TECHNICAL REPORT

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Title: Observatory Utilization Impact caused by Perturbation of the Planned Schedule	Doc #: JWST-STScI-000793, SM-12 Date: February 2, 2006 Rev: Baseline (-)
Authors: W. Kinzel, R. Hawkins, M. Giuliano, G. Chapman Phone: 410-338-4498	Release Date:

1.0 Abstract

We have studied the change in the utilization rate of JWST caused by uncertainties in the planned visit overhead estimates and visit failures by simulating the construction and execution of 10 day Observation Plans using visits from the Science Operations – Design Reference Mission (Petro 2005A). We find that the simulated scheduling process, including a planned Overhead estimate that is too large by 10%, combined with a random visit failure rate of 2% produces a gap time of 4 days over a period of 360 days. This is about half the expected allocation to the Proposal Planning System (PPS) process. We conclude that the utilization impact caused by uncertainties in the planned visit overheads combined with visit failures does not currently justify the implementation of contingency visits.

2.0 Introduction

JWST will orbit the sun-earth L2 point allowing long continuous observations not interrupted by earth occultations. This fact has motivated a Mission Level observatory utilization requirement that has flowed down into a Ground Segment requirement on the utilization:

> The S&OC shall, after commissioning contribute observation idle time overhead of no more than 1807 hours over a 5-year period due to the following overhead activities: Observation Plan Scheduling, Target of Opportunity Scheduling, Anomaly Recovery for all Safemode Events, Ground Segment-caused Safemode Events, S&OC Outages interfering with observations, and Engineering Tests. The allocation is based on and will be verified by a hypothetical science program designed with 500, 90 degree slews and 8,000 small angle slews per year. [GS-136] (GSRD 2005)

While the exact amount of idle time allocated to PPS scheduling is not determined, we assume about half of the 1807 hours will be allocated to Observation Plan Scheduling.

Observatory utilization is defined as the time when JWST is performing a useful (prime) activity.

There are several ways idle time (no activity) can occur in the timeline:

- The created schedule is not full.
    - The created schedule is too short (highly unlikely).
    - Visits of the right size to exactly fill a gap before a time critical visit do not exist.
- Inaccurate estimates of activity durations during planning and scheduling.
    - Activities shorter than expected, opens a gap before a time critical visit
    - Activities longer than expected could cause the last visit before a time critical visit not to execute because its execution would interfere with the starting of the time critical visit.
- One or more visits fail and:
    - A later visit could not execute early because of its Observation Plan (OP) window.
    - The OP runs out of things to do.

The first item, activity gaps in the initial schedule, is investigated in Long 2005, and Petro et al. 2005. The last two items, the impact to observatory utilization caused by overhead variation and visit failures are the focus of this Technical Memo. The impact of timeline perturbation on momentum management is investigated in Kinzel 2005.

3.0 OP Execution

3.1 OP Description

The OP is a sequence of visits. During the planning and scheduling process, each visit will be assigned an orientation and an OP Window consisting of an Earliest-Start Time (EST), a Latest-Start Time (LST), and a Latest-End Time (LET). The OP window defines a continuous time interval where the execution of the visit satisfies observatory constraints and, if provided, science constraints. The OP windows allow control of the execution of the OP. The visits in an OP are processed sequentially by the Observation Plan Executive (OPE). If a visit is being processed by the OPE and the current time is later than or equal to the Latest End time, the OPE will stop execution of the current visit and proceed to the next visit in the queue. If the Earliest Start time of the next visit in the queue has not occurred, the OPE will wait until that time to start the next visit. If the current time is later than the Latest Start time of the next visit in the queue, the visit will be skipped and the following visit in the queue will be processed. The OP windows can be no larger than the visit constraint windows and in some cases will be smaller. For example, critical visits that are also very time constrained have to execute at their needed time and cannot be skipped because an already executing visit takes too long to finish. During the OP window assignment phase, visits scheduled earlier than the critical visit will have their OP windows truncated such that their Latest End time is no later then the Latest-Start time of the critical visit. (The Latest-End time will need to be set earlier than the Latest-Start time of the critical visit to allow time for the OPE to abort the earlier visit.) This functionality is enabled by allowing Visits to be identified as "critical" in the PPS.

3.2 Overhead Variation During OP Execution

The Overheads in a visit can be deterministic or non-deterministic.

For example, it is possible to model the time it takes to rotate a filter between two positions. However, without detailed modeling and enhancing the ground system to perform filter wheel history keeping, the ground system will not be able to accurately predict filter wheel motion times. The JWST concept is not to model Overheads to this level because it adds complexity and cost to the mission.

With some overheads, the actual duration of the activity can not be known until the Visit actually executes. This is the situation with guide star acquisitions. On JWST, each Visit may be assigned up to three candidate Guide Stars. The Guide Star acquisition may take 5 minutes, 10 minutes, or 15 minutes depending upon the number of candidate stars attempted before successful acquisition, assuming 5 minutes per attempt.

For this study, it is expected that the ground system will model the observatory slew times at a reasonably high level of fidelity so that slew time will not contribute significantly to the visit overhead uncertainty. Thus for this study we only varied the amount of time allocated to guide star and target acquisitions, science instrument setup, dither activities, etc.

Overhead uncertainty can cause activity gaps to form in the execution timeline when the overheads are shorter than planned and also when the overheads are longer than that planned.

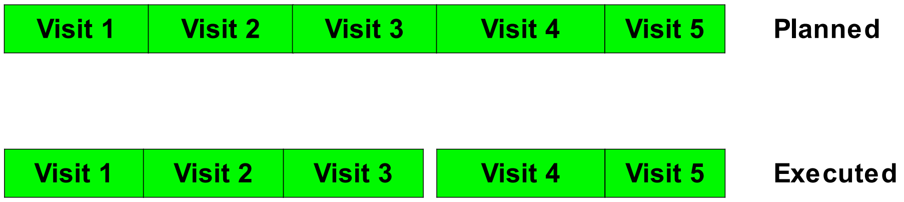

Figure 3-1 Example of visit contraction during execution.

In Figure 3-1 Visit 4 is scheduled up against its Earliest Start Time. If Visits 1, 2, and 3 execute in slightly less time than planned, Visit 4 cannot start execution earlier, thus creating a gap between the Visit 3 and Visit 4 activities during execution.

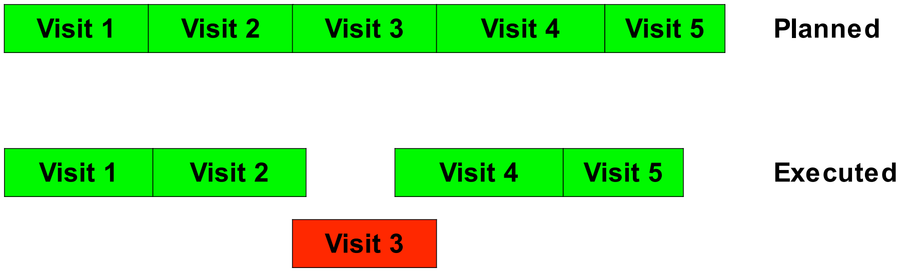

Figure 3-2 Example of visit expansion during execution.

In the example in Figure 3-2, Visit 4 is a time constrained critical visit. Thus Visit 3 (and Visits 1 and 2) had their Latest Start Time and Latest End Time set so their execution could not interfere with the execution of Visit 4. Visit 2 started where scheduled, but took slightly longer to execute than planned. When Visit 2 finished executing, the current time is after the Latest Start Time for Visit 3, so Visit 3 is skipped and did not execute. Visit 4 and Visit 5 were able to start execution slightly earlier and partially fill the gap after Visit 2.

3.3 Visit Failure During OP Execution

Figure 3-3 Example of a Visit failure during execution.

In the example in Figure 3-3, Visit 4 is scheduled up against its Earliest Start Time. If Visit 2 fails to acquire Guide Stars and is terminated, then Visit 3 can immediately start after the failed Guide Star Acquisition. But once Visit 3 is finished, JWST has to sit idle until Visit 4 can start.

3.4 Contingency Visits

The concept of contingency visits has been suggested to prevent gaps from forming in the executing timeline. Contingency visits (or alternate visits) are visits placed on an OP that will only execute if particular visits fail execution. Contingency visits can be implemented using the current OP constructs of Earliest-Start, Latest-Start, and Latest-End times and do not impact the current design of the OPE.

However, there would be impacts to PPS: identifying the contingency visits, tracking them through the system, and enhancement of the scheduling software. Given the expected limited personnel for planning and scheduling, we would want a fully automated contingency visit scheduling process, and therefore the costs of the automated capability would have to be traded against whatever increase in utilization we can expect.

Visit ID	Earliest Start	Latest Start	Latest End	Planned Start	Visit Duration
1	0.0	3.5	4.0	2.0	0.5
2	0.0	2.51	4.0	2.5	1.5
3	0.0	3.0	4.0	2.5	0.95
4	0.0	3.5	4.0	3.5	0.45

5	3.9	4.1	5.1	4.0	1.0

Table 1Using Visit OP windows to create contingency visits in an OP.

Table 1 gives an example of how OP windows are used to create contingency visits in an OP. In this example, Visits 1, 2, and 5 are the visits that are expected to execute. Visit 5 is critical and time constrained, thus all the visits scheduled earlier than it have their latest end time set to the planned start time of Visit 5. As the OPE processes the visits, if visits 1 and 2 correctly execute, when Visit 2 finishes, the current time will be later than the Latest-Start times for both Visits 3 and 4. The OPE will skip these visits and proceed to Visit 5. If Visit 2 fails, then visits 3, 4, and 5 will execute. If visit 1 fails, visits 2 and 5 will execute. Thus in theory, contingency visits could mostly fill in gap time created during OP execution when guide Star Acquisitions or Target Acquisitions fail.

4.0 Simulations

4.1 JWST OP Simulation

The Utilization Study used a set of three tools to simulate the impact of visit overhead variation and visit failures on JWST utilization:

1. JMS Spike
2. OP Generator
3. JWST Simulator

A brief description of the tools and the simulation process are in the following sections.

4.1.1 JMS Spike

JMS Spike incorporates a sample SO-DRM and creates a schedule for the 2 year period from April 1, 2012 to April 1, 2014. OP Simulations were studied on the first year of this interval, due to the low utilization rate in the second year.

- JMS Spike gets event windows, links, momentum data, visit data etc. from JMS and uses this data to produce schedules.
- Scheduler uses a 1/40 day (36m) time step (quanta) granularity.
- Visit durations in the schedule are rounded up or down to the closest quanta
- The JMS Spike scheduler algorithm emphasizes packing the schedule to avoid gaps as much as possible.

4.1.2 OP Generator

- The OP Generator takes as input a time range and the schedule produced by JMS Spike
- Output is an ordered list of visits that were scheduled during that 10 day interval.
- OP Windows are the intersection of the sub window of suitability that overlaps the OP, but the OP boundaries are not used to determine the visit's windows. This is described in the following paragraph.

The OP Generator collects all Visits which have scheduled start times within the duration of the requested OP. The OP Generator creates the OP Windows for each Visit by finding the positive interval within its suitability function that contains its scheduled time. This interval is used for the earliest-start and latest-start window times. The latest-end time is generated by adding the maximum expected visit duration to the latest-start time. For visits in link sets, the OP windows reflect the constraints imposed from visits scheduled earlier in the timeline.

4.1.3 JWST Simulator

- Simulator uses a 1 minute time step (quanta) granularity.
- Simulator handles:
  - Random or specific visit failures
  - Random or specific visit overhead errors (expand or contract overheads by a percentage)
- Produces simulation reports which show:
  - Ordered list of visits as simulated
  - Visit start and end, new duration, requested duration, windows
  - Gaps
  - Failures (either generated or caused by other factors such as overhead error)
  - Momentum accumulation over the OP interval, as simulated

4.1.4 The Simulation Process

Starting at the beginning of the simulated timeline, the series of OP generation and execution is simulated.

The first Visit in an OP is executed at exactly the time JMS Spike scheduled it. Thereafter, Visits are shifted forward or backward in time based on the end time of the preceding Visit. If, at any time, the next Visit's earliest-start has not been reached, the simulator accumulates idle time until the earliest-start time, leaving a gap between the 2 Visits.

Visits are executed with an exact duration as indicated in JMS (rounded to the minute). Overheads are expanded or contracted based on an input percentage change. Overheads are calculated from JMS Data: Total Visit Duration – Slew Duration – Exposure Duration = Overhead Duration. The overhead time is multiplied by the error percentage and then added to the slew and exposure durations to create the new visit duration.

Due to the difference in quanta between JMS Spike and the simulator, there can be up to ~18 minute gaps or overruns per visit in the same schedule as simulated (when a Visit's duration was rounded up or down, respectively, in JMS Spike). Visits could extend beyond the planned end time of the OP or a gap could form at the end time of an OP, either because of the quanta difference or because of the simulated visit contraction or expansion. These events were ignored because it was assumed during normal operations, the following OP would be generated using that information as a starting boundary condition.

The simulator run executes each Visit in the Observation Plan, unless the Visit fails. A visit could fail due to:

- Falling outside its late window boundaries (latest start, end)

- Random or specific induced failure

Inter-OP Constraint propagation was not handled in this iteration of the toolset (the simulated OPs were run in isolation, as it were). It is assumed that constraints would be updated prior to the next OP generation, in operations. Intra-OP constraint propagation was not handled (as JWST will not do this either) in the simulation process. However, it is felt that this is not a problem as for example; tight timing links would be enforced in the OP by setting the OP windows for visits in the link set to about one half the delta of the timing link. For the simulation, it was assumed the OP windows for each visit were set to the same size as the visit Constraint Windows and again we only analyzed the first 35 simulated OPs.

4.2 Overheads in JMS and the SO-DRM

The Science Operations – Design Reference Mission (SO-DRM) is an attempt to create a set of realistic JWST observations given what we currently know about the observatory and the expected science to be accomplished (Petro, 2005A). The JWST Mission Simulator (JMS) is a tool developed to calculate expected exposure times, generate observation schedules, and also model the overheads in JWST observations. JMS currently is input fixed values for the various overhead activity durations and JMS includes these times in the overall visit duration as needed (Petro, 2005B). A modified version of JMS outputs a report that for each visit reports the time contained in the overhead and exposure time. In JMS the slew time at the start of each visit is currently a constant of 45 minutes with a 15 minute major slew settle time. In Figure 4-1 the fractional overhead per visit is displayed for visits in the SO-DRM (JMS 1.4) as calculated by JMS.

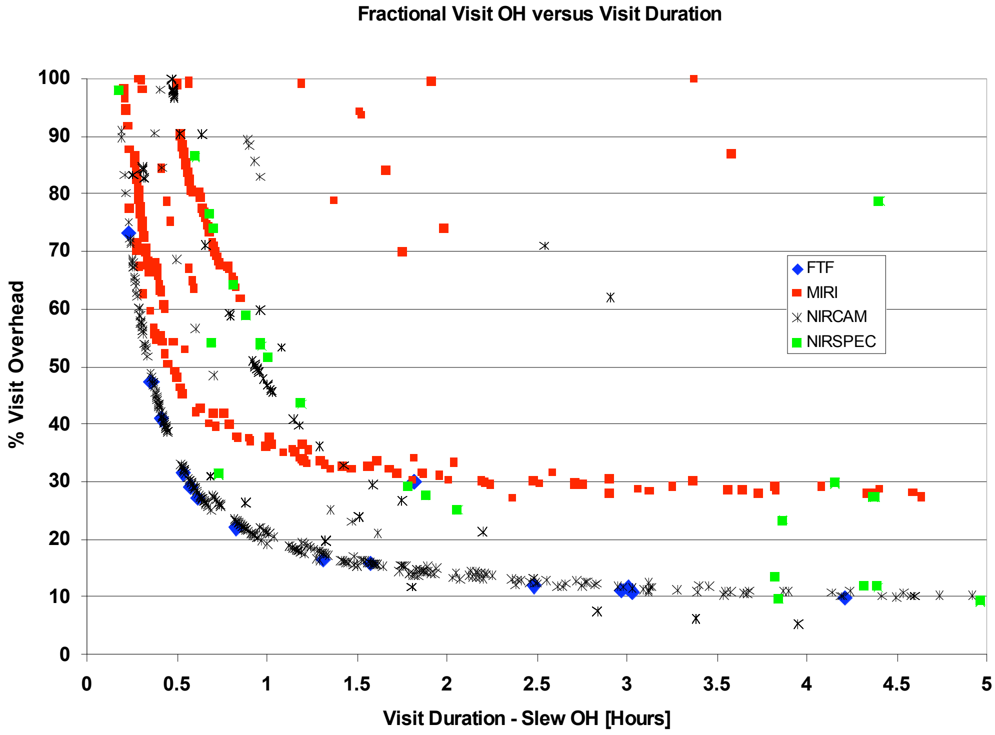

Figure 4-1 Fractional total visit Overhead per visit, by instrument.

For most visits longer than about 1.5 hours, the overheads make up about 10% to 30% of the total visit duration (excluding just the major slew OHs). For visits with durations less than 1.5 hours, the fractional overhead grows to nearly 100% as the visits get shorter and shorter. This is due to the fixed duration visit overheads and the exposure time taking up less and less of the total visit duration. The non major slew overheads compose about 21.5% of all the timeline activities.

4.3 The Baseline Simulation

The baseline simulation scheduled all of the visits available in the SO-DRM assuming no overhead uncertainty or visit failures. The total visit duration is about 1.5 years. About 360 days after the start of the timeline, large gaps started to occur in the timeline because of the fewer visits available for scheduling, so we only analyzed the first 35, 10 day long simulated OPs. Gaps that occurred in the analyzed baseline timeline were caused by a visit being scheduled at its Earliest-Start Time, and the scheduler not finding a proper sized visit to fill the hole earlier than the constrained visit. There were about 25 visits scheduled at their Earliest-Start Time s. In addition, there were 5 gaps in the baseline greater than 0.4 days and most of these gaps occurred in the last 20 days of the analyzed timeline. These 5 gaps were removed from the analysis assuming that in operational OPs large gaps such as these either would have not occurred using a more sophisticated scheduling algorithm or would be removed by manual scheduling. With these assumptions, the total gap time in the analyzed baseline timeline was 1.24 days. The gaps in the baseline timeline are shown in Figure 4-2.

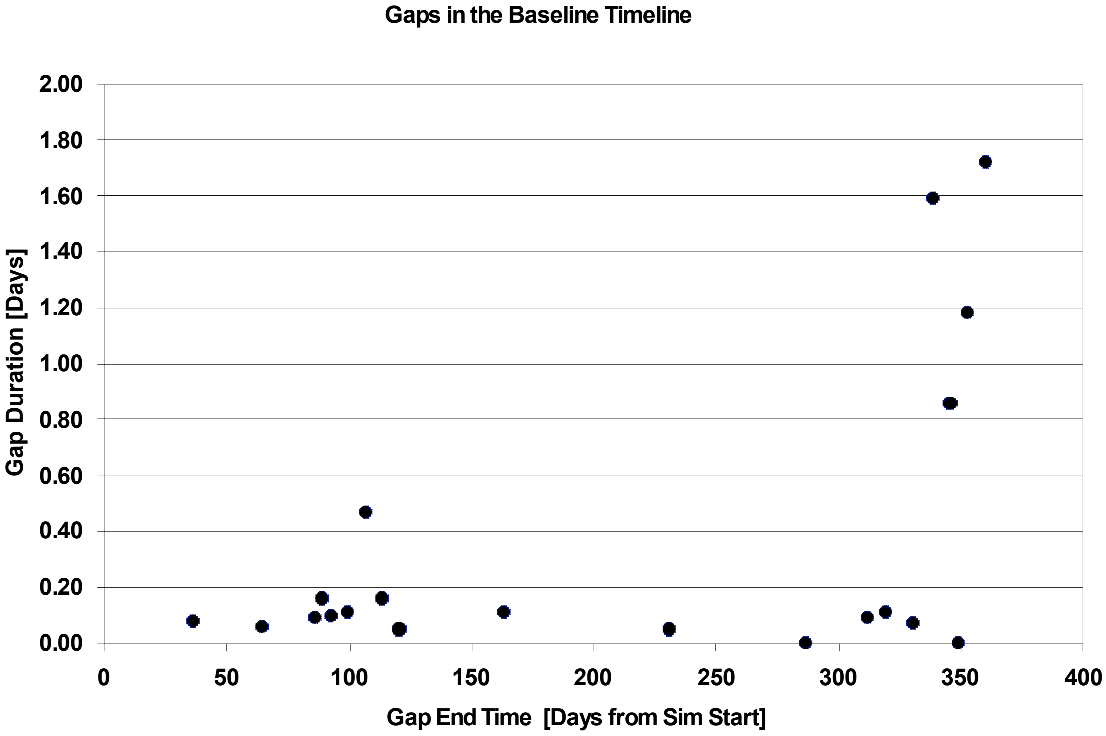

Figure 4-2 Scheduling gaps in the baseline timeline. The gaps longer than 0.4 days were excluded from the analysis .

4.4 Overhead Variation Simulations

We studied the two extremes of Overhead variation, that is, the non major slew overheads in all the visits in the schedules used a fractional amount of time less than planned to execute, and all the overheads in all the visits used a fractional amount of time more to execute than planned. In both cases we assumed no visit failures. The gap time is a linear function of the percentage of Overhead change. The slope of the function decreases (steepens in a negative direction) as more gaps are opened in the timeline because of the visit contraction. The slope of the function increases (becomes more horizontal) as more gaps are closed because of the visit expansion. The change in gap time in the executing timeline as a function of visit overhead expansion or contraction is shown in Figure 4-3.

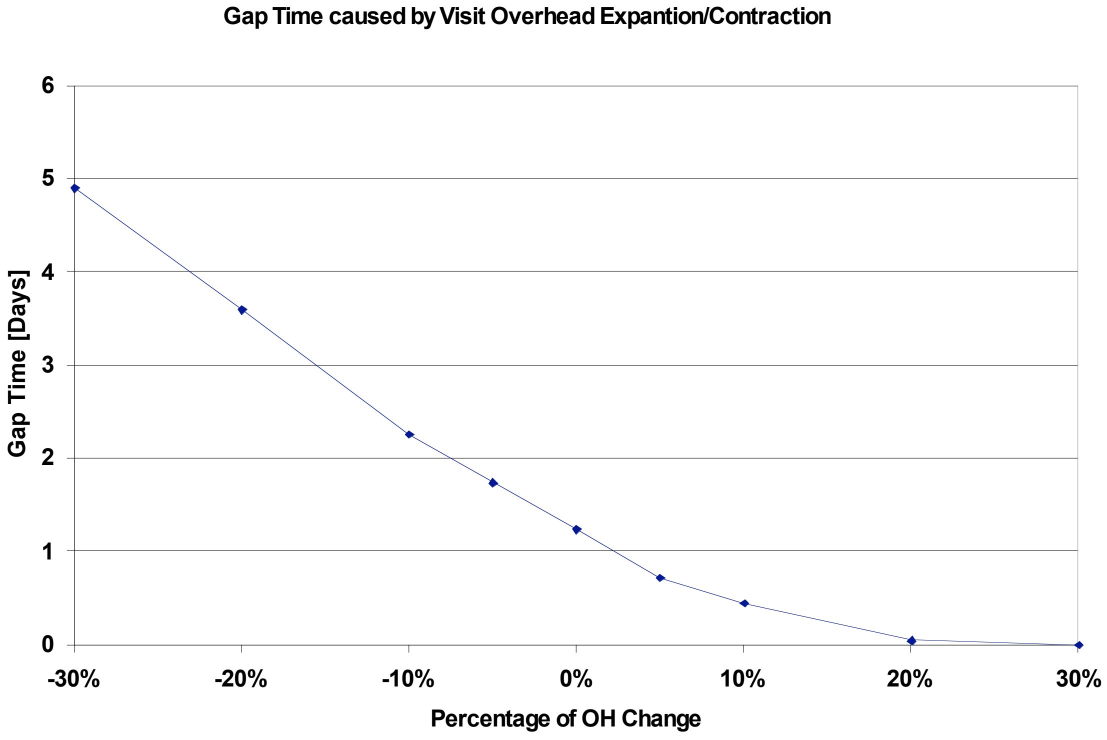

Figure 4-3 Total gap time over 360 days as a function of the Overhead change per visit.

Shrinking the OH time in each visit by 30% increased the gap time in the timeline by 3.6 days. These simulations did not encounter a single case where the expanded overhead time caused a trailing visit not to execute. This was caused by two factors. The original schedules created by JMS-SPIKE had small gaps in them caused by the visits scheduled at their Earliest-Start Times. Thus when visits expanded, they partially filled the existing gap time. This caused the total gap time to decrease as the planned OH time was increased (Figure 4-3). The second factor is because the scheduling algorithm tended to have placed visits near the start of their constraint windows. Thus visits could execute at later times than planned when pushed later by the visit expansion.

In general, the gap time occurring in an executed timeline is not sensitive to overhead uncertainty. That is, a 30% decrease from the planned overhead time resulted in an increase in the gap time of 3.6 days, roughly 1% of the wall clock time.

4.5 Visit Failure Simulations

The impact of visit failures on JWST utilization was examined using JMS SPIKE to simulate random visit failures at different visit failure rates and modeling the expected behavior of the executing timeline. The change in gap time in the executing timeline as a function of the visit failure rate is shown in Figure 4-4.

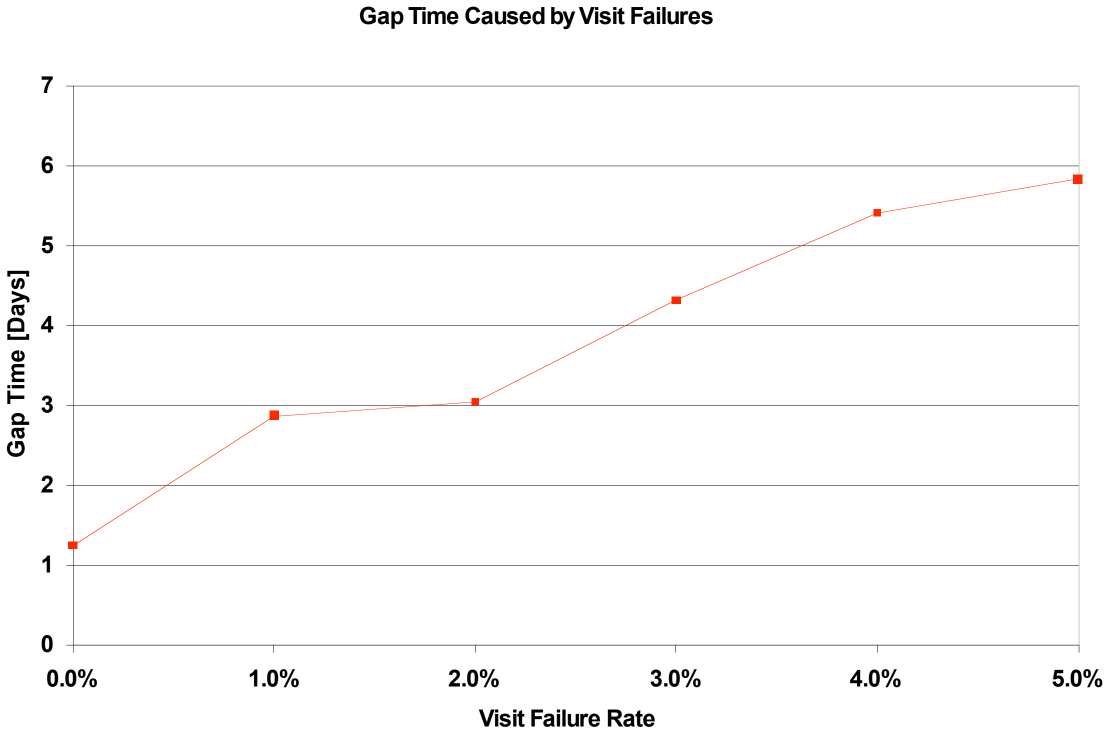

Figure 4-4 Total gap time over 360 days as a function of the visit failure rate.

At visit failure rates approaching 5%, the total gap time grows to about 5.8 days. These results should be considered upper limits for two reasons. First, as mentioned before, the scheduling algorithm was not biasing visits away from constraint boundaries. Second, a visit failure's impact was propagated along the entire simulated OP of 10 days duration. During operations it is expected that the OP will be updated roughly weekly. In addition, if a visit failure was going to cause a gap in the timeline say three or four days later, operations would have the option of updating the OP thus filling the gap.

5.0 Discussion

The scheduler in this simulation did not attempt to actively schedule visits away from their constraint boundaries. Every gap in the baseline OPs occurred just in front of (earlier) a visit that was scheduled at its Earliest-Start Time and when visits took less time to execute than planned or visits failed, additional gaps formed in the timeline. Basically if a visit's Planned Start Time – Earliest-Start Time is smaller than the duration of an earlier failed visit, a gap will occur. Thus this implies visits should be scheduled away from constraint boundaries. However, the possibility exists that operational observations will contain link sets or other constraints that force the visits to schedule at their constraint limits.

Currently in the JWST Operations Concept, there are only two known visit types that are classed as critical, Momentum Dump visits and place holder engineering visits to allow time to be blocked out in the timeline for Real Time engineering activities such as Station Keeping maneuvers or Flight Software updates.

The Real Time engineering visits will be very tightly time constrained with a start tolerance of about 1 hour in order to synchronize the observatory activities with a scheduled ground contact. These visit types are expected to occur at most about 20 times per year; that is, about 16 Station Keeping visits and ~4 Flight Software update opportunities. Visits of these types were not represented in programs used in this study. However, their expected number ~20 matches closely with the number of visits that were scheduled at their Earliest-Start Time (~25). Thus given a better scheduler algorithm and the inclusion of engineering visits a follow up study should find the amount of expected gap time does not exceed that found in this study.

From this study, we can make several scheduling suggestions.

If possible, the PPS should schedule all visits at least one mean visit duration away from constraint boundaries to allow for execution flexibility during OP execution.

Each visit's Latest Start Time and Latest End Time should be consistent with the maximum possible visit duration to avoid the possibility of the OPE having to abort a visit. Thus the visit duration should include the maximum slew duration, the duration of the maximum number of possible Guide Star Acquisitions, and the maximum duration of the other Overheads inside the visit.

OP windows should not be bounded by an OP segment boundary to allow visit execution flexibility.

This study used fixed overhead values from JMS and consistently made them larger or smaller. In reality, each type of overhead will have a minimum, maximum, and mean value as the duration of the overhead for a particular visit execution may depend upon the previous (unknown) state of the observatory or instrument.

While possibly rare, to avoid a visit being skipped because of visit expansion, the Overhead estimates used in the planning and scheduling process should be slightly larger than the mean so that during execution, the timeline will consistently slide early if at all. The exact values to use will need to be determined once better estimates on the actual visit overheads and their behaviors are determined.

6.0 Conclusions

We have shown that inter-visit gap time is not sensitive to uncertainties in the overhead model used in planning and scheduling.

The inter-visit gap time is more sensitive to visit failures. However, even at an extreme visit failure rate of 5% the induced gap time in the timeline was about 1.3%. If we assume that all the Overheads in each visit are too large by 10%, implying an additional gap time of 1.0 day, and a visit failure rate of 2%, implying an additional gap time of 1.8 days, and using the baseline Overhead gap time of 1.2 days gives a total of 4.0 days. This is about 53% of the 7.4 days that we assume would be allocated to PPS scheduling for a 360 day interval.

This result does not require the implementation of contingency visits in order to meet the PPS utilization requirement. However, if future observatory utilization estimates of the initial constructed OPs are significantly lower than that presented here, the use of contingency visits may have to be revisited.

7.0 References

Ground Segment Requirements Document (2005), JWST-RQMT-001056, Revision B, August 18, 2005.

Long, K. (2005). *Monte Carlo Estimates of JWST Observatory Utilization*, JWST-STScI-000665, Rev. B, August 23, 2005.

Kinzel, W. (2005) *Using Spacecraft Roll to Control JWST Momentum Buildup,* JWST-STScI-000729, Rev A, November 1, 2005.

Petro, L. (2005A). *Science Operations–Design Reference Mission*, JWST–STSCI–CI–0045, Rev. A, January 31, 2005.

Petro, L. (2005B) *JWST Mission Simulator*, http://www.stsci.edu/jwst/science/jms/index.html

Petro, L., Stys, J., Raer, R., Jones, D. (2005). *An empirical study of the effects of proposal over-subscription on long-range observing schedules*, JWST- STSCI-000644, Rev. A., July 15, 2005.