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Science Planning for the NASA Mars Reconnaissance Orbiter Mission

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The Mars Reconnaissance Orbiter (MRO), launched on August 12, 2005, carries six science instruments, each with unique requirements for repetitive global monitoring, regional or global survey mapping, and/or targeted observations of Mars. Some prefer nadir-only observations, while other instruments require many off-nadir observations (especially for stereo viewing). Because the operations requirements are often incompatible, an interactive science planning process has been developed. This process is more complex than in some recent NASA Mars missions, but less complex (and more repetitive) than processes used by many large planetary missions. It takes full advantage of MRO's novel onboard processing capabilities, and uses simple electronic interactions between geographically distributed teams. This paper describes the process used during MRO's Primary Science Phase (PSP) to plan both interactive and non-interactive observations of Mars, and what has already been learned in the tests and rehearsals preparing for PSP.

I. Nomenclature

C	=	CRISM instrument
D	=	MCS instrument
H	=	HiRISE instrument
IO	=	interactive observation
IPTF	=	integrated payload target file
ITL	=	integrated target load
M	=	MARCI instrument
NIO	=	non-interactive observation
PSP	=	primary science phase
PTF	=	payload target file
S	=	SHARAD instrument
SOT	=	science operations team
X	=	CTX instrument

II. Introduction

During PSP, MRO will follow a 255 x 320 km altitude near-polar sun-synchronous orbit, with periapsis frozen over the South Pole, and equator crossing at a Local Mean Solar Time (LMST) of 3:00 p.m.[1] The goals of MRO's remote sensing investigations are to:

- Advance our understanding of Mars' current climate, the processes that have formed and modified the planet's surface, and the extent to which water has played a role in surface processes;
- Identify sites of possible aqueous activity indicating environments that may have been or are conducive to biological activity; and
- Thereby identify and characterize sites for future landed missions.

These science objectives will be accomplished by conducting a program of:

- Global repetitive monitoring,
- Regional and global survey, and
- Globally distributed targeted observations

for one Mars year and by analysis of the returned data.

MRO instruments have higher resolution than their predecessors and will return more data. They require more uplink planning than recent NASA Mars missions, to observe more targets for more teams and to patch observations into useful survey patterns. MRO's three targeting instruments have restricted fields of view; each has its own off-nadir observing requirements and the teams have possibly competing desires. In addition, coordinated multi-instrument targeting of many sites is required for characterization and certification of potential landing sites, and stereo imaging is required for science as well as site certification. See Table 1 for a description of MRO's six science instruments.

Instrument	***Type***	***Measurement Objectives***	***Science Goals***	***Attributes***
CRISM (C)	High-resolution Imaging Spectrometer	• Hyper-spectral Image Cubes • 514 spectral bands, • 0.4 - 4 μm, 7 nm resolution • 20 m/pixel, 11 km swath	Regional & Local Surface Composition; Morphology	1. Moderately-High Spectral & Spatial Resolution 2. Targeted Observing & Global Survey 3. Very High Data Rate
CTX (X)	Mono-chromatic Context Camera	• Panchromatic Images • 6 m/pixel; 30 km swath • [Context Imaging for HiRISE/CRISM]	Regional Stratigraphy; Morphology	1. High Resolution with Coverage 2. Targeted Observing & Regional Survey 3. High Data Rate
HiRISE (H)	High-resolution Camera (0.5 m aperture)	• Color Images, • Stereo by Site Revisit • 0.3 m/pixel, 6 km swath (red) • 1.2 km swath (3 colors)	Stratigraphy; Geologic Processes; Morphology	1. Very High Resolution 2. Targeted Imaging 3. Very High Data Rate
MARCI (M)	Wide-angle Color Imager	• Atmospheric cloud & haze, O_3, surface albedo • 7 bands: 0.28 - 0.8 μm	Global Weather; Surface Change	1. Daily Global Mapping, 2. Continuous Dayside Operations 3. Moderate Data Rate
MCS (D)	Atmospheric Sounder	• Temperature, H_2O, Dust • Polar Radiation Balance • 0-80km vertical coverage • Vertical Resolution ~ 5km	Atmospheric Structure; Transport; Polar Processes	1. Daily Global Limb & Nadir Sounding, 2. Continuous Operations 3. Low-Data Rate
SHARAD (S)	Shallow Subsurface Radar	• Ground Penetrating Radar • Split band at 20MHz • 10 - 20 m vertical resolution • 1 km x 5 km horiz. res'n.	Regional Near-Surface Ground Structure	1. Shallow Sounding 2. Regional Profiling 3. High Data Rate

CRISM:	PI, Scott Murchie, Johns Hopkins University Applied Physics Lab (JHUAPL)
CTX:	TL, Michael Malin, Malin Space Science Systems (MSSS)
HiRISE:	PI, Alfred McEwen, University of Arizona
MARCI:	PI, Michael Malin, Malin Space Science Systems (MSSS)
MCS:	PI, Daniel J. McCleese, Jet Propulsion Lab (JPL)
SHARAD:	TL, Roberto Seu, University of Rome, Italy; DTL Roger Phillips, Washington University

Table 1. MRO Science Instrument Descriptions.

III. Experiment Observation Goals

CRISM: The Compact Reconnaissance Imaging Spectrometer for Mars has three primary modes of operation, with different observational goals.

- Multi-Spectral Survey: Over the 2-year PSP, the CRISM Team will attempt to map the entire Mars surface in 70 spectral channels at 100-200 m resolution, via fixed nadir viewing.
- Atmospheric Survey: CRISM will periodically monitor Mars' multi-angle reflectance (emission phase function or EPF), over a grid of surface locations, via gimbaled multi-angle measurements while MRO is nadir-oriented.
- Targeted Observation: CRISM will observe several thousand targets on Mars in all spectral channels at 15-40 m resolution, via off-nadir pointed MRO operations. These will include gimbaled multi-angle EPF measurements.

CTX: The Context Camera will acquire 30-km wide images at 6 m resolution in one band, to provide larger-field contexts for CRISM and/or HiRISE observations. In addition, the CTX Team plans to image a variety of targets, many in stereo, via pointed off-nadir operations, and to image much of Mars via nadir operations (often multiple times to detect change).

HiRISE: The High-Resolution Imaging Science Experiment will observe smaller targets on Mars at very-high spatial resolutions, down to 0.3 m, over swaths as wide as 6 km. HiRISE's 14 CCDs are independently commanded, offering a wide variety of operating modes. The HiRISE Team plans to acquire ~1000 stereo pairs, and observe thousands of other targets without stereo. Because of MRO's accurate off-nadir roll capabilities, the most important HiRISE images will be acquired via off-nadir targeted MRO operations. In order to observe at the highest resolutions (requiring high stability), solar array and MCS instrument motions are paused for about 90 s.

MARCI: The Mars Color Imager will continuously image the dayside of Mars in five visible and two UV bands, at 1-10 km resolution, to monitor Mars' weather and climate. MARCI images limb-to-limb, as long as MRO is not rolled more than 20° off-nadir.

MCS: The Mars Climate Sounder is a multi-channel thermal infrared sounder capable of retrieving profiles of atmospheric temperature at 5 km vertical resolution, and humidity profiles, via continuous day and night sounding of the nadir and Mars' limb. It will also characterize atmospheric dust and condensates, and measure the radiation balance at Mars' poles. MCS' normal observing strategy works only when MRO is oriented within 9° of nadir.

SHARAD: The Shallow Radar Sounder will characterize the upper few hundred meters of Mars' subsurface, via active sounding at 15-25 MHz, with a vertical resolution of about 7 m and a horizontal resolution of ~1-5 km (size of the Fresnel zone). The dipole antenna has a large beam width, so SHARAD is capable of well-characterized observation of the nadir even when MRO rolls up to about 10° off-nadir. It can operate day or night. The SHARAD Team plans to acquire a globally distributed set of observations, with more densely-space observations in critical locations. They also plan to observe polar areas above 60° latitude, in continuous swaths, in both winter and summer.

IV. Spacecraft Capabilities

Off-Nadir Targeting: MRO can support off-nadir targeting, with rolls up to 30˚ for as many as 4 different targets per orbit. Scientists generate a simple list of points on Mars, designated by latitude, longitude, and rough overflight time, which is uplinked to the spacecraft as an Integrated Target List (ITL). Using the current on-board Mars ephemeris file, FSW computes an accurate time of target over-flight and initiate a series of on-board command blocks to execute the spacecraft and instrument sequences. Timing changes due to updates in predicted orbit are handled by simply uplinking a new spacecraft ephemeris.

Navigation: MRO's Primary Science Orbit (PSO) is designed to simplify science operations. This frozen nearly-circular orbit has altitudes from 255 km (at 90S) to 320 km (at 90N). Frozen orbits simplify operations planning and provide more systematic coverage. Low altitude enhances spatial resolution without being so low that it becomes impossible to target precisely.

The PSO will nearly repeat every 17 days to provide global access and repeated targeting opportunities. Nearly every place on the planet can be viewed at least once (and usually twice) at <20˚ off-nadir, providing multiple opportunities each month to observe specific sites. The orbit will also provide long-term global coverage of Mars with ground track spacing of less than 5 km. Orbit control via small orbit trim maneuvers (OTMs) should maintain spacing to better than 2 km.

SSR: MRO has a solid-state recorder with a 100 Gbit end-of-mission storage capability. The SSR is divided into two areas of memory, one for the storage of the raw science data produced by the instruments and the second for the storage of framed data awaiting downlink to Earth.

To provide operational independence, each instrument has its own dedicated hard partitions to store raw data generated with each observation. Spacecraft flight software reads data from each instrument's raw partition into the processing buffer. The framed data area of the SSR is configured as one large hard partition for X-band downlink (and another for Ka-band), subdivided into smaller soft partitions and managed by the FSW.

Data flow: MRO flight software reads science data from a raw partition and generates CFDP (CCSDS File Delivery Protocol) product telemetry out of it. The science product telemetry is packetized, framed, and then sent to a pre-SSR framed data buffer for eventual storage in an SSR soft partition. The FSW controls the writing of an instrument's framed data into the SSR, based on agreed downlink bandwidth percentages. If an instrument generates more data for transfer to a framed buffer than its allocation allows, the FSW will pause that instrument from being able to write additional data until space has been freed up (via reading data out of the framed buffer for downlink). If an instrument generates more data when its raw buffer is full, that data (generally including the remainder of a given observation) is truncated and lost.

Much of the data management process outlined above is configurable via a set of FSW configuration files. Hard partition updates will result in the loss of all data not yet transmitted off the spacecraft. However, the soft partitions (for framed data) can be resized without losing data. This allows updates to the instrument downlink allocation percentages without data loss.

V. Definition of Terms

Interactive Observations: An instrument observation that affects operations of the spacecraft or another instrument. IO planning is multi-instrument and collaborative. IOs are planned on a 14-day execution cycle.

Non-Interactive Observations: An instrument observation is non-interactive if it does not affect spacecraft or any other instrument's operations. Each instrument team can plan their NIOs independently, if they so choose. Orbit timing uncertainties, and therefore ground-track uncertainties, have led the project to plan NIOs on a 7-day execution cycle.

Project Science Group: The PSG consists of all MRO's Principal Investigators and Team Leaders. It meets every quarter.

Target Acquisition Group: The TAG consists of the PI or TL of each experiment (or his/her representative). It meets every two weeks to schedule the few most critical observations (Must-Have Observations) and the orbit segments reserved for global/regional survey.

Science Operations Team: Each science instrument PI employs a Science Operations Team (SOT), to control his/her instrument.

Payload Operations Support Team: MRO's Payload Operations Support Team (POST) provides assistance to the SOTs and helps coordinate the collaborative efforts of those teams. POST has an Investigation Scientist for each instrument and two Science Operations System Engineers. During each 14-day science sequence, one scientist acts as Cycle Coordinator (CC).

Payload Target File: When planning their observations (IOs and NIOs) an SOT generates a Payload Target File (PTF), which lists the targets (locations) and orbits on which to view them, along with a variety of other observing parameters, and submits the file to the Project.

Integrated Payload Target File: The POST merges PTFs into a conflict-free Integrated PTF (IPTF). This is done several times during the planning process.

Integrated Target Load: The Flight Engineering Team converts the IPTF into a binary Integrated Target Load (ITL), which lists locations at which the spacecraft must point for instrument observations and rough times for these pointing events. MRO's flight software converts this information into slewing and instrument commands, based on the latest onboard ephemeris.

VI. Planning Challenges

Off-Nadir Observations: MRO has planning challenges compared to recent Mars missions due to the need to routinely target off-nadir during PSP. A robust science planning design must provide the same planning process for each 14-day science execution cycle, with up to 280 conflict-free targeted off-nadir IOs (based on 20 per day x 14 days) for CRISM, HiRISE, and CTX, with roll angles up to ±30° about the X-axis. The IO selection process must also include targets to support the Mars Exploration Program (MEP) for landed assets.

Orbit Prediction: The science planning process must account for uncertainties in the orbit prediction. Small timing uncertainties in the along-track direction translate into notable cross-track uncertainties in the position of the ground-track. This must be accounted for in two steps.

- Off-nadir IOs: Off-nadir observations must be planned close enough to the event that targets are identified that fall within the spacecraft roll capability. Figure 1, a plot of the predicted pointing angle uncertainties vs. days since OD cutoff, illustrates the error in the Navigation orbit prediction expected over 7 weeks.
- Nadir NIOs (and IOs): Nadir observations must be planned close enough to the event that planned targets do not move out of an instrument's nadir FOV.

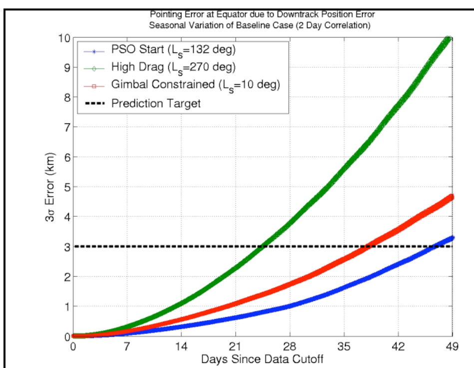

Figure 1. Ground track uncertainty in as a function of time.

Concerns about orbit prediction accuracy in MRO's very low altitude orbit are handled in two ways. (1) The Project has adopt a 14-day science execution cycle to minimize forecast off-nadir roll angles. (2) Each contains two 7-day NIO execution cycles embedded within it to minimize errors in ground-track forecasts (see Fig. 1).

VII. Interactive Observation Planning

Context for IO Planning Process: Before Science Teams can plan their IOs, they need a background of spacecraft activities, especially the downlink schedule. The Background Sequence will be developed using well-established processes, every 28 days. Teams also need to know the orbit prediction over a time span of about 40 days (from beginning of planning to completion of a 14-day science sequence). The Navigation Team will generate a long-term orbit ephemeris every week on Thursday, again using well-established processes. Before any planning can begin, the PSG establishes certain planning rules and a downlink allocation for each instrument. With these inputs science teams can plan their Interactive Observations for each 14-day cycle.

Non-interactive observations (NIOs) are planned on a weekly basis, to improve the ability to accurately plan observations on the nadir groundtrack. Each week, NIO plans are merged with IO plans in an Integrated Payload Target File (IPTF) and sent to the S/C team, to be converted into an ITL for uplink to MRO.

Components of IO Planning: There are several steps in planning IOs, primarily involving the CRISM, HiRISE, and CTX Science Teams (collectively called C/H/X) and the Cycle Coordinator. Figure 2 shows the process flow of the bi-weekly IO planning cycle. Yellow boxes show IO planning activities at individual Science Team sites and green boxes show activities handled at the Project level. The process shown takes one week to complete.

In order to make this work within a week, without re-inventing the wheel, mission operations are designed to evolve existing Mars Mission approaches to meet MRO needs. For example, the MOS is designed to retain a distributed science experiment commanding and data processing approach, provide required tools for targeting and data tracking, provide a forum (i.e., TAG) for coordinating strategic observation planning, provide the ability to coordinate interactive observations while preserving non-interactive planning, provide a process that resolves conflicts based on agreed rules and priorities, and retain ability for science investigations to plan their observations within defined data allocations.

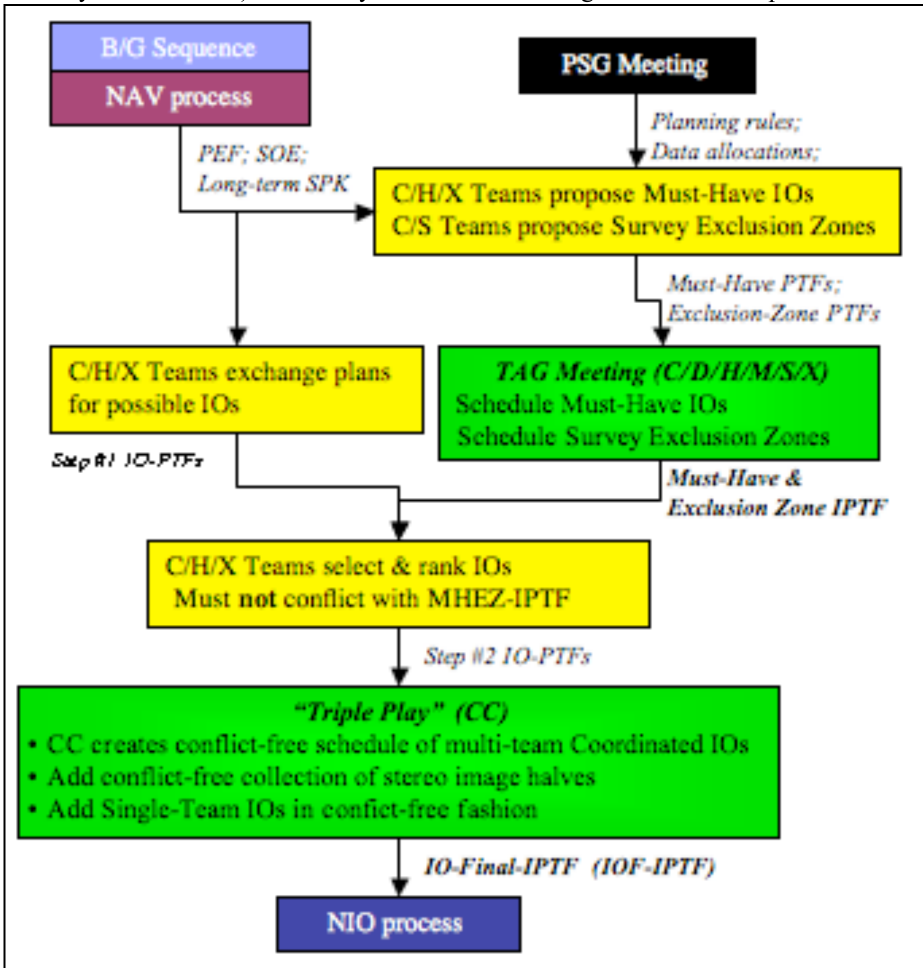

Figure 2: Flow of activities and information in IO planning process

A. PSG Meetings

The PSG will meet quarterly to discuss and modify, if necessary, science planning rules and data allocations and to make decisions on major observation campaigns (e.g. landing site characterization). Examples of science planning rules are:

- MCS rules limit the number of large (>9°) off-nadir slews and their distribution (e.g. in adjacent orbits).
- CRISM rules reserve a certain number of orbits for nadir survey observations. In early PSP, every other orbit is a No-Slew Zone.
- SHARAD rules provide priority in observing conflicts on the nightside. Others have priority on the dayside, except in scheduled SHARAD exclusion zones.
- CTX rules dictate how CRISM and HiRISE can demand CTX support imaging (perhaps 50% of CTX' data allocation).

B. Time-Critical Observations and Survey Zones

Each 14-day cycle, in the days before a TAG Meeting, the CRISM, HiRISE, and CTX (C/H/X) Teams generate PTFs describing their most time-critical ("Must-Have") observations for the upcoming cycle, while the CRISM and SHARAD teams generate PTFs describing their preferred orbit segments for global or regional survey in the next cycle. Note that the CRISM and SHARAD Teams have developed a technique and timeline for coordinating their requests for exclusion zones.

C. TAG Meetings

The Targeting Acquisition Group (TAG) will meet Monday afternoon, in the first and third week of each Background Sequence execution (the weeks when IOs are scheduled). The TAG includes science investigation PI/TLs; an Electra representative during PSP relay; MRO Project Scientist, Deputy Project Scientist, and an MEP representative to support landing site studies and/or relay activities. These TAG meetings:

- Schedule "Must-Have" observations (incl. selected MEP targets and Relay opportunities);
- Schedule Exclusion Zones for CRISM Atmospheric and Multi-Spectral Surveys; and
- Schedule Exclusion Zones for SHARAD Polar Survey.

D. Inter-Team Observation Coordination

Each 14-day cycle, before the TAG Meeting, the C/H/X Teams exchange information about areas they may want to observe in the upcoming cycle. The day after each TAG Meeting they exchange "Step #1" IO-PTFs (IO1-PTFs), defining their most likely targets and observing times for upcoming IOs.

E. IO Scheduling

On the Thursday after each TAG Meeting, the C/H/X Teams submit Step #2 IO-PTFs that are ranked-lists of all their desired Interactive Observations. Having examined each other's IO1-PTFs, these are likely to have many coordinate-able observations. The Cycle Coordinator processes these to schedule Coordinated IOs. Immediately following this, he/she processes these to schedule a collection of images that form halves of stereo pairs. Finally, Single-Team IOs are scheduled from among the remainder of the proposed IOs in the IO2-PTFs. This procedure is referred to as "the triple play." A conflict-free Integrated PTF (IPTF) of IOs (IO-Final-IPTF) is generated mid-Friday.

VIII. Non-Interactive Observation Planning

F. Context of NIO Planning

Figure 3 below shows the planning flow for NIOs (in yellow and green boxes). Note that short-term orbit predictions enter the process three times per week. The short-term ephemeris will be used to generate MRO's on-

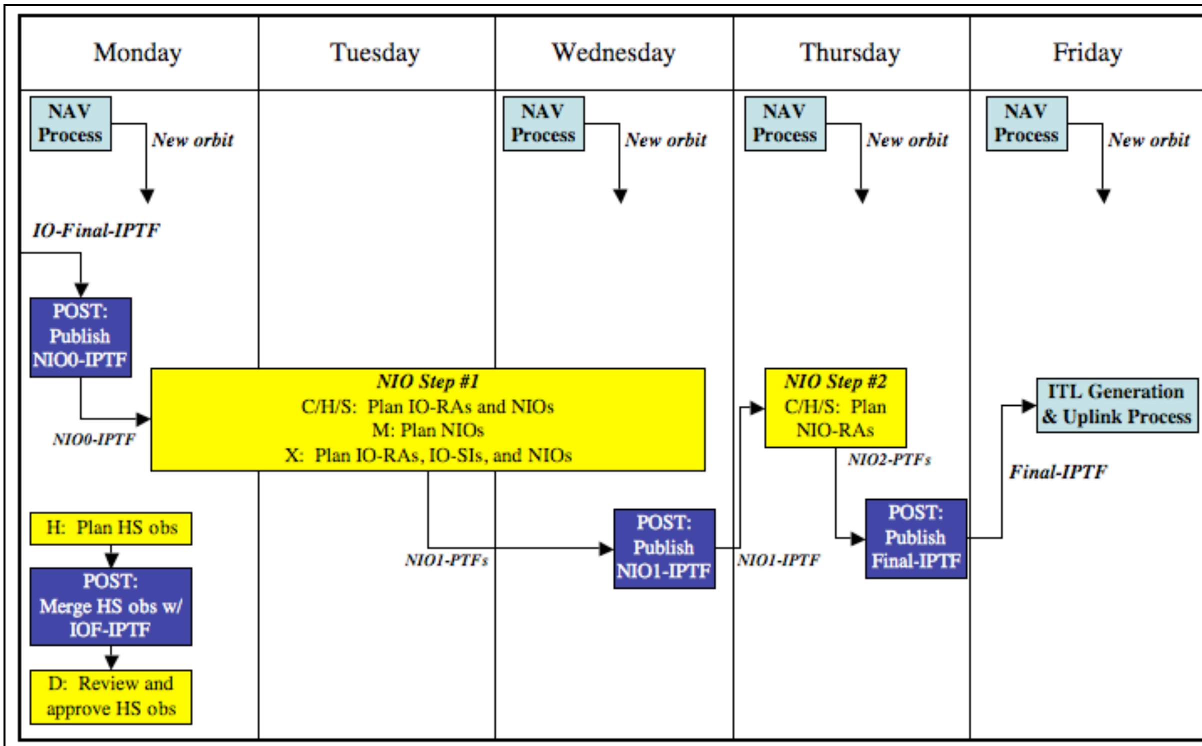

Figure 3: Flow of activities and information in NIO planning process

board ephemeris file and to support the non-interactive science planning process. Depending on the season and atmosphere predictability, updates may be as frequent as every day, to satisfy the 3σ short-term orbiter position requirements for the downtrack, crosstrack, and radial uncertainties of 1.5 km, 0.05 km, and 0.04 km, respectively.

A Non-Interactive Observation (NIO) is any instrument observation that does not affect the operation of the spacecraft or another instrument. Before one can plan NIOs, one needs to know what IOs have been planned and when. Thus, the Science Teams adds NIOs on a weekly basis, using the IO-Final-IPTF generated in the IO process. NIOs:

- require nadir orientation; and
- are defined by Mars latitude and orbit (i.e., time).

NIOs include both observations of specific targets which are forecast to lie along the ground-track and also larger nadir observations taken as part of global or regional surveys.

G. Two-step NIO Planning Process

The science teams have developed a two-step process, which allows them to coordinate NIOs, as illustrated in the figure. The output of the NIO process is the "Final-IPTF" which includes all the observations to be taken by CRISM, HiRISE, MARCI, SHARAD, and CTX for an entire week. The Final-IPTF is used to generate the ITL. [However, MARCI and CTX NIOs are not included in the ITL; they are controlled by absolute time-tagged command sequences.]

At each step in the process, the teams can determine what observations scheduled by other teams they want to "ride-along."

The process starts with the POST generating the basis IPTF for the week (NIO0-IPTF) which is one half of the IO-Final-IPTF for the two-week sequence. The Science Teams plan their NIOs and Ride-Alongs to already-scheduled IOs and submit the results as Step #1 NIO-PTFs. The CTX Team is required to schedule "support imaging" for CRISM and HiRISE, when requested, so they plan IO Support Images at this time. In the second optional step, the teams examine NIOs planned by other teams, and they can add Ride-Alongs to any of those.

H. ITL

The uplinked ITL file is a time ordered listing of observations, containing both nadir and off-nadir targets, specified by target latitude (areodetic coordinate frame) and longitude. Additionally, an altitude bias can be input to target different terrain types, like mountains, craters walls or valleys. It is generated from the Final IPTF emerging from the NIO process.

The spacecraft uses the current on-board Mars ephemeris file to compute the time of target over-flight and initiates a series of on-board command blocks to execute the spacecraft and instrument sequences specified in the ITL. Timing updates due to navigation orbit prediction updates are handled by simply updating the onboard spacecraft ephemeris.

The ITL contains an observation type parameter. This is used to designate the type of observation to be executed:

- Nadir (nominal or high-stability);
- Small-angle off-nadir (nominal or HS); or
- Large-angle off-nadir (nominal or HS).

Rolls >9 deg off-nadir are considered large-angle. They take longer and cause MCS to execute special operations.

The ITL file also contains references to specific command sequences that control an instrument during any specific observation.

IX. Instrument Command Sequences

All science observations by the CRISM, HiRISE, and SHARAD instruments are controlled by the ITL and scheduled in the IPTF. For each one, however, an SOT must uplink an appropriate series of commands to be executed by the instrument at a time determined by the ITL. The technique used by each instrument is different, but each SOT uses the Non-Interactive Payload Command (NIPC) or Non-Interactive File Load (NIFL) process to generate these commands and uplink them to the spacecraft.

The NIFL/NIPC process allows an SOT to modify the specifics of an observation up to a few hours before the observation event itself. The major goal of doing this is to adjust the data volume being generated by an instrument so that is does not cause a data truncation in the SSR, while at the same time not causing the bandwidth to be wasted.

X. Operations Tests

Before the beginning of PSP, the MRO SOTs and POST will have participated in:

- Two science planning thread tests;
- Two science planning rehearsals; and
- Two PSP Operational Readiness Tests.

I. Science Planning Thread Tests

The science planning thread tests were used to test the software and interfaces used in the processes described here, as well as to test the efficacy of those processes. Two major process-related results came from these thread tests:

- Pre-scheduling IO coordination was difficult and needed to be choreographed on a well-defined schedule. The payoff is higher-value science with fewer off-nadir rolls.
- SOTs need a well-defined background of already-scheduled observations against which to plan the next lower priority set of observations.

In addition, the PTF specification was greatly improved and a number of bugs in science planning software were discovered and fixed.

J. Science Planning Rehearsals

The science planning rehearsals tested the procedures used in science planning, on a strict timeline established for the process. They also continued to test the software, interfaces, and overall process.

The rehearsals led to two major changes:

- Some of the minor steps added after the thread tests were removed, for lack of usefulness.
- Some changes were made in the algorithm used to select IOs in the final parts of the IO Planning Process.

One major discovery in the rehearsals was that the timeline was fairly full. Until the SOTs and POST gain more experience, they will work hard to accomplish everything in time. However, with the then-current process design[2], if an SOT fell behind it could skip a step and fill out the schedule or downlink in a later stage of the process. Thus, although the planning timeline is full, if you miss a step you don't have to give up observations or data volume.

K. Primary Science Phase (PSP) Operations Readiness Tests (ORTs)

In MRO's first PSP ORT, the SOTs for the first time exercised the following four processes in parallel:

- IO planning;
- NIO planning;
- Instrument monitoring; and
- Science data processing.

The primary finding from this ORT was that the Science Planning process had too many steps and was too complex. The burden on the SOTs and the POST could not be sustained during PSP. This led to two changes:

- One step was removed from IO planning. The SOTs now submit one IO-PTF that is used by the POST to generate conflict-free schedules of Coordinated IOs and Single Team IOs, in rapid succession.
- One step was removed from NIO planning. The SOTs now submit an NIO-PTF on Wednesdays. They have only one optional step to add NIO Ride-Alongs.

Although the resulting process has less flexibility and can't promise the same level of schedule excellence, all teams involved felt that simplification was necessary.

XI. Actual Flight Experience

In addition to exercising the PTF/IPTF interfaces and onboard ITL and instrument command sequences during various tests, it has been exercised for actual MRO flight operations. Approximately two weeks after Mars Orbit Insertion, the CRISM, CTX, HiRISE, and MCS instruments were turned on for some engineering tests. The ITL was used to operate MCS, CTX, and HiRISE to a greater or lesser degree. PTFs and IPTFs were used to plan and schedule these events. The outcome was successful. Some of the largest high-resolution images of Mars were acquired and are already being used to improve science data processing software.

XII. Conclusion

The MRO Project has developed a unique science planning and scheduling process that operates on a waterfall basis. Spacecraft activities are scheduled first. The highest-priority, most time-critical observations are planned around these. Less critical interactive observations and non-interactive observations are then planned in a series of steps. At each step, the activities being scheduled are planned against a known background.

This process should make it possible for six science teams with divergent interests to collectively acquire a large and valuable Mars dataset.

XIII. Reference

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[2]Jai, B., Wenkert, D., Kloss, C., Hammer, B., Carlton, M., and Sidney, W., "The Mars Reconnaissance Orbiter Mission Operations: Architecture and Approach", *6th IAA International Conference on Low-Cost Planetary Missions Proceedings*, October 11-13, 2005.

XIV. Acknowledgments

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