TECHNICAL REPORT

Title: Stability of long–range scheduling		Doc #: JWST-STScI-000756, SM-12 Date: October 23, 2005 Rev: -
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1.0 Abstract

The “greedy” long-range scheduling algorithm used in JMS is shown to be stable with respect to sufficiently small perturbations to the order in which visits are scheduled onto observing calendars, as judged from the utilization of the calendar and the observing dates of visits. Scrambling the scheduling order of similarly scored visits perturbs the utilization of the schedule, with the amount of perturbation increasing as the range of reordering the scheduling order increases. This scrambling also reorders visits on the observing calendar. The distribution function of schedule utilization is symmetric about the typical value. For JMS schedules of the Science Operations Design Reference Mission (SO–DRM), the perturbations of utilization are ≤1%, but the visit stability ranges up to 50 days.

2.0 Introduction

The objective of scheduling a space telescope is to produce a time-ordered list of activities, the timing of which satisfy constraints specified by the mission and by the observers themselves. However, many such time-ordered lists may satisfy those constraints, and therefore the scheduling process will generally attempt to optimize unconstrained factors, such as the total amount of science accomplished (otherwise known as the utilization, or simply the efficiency), or the amount of consumables used (especially fuel, or thruster reaction mass). The schedule of activities will depend upon the specification of those activities themselves, the constraints imposed, the optimization factors, and the particular algorithms used to search for feasible and optimal schedules. Furthermore, when operating a space telescope, stability of the planning and scheduling process is desirable, especially when observations are revised, or the process itself is modified. When designing the operations of a space telescope, consideration of constraints and science policies that promote stability is desirable.

The purpose of this study is to consider the stability of the scheduling process for JWST as implemented in JMS by using a science program that is representative of the expected patterns of utilization, constraints that may be specified by observers and by mission rules, and a commonly used scheduling algorithm. This is important because JMS has been used for the vast majority of studies of scheduling of JWST. In general, the "greedy" scheduling algorithm used in this study schedules activities in an order determined by a score that is assigned to each activity. That score is intended to allow the schedule to be optimized. In particular, in JWST Mission Simulator (JMS), the score is intended to optimize the utilization of the observing calendar and to minimize the number of un-schedulable observations.

In this study, the success of the scheduling process is assessed by the two quantities under variations of the scheduling process (with the observations themselves held constant): *i*) utilization of the observing calendar and its stability and *ii*) stability of date of execution of visits.

3.0 Methodology

One hundred one-year schedules are prepared with JMS for the same pool of visits and user–specified visit scheduling constraints by randomly perturbing the scheduling process. The success of each schedule is measured by the utilization of the observing calendar, *i.e*., the fraction of the calendar with a scheduled activity and by the stability of date of visit execution. Further information on the two pools of visits used in the study and the scheduling perturbation are presented in the following subsections.

3.1 Design Reference Mission

Two pools of visits are selected from the Science Operations Design Reference Mission (SO-DRM, Petro 2005). These subset DRMs are two of the fifty Monte Carlo subset DRMs generated for a study of the effects of pool oversubscription on scheduling (Petro *et al*. 2005). The duration of the visits in the first pool is 1.0 yr (*i.e.*, it matches the duration of the available calendar, or no over-subscription) and the second oversubscribes the calendar by 10%. The calendar utilization of each of these two DRMs is the median of the ten DRMs of the same nominal subscription in the oversubscription study. Thus, these two DRMs are "typical" of the 1.0-year and 1.1-yr calendars from the previous study.

3.2 Monte Carlo Scheduling Perturbation

The random perturbation of the greedy scheduling algorithm is applied only to the order in which visits are added to the observing calendar. The unperturbed greedy algorithm adds visits to the observing calendar in order of a score assigned to each visit. The perturbed greedy algorithm bins the visits by score and randomly selects from each bin the next visit to be scheduled, until the bin is exhausted. Scheduling begins with the highest ranked bin. The width of the bins in this study is a fixed percentage of the score of the top of the bin. Bin widths of 1%, 10%, 30%, and 50% are used for the utilization study. The "perturbation" of the scheduling process is to treat visits with nearly equal scores as equally likely to be added next during scheduling, thereby scrambling the order in which visits within a bin are added to the calendar. As for the unperturbed JMS greedy scheduling algorithm, all visits in a linkset are added to the observing calendar at once.

Visits are scored according to an estimate of the likely difficulty finding a place for that visit on the observing calendar. Thus, longer–duration visits, user-constrained visits, and large sets of linked visits receive higher scores.

The number of scores in each of the bins for the 1.0-yr subset DRM and four binning widths is shown in Figure 1. The distribution is smooth, with higher scores being more common. As described above, the low-scored visits are single, unlinked visits of duration ~0.8 hr, and without user-specified scheduling restrictions. The dynamic range of the scores (maximum / minimum) is ~7,400 for both the 1.0-yr and the 1.1-yr DRM. The effect of the Monte Carlo selection of visits from a scoring bin is to scramble the order in which those visits are added to the observing calendar. The amount of re–ordering depends upon the number of visits within a bin and will average, for any particular visit, one–half that number of visits. For example, many of the 50% scoring bins are comprised of a few hundred visits, so the order in which any particular visit is added to the calendar will be changed by of order one hundred, or more.

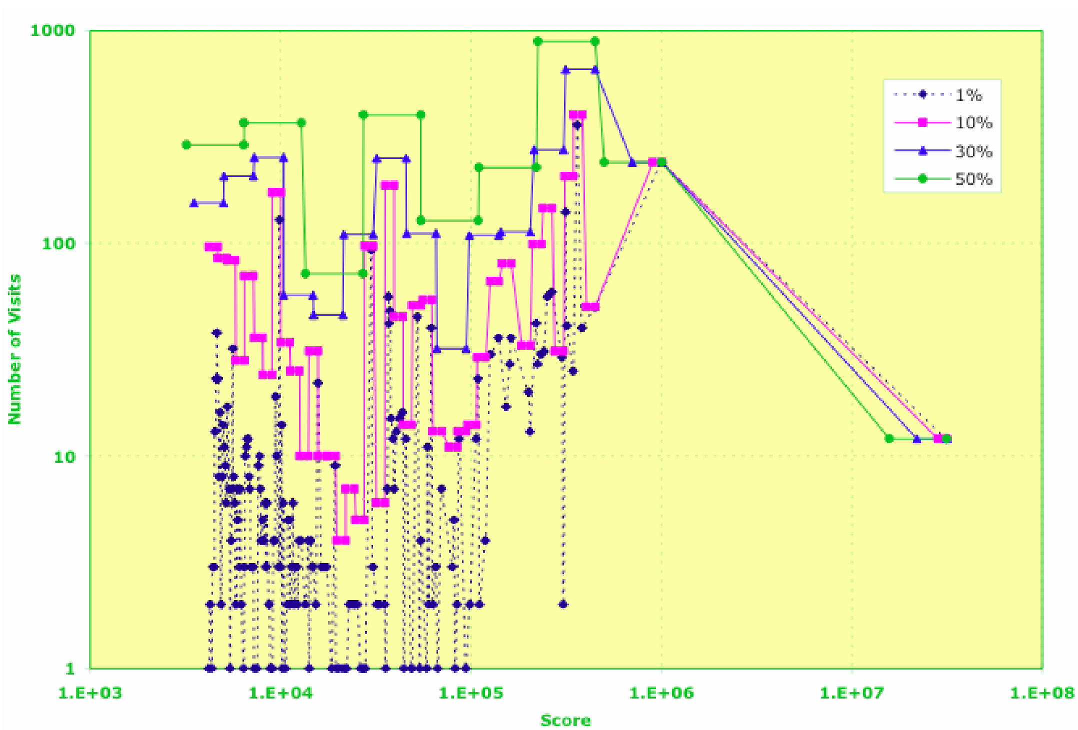

Figure 1 • Monte Carlo Scoring Bins The number of visits in each scoring bin for widths = 1%, 10%, 30%, and 50% is shown.

The total number of Monte Carlo schedules in this study is 800, 100 each for the 2 DRMs and 4 binning widths.

4.0 Results

In the following two subsections we describe the results from two sets of scheduling that we performed to study quality of scheduling. First, the quality of calendar utilization is presented and then the stability of visits on those calendars is presented.

4.1 Utilization

The results of the Monte Carlo scheduling perturbation trials are shown in Figures 2 (for the 1.0-yr subset DRM) and 3 (for the 1.1-yr subset DRM). The typical utilization is larger for the oversubscribed DRM (1.1 yr) than for the DRM with visit duration matched to the calendar duration (1.0 yr): 95% *vs*. 90%. For both DRMs, the range of utilization broadens as the Monte Carlo scheduling scrambling width increases. The typical utilization also increases as the scrambling width is increased from 1% to 50%, although only slightly. The distribution of utilizations is symmetric, at least to the degree of accuracy allowed by these 100-trial experiments. In other words, locally scrambling the order in which visits are added to the observing calendar is equally likely to improve the result as it is to harm it.

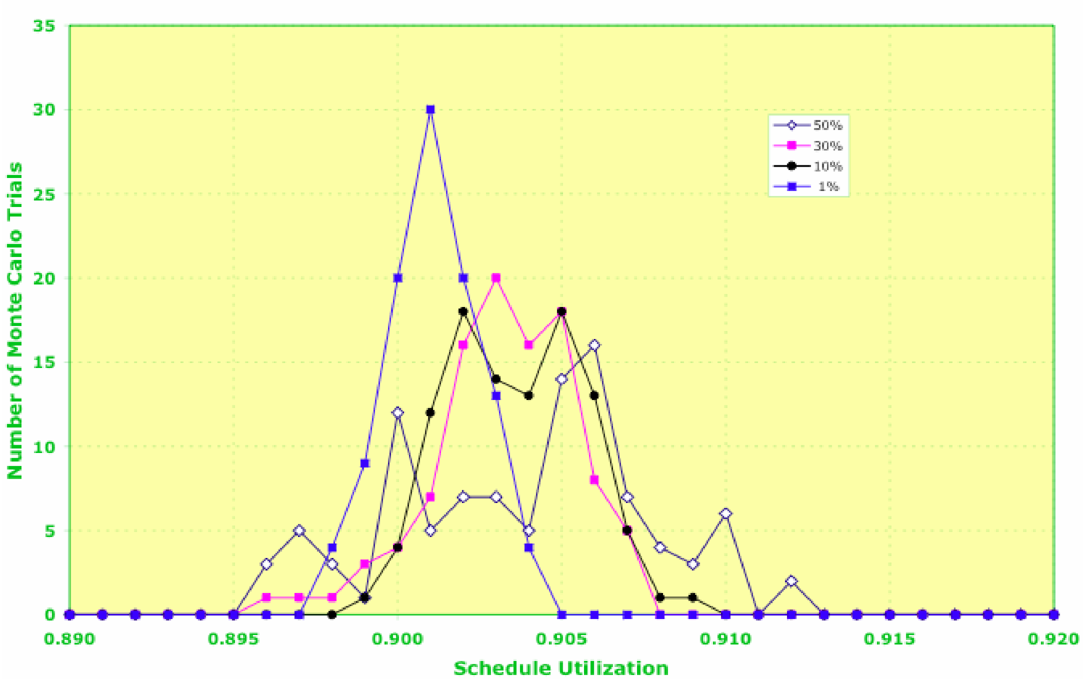

Figure 2 • Calendar Utilization: 1.0-yr DRM For the 100 Monte Carlo trials of each score binning (*i.e.*, width = 1%, 10%, 30%, and 50%), the frequency of occurrence of calendar utilization is plotted.

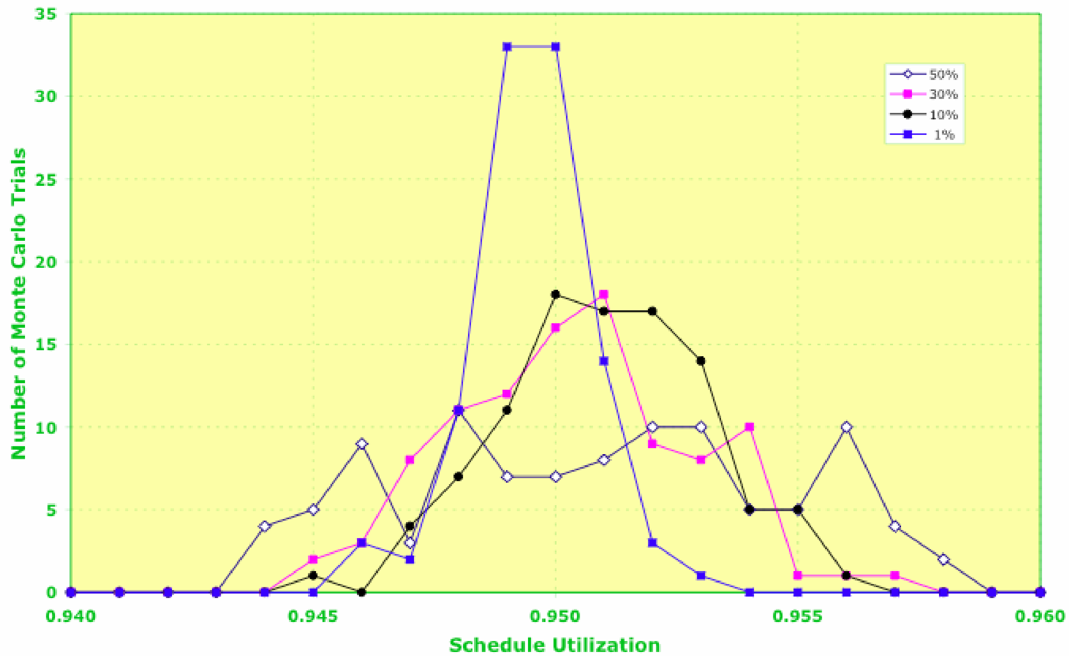

Figure 3 • Calendar Utilization: 1.1-yr DRM For the 100 Monte Carlo trials of each score bin width (1%, 10%, 30%, and 50%), the frequency of occurrence of calendar utilization is plotted.

The results of 100-trial Monte Carlo-perturbed scheduling are summarized in Figure 4. During operation of JWST only one schedule will be flown (although it will be modified during the year in which it is executed). Therefore, two questions are of interest to this study, as noted in the Introduction: What is the likelihood that that schedule will catastrophically diverge from typical? Conversely, can this Monte Carlo technique significantly improve upon the typical schedule? In terms of the distribution functions shown in Figures 2 and 3, these questions ask about the width and symmetry of the distributions. As already noted, the functions are symmetric: a high utilization (relative to typical) is no more or less likely than a low utilization. A measure of the extremes is the "range," which is defined as the difference between the maximum and the minimum utilizations for a 100-trial set of schedules. As the Monte Carlo bin width increases from 1% to 50%, the range doubles from ~0.007 to ~0.015, as shown in Figure 4. The typical utilization for the 1.1-yr DRM is ~95%, so this represents a small effect. *For these trials a catastrophic result is not found.* The benefit of selecting the best Monte Carlo schedule can be measured by the difference between the maximum utilization and the expected result were only one schedule to be formed (measured here by the median utilization). As shown in Figure 4, the "benefit" increases from 0.003 to 0.007 as the Monte Carlo bin width increases from 1% to 50%. Although small, this is non-negligible benefit.

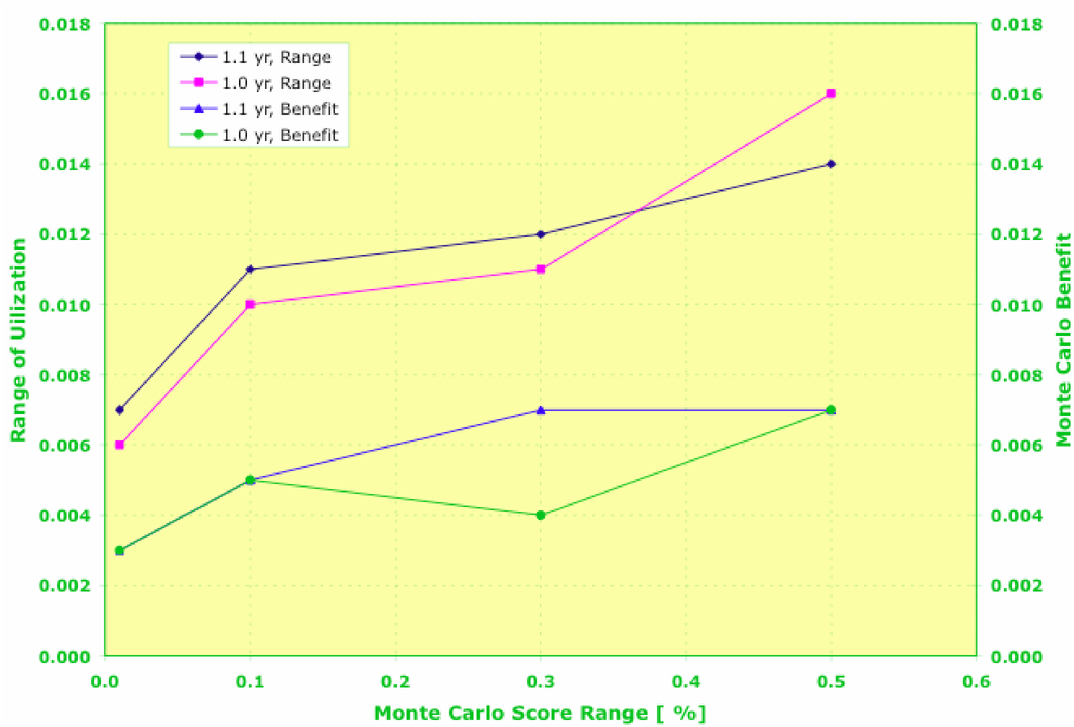

Figure 4 • Scheduling Stability and Monte Carlo Benefit The range of utilization for 100 Monte Carlo trials is plotted for the 1.0-yr and 1.1-yr subset DRMs. The range is the difference of the maximum and minimum utilization. The "benefit" is the difference of the maximum and median utilization.

4.2 Visit Stability

Observers and science operations personnel each benefit from a scheduling algorithm that places visits onto the observing calendar in a stable manner. That is to say, if a visit is placed on the observing calendar for execution on a particular date, then a subsequent and slightly modified execution of the scheduling algorithm would place that visit on the observing calendar at a not too distant date. We have carried out such experiments using Monte Carlo perturbation of binned scores, as described above. As before, for a particular binning of the greedy algorithm scores, a set of 100 schedules was created for a Monte Carlo perturbation of the visit scheduling order within scoring bin. The scoring bins in are defined by their width such that the ratio of the upper and lower limits of each scoring bin are in the ratio $score_{upper} / score_{lower} = x$. Thus, each set of 100 schedules is characterized by the value of the scoring bin width x. For the SO–DRM, scores of the visits range from 4,223 to 1×10^9. The results of these scheduling experiments are presented here in terms of the number of scoring bins, N_{bin}, which is related to the width of the bins x by

$$N_{bin} = \log_{10}(score_{max} / score_{min}) / \log_{10}(1 + x)$$

As for the utilization experiments, two subset DRMs were drawn from the full SO–DRM, one of which is comprised of visits with total duration equal to 1 year and the other equal to 1.1 year total duration. For each these two DRM, 8 binnings of the visits scores were formed, with the number of bins varied from approximately 3,000 to 1. The latter case corresponds to complete randomization of the order in which visits were placed on the observing calendar (*i.e.*, strictly not greedy), and the former corresponds to strict adherence to the visits' scores. The results of the 16 experiments are presented in Figure 5. As before "utilization" is defined as the fraction of the 1-year calendar occupied by scheduled activities and is computed here as the average (not the maximum) of a set of 100 Monte Carlo schedules. The "stability" of a visit is defined as the standard deviation of the sample of scheduled dates for that visit. The stability of each visit was computed for each set of 100 Monte Carlo schedules if that visit was placed on 50 or more schedules. For each of the 16 Monte Carlo experiments, the visit stability was computed from average variance of all the visits in the appropriate DRM.

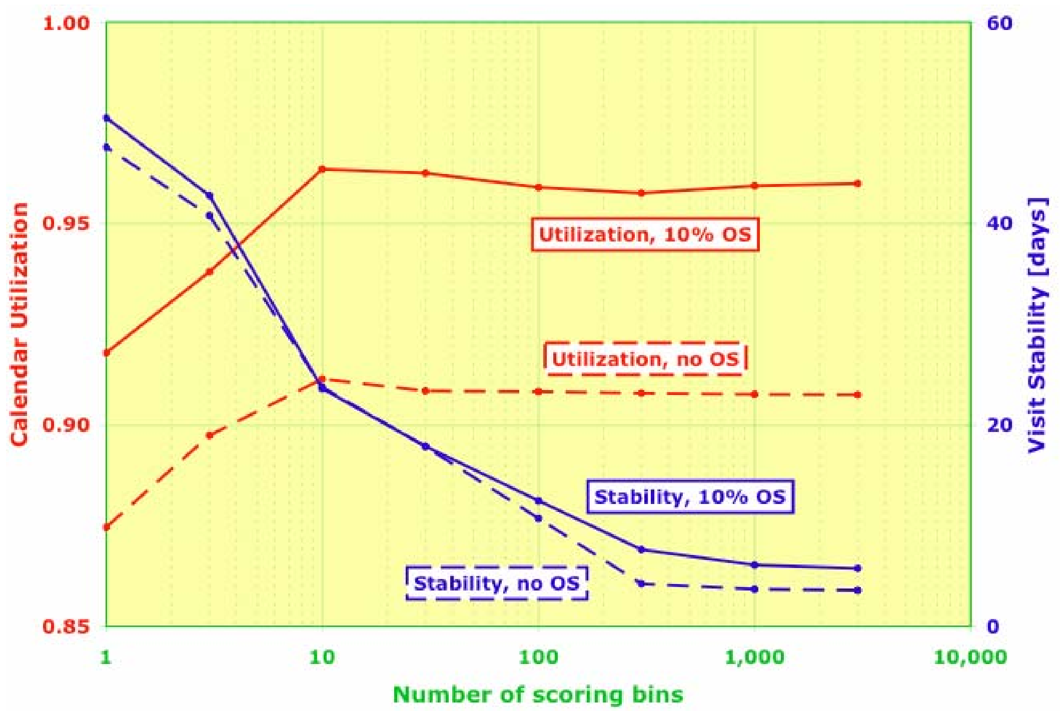

Figure 5 • Quality of scheduling: calendar utilization and visit date stability The fraction of the observing calendar containing visits (the "utilization") and stability of date of execution for visits are statistical functions of the number of Monte Carlo scoring bins. These statistics are computed from 100 Monte Carlo schedule trials for each score binning (represented here by the number of scoring bins in that binning.) Scheduling quality is degraded by a small number of scoring bins. Oversubscription (by 10%) of the calendar by the scheduling pool improves utilization, but does not significantly affect visit stability.

As seen in Figure 5, the "quality" of scheduling degrades as the amount of randomization of the scheduling order increases (*i.e.*, as the amount of deviation from individual visit greedy scores increase.) Here "quality" is taken to mean the joint calendar utilization and visit stability. It should be noted that the randomization of the greedy scoring order increases as the number of scoring bins decreases. Both the calendar utilization and the visit stability are effectively unaffected as the amount of randomization increase up to a critical point, which is different for these two measures. Utilization is unaffected until the number of scoring bins is reduced from 3,000 to 10, but visit stability is unaffected only if the number of bins is greater than 300. This latter value corresponds to bin width x = 4% and approximately 10 visits per bin. The best visit stability is 4 days for a DRM with no oversubscription and 6 days for 10% oversubscription.

5.0 Conclusions

The utilization of observing calendars scheduled with the JMS greedy algorithm is stable to randomization of the scheduling order on scales up to 50% of the score. The distribution function of calendar utilization is symmetric, favoring neither large, nor small deviations from the typical utilization. The benefit in utilization that can be obtained by selecting the best Monte Carlo schedule is 0.007 and 30% wide bins. However, to maintain stability of visit date requires scoring bins of less than 4% width.

6.0 References

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

Petro, L., Stys, J., Rager, R., and Jones, D. 2005 An Empirical Study of the Effects of Proposal Over-subscription on Long-range observing schedules (STSCI-JWST-TM-000644, Rev. A., July 8, 2005).