JET PROPULSION LABORATORY INTEROFFICE MEMORANDUM

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November 12, 2001

TO: G. Burke

FROM: S. Lineaweaver

SUBJECT: Mars Reconnaissance Orbiter 2005 Support Evaluation

REFERENCE: User Loading Profile, MRO 2005-2010

As requested, the Resource Analysis Team evaluated the Mars Reconnaissance Orbiter 2005 (MRO) support requirements. This paper focuses on support that MRO should expect to receive during their prime mission and the effect MRO requirements have on other project support and Deep Space Network (DSN) resources.

Analysis was accomplished using the FASTER (forecasting and scheduling tool for earth-based resources) forecasting system and the mission set database from the August 2001 Resource Allocation Review Board. The analysis assumes (1) launch will occur on the first day of the launch period and (2) 34-meter X-band uplink and downlink support is requested with 70-meter support as noted.

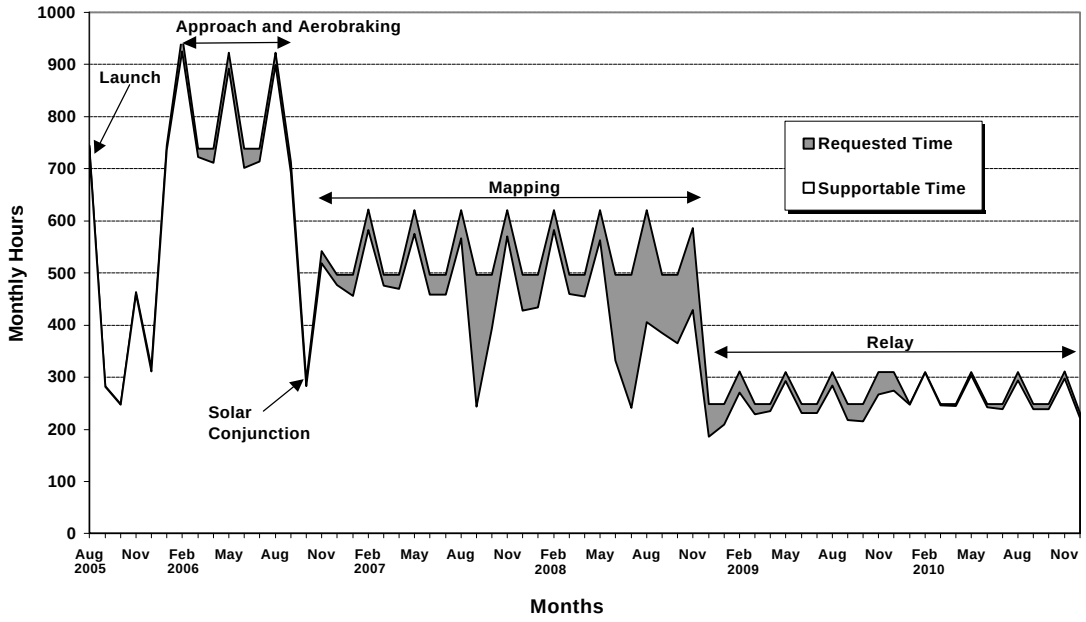
Key MRO mission events and tracking requirements are summarized below.

Launch Phase	08 Aug 2005 to 06 Sep 2005	24 h/day
Cruise	07 Sep 2005 to 02 Jan 2006	8-h pass, 1/day
Approach and arrival	03 Jan 2006 to 01 Apr 2006	24 h/day
Mars orbit insertion	03 Mar 2006 (70 meter support)	MOI -12 h to MOI+12 h
Aerobraking	02 Apr 2006 to 28 Sep 2006	24 h/day
Mapping	29 Sep 2006 to 26 Nov 2008	8-h passes, 2/day
Solar conjunction	06 Oct 2006 to 07 Nov 2006	8-h pass, 1/day
Ka-band Demo (D/L)	08 Nov 2006 to 26 Nov 2008	8-h pass, 2/week
Relay	27 Nov 2008 to 31 Dec 2010	8-h pass, 1/day

Initial Assessment

Figure 1 shows the forecast monthly supportable hours of Mars Reconnaissance Orbiter's prime mission requirements. The periodic spikes seen on the chart are due to distributing 4 or 5 weeks within monthly boundaries. MRO is forecast to receive on average greater than 95% of the time requested from launch through the end of the aerobraking phase and above 90% of the time requested from the beginning of mapping through August 2007. Four periods of time are identified between August 2007 and November 2008 where the average supportable time falls below 90% and ranges as low as 55%. During the relay phase MRO is forecast to receive on average 95% of the time requested. Two periods of

Figure 1. Mars Reconnaissance Orbiter 2005 Prime Mission Forecast



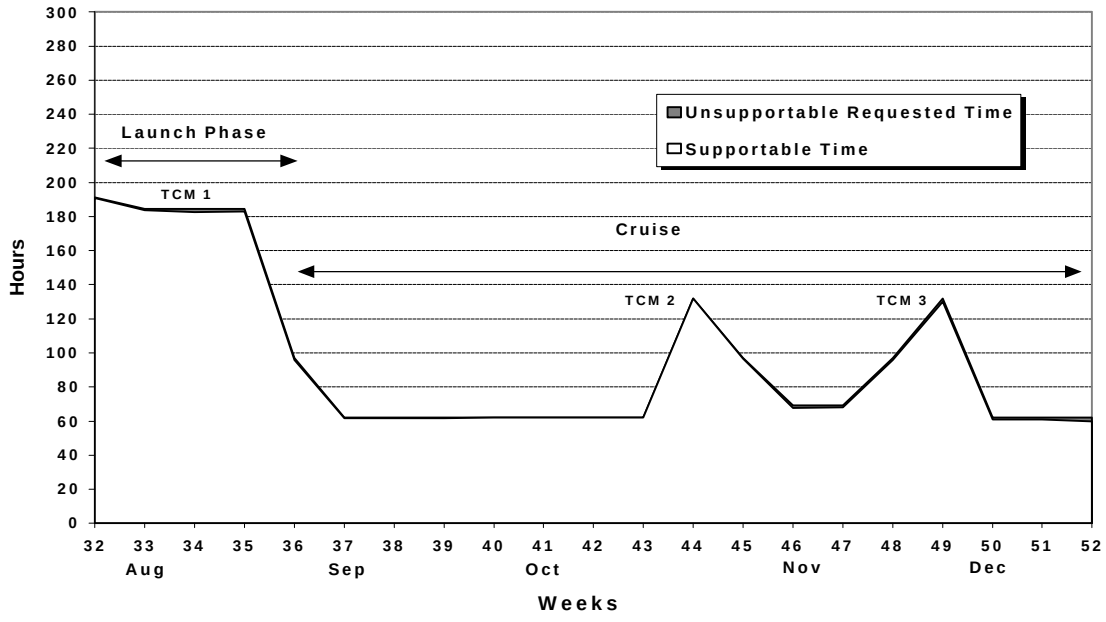
contention are identified during relay operations, in December 2008 and again in October of 2009, where supportable time drops below 90%.

Detailed Assessment

Launch Phase (August 8 through September 6, 2005)
The launch phase requested and forecast supportable hours are shown in Figure 2. Based on the current forecast results, MRO launch requirements are fully supportable. MRO should expect to receive greater than 95% of the time requested.

Cruise (September 7, 2005 through January 2, 2006)
Figure 2 also shows MRO's cruise phase requested and forecast supportable hours with support planned on the 34-m high efficiency (34HEF) subnet. Supportable time exceeds 95% throughout the phase. MRO should expect to receive nearly all of the support requested through early November 2005. After November some residual impact to the supportable time forecast for MRO is possible due to heavy loading on the 34-m beam wave guide (34BWG) subnets. Beginning in week 45 of 2005, loading on the 34BWG antennas increases markedly due to the STEREO Ahead (STA) and STEREO Behind (STB) launches. At the same time the 34BWG antennas are supporting Mars Express orbital science collection, Mars Odyssey relay operations, Rosetta's Mars swingby, and Stardust's maneuvers. The MRO view period fully overlaps the view periods of these six missions. Shifting some user support from the 34BWG antennas to the 70-meter subnet where antenna demand is low or the use of the DSN's multiple spacecraft per aperture (MSPA) capability may remedy the excess load on the 34BWG antennas. This time period should be watched for changes in contention as MRO and other user's requirements are modified and refined.

Figure 2. Launch and Cruise
August 8, 2005 through January 2, 2006



Approach and MOI (January 3, 2006 through April 1, 2006)

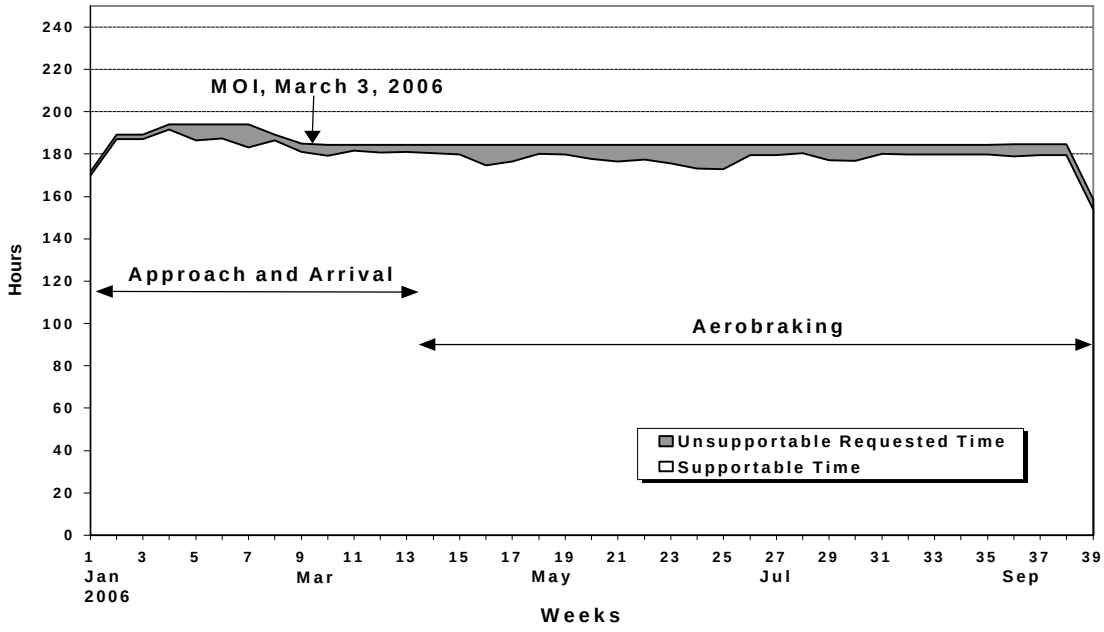
Approach and arrival support requirements are from January 3 through April 1, 2006 with Mars orbit insertion (MOI) to occur on March 3rd. Support is planned on the 34HEF and 34BWG2 antennas with 70-meter support requested at MOI. Figure 3 combines the requirements requested for both 70 and 34-meter support. MRO is forecast to receive greater than 95% of the time requested. Mars Odyssey's daily 8-hour relay support in week 9 is in conflict with the MRO requirement for 24 hours of 70-meter support around MOI. Shifting Mars Odyssey's support to a 34-meter antenna should resolve the conflict.

Aerobraking (April 2, 2006 through September 28, 2006)

Figure 3 shows the requested and forecast supportable hours for MRO's aerobraking phase. Overall MRO should expect to receive greater than 95% of the requested support. The MRO and maintenance view periods reach 100% overlap by week 38 and MRO has significant contention with maintenance after week 20. The periodic increases in unsupportable hours shown in Figure 3 are the result of 24-hour support requests for Ground Based Radio Astronomy host country and Space Geodesy Program crustal dynamics support while MRO is requesting continuous coverage. A natural remedy to resolve contention is to utilize the MSPA capability and combine some of the requested MRO support with that of another mission in orbit around Mars. To this end clarification of the MRO Project uplink and downlink requirements during aerobraking and an assessment of the possibility of sharing the uplink capability with another mission while in an MSPA configuration is needed.

Note that the 34-meter subnets are near capacity in the Mars view in 2006 weeks 23 through 27. The Starlight Mission launches in week 23, requesting continuous support through week 26 and 16 hours per day in week 27 on the 34BWG1 antennas. Support for

Figure 3. Approach and Aerobraking
January 3, 2006 through September 28 2006

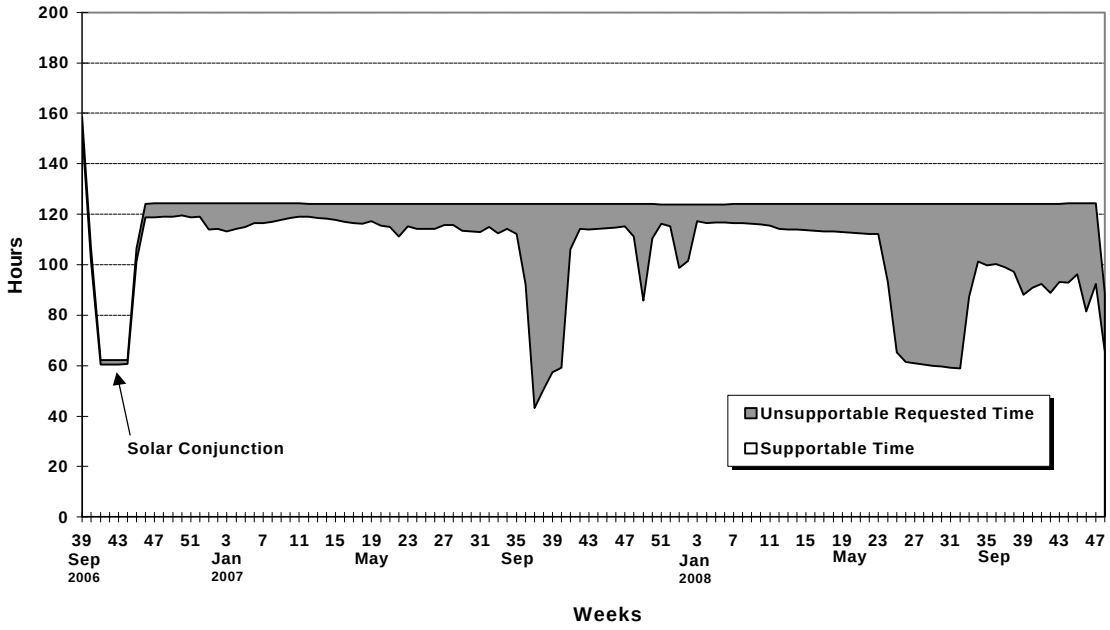


CONTOUR's SW3 encounter peaks in weeks 24 and 25 with near continuous support requested on the 34HEF antennas, MRO aerobraking requires continuous 34-meter support, and DSS maintenance requires 6 to 8 hours of weekly maintenance at each 34-meter antenna. In these weeks project view periods are stair-stepped, with rise times offset from each other by 2 to 4 hours, each overlapping the MRO view period by 50 to 75%. MRO aerobraking requirements are forecast 94 to 97% supportable in these weeks but because antenna loading in the Mars viewperiod is close to capacity, this period should be watched for changes in contention as user requirements are modified and refined.

Mapping (September 29, 2006 through November 26, 2008)

Figure 4 shows MRO's requested and forecast supportable hours throughout the mapping phase. With the exception of the four periods of time where marked change in supportable time is identified, MRO's mapping requirements are 90 to 98% supportable. In the weeks outside of the excepted periods, antenna loading on the 34-meter antennas is relatively low with the subnet average weekly unsupportable percentage between 6 to 8%. MRO is forecast to achieve nearly all of the support requested in these weeks. Resolution of low contention with other users or improved supportability may be achieved by periodic moves to antennas where additional loading in the Mars view is possible or by utilizing the MSPA capability with Mars Odyssey.

Figure 4. Mapping
September 29, 2006 to November 26, 2008



As mentioned above there are four periods of time where MRO's supportability declines below 90% and where MRO has high to extreme contention with other users in the mission set. A detailed discussion of the status and cause of contention during each of the four periods follows:

(1) September 3, 2007 through October 14, 2007 (weeks 36-41)

In this 6-week period the MRO mapping requirements are forecast 35 to 89% supportable. MRO should expect to receive 74 to 89% of the requested support in weeks 36 and 41 but from DOY 252, in week 37, through DOY 277, in week 40, 34-meter resources are oversubscribed in the Mars view and MRO supportability worsens to between 35 and 48%.

High contention and resource over-subscription is due to four missions that launch in week 36. Mars Smart Lander 2007 (M07L) and Mars Competed Scout 2007 (M07S) launch on Tuesday DOY 247 and Mars CNES Orbiter 2007 (M07O) and Mars ASI/NASA Telecommunications Orbiter 2007 (M07T) launch on Sunday DOY 252. Each of the four missions requires continuous support on 34-meter antennas from launch to launch +30 days, ending launch support on Thursday DOY 277 in week 40 and Tuesday DOY 282 in week 41 respectively.

There are nine 34-meter antennas available to support these newly launched missions and all other projects in the mission set that require 34-meter support. Four antennas are located at Goldstone, CA, USA, two are located in Canberra, Australia, and three are located at Madrid, Spain. In general, when more than two missions with identical view periods require continuous 34-meter support, and support is needed from all three

complexes to satisfy the request, capacity is exceeded because only two antennas are available at the Canberra location. To support just the requirements of the four 2007 Mars Missions, capacity is exceeded at the Canberra and Madrid locations.

During 2007 weeks 36-41, the MRO, M01O, M07L, M07O, M07S, and M07T view periods overlap fully. In addition to the four missions requiring continuous support, MRO requires two 8-hour passes daily and M01O requires one daily 8-hour pass until the end of relay and mission operations in week 38.

Requirements for a number of other 34-meter users add contention because view periods for these missions overlap the Mars view period by more than 50%. Cassini tour requires a daily 9-hour pass, STEREO Ahead routine tracking requires a daily 4-hour pass, MESSENGER routine tracking requires one to two weekly 4-hour passes, and each week DSS maintenance requires one 6 to 8-hour support for routine maintenance at each of the nine antennas.

Because DSN capacity within the Mars view period is the issue in 2007 weeks 36 through 41, an easy remedy to resolve contention does not exist. Almost certainly reductions in requested time will be necessary for all missions that overlap the Mars view period. Alternate means of support to reduce unsupportable time need to be investigated, understood, and clearly defined.

MRO and all missions mentioned above should consider defining support requirements in the following terms:

- What amount of time is needed to assure the health and safety of each spacecraft?
- Is the MSPA capability, including dividing the uplink period, useful to satisfy the requirements of both MRO and M01O? Note: MSPA is only possible for use by missions already in orbit around Mars; therefore, this capability is an option only until the end of M01O's mission operations in week 38.
- Can 70-meter support be substituted for 34-meter support?
- Can 34-meter Ka-band support at a higher bit rate be used to reduce the amount of DSN time needed?
- Are non-DSN resources available to support or supplement requirements?

(2) December 3 through December 16, 2007 (weeks 49-50)

In this 2-week period MRO requirements for mapping are forecast 69 and 89% supportable. Mapping support requires two daily 8-hour passes. MRO has contention with M07L, M07S, M07O, and M07T because each 2007 mission requires six days of continuous maneuver support. The Mars view periods overlap fully. The 2007 mission maneuvers are staggered with only two missions requiring continuous support each day except on Wednesday of week 49. On this day all four 2007 missions require continuous maneuver support and DSN capacity in the Mars view is exceeded. Utilizing some of the methods suggested in the bulleted material in item (1), may help to reduce contention and unsupportable hours.

On the remaining days in this period, adjusting MRO support to underutilized 34-meter antennas at Goldstone and Madrid should easily resolve contention and improve supportable hours for MRO mapping to above 90%.

(3) December 31, 2007 through January 14, 2008 (2008 weeks 01-02)

In this 2-week period MRO requirements for mapping are forecast 80 and 82% supportable. Mapping support requires two daily 8-hour passes. MRO has contention with M07L, M07S, M07O, and M07T and the circumstances of contention are nearly identical to that described in item (2) except that the overlap maneuver day occurs on Friday of week 01. On this day all four 2007 missions require continuous support and DSN capacity in the Mars view is exceeded. Using the methods for defining requirements suggested in the bulleted material in item (1), may help to reduce contention and unsupportable hours.

On the remaining days in this period, adjusting MRO support to underutilized 34-meter antennas at Goldstone and Madrid should easily resolve contention and improve supportable hours for MRO mapping to above 90%.

(4) June 11 through November 25, 2008 (weeks 24-47)

The MRO mapping requirement of 2 daily 8-hour passes continues throughout this period and forecast supportable hours in weeks 24 through week 33 ranges between 47 and 70%. Supportability increases to 71-82% in weeks 34 through 47.

DSN 34-meter antennas are oversubscribed from Friday of week 24 through the end of week 33. MRO mapping requirements are in contention with M07L, M07S, M07O and M07T requirements for approach, orbit insertion, entry decent and landing (EDL), trajectory change maneuvers (TCM) and delta differential one-way ranging (DDOR). View periods for these missions are fully overlapped with the MRO view period. Each 2007 mission requires continuous 34-meter support and 1 to 2 additional 4-hour DDOR passes each week.

Adding to contention in these weeks, a number of other projects with requirements for 34-meter support are planned and view periods for these projects overlap the Mars view period by more than 50%. Cassini tour requires 9 hours of tracking daily. Chandra routine tracking requires 21 weekly 1-hour passes, DSS requires 6 to 8 hours of weekly maintenance support at each 34-meter antenna, and Mars Express Orbiter occultation support, in week 30 and 31, requires a daily 13-hour pass from Goldstone or Madrid. MESSENGER routine tracking requires 1 to 2 weekly 4-hour passes, Rosetta asteroid flyby requires a daily 4-hour pass from week 26 through 33, and STEREO Ahead (STA) and STEREO Behind (STB) each require a daily 4-hour pass for routine tracking.

Contention in weeks 24-33 is extreme with the capacity of the DSN in the Mars view period exceeded and without easy remedy. Almost certainly reductions in requested time will be necessary for all missions that overlap the Mars view period. Alternate means of support to reduce unsupportable hours need to be investigated, understood, and clearly defined. Using some of the methods for defining requirements that are suggested in the

bulleted material in item (1), including MSPA between MRO and MEX in weeks 30 and 31, may help to reduce contention and unsupportable hours.

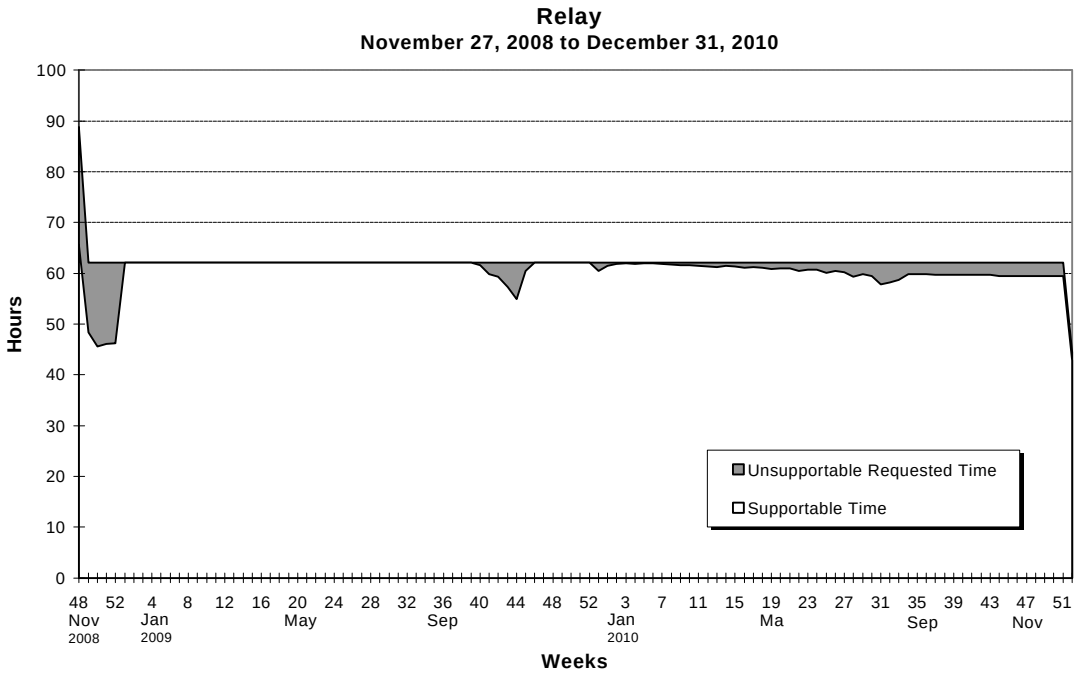
After Tuesday of week 34 through week 47 and the end of the MRO mapping phase forecast supportable hours range between 71 and 80%. The 2007 missions are in orbit about Mars or landed on the surface. Each 2007 mission requires a daily 8-hour pass for surface or relay operations. In week 46 M07O requires 3 days of continuous support for an orbital sample capture and rendezvous (OSCAR) demonstration. Requirements for MRO mapping, Cassini, Chandra, DSS maintenance, STA and STB are unchanged from those described above. From week 39 and into week 43 the MESSENGER requirement increases to a daily 8-hour pass for Mercury flyby. Europa (EURO) routine tracking requires 2 weekly 4-hour passes, in week 44 EURO requires seven 8-hour passes for TCM support, and in week 45 ten 8-hour passes are requested for instrument calibration. The Mars mission and DSS maintenance view periods are near to fully overlapped and the CAS, EURO, MSGR, STA, and STB view periods overlap the Mars view by more than 50%.

Resolution of contention and possibly improved supportability may be achieved in these weeks by periodic moves to antennas where additional loading in the Mars view is possible or utilizing the MSPA capability, including dividing the uplink period, between MRO and one or all of the 2007 Mars missions. Clarification of MRO and the 2007 Mars mission uplink and downlink requirements are needed to better and more accurately model antenna loading in these weeks.

Ka-band Downlink (08 Nov 2006 to 26 Nov 2008)
The MRO request for two 8-hour passes for gathering Ka-band downlink data (in addition to the 14 passes requested for mapping) are supportable except during periods of high to extreme contention described in mapping items (1) through (4) above. Current implementation plans show Ka-band downlink capability available at all of the 34BWG1 and 34BWG2 antennas as of August 1, 2006. Analysis of MRO mapping requirements was performed with 14 passes forecast on three 34BWG antennas. In weeks outside the 4 periods of extreme contention mapping requirements were forecast above 90% supportable. Increasing the mapping request on the three 34BWG antennas to 16 passes/week increases the forecast unsupportable hours but the additional Ka-band downlink passes are supportable on the 34BWG antennas if 2 to 3 mapping passes are moved to the 34HEF subnet.

Relay (November 27, 2008 through December 31, 2010)
Figure 5 shows MRO's weekly requested and forecast supportable hours throughout the relay phase. MRO should expect to receive nearly all of the time requested. MRO however has contention with a number of other missions in December 2008 and again in October 2009 when supportable time drops below 90%.

MRO requirements in December 2008 are forecast 73 to 78% supportable on 34BWG1 and 34BWG2 antennas. Moving some MRO support to 34HEF antennas where loading in the Mars view is possible or periodic use of the MSPA capability with M07L, M07O, M07S, or M07T should improve supportability to above 90%. MRO requirements in October 2009 are forecast 83-97% supportable however Mars ASI/NASA Science



Orbiter 2009 (M09O) launch operations are planned on the 34HEF-subnet beginning in 2009 week 40, ending in week 45, and some contention on the 34-meter subnets is expected.

In these weeks M09O requires continuous support. At the same time MRO, M07L, M07O, and M07T each require one daily 8-hour pass on 34-meter antennas to support relay and surface operations. MESSENGER requires a daily 8-hour pass on 34-meter antennas after Mercury orbit insertion in week 40, Cassini tour requires a daily 8-hour pass, and STA and STB each require 4 hours daily for routine tracking. DSS maintenance requires 6 to 8 hours of weekly maintenance at each of the nine 34-meter antennas. The Mars mission view periods fully overlap while overlapping the view periods of other missions and maintenance by more than 50%. During these weeks the 34-meter subnets are fully subscribed and contention is primarily caused by each of the flight missions overlap into the maintenance view period. MRO supportability may suffer additional impact as missions move to avoid antennas down for maintenance. Moving some users support to the 70M or periodic MSPA between MRO, M07L, M07O, or M07T should help to sustain MRO supportability above 90%.

Summary

This support evaluation reviewed the Mars Reconnaissance Orbiter requirements during each key phase of the mission. MRO should receive most of the support they request. However, the forecast does indicate some problems during mapping and relay operations.

MRO launch, cruise, approach, including MOI, and aerobraking phases are above 90% supportable. MRO should expect to receive nearly all of the time requested with minimal negotiation required to reduce contention with other users.

Mapping and Ka-band downlink requirements are also forecast above 90% supportable except during four periods of time when DSN 34-meter antennas are oversubscribed. Antenna over-subscription primarily within the Mars view period occurs after the launch of four Mars missions in 2007. During these four periods, September 3 through October 14, 2007, December 3 through December 16, 2007, December 31, 2007 through January 14, 2008 and June 11 through November 25, 2008 MRO requirements are forecast between 47 and 89% supportable. In order to reduce unsupportable hours any and all alternate means of support need to be investigated. Uplink and downlink requirements need to be better defined by MRO and other missions overlapping the Mars view period. Questions of MRO using the MSPA capability with other missions orbiting Mars including dividing the uplink period while in the MSPA configuration need to be answered.

Relay operations are forecast above 90% supportable for most of the phase. In December 2008 and October of 2009 a minimum amount of negotiation with other projects and periodic utilization of the MSPA capability or redistribution of support requests to underutilized 34-meter antennas should resolve contention and assure nearly all of the time requested.

As always, the results of this evaluation are preliminary in that the network load changes as requirements for planned missions are input and updated.

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