paging script (`paging.pl`) written in Perl. This paper will explore the principles, objectives, and various modes of operation for MESSENGER track automation with an emphasis on the first of these scripts—the STOL Automated Monitoring Procedure (STAMP).

II. MESSENGER Real-Time Track Environment

All MESSENGER real-time contacts are supported by personnel at DSN stations and by the real-time mission operations team in the project's Mission Operations Center (MOC) at JHU/APL. Track support typically requires at least one station operator at the DSN station and two real-time operators in the MOC. The JHU/APL operators' primary source for all spacecraft telemetry and station information is the ISI EPOCH 2000 tracking and control software running on a UNIX platform. EPOCH provides stream viewers, which are used to view telemetered spacecraft mnemonics as well as DSN facility and ground system information. EPOCH software not only provides visibility into this information but also is configured with a telemetry database to check points against defined limit conditions. The stream viewer then displays messages when mnemonic values exceed these limits. This information is the starting point for any real-time response to spacecraft subsystem, instrument, or ground system anomalies.

It is important to note that the MESSENGER concept of automated operations applies only to planned downlink-only support activities and that commanding tracks are excluded. Commands sent to the spacecraft are always verified by two MESSENGER operations team members located in the control center. Furthermore, STAMP is not a "lights-out" tool, run without any supervision; an operator and designated backup are assigned remote monitoring responsibilities for all automated tracks. These remotely monitored contacts allow for reduced staffing schedules because only one individual is needed to monitor remotely with STAMP providing supplemental monitor and alert functionality.

III. Automation Approach

The interaction of two scripts, one written in STOL and one in Perl, accomplishes the most critical functions of the automated track coverage.

A. STOL

EPOCH STOL is used extensively throughout the spacecraft operations industry, and different versions of STOL contain only minor syntax variations. These characteristics make it an ideal choice for use in the MESSENGER automation strategy. The broad STOL knowledge-base of MESSENGER personnel, combined with the language's intuitive and easy syntax, provides flexibility for original development and for future upgrades and maintenance, because these can be performed directly by MESSENGER operations personnel and do not require external developers.

Furthermore, STOL is already in place for operational use on MESSENGER, and it has a proven track record. Using another language to extract the needed telemetry information would have incurred unnecessary time and cost. EPOCH and STOL contain all of the basic functionalities needed to create robust automation software.

STOL allows users to interface with EPOCH via directives. STOL scripts composed of operator inputs, directives, and flow-control statements are the most common and effective way for real-time operators to conduct real-time operations. STAMP is one such script.

For each type of MESSENGER automated track (telemetry, carrier only, and Delta DOR), STAMP successfully achieves the following objectives:

- 1) Accepts operator input for information about an upcoming DSN support interval
- 2) Reads the values and status of telemetry from the MESSENGER spacecraft
- 3) Reads the values and status of the DSN Monitor 01-58 data
- 4) Writes to the EPOCH event log for archive and investigative purposes
- 5) Reacts to time-driven events based on Greenwich Mean Time
- 6) Builds messages based on link status
- 7) Executes a program to deliver messages to staff for anomaly diagnosis and response

EPOCH and STOL routinely accomplish the first four tasks above during nominal staffed DSN support periods with the MESSENGER spacecraft. The remaining three tasks, although not typically performed during nominal operations, have been used and proven in the development and testing of MESSENGER's automation. For automated telemetry tracks, STAMP performs the additional task of building messages based on EPOCH-reported mnemonic limit violations.

B. Perl

A Perl script is used to send out-of-limit and anomalous condition messages built by STAMP to designated MESSENGER team members. The alert functionality of the Perl script is legacy from the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) and the Solar TERrestrial Relations Observatory (STEREO) missions and is well established. The adaptation of that Perl program to MESSENGER needs was more efficient than developing new code. This decision was also influenced by the fact that the original developers of the Perl program were still available at JHU/APL for technical assistance. The simple script receives three arguments, which are then forwarded to a configurable list of team members via text messages and e-mail.

The Perl paging program transports easily from one UNIX system to another, greatly adding to its usefulness. The system architectures of the STEREO and MESSENGER missions are also similar enough that very little adaption was required for the migration. Indeed, the paging program has undergone very few updates and no major revisions since its initial adaptation to the MESSENGER mission. The extent of the updates has been to correct directory names used by the script and to change user and file associations.

A final factor for consideration is that the alternatives to Perl were a C program or a UNIX shell script. Neither of these options was deemed attractive enough to warrant the development time needed to replace a working Perl executable code. Programming in C often demands more overhead than Perl when compiling or when transporting it from one directory to another. UNIX scripts, like Perl, transport easily and do not require a compiler, but they are less elegant and less capable of doing the same tasks that Perl can easily achieve.

IV. Support Profiles

Use of the MESSENGER automation system began with stand-alone Delta DOR off-hour and weekend support, has expanded to include telemetry tracks, and will soon be expanded to cover beacon-only support activity.

A. Delta DOR Support

The MESSENGER mission uses Delta DOR radio tracking to provide accurate measurements of spacecraft trajectory. As described by the DSMS Telecommunications Link Design Handbook:

Delta Differential One-way Ranging uses the differential one-way range technique to provide information about the angular location of a target spacecraft relative to a reference direction where the reference direction is defined by the direction of arrival of radio waves from a distant known source whose direction is well known. This is the origin of the “Delta” in the name Delta DOR. The reference source...is a quasar whose angular position in the sky is well known and cataloged, having been previously measured and studied.

To perform a measurement, the two Deep Space Stations forming the very long baseline interferometer make a series of observations to determine the differential one-way range to the target spacecraft and the reference source that preferably has a small angular separation from the target spacecraft.... Each observation is referred to as a scan. In a typical Delta DOR tracking pass of approximately one hour, the spacecraft and reference are alternately observed and a total of 5 to 10 scans, each lasting 5 to 10 minutes, are typically recorded.¹

Delta DOR support periods are <1 hour in length and require only one-way ranging (downlink from the spacecraft) in order to be useful. However, they do preclude receiving telemetry while the reference source is being viewed.

Automation supports both monitoring and alert functions for Delta DOR activities. Because Delta DORs are often placed stand-alone in off-hour time slots and on weekends, they are ideal for reduction of staffing costs via automation.

Attending to Delta DOR support activities in real time is not operationally complex. Carrier lock to the spacecraft downlink at appropriate times and indication that both antennas are pointing from reference to spacecraft and back are indicative of a successful Delta DOR track from a mission operations perspective. Thus STAMP is time driven, needing only to check for carrier lock at expected times and to produce a plot that demonstrates that each antenna points from spacecraft to quasar and back appropriately. A simple plot of antenna elevation over time for the duration of the support period provides a useful visual indicator of overall DSN antenna performance.

As a Delta DOR track proceeds, STAMP builds messages that indicate the beginning of Delta DOR tracks and carrier lock at appropriate times. These messages are passed as arguments to the Perl paging script for distribution to operators responsible for the support activity.

Delta DORs give no indication of spacecraft health other than successful carrier lock, and extra observations are always scheduled; therefore, parallel monitoring by a staff member is unnecessary. In addition, these events are so short that if they are off-nominal, very little real-time troubleshooting with the DSN could be conducted. If a DSN problem is not explicitly confirmed on subsequent analysis of a Delta DOR negative acquisition, then appropriate personnel are notified and present during the next regularly scheduled telemetry support period. For these reasons, STAMP's monitor and alert capabilities are considered robust enough to be sufficient for real-time Delta DOR support activities. This functionality allows valuable time savings in real-time operator schedules because automation can be relied on to monitor for anomalous conditions, and the alert function can communicate the need for later investigation. This use has already led to considerable staffing reduction during MESSENGER's cruise phase, especially during dense track periods.

B. Telemetry Support

MESSENGER automation has its roots in Delta DOR monitoring but reaches its full potential in telemetry support activities. MESSENGER real-time operations for telemetry support require monitoring the communication link to the spacecraft and indicators of spacecraft health and safety via downlink of housekeeping data as well as subsystem and instrument information.

1. Link Status Monitoring

Receiving spacecraft health and safety information is predicated on good links between the spacecraft and the DSN, and between the DSN and JHU/APL. Therefore, monitoring these links is a primary function of real-time support. Monitor 01-58 data are the best indicator of carrier, symbol, and ultimately telemetry lock to the spacecraft's downlink. Here mnemonics indicating a solid link are consistently checked. Actual data monitoring and out-of-limit checking will not be performed by STAMP until it is established that carrier is in lock, symbols and turbo decoder are in lock, and telemetry packets are being received and incrementing. If any of these is counter-indicated, the Perl paging script will be invoked, and STAMP will continue to check for nominal link status before proceeding with data checks.

All nominal MESSENGER tracks have an expected loss of link one round-trip light time (RTLTL) from the time that uplink is initiated on the ground. This expectation is a result of establishing a coherent carrier lock with the spacecraft. At acquisition of signal, the DSN locks to the carrier "one way" from the spacecraft. Five minutes after Beginning of Track (BOT), the station initiates the uplink carrier. Once the spacecraft receives the uplink, it converts the frequency and rebroadcasts it to the ground, at which time the station takes a non-negligible amount of time to lock to the new frequency. The STAMP algorithm accounts for this loss of lock and does not build unnecessary error messages for distribution during this time.

2. Telemetry Monitoring

MESSENGER telemetry follows Consultative Committee for Space Data Systems (CCSDS) protocols for packetized data.² Once a track begins, subsystem and instrument telemetry is organized onboard into application IDs (APIDs) that are downlinked via prioritized circular list. While packets are being received, EPOCH stream processes display mnemonics and compare

their values against predefined limits in the EPOCH database and then write any limit violation messages to the EPOCH viewer event log.

A configurable table of alarmed mnemonics contained in the circular list is maintained by operations. On execution, STAMP ingests this table. Once link status is verified, STAMP cyclically checks the points in this table for EPOCH limit violations. If out-of-limit conditions are detected, STAMP identifies the type of violation, builds a message, and passes the information to the Perl paging script. This process mimics a second operator's set of eyes on telemetry.

3. Alert/Report

The alert functions for telemetered support activities are more complex than those of Delta DOR support activities because they indicate much more than in-lock or out-of-lock carrier link status. This processing is handled entirely by STAMP. Although the Perl paging script receives the same number and type of arguments as for a Delta DOR support activity, the messages built by STAMP for telemetry support activities are based on its internal data checking algorithms.

V. Delta DOR Track Automation

Automation of MESSENGER's delta differential one-way ranging tracks was the first implemented. Relative to telemetered support activities, Delta DORs are limited in scope. Delta DOR support periods are short-duration events where carrier lock with the spacecraft is expected only when the antennas are spacecraft pointed rather than pointed at the reference quasar. Spacecraft lock occurs only for brief periods of time within the overall Delta DOR event. Therefore STAMP's Delta DOR algorithm is time driven, looking for carrier lock at the specific times it is expected.

The success of Delta DOR support activity is binary in nature: either the Delta DOR was successful or it was not. The clearest way for mission operations personnel to verify success is to ensure that the track proceeded nominally. Processing and verification of the actual ranging data are not done by the MESSENGER operations team, so real-time authentication of the ranging data collected is not practical as a means to verify success of the real-time support activity. The procedure was designed to mimic the steps taken by a real-time operator observing the support activity.

The real-time operator during a Delta DOR nominally looks for two indicators verifying a successful support. The first indicator is timely carrier lock between the spacecraft and the DSN antennas. The second is a visual check of the elevation plot of the DSN antennas during the support. The carrier lock check is easily automated because it is expected at specific times. The rest of the time during Delta DOR support, the DSN antennas are pointed at quasar sources or are in transition between sources. Except for those specific times when carrier lock is expected, there is nothing from the DSN monitor data or from the spacecraft that provides any useful insight into the status of the Delta DOR support, with one important exception. That exception is the pointing direction of the DSN antennas.

A simple plot of antenna elevations over time for the duration of the support period provides a useful visual indicator of overall DSN antenna performance and Delta DOR success. Nominally this information is checked by the MESSENGER real-time operator at the conclusion of the support period. Although no two Delta DOR support intervals will produce precisely the same plot, there is a fairly consistent shape (Figure 1) that can be visually confirmed by an operator once the support period has been completed.

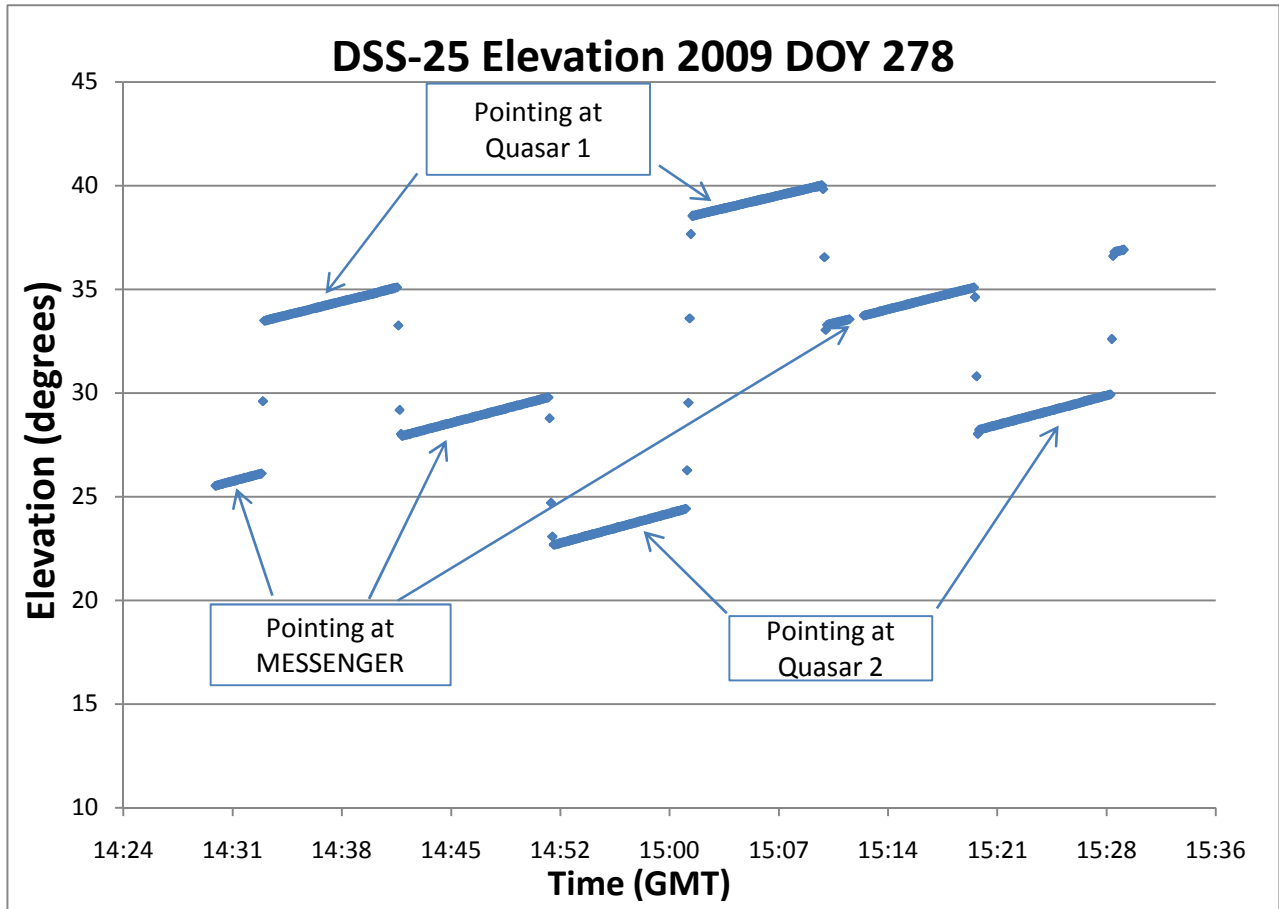


Figure 1: DSN antenna elevation profile for a typical 60-minute MESSENGER Delta DOR support period.

A. STOL Implementation: Link Status Monitoring

During Delta DOR support activities, STAMP verifies ground system status and the status of carrier lock with the spacecraft. A flow chart of the status-checking algorithm is provided in Figure 2. As stated, during Delta DOR support activities there is no spacecraft telemetry to verify spacecraft health and safety. Instead, STAMP verifies that the spacecraft radio frequency (RF) carrier signal is in lock at the appropriate times based on the specific type of Delta DOR activity profile.

Delta DOR Procedure Flow

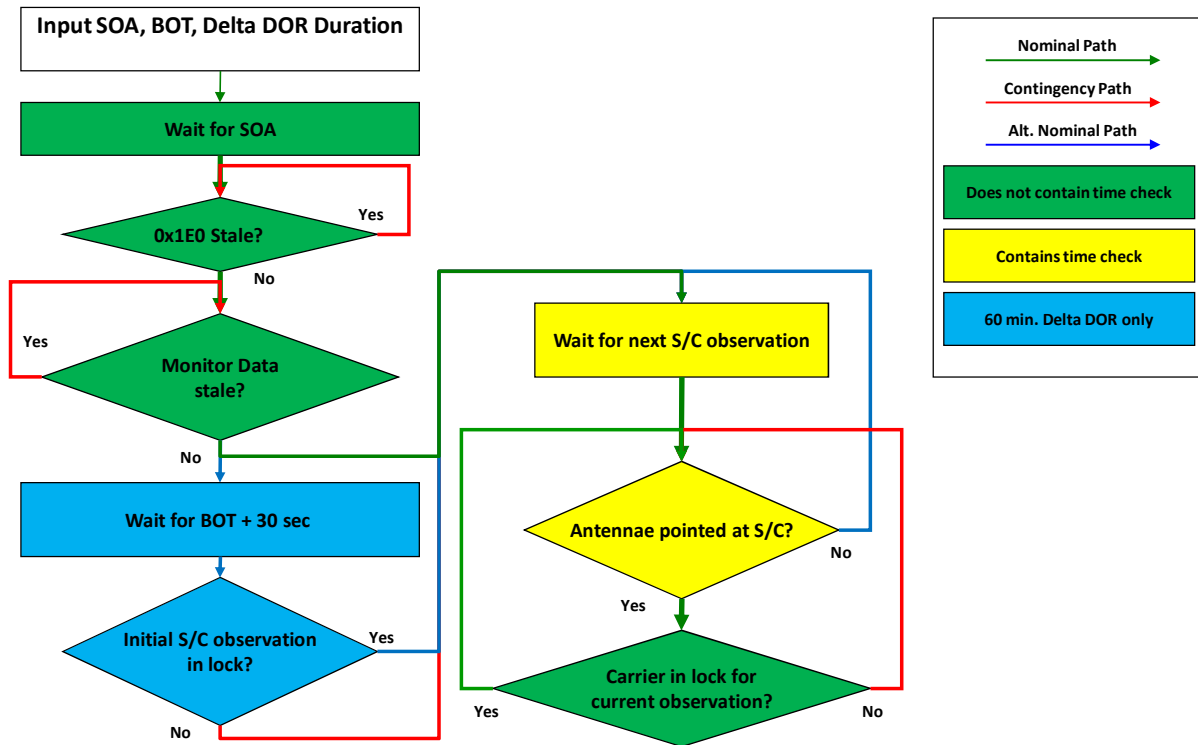


Figure 2: Procedural flow of the Delta DOR automation portion of STAMP. S/C, spacecraft; SOA, start of allocation/activity (for a DSN track), typically 1 hour before BOT.

After collecting the inputs from the operators during setup, STAMP first verifies the condition of the Monitor 01-58 data from the DSN station. If these data are not found, STAMP calls a child procedure, which in turn accesses a Perl paging script. If the Monitor data are found, STAMP waits until the expected times after BOT to start looking for RF carrier from the spacecraft.

MESSENGER Delta DOR tracks have one of three possible durations: 30, 40, or 60 minutes. STAMP handles all three durations, and the operator setting up the automation will enter the duration as a procedure input. From that input, STAMP will search for the RF carrier only at the times when it should be expected. For the rest of the support interval, STAMP cannot verify that the DSN antennas are pointed correctly at the quasar sources, so it waits for the next spacecraft observation or for the end of the support interval as appropriate.

In the event that the spacecraft RF carrier is expected and not found, STAMP will send out a page. As long as the RF carrier is expected, it will check for it every 30 seconds. However, STAMP will send pages about the missing carrier only up to three times per spacecraft observation. This limit was set to avoid sending many pages for the same problem. Unlike the shorter-duration Delta DOR tracks, the 60-minute Delta DOR tracks have more than one period when the DSN antennas are pointed at the spacecraft. During each of those periods, STAMP will send only up to three messages in the event of a missing RF carrier.

At the end of the support period, STAMP produces the printout of the elevation plots for each of the DSN stations involved in the support activity. Although STAMP does not verify the contents of the plots, the MESSENGER operator can later evaluate the profiles of the elevation plots to further analyze the performance of the Delta DOR support activity.

B. STOL Implementation: Messaging

The paging subroutine is called any time a message is to be sent. This procedure accepts Subject and Message arguments built and passed by STAMP, which it forwards to responsible personnel.

The first argument, Subject, is used as the subject line in an e-mail or text message. STAMP determines the content of this variable, but Delta DOR tracks use only one level of alert; “DDOR Track Status” is used for all messages.

The second argument, Message, is the text of the message itself. As with Subject, it is determined by STAMP. This one-line statement succinctly states the condition being reported. For Delta DOR activities, it will report both the station ID and the appropriate carrier lock condition, or it will report the end of the support period.

The third and final argument is the Response. This argument is limited to one of two choices: PageMe or MailMe. MESSENGER currently uses only the PageMe option, although the functionality remains in place for MailMe. This limited response allows for the use of only one easily configurable list of personnel to be notified. This list is maintained separately from the broader distribution list used for telemetry support activities.

VI. Telemetry Track Automation

Automation of MESSENGER’s telemetry tracks is driven by STAMP and uses a Perl script for paging. STAMP handles the time-sensitive verification of DSN monitor data and spacecraft telemetry to establish the status of the ground system and the health and safety of the spacecraft, respectively. As stated, STAMP builds messages in response to anomalous conditions and passes arguments to a Perl script for distribution to personnel. Following is a detailed explanation of STAMP’s Link Status Monitoring, Data Monitoring, Alert/Reporting, and Messaging functions.

A. STOL Implementation: Link Status Monitoring

STAMP’s telemetry track automation algorithm follows the flow chart in Figure 3. After accepting inputs from the user to define the track timing and DSN station, it determines whether the Monitor 01-58 and DSN telemetry interface (DSNTLMIF, also referred to as APID 0x1E0) data flow is not stale. It then evaluates whether the expected DSN station is sending the data to the MESSENGER MOC. If the correct station is found, STAMP then detects which DSN Downlink Control Channels (DCCs) are sending the data because there may be more than one and as many as four being used.

Telemetry Procedure Flow

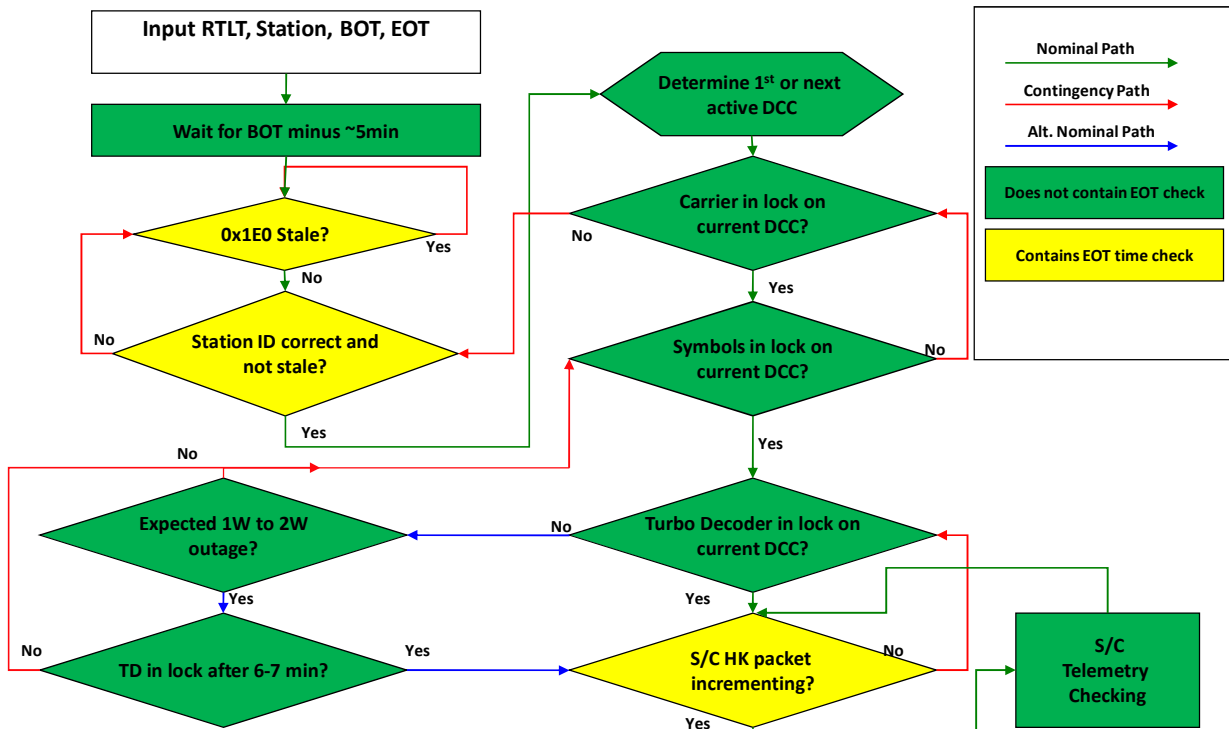


Figure 3: Procedural flow of the telemetry automation portion of STAMP. HK, Housekeeping telemetry; TD, Turbo Decoder.

Five minutes before BOT, STAMP begins checking the monitor data from the DSN station for the status of the carrier signal from the spacecraft. It checks only on those DCCs that were found to be active in the previous step, and the check proceeds for only one DCC at a time. If an active DCC fails this check, the next active DCC is checked. If no active DCC has carrier lock, STAMP backtracks to the station check and starts over. It continues to loop in this manner until the carrier is locked on at least one DCC or until the End of Track (EOT) time is reached.

Once carrier lock has been established, STAMP checks to make sure that the symbol loop is in lock for the DCC. Failure to detect symbol loop lock causes it to loop back and verify the carrier check and retry the symbol loop again. Success allows it to proceed to the Turbo Decoder check.

The Turbo Decoder lock is checked for the current DCC. If it is unlocked, the time is checked for the outage that occurs during the expected one-way to two-way telemetry coherency transition as part of nominal DSN support activities that use the station's transmitter. If this outage is not expected at the time that the Turbo Decoder lock check fails, then STAMP falls back to the symbol loop check and retries. If the time is correct for the expected outage but the Turbo Decoder fails to relock after the outage duration, STAMP goes back to the symbol loop check.

Once the Turbo Decoder lock is verified, STAMP checks the housekeeping telemetry to ensure that the data are being received from the spacecraft. Because data from the spacecraft may

be long frame (8920 bits per frame) or short frame (1784 bits per frame), the frame size being used by the station is recorded. This information also dictates which APID packet counter is monitored by STAMP. MESSENGER APID 0x405 is checked for long frame, and APID 0x406 is checked for short frame. Short-frame telemetry is not expected to be used with automation, but the functionality has been kept. If the packet counter for the appropriate APID is not changing and STAMP finds that no other expected spacecraft telemetry APIDs are active, then STAMP will go back to the Turbo Decoder check. If the packet counter is not changing but other APIDs appear to be flowing, STAMP simply extends the waiting time for the next housekeeping packet to update. Only when the housekeeping APID packet is seen to update will STAMP then allow the monitoring of the telemetry points themselves.

This housekeeping packet check also includes checks for solid-state recorder (SSR) playback status, and the EOT time. As long as the telemetry continues to flow, even after EOT, STAMP continues to check data opportunistically. Once STAMP fails to detect a new housekeeping packet for any reason, it checks for changes to the playback status, which affects the wait time between housekeeping packets, and it checks to see whether EOT has been reached. Changes to SSR playback simply result in STAMP reinitiating its housekeeping check, but with different loop timing based on the new information. If STAMP finds that EOT has been reached, it reports this finding to the event log without paging and terminates nominally.

B. STOL Implementation: Telemetry Monitoring

Because there are >800 MESSENGER telemetry points to be checked and each one is checked for red and yellow limit violations, STAMP checks them only when it verifies that a new housekeeping telemetry packet has been received. This rule avoids unnecessary processing cycles through the loops required to check the limits. Each point has one of three possible states: nominal (green), warning (yellow), and error (red).

The status of each point is determined once STAMP detects that a new packet has arrived. This verification is accomplished by comparing the current packet counter value of the housekeeping APID with the previous value. If the value has changed, then the housekeeping packet has updated. The current status (red, yellow, or green) for each point is then checked against its status from the previous housekeeping packet. All status changes are reported once detected but are not reported again unless another status change occurs.

The timing between the limit checking is not static but rather is initially determined by calculating an effective downlink rate from the telemetry rate minus the data rate of the SSR playback, if applicable. This initial estimate of the wait time between checks is calculated just prior to entering the limit checking loop. The estimate is conservative, and STAMP reduces the wait time by 1 second every limit check loop until this reduction causes the loop to occur too often (i.e., the housekeeping packet counter does not change during the shortened wait time, but the other telemetry packets are not stale). Once the looping has occurred too often, the wait time between checks is extended 10 seconds, and then the process of reducing the wait time by 1 second every cycle begins again in the following loop. This dynamic wait-time cycle repeats until STAMP breaks out of the limit checking loop for any reason. Allowing the wait time to shrink and expand in this way enables STAMP to check the telemetry as often as possible without checking the same packet twice. This procedure is very useful for MESSENGER operations, during which the telemetry rates can vary markedly over a range from 10 bps to 104 kbps, on the basis of RF link margin restrictions throughout the mission. The effective housekeeping telemetry rate can also change within a DSN support interval, if SSR playback

status is changed via onboard command or via a sequence of staggered downlink rate-stepping commands.

C. STOL Implementation: Alert/Reporting Functions

All reporting of status changes and problems is sent to the viewer event log. The viewer log records all of the information about an automated DSN support interval. Paging and e-mailing are a smaller subset of the information in the viewer event log that focuses on configuration problems, unexpected telemetry limit violations, and any recoveries from these events. Therefore, all nominal status changes and events detected by STAMP are not reported via personnel notification. Instead, they are reported by statements that are written to the viewer log. Each of these statements has the same special text identifier in front of it, making it easy to search the log for those messages.

Nominal events include the expected initial telemetry acquisition steps: detection of monitor data from the DSN station, RF carrier lock, symbol loop lock, turbo decoder lock, and detection of the housekeeping telemetry. In addition, the following events are considered nominal, and they are also only reported to the viewer log: the temporary, expected telemetry outage that accompanies the transition from one-way to two-way mode shortly after the DSN transmitter turns on and sweeps the uplink; reacquisition of telemetry after the one-way to two-way outage; and changes in the status of the SSR playback.

Any of the following error conditions in the telemetry status are reported via both event log statements and e-mail/paging: failure to initially acquire telemetry at any of the expected steps from monitor data verification through housekeeping packet validation; unexpected loss of telemetry; unexpected out-of-lock conditions at carrier loop, symbol loop, or turbo decoder; loss of Monitor 01-58 data or improper Monitor 01-58 data (e.g., data from an unexpected station); and delayed/failed recovery from expected one-way to two-way transition.

STAMP avoids sending messages for the routine operations and always informs the responsible personnel if the telemetry is recovered after an error condition. Thus the nominal checks for the initial acquisition of telemetry do not generate e-mails or paging messages, but recovery from errors at those same steps does generate messages. For example, there is no paging or e-mail message from STAMP when the carrier first locks at BOT or relocks after the expected transition to two-way telemetry, but there is a message if the carrier relocks after an unexpected loss of signal.

In the case of telemetry limit checking, this method of reporting becomes even more important. Reporting the nominal status of hundreds of telemetry points is neither practical nor useful, but reporting when a telemetry point goes out of limits and when it returns is necessary. Furthermore, telemetry points have two potential levels of problems to report: warning (yellow) and error (red). Transitions in either direction between warning and error status are reported, as well as when the point initially violates a limit or returns to within the nominal limits.

In previous designs of STAMP, it was possible for no messages to be generated during an entire DSN support interval. This outcome would have occurred if no error conditions whatsoever were encountered. Now, however, STAMP sends a message immediately after the setup to inform responding personnel of the setup parameters entered for upcoming DSN support activity.

D. STOL Implementation: Messaging

The paging subroutine is called any time that link status is off nominal or telemetry is detected out of limits. As in Delta DOR automation, the Subject argument is used as the subject line in an e-mail or text message, and STAMP determines the content of this variable. For telemetry automation, there are two possible subjects. "Tlm Track Alert" is used for any error or unexpected condition in either the ground system or the spacecraft telemetry. "Tlm Track Status" is used for a return to nominal condition.

The second argument, Message, is also used by STAMP in a manner similar to its usage for Delta DOR automation. In the case of the DSN status and error messages, it will report both the station ID and the appropriate condition. For the telemetry, it will report the point and its limit state. The third and final argument, Response, also uses only the PageMe option so that only one list of addresses needs to be maintained. These three arguments are passed to the Perl script for distribution.

VII. Conclusion

MESSENGER enters into orbit about Mercury in March 2011, where it will collect science for a minimum of one Earth year. During the orbital phase of the mission, real-time operations will become more complex and demanding. Without automation, this phase would require additional support personnel. However, MESSENGER automation has already begun its formal review process in preparation for orbit phase readiness and is expected to be complete by fall 2010. It is expected that this automation will mitigate the need for additional personnel during the orbit phase. Indeed, STAMP has already been extensively and successfully tested in a real-time environment.

In addition to any updates that are required for review, STAMP modifications will be put in place to handle MESSENGER support activities that are predicated on the receipt of only unmodulated RF carrier from the spacecraft, or only beacon signal. These beacon-only support periods—more akin in track profile to telemetry support periods than Delta DORs—will become a standard part of orbital operations along with telemetry tracks, whereas Delta DORs will be discontinued. Therefore, STAMP will continue to evolve from its simple beginnings in Delta DOR automation toward a more robust form that includes automated monitor and alert functionalities not only for telemetry and Delta DOR support activities but also for the full complement of MESSENGER real-time on-orbit track activities.

¹Kinman, P. W., "DSMS Telecommunications Link Design Handbook," NASA 810-005, Rev E., Module 210, 2004.

²CCSDS Secretariat, "Telemetry Summary of Concept and Rationale," CCSDS, Report 100.0-G-1 Green Book, Dec. 1987.