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Stochastic Resource Constrained Project Scheduling With Stochastic Task Insertion Problems

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STOCHASTIC RESOURCE CONSTRAINED PROJECT SCHEDULING WITH STOCHASTIC TASK INSERTIONS PROBLEMS

by

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ABSTRACT

The area of focus for this research is the Stochastic Resource Constrained Project Scheduling Problem (SRCPSP) with Stochastic Task Insertion (STI). The STI problem is a specific form of the SRCPSP, which may be considered to be a cross between two types of problems in the general form: the Stochastic Project Scheduling Problem, and the Resource Constrained Project Scheduling Problem. The stochastic nature of this problem is in the occurrence/non-occurrence of tasks with deterministic duration. Researchers Selim (2002) and Grey (2007) laid the groundwork for the research on this problem. Selim (2002) developed a set of robustness metrics and used these to evaluate two initial baseline (predictive) scheduling techniques, optimistic (0% buffer) and pessimistic (100% buffer), where none or all of the stochastic tasks were scheduled, respectively. Grey (2007) expanded the research by developing a new partial buffering strategy for the initial baseline predictive schedule for this problem and found the partial buffering strategy to be superior to Selim's "extreme" buffering approach. The current research continues this work by focusing on resource aspects of the problem, new buffering approaches, and a new rescheduling method.

If resource usage is important to project managers, then a set of metrics that describes changes to the resource flow would be important to measure between the initial baseline predictive schedule and the final "as-run" schedule. Two new sets of resource metrics were constructed regarding resource utilization and resource flow. Using these new metrics, as well as the Selim/Grey metrics, a new buffering approach was developed that used resource information to size the buffers. The resource-sized buffers did not show to have significant improvement over Grey's 50% buffer used as a benchmark. The new resource metrics were used to validate that the 50% buffering strategy is superior to the 0% or 100% buffering by Selim.

Recognizing that partial buffers appear to be the most promising initial baseline development approach for STI problems, and understanding that experienced project managers may be able to predict stochastic probabilities based on prior projects, the next phase of the research developed a new set of buffering strategies where buffers are inserted that are proportional to the probability of occurrence. The results of this proportional buffering strategy were very positive, with the majority of the metrics (both robustness and resource), except for stability metrics, improved by using the proportional buffer.

Finally, it was recognized that all research thus far for the SRCPSP with STI focused solely on the development of predictive schedules. Therefore, the final phase of this research developed a new reactive strategy that tested three different rescheduling points during schedule eventuation when a complete rescheduling of the latter portion of the schedule would occur. The results of this new reactive technique indicate that rescheduling improves the schedule performance in only a few metrics under very specific network characteristics (those networks with the least restrictive parameters).

This research was conducted with extensive use of Base SAS v9.2 combined with SAS/OR procedures to solve project networks, solve resource flow problems, and implement reactive scheduling heuristics. Additionally, Base SAS code was paired with Visual Basic for Applications in Excel 2003 to implement an automated Gantt chart generator that provided visual inspection for validation of the repair heuristics.

The results of this research when combined with the results of Selim and Grey provide strong guidance for project managers regarding how to develop baseline predictive schedules and how to reschedule the project as stochastic tasks (e.g. unplanned work) do or do not occur. Specifically, the results and recommendations are provided in a summary tabular format that

describes the recommended initial baseline development approach if a project manager has a good idea of the level and location of the stochasticity for the network, highlights two cases where rescheduling during schedule eventuation may be beneficial, and shows when buffering proportional to the probability of occurrence is recommended, or not recommended, or the cases where the evidence is inconclusive.

This work is dedicated to my life's teachers

and especially to my husband Corey Archer, and our future together.

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LIST OF ACRONYMS/ABBREVIATIONS

ADFF	Activity Dependent Float Factor
BPGA	Bi-Population Genetic Algorithm
CC/BM	Critical Chain / Buffer Management
CE	Cross Entropy
CI	Complexity Index
DRCPSP	Deterministic Resource Constrained Project Scheduling Problem
ES	Earliest Start
GA	Genetic Algorithm
GERT	Graphical Evaluation and Review Technique
GRASP	Greedy Randomized Adaptive Search Procedure
GRCPSP	Generalized Resource Constrained Project Scheduling Problem
HGA	Hybrid Genetic Algorithm
IB	Initial Baseline
ILP	Integer Linear Programming
MAC	Minimizing Activity Costs
MB	Modified Baseline
MRCPSP	Multiple Mode Resource Constrained Project Scheduling Problem
OS	Order Strength
PERT	Program Evaluation and Review Technique
PK	Perfect Knowledge
RC1	Resource Constrainedness

RCPSP	Resource Constrained Project Scheduling Problem
RF	Resource Factor
RFDFF	Resource Flow Dependent Float Factor
SA	Simulated Annealing
SGS	Schedule Generating Scheme
SRCPSP	Stochastic Resource Constrained Project Scheduling Problem
STI	Stochastic Task Insertion
Stochasticity Level	H = High; L = Low
Stochasticity Timing	E = Early; L = Late
Buffering Methods	O = Optimistic; P = Pessimistic; B5 = 50%; BR1-BR4= Resource

Network and Resource Parameters Studied (Selim, 2002)

	Resource Parameter			
Network Parameter	Low	Network No.	High	Network No.
Low	OS = 0.40 CI = 13 RF = 0.40, 0.45, 0.50 RC = 0.25	1004 1010 1015 1020 1028	OS = 0.40 CI = 13 RF = 0.75, 0.80, 0.85 RC = 0.75	1102 1105 1112 1119 1127
High	OS = 0.85 CI = 21 RF = 0.40, 0.45, 0.50 RC = 0.25	1200 1201 1212 1222 1225	OS = 0.85 CI = 21 RF = 0.75, 0.80, 0.85 RC = 0.75	1300 1304 1308 1314 1325

Summary of Metrics

Robustness Metrics					**Comparison**
Selim	Duration	Metric 1	% change in duration	MB	PK
Selim	Duration	Metric 2	% change in duration	MB	IB
Selim	Stability	Metric 3	# tasks with changed start times (rev to %)	MB	PK
Selim	Stability	Metric 4	# tasks with changed preceding tasks (rev to %)	MB	PK
Selim	Stability	Metric 5	# tasks with additional preceding tasks (rev to %)	MB	PK
Selim	Stability	Metric 6	combination of metric 4 & 5	MB	PK
Grey	Duration	Metric 7	% change in duration	IB	PK
Grey	Stability	Metric 8	coef of var for changed start times	MB	PK
Resource Metrics					
Archer	Resource util	RMetric 1	resource consumption for each time pd	MB	IB
Archer	Resource util	RMetric 2	change in "resource-hours"	MB	IB
Archer	Resource flow	RMetric 3	change in number of resource units used	MB	IB
Archer	Resource flow	RMetric 4a	change in number of resource hand-offs	MB	IB
Archer	Resource flow	RMetric 4b	change in volume of resource hand-offs	MB	IB
Archer	Resource flow	RMetric 5a	change in idle time units	MB	IB
Archer	Resource flow	RMetric 5b	change in idle "resource-hours"	MB	IB

CHAPTER ONE: INTRODUCTION

Stochastic Resource Constrained Project Scheduling

Scheduling is the process of developing a plan for a set of individual tasks, or activities, that comprise an overall job or project. Generally, tasks are ordered to comply with a set of precedence constraints and to optimize an overall project objective. Studies of this important topic in the area of project management expanded rapidly in the latter half of the last century with the increased ability to test various scheduling techniques on variations of the problem using computer technology. The area of focus here is the Stochastic Resource Constrained Project Scheduling Problem (SRCPSP) with Stochastic Task Insertion (STI). The STI problem is a specific form of the SRCPSP, which may be considered to be a cross between two types of problems in the general form: the Stochastic Project Scheduling Problem, and the Resource Constrained Project Scheduling Problem.

Stochastic project scheduling is generally concerned with developing an optimal task order that is robust to uncertainty in certain areas. These areas may include possible resource breakdowns, uncertain resource availability, or variable task durations. Project managers may develop an initial plan before work begins (predictive) or react to events as they occur and reschedule tasks as necessary (reactive), generally with the objective to minimize expected project duration.

Resource constrained project scheduling is a form of the general resource allocation problem that includes various methods for project managers to deal with limited resources. Resource allocation problems include resource leveling (minimizing the variation in resource

levels required over the course of the project) and time/cost trade-off (determining the value of project time completion in terms of resource cost). Variations of resource constrained project scheduling include multi-project scheduling, multi-mode resource constrained project scheduling with and without activity splitting, renewable and non-renewable resources, and preemption and non-preemption constraints. The Deterministic Resource Constrained Project Scheduling Problem (DRCPSP) assumes deterministic resource availability and task duration, and is concerned with the ordering of activities to optimize an objective, usually project duration. There are many heuristic solutions and exact algorithms in the literature for solving various cases of this problem, as outlined in surveys provided by the following authors: Icmeli, Erenguc, et al. (1993) provided a survey of predictive techniques; Ozdamar and Ulusoy (1995) focused on listing the current heuristics and mentioned a need for flexible heuristic decision-making procedures to meet the needs of practitioners; Herroelen, De Reyck, et al. (1998) provided a survey of scheduling heuristics with a detailed description of newly developed heuristics including the DH procedure and an explanation of the widely used problem sets such as the 110 Patterson set and the KS sets developed with RanGen; Brucker, Drexl, et al. (1999) provided a classification scheme (a description of the resource environment, activity characteristics, and objective function) and reviewed exact and heuristic algorithms for the problem cases including: single and multi-mode case, time/cost trade-off, minimum and maximum time lags, alternative objectives (rather than makespan minimization) and stochastic activity durations; Kolisch and Padman (2001) provided a survey of the literature and integrated the models, data, and optimal and heuristic algorithms for the major classes of problems and discussed recent surveys comparing commercial project scheduling systems; and Demeulemeester and Herroelen (2002) provided an exhaustive review of available techniques in a textbook format.

General SRCPSP

The general SRCPSP assumes deterministic resource availability, but is concerned with optimizing one or more objective functions in an environment where task durations are uncertain. Stork (2001) described the solution for the SRCPSP as a policy that defines actions for a decision maker or project manager to take at various points in time during project execution. The objective function for the SRCPSP is usually to minimize expected project duration; however, it is often appropriate to define alternative objectives, such as stability costs, including financial costs, inventory costs, or various organizational costs associated with deviations from a project plan used to organize resources and negotiate contracts with subcontractors (Van de Vonder, Demeulemeester, et al. 2006b).

SRCPSP with STI

Selim (2002) defined the STI problem as one in which some project activities may or may not occur with a certain probability, and terms these activities as "unplanned". Under resource constraints, the occurrence of an unplanned activity may cause other activities to be delayed due to resource usage by the unplanned activity or necessitate a re-sequencing of activities to accommodate additional predecessor constraints. There is limited research on the STI variation of the SRCPSP. Selim (2002) developed a new set of performance measures focusing on a schedule's robustness to disruptions, examined the effect of network, resource and stochastic factors on schedule robustness, and also provided insights into two extreme approaches to obtaining a baseline schedule. Grey (2007) introduced a partial buffering heuristic for the STI, applying concepts from Goldratt's (1997) Critical Chain and Buffer Management

method for baseline schedule development for project planning under uncertainty. The author demonstrates that a partial buffering approach may improve project duration and other metrics for project duration and stability.

While Selim and Grey provide heuristics for developing a robust baseline schedule before any work begins (predictive), other authors focus on how project managers may deal with inserting an unplanned task into an existing schedule (reactive). A polynomial insertion algorithm for the RCPSP is provided by Artigues, Michelon et al. (2003) and used for rescheduling with the occurrence of an unexpected activity. Similarly, Duron, Proth et al. (2001) developed an algorithm to insert a randomly occurring task of stochastic duration into a single-resource constrained schedule with the goal of completing this random task by its due date while minimizing the sum of the delays of the initial task schedule. Ourari and Bouzouia (2003) have also developed algorithms for task insertion on single-machine job shop scheduling problems.

Techniques applied by other researchers to the general form of the SRCPSP may not be appropriate for the STI problem. Therefore, the opportunity exists to examine various solution methods and heuristics that have been developed for the general SRCPSP problem and test their use on the STI variation of the problem. There are additional opportunities to expand upon the work of Selim (2002) and Grey (2007) by testing their techniques on various configurations of the problem and determining if new techniques may be appropriate under these conditions.

Research Objective

The intent of this research is to expand upon the body of knowledge of the stochastic resource constrained project scheduling problem with stochastic task insertion, and the research

findings of Selim (2002) and Grey (2007) on the SRCPS problem with STI. The opportunity exists to develop new predictive heuristics for developing robust baseline schedules that have been identified for the general form of the SRCPSP and test their appropriateness on the STI variation of the problem. Additionally, the opportunity exists to develop reactive heuristics for a project manager to deal with unplanned work as defined by Selim (2002) under multiple resource constraints. New metrics may be established to judge the usefulness of these new rescheduling heuristics. Implementing the automation of these heuristics with computer programming will allow multiple trials on problems with various characteristics. Specifically, research goals for the SRCPSP with STI include the development of new metrics associated with resource usage and flow (resource hand-off), new buffering techniques that use information about resource usage or prior knowledge of occurrence probability, and new rescheduling polices. This research also assesses predictive and reactive scheduling techniques that are most appropriate for networks of varying characteristics.

The literature review that follows in Chapter Two contains a brief summary of the surveys of relevant research in stochastic project scheduling, resource allocation problems, and the SRCPSP as provided by Selim (2002) and Grey (2007) as well as an update of recent developments in these areas. Chapter Three then describes specific areas in the literature that point to opportunities for research and descriptions of methods used by other researchers to conduct research on similar problems as justification for this research. Chapter Four provides details on how this research was conducted, including the specifics of software implementation. Chapters Five, Six and Seven contain the results of each phase of research and details of the findings. Finally, Chapter Eight concludes the research with an overview summary of the research findings and highlights areas for future research.

CHAPTER TWO: LITERATURE REVIEW

This literature review represents an update to the work provided by Selim (2002) and Grey (2007) for their study of the SRCPSP with stochastic task insertion. The literature review extends to the areas of stochastic project scheduling, resource allocation problems, and finally the intersection of the two, the stochastic RCPSP. A brief reference to the works cited by these authors is updated with a review of recent work in each of the corresponding areas. A diagram with the literature highlights is contained in Appendix A.

Stochastic Project Scheduling

The field of stochastic project scheduling includes areas in which project scheduling may face uncertainty. This includes resource breakdowns or stochastic availability, and stochastic task durations. Project managers may deal with these areas of uncertainty by various means, often without taking the computational expense of developing sophisticated models. However, Elmaghraby (2005) argued against the practice of managers estimating randomness by planning based on the averages of random variables, which may lead to gross errors.

Analytical Approaches: Predictive and Reactive Scheduling

To handle uncertainty in a project schedule, project managers have two approaches to take: a predictive (or proactive) scheduling technique develops a baseline schedule before work begins that is believed to be robust to uncertainty in the schedule, or a reactive scheduling technique that provides decision points once work has begun to react or reschedule in light of the

outcome of uncertain events. Many managers may apply a combination of both of these techniques.

Predictive Scheduling

Predictive or proactive scheduling techniques allow a project manager to develop a baseline schedule to protect the project against the effects of uncertainty. Analytical approaches and techniques for developing robust proactive schedules have been extensively studied ((Wu, Storer, et al. 1993), (Mehta and Uzsoy 1998), (Aytug, Lawley, et al. 2005), (Herroelen and Leus 2005)). Approaches include redundancy-based techniques that allow for extra time in each activity, or alternatively, scheduling extra resources. Another approach is robust machine scheduling techniques to develop schedules that minimize the consequences of the worst case scenario.

Predictive Scheduling – Buffering

Goldratt's (1997) Critical Chain and Buffer Management Method (CC/BM) gives a heuristic framework and guidelines for project managers on how to plan, schedule, and control their projects, but leaves it to the user to determine exact implementation. The method identifies the critical chain, or the set of tasks that results in the longest path to project completion, considering both precedence and resource constraints. A "feeding" buffer is placed at points in the schedule where resources feed into the critical chain path to protect the critical chain, while a "project" buffer protects overall project completion time (Grey 2007). The example below explains the use of CC/BM in project scheduling and is from the ProChain Solutions website (ProChain Solutions Inc. 1998 - 2007). In the figures below, each rectangle represents a task,

with the horizontal lengths of the rectangles proportional to expected task durations. The task duration and required resource type is noted inside each rectangle, which includes a customer service representative (CS), an engineer (Eng), a hardware technician (HW), and a programmer (Prog). Rectangles immediately before another, as well as the arrow, represent predecessor constraints. The initial project plan in Figure 1 would require at least two hardware technicians to complete task 3 and 5 at the same time. The CC/BM method is applied in Figure 2 and shows that the required resources are leveled so only one technician is needed, and identifies the critical path (in bold outline). A feeding buffer is inserted to ensure that the programmer's work is complete when the hardware technician is ready to begin his second task as well as an overall project buffer to protect overall project completion time.

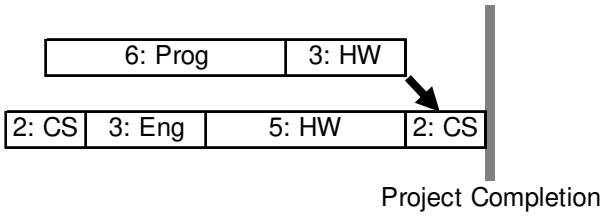


Figure 1: Initial Schedule

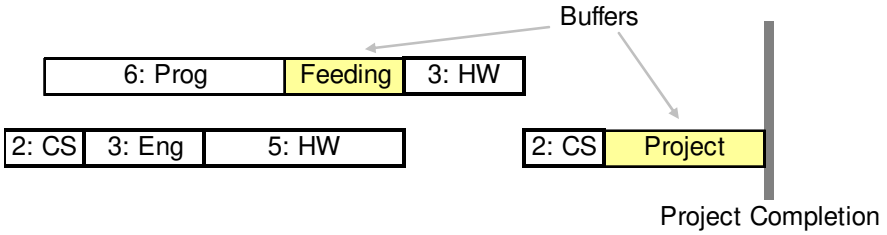


Figure 2: Buffered Schedule

Tavares, Ferreira et al.(1998) have applied the concept of using buffers to protect the schedule by adding time buffers throughout a baseline schedule, although their method does not prohibit resource conflicts from occurring. This method was then developed into an adapted float factor heuristic (ADFF) by Leus (2003) and was adapted to the resource constrained version

by Van de Vonder, Demeulemeester, et al. (2004; 2005b). Additionally, Van de Vonder, Demeulemeester et al. (2005a; 2006a) introduced multiple algorithms to include time buffers in a given schedule while a predefined project due date remains respected. At the same time, Trietsch (2006) developed a method involving optimal feeding buffers to protect against tardiness and suggested the marginal cost of a buffer should match its criticality, even for the case of unknown project completion time distribution. Additional details regarding the use of buffers for project scheduling **under resource constraints** is addressed later in this chapter.

Predictive Scheduling – Other Methods

There have been many recent developments in the area of developing robust baseline schedules. Ke and Liu (2005) designed a hybrid intelligent algorithm using stochastic simulation and genetic algorithms to solve the project scheduling problem with stochastic activity duration times to minimize total cost under completion time limits. Sakka and El-Sayegh (2007) developed a method to quantify risks associated with float loss in construction projects. Zhu, Bard et al. (2007) approached the concept of setting due dates for project activities with random durations as a two-stage integer program to balance project completion cost and late penalties.

Reactive Scheduling: Reacting to Changes

Instead of, or in addition to, anticipating uncertainty, managers must be prepared to make decisions as the project progresses in light of current events. Managers may utilize the technique of contingent schedules, by developing multiple schedules at once. As the project progresses, the project manager may switch to the schedule corresponding to the events that have occurred (Davenport and Beck 2002). This technique, focuses on flexibility and is valuable for time-

critical reactive scheduling. GERT (Graphical Evaluation and Review Technique) is a tool that allows managers working with stochastic project networks to review projects with a stochastic evolution structure. There have been many heuristic solutions proposed, including those that offer a full-rescheduling option, depending on the project objective function (Demeulemeester and Herroelen 2002; Herroelen and Leus 2004b).

Schedule repair includes simple control rules such as a right-shift rule (Sadeh, Otsuka, et al. 1993) which involves moving activities affected by the schedule breakdown forward in time. However, Herroelen and Leus (2004b) warned that this reactive strategy may lead to poor results, since it does not re-sequence activities.

Measures of Performance

Selim (2002) provided a comprehensive review of measures for stochastic project scheduling, which is briefly summarized here. Measures of performance for scheduling techniques (predictive or reactive) have evolved from measures developed with PERT (Program Evaluation and Review Technique), including mean project duration, or the probability for the project duration to exceed a set deadline. For PERT networks without resource constraints, criticality is a measure for the probability that a path is a critical path or the probability an activity lies on the critical path (Williams 1993). Bowers and Mould (1994) highlighted issues with this index and provided a cruciality index as the correlation between the project duration and activity duration, which reflects both impact and uncertainty. An uncertainty measure introduced by Cho and Yum (1997) helps determine which activities need more attention in order to reduce overall project completion time uncertainty.

The most common measure for the stochastic scheduling problem is the minimization of expected project duration; however the measures may vary depending on the objective of the problem variation. For example, Moo Young (1995) examined the risk of missing a critical deadline. Another measure developed by Pet-Armacost, Armacost et al. (1999) is the variance of project duration (or cost), and may be useful as a measure of risk when the mean is the desired goal. Other measures include the probability that a critical outcome is exceeded, and the pth percentile of the outcome (Pet-Armacost, Armacost, et al. 1999).

The measures above focus on overall outcome, but not on a schedule's ability to adapt to changes, as will occur with the stochastic task insertion problem. Selim (2002) looked to the job shop literature for measures of robustness in scheduling. Leon, Wu et al. (1994) term a schedule as "robust" if the performance of the scheduling objectives remain high in the presence of disruptions. The job shop literature provides several measures for schedule robustness, including a comparison of the optimal schedule to actual as a measure of performance (Daniels and Kouvelis 1995).

Determining Project Duration

Many performance measures for scheduling evaluate timely completion of the project. As such, studying the overall project duration is an important aspect of evaluating the value of a scheduling technique. The **distribution** of project duration may be considered a performance measure for a schedule ((Tavares 1990), (Fernandez, Armacost, et al. 1998), (Fernandez 1995)). Fernandez (1995) developed methods to determine project duration distributions for projects with stochastic task durations and Azaron and Fatemi Ghomi (2008) continued this work by

applying a stochastic dynamic programming method to obtain a lower bound for mean project duration. Azaron and Tavakkoli-Moghaddam (2007) constructed a continuous-time Markov chain to determine project duration distribution and used this to evaluate the time-cost tradeoff by formulating a multi-objective optimal control policy. Additionally, Pollack-Johnson and Liberatore (2006) applied concepts from the analytic hierarchy process (AHP) to develop a method for project managers to develop quality level curves to illustrate the tradeoffs between the timely completion of the project, cost, and quality.

Resource Allocation Problems

Resource allocation problems deal with scheduling in an environment where resources are scarce, and are either renewable, non-renewable, or doubly constrained (limited availability per time period) (Klein 2000). Areas of study include resource leveling, time/cost tradeoff, resource allocation, and variations of the resource constrained project scheduling problem (RCPSP). Recent advances in the area of resource allocation include the development of a multi-objective model for the time-cost tradeoff problem using a genetic algorithm where the decision variables are the allocated resource activities (Azaron, Perkgoz, et al. 2005) and an optimal resource allocation model within a framework of an integration model that uses genetic algorithms to search for new-optimal solutions (Ellis and Kim 2005). Burdett and Kozan (2004) addressed the resource constrained permutation flowshop, specifically to assign operations to workers and classified the problem as a form of the multi-period precedence constrained non-linear assignment problem.

Deterministic Resource Constrained Project Scheduling Problem (DRCPSP)

The objective of the DRCPSP is to minimize project duration where resource availability and task duration are both deterministic. However, other optimization criteria may include net present value (NPV) maximization (Bey, Doersch, et al. 1981) or cost minimization (CM), which is often applied to the multi-mode case (Al-Fawzan and Haouari 2005). Additional objectives include the minimization of weighted tardiness and the minimization of weighted resource consumption costs (Ozdamar and Ulusoy 1995). New heuristics for the RCPSP with the objective of cost minimization have recently been developed (Liu and Wang 2006). Please see Klein (2000) for several formulations of the problem along with its variations.

DRCPSP: Multi-Project Scheduling Variation

Multi-project scheduling involves the allocation of resources over several tasks that span multiple projects. There have been many recent developments in the study of the multiple-project RCPSP. Cohen, Golany et al. (2007) addressed the problem of resource allocation in a finite-capacity, stochastic and dynamic multi-project system with a Cross Entropy (CE) based approach to find near-optimal resource allocations. Deng, Lin et al. (2007) provided a topological optimization algorithm to solve the resource and priority constrained multi-project scheduling problem to minimize makespan. Hans, Herroelen et al. (2007) proposed a framework for distinguishing among types of project-driven organizations to aid managers' decisions among various planning approaches for the multi-project planning under uncertainty. Kao, Hsieh et al. (2006) applied high level Petri nets to simulate multi-project networks to generate schedules and react to uncertainty in order to minimize makespan and preserve resource feasibility. Kovacs and

Vancza (2006) defined a method to order corresponding tasks of similar projects to reduce the search space for progressive solutions and demonstrated the application on two sets of industrial problems. Lin and Yao (2007) analyzed the characteristics of the multi-project task scheduling problem under multi-resource constraints and demonstrated the effectiveness of a developed heuristic for the shortest delay time.

DRCPSP: Multi-Mode Project Scheduling Variation

Often in application, the duration of a job may be decreased by providing additional resources (Klein 2000). The multi-mode resource constrained problem is where each mode is characterized by a specific time duration and resource consumption (Al-Fawzan and Haouari 2005). This problem variation has also received much attention in the recent literature. Simulated annealing (SA) algorithms have been developed for the multi-mode resource constrained project scheduling problem (MRCPSP) (Bouleimen and Lecocq 2003). Liu and Wang (2007) provided a parallel scheduling schema for the multi-mode RCPSP – MAC (Minimizing Activity Costs). Ranjbar and Kianfar (2007) have developed a metaheuristic procedure for solving the discrete time/resource trade-off problem. Zhu, Bard et al. (2006) provided an exact branch and cut algorithm based on an integer linear programming (ILP) formulation for the multi-mode RCPSP. Zhang, Li et al. (2006a) provided a heuristic for scheduling repetitive multi-mode projects by ranking possible combinations of activities. Buddhakulsomsiri and Kim (2007) developed a priority rule-based heuristic for the multi-mode resource constrained project scheduling problem with activity splitting to minimize makespan.

DRCPSP: Other variations

Non-preemption is when a task that has already begun may not be interrupted; in practice, this assumption is frequently not justified (Klein 2000). Damay, Quilliot et al. (2007) presented a solution to the RCPSP with activity preemption by using a linear programming model. This solution was found to be most useful when preemption was permitted.

Buddakulsomsiri and Kim (2003; 2006) also provided a study of the problem when resources may be temporarily unavailable. De Frene, Schatteman et al. (2007) presented a heuristic method for solving the RCPSP with renewable and spatial resources, as encountered in construction project applications. The method applies a schedule generation scheme on a priority list of activities.

Variations of the problem also include fuzzy resource-constrained project scheduling. Fuzzy set scheduling is used when activity durations are modeled with vague or imprecise information, rather than probability distributions (Herroelen and Leus 2005). Fuzzy scheduling techniques have only recently been applied to the RCPSP ((Hapke and Slowinski 1996; Hapke, Jaskievicz, et al. 1999), (Hapke and Slowinski 2000), (Wang 1999; Wang 2002; Wang 2004), (Özdamar and Alanya 2000)).

Approaches to the Deterministic Resource Constrained Project Scheduling Problem (DRCPSP)

Klein (2000) provided a comprehensive review of solution methods for the DRCPSP, beginning with lower bound methods. Lower bound methods include computing a lower bound on the smallest project completion time. The gap size between the lower bound and the determined solution completion time may provide a decision maker with a measure to determine

if investing additional planning efforts into improved solutions is warranted (Klein 2000). The author also provided a review of many heuristic and exact procedures, and provided computational experiments to examine the efficiency of lower bound arguments and solution procedures.

Kolisch and Hartmann (2006) provided an update to a 2000 survey of heuristics for the RCPSP and included a computational study to compare recently proposed methods. Shouman, Ibrahim et al. (2007) presented a study of fifty-five heuristic rules for single and multiple RCPSP and tested them on fifty test problems.

DRCPSP Approach: Resource Flow Networks

Leus (2007) investigated the relationship between resource allocation and earliest start-policies (scheduling policies for stochastic scheduling) and represented resource allocation decisions as resource flow networks.

DRCPSP Approach: Artificial Intelligence

Artificial intelligence applications, or agent methods, include developing a system that perceives and acts rationally (Russell and Norvig 1995). The ISIS/OPIS/CORTES system (Fox 1990) was developed and has been implemented in industry (Russell and Norvig 1995) and uses a hierarchical, least-commitment search to find plans that deal with a full range of real-world constraints. Since a feasible solution may not exist, constraints are systematically relaxed to find a solution that best satisfies the constraints. Resource constraints cause the scheduling process to switch back and forth between a job and a resource centered perspective. Agarwal, Tiwari et al.

(2007) applied an artificial intelligence based optimization technique known as Artificial Immunized System (AIS) to the deterministic RCPSP to minimize makespan.

DRCPSP Approach: Evolutionary Algorithms

Lancaster and Ozbayrak (2007) provided a review of evolutionary algorithms applied to the project scheduling problem and utilized the classification system proposed by Herroelen, Demeulemeester et al. (2001) to identify problems studied under each application. Shou (2006) provided an ant colony algorithm to coordinate resource allocation to improve net present values for resource constrained projects.

Genetic algorithms have been applied to many optimization problems, and are a promising metahureistic for the single-mode resource constrained project scheduling problem (Alcaraz and Maroto 2001), beginning with the methods initially developed by Hartmann (1998). There has been recent work in the literature that applies genetic algorithms to the RCPSP. Debels and Vanhoucke (2005) have developed a new genetic algorithm heuristic for the RCPSP by using a bi-population genetic algorithm (BPGA) with the left-justified and right-justified schedules as the populations. Kim, Yun et al. (2005) proposed a hybrid genetic algorithm with fuzzy logic controller to solve the multi-project version. Liu and Wang (2005) developed a genetic algorithm for the RCPSP to minimize activity cost and provided a hybrid genetic algorithm for the multi-project case (Liu and Li 2005; Liu, Wang, et al. 2006). The same research team also provided genetic algorithms to solve the classic RCPSP (Wang, Lin, et al. 2005b), as well as the cases with fuzzy task durations (Wang, Lin, et al. 2005a) and the multi-mode, mulit-objective case (Wang, Lin, et al. 2005c). Zhang, Li et al. (2006b; 2006c) used a

particle swarm optimization based approach. Valls, Ballestin et al. (2008) proposed a hybrid genetic algorithm (HGA) for the RCPSP that employs a two phased approach. Seda (2006) described a new technique to minimize duration for the RCPSP by transforming the problem into a sequence of multi-knapsack problem solutions and compared the results of applying a genetic algorithm to a simulated annealing approach.

DRCPSP Approach: Other Methods

The literature provides numerous examples of recent work by researchers taking creative approaches to the DRCPSP. Shou (2005) provided a feed-forward neural network to select suitable priority rules for each stage of project scheduling. Zamani (2004) provided a method of scheduling the RCPSP using time-windows, considered to be a set of sub-projects with its own constraints. Liess and Michelon (2008) provided a constraint programming approach to the deterministic version of the RCPSP by inserting a set of "sub-constraints" to prevent any set of activities scheduled to occur at the same time in which resource availability would be over the limit. Bonnal, Gourc et al. (2005) provided a linear scheduling formulation with resource and space constraints and demonstrated its application on a construction project where activities may be repetitive or with linear developments. Carlier and Néron (2007) enumerated redundant resources using redundant functions (related to the dual solution) and provide bounding for the problem that are shown to be useful for solving RCPSP. Cohen, Sadeh et al. (2005) presented a heuristic scheduling technique for the RCPSP that iterates all combinations of activities at each stage (one stage for each activity) forming a non-delay, feasible, efficient schedule. Savelsbergh, Uma et al. (2005) provided an experimental study of algorithms developed with the goal to

minimize average weighted completion time of scheduled jobs on one machine and extended the techniques to the RCPSP.

Stochastic Resource Constrained Project Scheduling Problem (SRCPSP)

The classic SRCPSP has the objective to minimize expected project duration with deterministic resource availability. Techniques to solve the problem include predictive scheduling – developing baseline schedules that protect the project duration, and reactive scheduling – providing managers with a plan for rescheduling in real-time with current information. The literature is dominated by methods to develop a robust baseline schedule. Some research into the timing of activity variability on overall project duration has shown that projects may benefit from efforts to reduce activity variability early rather than late in the schedule (Gutierrez and Paul 2001).

SRCPSP Measures of Performance

After an extensive study of the literature and experimentation, Selim (2002) introduced two sets of robustness measures for the SRCPSP and described them as duration-related and re-sequencing (or stability) related. The two duration-related measures compare the project duration of a modified base schedule with that of a perfect knowledge schedule, and the original baseline schedule. The four re-sequencing measures evaluated changed task start times, additional predecessors, changed predecessors, and both additional and changed predecessors.

Grey (2007) presented a new metric to account for changes in task start time by calculating the absolute value of differences between the corresponding start times of the

comparison schedules and using the average coefficient of variation of these differences as a performance metric.

Van de Vonder, Demeulemeester et al. (2007) described the stochastic resource constrained project scheduling problem's goal to make a project "quality robust", or insensitive to disruptions that affect performance metrics (most frequently makespan performance). They also suggested that project plans have stability or "solution robustness", which is the insensitivity of planned activity start times to schedule disruptions. The authors provided a set of stability metrics based on the ADFF - Activity Dependent Float Factor (Leus 2003; Van de Vonder, Demeulemeester, et al. 2005a).

Analytical Approaches to the SRCPSP: Predictive and Reactive Scheduling

The SRCPSP with stochastic task durations can be formulated as a multi-stage stochastic programming problem, and may be written as (Fernandez 1995):

Find a policy $\beta^*(\Psi_g)$ that

Minimizes $E(\max_i \; s_i + d_i)$

Subject to $s_i \geq s_j + d_j \,, \quad \forall_i \in I, \forall_j \in H_i, i \notin C_g, i \notin S_g$ (precedence constraints)

$$\sum_{i \in A_g} r_{ik} \leq b_k^{\,g} \;, \forall g, \forall k$$ (resource constraints)

$\beta^*(\Psi_g) \in n\,(\Psi_g)\,, \forall g$ (nonanticipativity constraint)

where,

$E(\bullet)$ = expected value of a random variable

r_{ik} = amount of resource type k required by activity i

b_k^g = total availability of resource type k at decision stage g

I = set of indices for the project tasks { 1, 2, … N }

N = the total number of tasks in the project

A_g = set of activities on-going immediately after the decision d_g at stage g

C_g = the set of completed tasks at decision stage g

S_g = the set of on-going at decision stage g

k = number of resource types

d_i = the duration of activity i, a random variable

Predictive Scheduling for SRCPSP

Robust project scheduling includes mathematical programming models for the generation of stable baseline schedules under the assumptions that the proper amount of resources can be acquired if booked in advance based on the pre-schedule and that activity disruptions (duration increases) may occur during schedule execution (Herroelen and Leus 2004a). The same authors also used a resource flow network resource allocation model that protects a given baseline schedule against activity duration variability (Leus and Herroelen 2004).

Stochastic task duration can be approached as a multi-stage decision process that uses so-called scheduling policies (Stork 2000). Scheduling policies have also been employed to minimize the expected project duration by developing multi-stage stochastic programming problems ((Fernandez, Armacost, et al. 1996), (Pet-Edwards, Selim, et al. 1998), (Fernandez, Armacost, et al. 1998)). Branch and bound methods have also been applied by both Igelmund and Radermacher (1983) and Stork (2000; 2001).

Al-Fawzan and Haouari (2005) provided a tabu search algorithm to generate a baseline schedule for the resource constrained problem with stochastic task durations to minimize makespan while maximizing robustness. However, Kobylanski and Kuchta (2007) questioned the methods in a note on their paper and provided their own definitions and methods of determining a robust schedule. They suggested fixing the makespan of the project and then determining a robust schedule for this fixed makespan. Their proposed robustness is measured by minimal free slack or the minimal ratio of free slack to activity duration as high as possible. Azaron, Perkgoz et al. (2005) evaluated the time-cost tradeoff with a multi-objective genetic algorithm that allocates resources as the decision variable while optimizing project cost, mean completion time, and the probability of the project exceeding a time threshold.

Ballestin (2007) evaluated when heuristic algorithms should be used to solve problems with stochastic task durations instead of working with the deterministic problem and provided heuristics to develop the baseline schedule when activity durations are given by a known distribution. The first algorithm is based on regret-based biased random sampling, that uses a Schedule Generating Scheme (SGS) by constructing different activity lists and a priority rule to calculate its possibility of being selected. The second is based on Hartmann's (1998) genetic algorithm and demonstrates the adaptability of this method to stochastic RCPSP. Ballestin and Leus's (2007) work continued in the development of a Greedy Randomized Adaptive Search Procedure (GRASP)-heuristic to develop baseline schedules for minimizing expected project makespan and evaluated the heuristic by studying the distribution of the possible makespan.

Deblaere, Demeulemeester et al. (2007) provided three integer programming-based heuristics and one constructive procedure to develop a baseline schedule and resource allocation plan for the RCPSP with activity duration variability to maximize stability.

Other approaches include that of Long and Ohsato (2007) who provided a genetic algorithm for the RCPSP with stochastic activity durations so optimal project duration is minimized. Shih (2006) proposed a greedy method for resource allocation to reduce completion time for the RCPSP with stochastic task duration.

DRCPSP Approach: Critical Path and Buffering Methods

Grey (2007) provided a detailed overview of Critical Chain and Buffer Management (CC/BM), its application for the RCPSP, and included a discussion of the CC/BM critiques. One concern is that the CC/BM technique generates a baseline schedule by solving the deterministic RCPSP and subsequently inserts buffers for robustness, instead of solving a stochastic RCPSP (Herroelen and Leus 2001), which may be an oversimplification of the problem (Herroelen, Leus, et al. 2002).

Most of the research encountered related to the use of buffers for project scheduling is in the job shop or machine scheduling literature and include time and resource redundancy (Grey 2007). Rabbani, Fatemi Ghomi, et al. (2007) developed a new heuristic for the RCPSP with stochastic task durations by using concepts from critical chain to determine the finish time of activities at certain decision points. Additionally, Van de Vonder, Demeulemeester, et al. (2006b) proposed a heuristic algorithm to protect the starting times of intermediate activities when multiple activity disruptions occur by adding intermediate buffers to a minimal duration RCPSP.

Kim and De La Garza (2005) proposed and evaluated the resource constrained critical path method (RCPM), that allows for the identification of alternative schedules by identifying the critical path and float data. Liu, Song, et al. (2006) proposed a multi-objective model for the

RCPSP and used a critical chain scheduling approach to insert feeding and project buffers into the approximate optimal project schedule to enhance stability. Grey (2007) suggested the possibility of using feeding and project buffers for the stochastic task insertion (STI) case as an area of future research.

Tukel, Rom, et al. (2006) have introduced two new buffering methods for determining feeding buffer sizes for applying critical chain project scheduling to the SRCPSP with stochastic task durations. One method uses resource utilization and the other uses network complexity.

Reactive Scheduling for the SRCPSP

Van de Vonder, Demeulemeester, et al. (2004; 2007) evaluated several predictive-reactive RCPSP procedures with the objective of maximizing stability and the probability of timely project completion. Herroelen and Leus (2005) described predictive-reactive scheduling techniques as those which repair a baseline schedule to account for unexpected events, and described the various reactive strategies a project manager may take. On one hand, a reactive effort may be a very simple schedule repair such as the right shift rule (Sadeh, Otsuka, et al. 1993) which will move forward in time all the activities that are affected and does not re-sequence activities. More complex techniques suggested by Herroelen and Leus (2005) include a full rescheduling of the remaining portion of the schedule. This full rescheduling action may be completed with a different set of objectives than those used to construct the original baseline schedule because an additional objective may include the minimization of deviations from the baseline schedule. The authors refer to this rescheduling case with new objectives as "ex post stability" measures of performance.

Variants of the SRCPSP

SRCPSP Variation: Stochastic Activity Interruptions

Many authors have recently researched the variation of the RCPSP with stochastic activity interruptions. This is the case where some activities may be interrupted for an uncertain amount of time (Valls, Laguna, et al. 1998; 1999). Lambrechts, Demeulemeester, et al. (2006) proposed and demonstrated the effectiveness of a tabu search procedure for the case of developing stable baseline schedules where disruptions may occur due to stochastic resource availability. The same research team inserted idle time in the project baseline schedule to protect it against possible disruptions caused by resource breakdown or unavailability (Lambrechts, Demeulemeester, et al. 2007a). The group's work also proposed exact and heuristic methods for optimizing a baseline schedule and proposed a new rescheduling heuristic that will take future uncertain availability of resources into account (Lambrechts, Demeulemeester, et al. 2007b).

Yang and Chang (2005) provided a model to schedule repetitive projects where resources are subject to uncertain resource supply. Van de Vonder, Ballestín, et al. (2007) provided a new heuristic reactive procedure to repair RCPSP baseline schedules where activities are disrupted. Zhu, Bard et al. (2005) proposed a classification scheme for different types of disruptions for the RCPSP and provided a formulation as an integer linear program.

SRCPSP Variation: Stochastic Resource Usage

Kis (2005) developed a branch-and-cut algorithm for finding an optimal solution for a resource constrained project scheduling problem in which resource usage of each activity varies over time.

SRCPSP Variation: Task Insertion Problems

The SRCPSP with stochastic task insertion (STI) is the case where the problem has deterministic task duration, resources, and costs, however some tasks will occur unexpectedly. Unplanned tasks were defined by Selim (2002) as routine (frequently occurring) or non-routine (infrequently occurring). Choi, Realff, et al. (2007) addressed a stochastic RCPSP with dynamic project arrivals with the added flexibility of project cancellation and resource idling. A Q-learning-based approach was used to solve the problem and the problem was formulated as a Markov Decision Process with defined states to develop a set of empirically learned state transition rules from simulation data.

Many of the problems dealing with task insertion are in the area of job-shop scheduling, where an unexpected task appears with a due date, and a project manager must decide the best way to accomplish this unexpected task given the current work plan. Reactive scheduling techniques include a polynomial activity insertion algorithm to reschedule when an unplanned activity occurs by evaluating insertion positions (Artigues and Roubellat 2000; Artigues, Michelon, et al. 2003). This insertion method is computationally superior to the rescheduling method, and the mean increase of schedule makespan is improved over rescheduling. Duron and Proth (2004) and Duron, Proth, et al. (2001; 2005) proposed the problem of single machine

(resource) and a set of tasks, each with a defined duration and due-date. These methods insert an unexpected task into the task sequence as to minimize the sum of activity delays. Gröflin and Klinkert (2007) and Gröflin, Klinkert et al. (2008) developed methods to enumerate feasible job and block insertions for the job shop problem, multi-processor task, and no-wait job shop where makespan is minimized. Ourari and Bouzouia (2003) addressed a one-machine real-time scheduling problem and characterized an insertion position to satisfy the time constraints and optimize the number of tasks executed.

SRCPSP with Stochastic Task Insertion – Summary of Recent Research

As discussed previously, existing performance measures did not address flexibility for unplanned work until Selim (2002) developed robustness measures for the SRCPSP with STI. One set of measures were project duration related, comparing the actual "as-run" work schedule (modified base) to the optimal (perfect knowledge) schedule and the original (baseline) schedule. The optimal (perfect knowledge) schedule assumes perfect knowledge of all tasks that occurred or did not occur after the fact. Another set of measures were re-sequencing related and considered the number of tasks whose start times varied between the modified base and perfect knowledge schedule.

Using these measures, Selim (2002) tested the effect of network factors on robustness including: network topology (order strength and complexity index), resource characteristics (resource factor and resource constrainedness), the location of the stochastic occurrence in the network (early or late), and the number of stochastically occurring tasks (high or low).

RanGen software developed by Demeulemeester, Vanhoucke, et al. (2003) was used by Selim to generate network instances of 32 tasks with order strength (OS), resource factor (RF)

and resource constrainedness (RC) as defined by Selim. RanGen generates random problem instances spanning the full range of problem complexity, and it has been proven by several studies to provide networks with complexity measures that are strongly related to the hardness of resource-constrained project scheduling problems (Van de Vonder, Demeulemeester, et al. 2006b). Selim constructed a full-factorial design for the high and low levels of network and resource parameters (four combinations), generated 30 schedules for each, and randomly selected 5 from each combination for study. This allowed Selim to experiment with the high and low settings of stochasticity and location of the stochastic events in the schedules. Selim applied two baseline scheduling techniques: optimistic (where none of the stochastically occurring tasks were scheduled) and pessimistic (all of the stochastically occurring tasks were scheduled). After identifying which tasks occurred for the optimistic case, a "right-shift" rescheduling policy was implemented to shift all tasks to the right to provide resources and ensure precedence constraint compliance for the unplanned work. Likewise, when tasks did not occur for the pessimistic case, a "left-shift" rescheduling policy was implemented to shift all tasks to the left to ensure minimization of project duration.

Selim's work provides insights into how the research factors studied affect schedule robustness. This type of information was intended to be used for guiding the development of heuristics for robust scheduling techniques for the SRCPSP with STI. When comparing results of the optimistic and pessimistic baseline scheduling techniques, Selim concluded that including more stochastic tasks in the schedule would generally lead to a more robust schedule. The other factors studied led Selim to the following conclusions: a schedule is more robust when the stochastic tasks occur earlier rather than later in the schedule, a high level of resource utilization leads to a less robust schedule, and fewer precedence constraints leads to a less robust schedule.

Inspired by Goldratt's (1997) concept of inserting buffers to protect a project schedule, Grey (2007) provided an extension of Selim's (2002) work on the SRCPSP with STI. Grey studied seven new buffer sizing techniques for this problem case: three were a fixed percent of task duration, and four were variable based on the location of stochastic tasks and task stochasticity characteristics. Grey replicated Selim's networks to provide a comparison of results among the methods, and also developed a new measure of robustness to account for the absolute difference in task start times between the schedules. Results allowed Grey to conclude that the four partial buffering heuristics which incorporated knowledge of the stochasticity of the tasks were improvements over the extreme (optimistic and pessimistic) approaches studied by Selim (2002). Additionally, it was demonstrated that the two best performing variable sizing techniques incorporated knowledge task location in the optimal sequence, and the fixed 50% buffer sizing rule provided similar results.

The literature review provided above has been summarized and organized in a graphical display in Appendix A. The right side of the graphic shows the recent work and researchers in the field of resource constraint project scheduling. The left side of the graphic shows the current research on stochastic project scheduling. Note that the research selected for highlighting in these two areas relate to the current research that is being conducted on the SRCPSP. Toward the bottom right of the graphic, the STI case is shown as case of the SRCPSP. Chapter 3 continues the literature review by highlighting specific areas in the literature that provide justification for research on the SRCPSP with STI.

CHAPTER THREE: RESEARCH JUSTIFICATION

The goal of this research is to expand upon the body of knowledge of the stochastic resource constrained project scheduling problem with stochastic task insertion. This includes:

- Metrics: introduce and develop new metrics for stochastic project scheduling associated with resource usage including efficiencies, utilization, idle time, and flow (resource hand-off)
- Predictive procedures: develop and test new buffering techniques that use information about resource usage or a priori knowledge about the probability of task occurrence to determine buffer sizing
- Reactive procedures: examine the effectiveness of rescheduling polices using new metrics and already established metrics of performance. The rescheduling policies to be examined include the right-shift and left-shift heuristic described by Selim, and new heuristics that re-optimize the schedule at certain decision points. This research will also assess predictive and reactive scheduling techniques that are most appropriate for networks of varying characteristics.

This chapter will elaborate on specific areas in the literature that provide justification for research into the areas listed above, and discuss the tools available for conducting this research.

Performance Metrics

Definitions

In the discussion of metrics, it may by helpful to establish the vocabulary associated with the metrics. The terms referred to in the next sections follow.

Definition of Schedule Types

The initial schedule provided at the start of a project before work begins is referred to in the literature as the **predictive** (Mehta and Uzsoy 1998), **proactive** (robust) (Herroelen and Leus 2005), **static** or **offline** (Leus 2007), **initial base (IB)** (Selim 2002), and **infeasible base** or **baseline** (Grey 2007) schedule. This research will refer to this schedule as the initial baseline (IB) schedule.

Modifying the initial baseline schedule during project execution is referred to in the literature as **reactive** (Herroelen and Leus 2005) or **dynamic** (Leus 2007) scheduling or **schedule repair** (Herroelen and Leus 2004b). The **modified base (MB)** (Selim 2002) schedule is also referred to the **as-run** (Grey 2007) schedule and represents the reported schedule after project completion. In Selim's and Grey's case, this schedule was the result of either right or left-shifting tasks as stochastically occurring tasks eventuate (either occur or do not occur). This research will refer to this as the modified base (MB) schedule.

The perfect knowledge (PK) schedule refers to the schedule containing the optimal task order (minimized makespan) if all uncertainty was known at the beginning of the project.

Definition of Performance Measures

The objective function for the SRCPSP is usually to minimize project duration; however, it is often appropriate to define alternative objectives, such as stability costs, including financial costs, inventory costs or various organizational costs associated with deviations from a project plan used to organize resources and negotiate contracts with subcontractors (Van de Vonder, Demeulemeester, et al. 2006b). Metrics in the literature that address how well a scheduling policy meets the objective of minimizing project makespan include **duration-related** (Selim 2002), **makespan**, and **quality** robustness (Herroelen and Leus 2004b). Those metrics which refer to changes within the schedule itself are referred to as **re-sequencing** related (Selim 2002), **stability** (Grey 2007), and **solution** robustness (Herroelen and Leus 2004b) . "Duration" and "stability" will be used here.

Description of Current Performance Metrics

Measures Developed by Selim and Grey

After an extensive study of the literature and experimentation, Selim (2002) introduced two sets of robustness measures for the SRCPSP and described them as duration-related and re-sequencing-related (stability). The two duration related measures compare the project duration of a modified base schedule with that of a perfect knowledge schedule, and the initial baseline schedule. The four stability measures evaluated changed task start time, additional predecessors, changed predecessors, and both additional and changed predecessors. Selim (2002) referred to these by the below numbering sequence:

- RM1: The percentage change in duration from the modified base (MB) to the perfect knowledge (PK)
- RM2: The percentage change in duration from the initial base (IB) to the modified base (MB)
- RM3: Count of tasks with changed start times from the modified base (MB) to the perfect knowledge (PK)
- RM4: Count of tasks with a changed preceding tasks from the modified base (MB) to the perfect knowledge (PK)
- RM5: Count of tasks with additional preceding tasks in the modified base (MB) than the perfect knowledge (PK)
- RM6: Combination of RM4 and RM5

Grey (2007) introduced two additional metrics (one for duration, and one for stability). We continue the numbering system developed by Selim here for ease-of-reference.

- RM7: The percentage change in duration from the initial baseline (IB) to the perfect knowledge (PK).
- RM8: The coefficient of variation (for all tasks in the project) of the absolute difference in task start times between the perfect knowledge (PK) schedule and the initial baseline (IB) schedule. (The average over the five networks studied in each resource and network parameter combination was computed to evaluate the stability metric.)

Other Measures

The Grey and Selim performance metrics focused on duration and stability. However, it is appropriate to develop new metrics to judge the performance for the objective of newly developed scheduling heuristics. For example, if the objective of a new heuristic is to develop an initial baseline resource flow plan as close as possible to the perfect knowledge or as-run schedule, then a new metric that measures the change in the resource flow is appropriate. Another example is if a heuristic is developed to minimize cost associated with a task change time, such as the ADFF method by Van de Vonder, Demeulemeester, et al. (2005b). In this case, the total cost incurred for moving from the baseline to the modified base would be an appropriate measure.

There may be a different objective of the rescheduling heuristic than there is for the original predictive scheduling technique used to develop the initial baseline. Van de Vonder, Demeulemeester, et al. (2004; 2007) evaluated several predictive-reactive RCPSP procedures with the objective of maximizing stability and the probability of timely project completion. Herroelen and Leus (2005) described predictive-reactive scheduling techniques as those that repair a baseline schedule to account for unexpected events, and described the various reactive strategies a project manager may take. On one hand, a reactive effort may be a very simple schedule repair such as the right shift rule (Sadeh, Otsuka, et al. 1993) which will move forward in time all activities affected and does not re-sequence activities. More complex techniques suggested by Herroelen and Leus (2005) include a full rescheduling of the remaining portion of the schedule. This full rescheduling action may be completed with a different set of objectives than those used to construct the original baseline schedule because an additional objective may

include the minimization of deviations from the baseline schedule. The authors refer to this rescheduling case with new objectives as "ex post stability" measures of performance.

Other optimization criteria for reactive procedures besides minimized makespan include net present value (NPV) maximization (Bey, Doersch, et al. 1981), or cost minimization (CM), which is often applied to the multi-mode case (Al-Fawzan and Haouari 2005). Additional objectives include the minimization of weighted tardiness time and the minimization of weighted resource consumption costs (Ozdamar and Ulusoy 1995).

Selim (2002) suggested for future research of the STI case the comparison of the resource utilization of two schedules, such as evaluating the resource utilization during each time period in the schedule for the initial baseline schedule and the modified base schedule.

Predictive Scheduling Methods

The duration robustness measures established by Selim (2002) and Grey (2007) provide the opportunity to explore additional predictive scheduling heuristics, or methods that would provide a robust initial baseline schedule. Grey (2007) was the first researcher to apply a buffering technique to the SRCPSP with STI. The buffering methods explored include seven new buffer sizing techniques for this problem case: three were a fixed percent of task duration, and four were variable based on the location of stochastic tasks and task stochasticity characteristics. Grey replicated Selim's networks and results allowed Grey to conclude that the four partial buffering heuristics which incorporated knowledge of the stochasticity of the tasks were improvements over the extreme (optimistic and pessimistic) approaches studied by Selim (2002). Additionally, it was demonstrated that the two best performing variable sizing

techniques incorporated knowledge of the optimal sequence of tasks, and the fixed 50% buffer sizing rule provided similar results. The following sections discuss ways in which the opportunity exists to expand upon this body of knowledge of applying buffer sizing methods for the SRCPSP with STI.

Buffers that Incorporate the Probability of Occurrence

If uncertainty in the environment can be quantified, this information can be used by a proactive scheduling technique (Davenport and Beck 2002). It would be appropriate to explore a different buffering approach if a probability of occurrence was specified for each stochastic task. This approach may use some of the concepts of the resource flow-dependent float factor (RFDFF) approach, as well as the other predictive heuristics that this method was benchmarked against by Van de Vonder, Demeulemeester et al. (2006b). These heuristics base buffer sizing on several factors including the variability of duration of each task, its predecessors, and its successors.

Buffers that Incorporate Resource Knowledge

Grey's (2007) research examined new buffer sizing techniques (referred to as JG5 and JG6) that allocate a larger percentage of buffers to the stochastic tasks that occur later in the optimal sequence. When resource parameters for a network are low, the JG6 method produced the best results for duration metrics. However, the 50% buffering approach performed best for networks with high resource parameters. This suggests that resource parameters have an effect on the best buffering technique for that network, and therefore considering resources in buffer

sizing may be an advantage. Grey (2007) explicitly suggested that new buffering rules may incorporate knowledge of resource requirements. In general, if a task has a high level of resource utilization, it is more difficult for a project manager to incorporate this task if it unexpectedly occurs. Varying buffer sizes based on the tasks' resource utilization may help account for the impact the stochastic task may have on the real-time schedule.

Kim and De La Garza (2005) proposed and evaluated the resource constrained critical path method (RCPM), that allows for the identification of alternative schedules by identifying the critical path and float data. As opposed to explicitly inserting buffers, this method identifies "phantom float" - the difference between the total float based solely on precedence constraints and the real remaining total float considering resource constraints. This information is used as part of a process that identifies the resource "links" or hand-offs of resources between activities for planning purposes. This also provides managers with the list of tasks that will not affect overall project duration in the case of unexpected longer duration, and is referred to as a set of alternative schedules. Although this is not a buffering method, the concepts used by these authors are interesting in that relationship between resource usage and float is examined. These researchers' work supports the direction of resource usage to help determine buffer sizing.

Additionally, Tukel, Rom, et al. (2006) have introduced two new buffering methods for determining feeding buffer sizes in critical chain project scheduling for the SRCPSP with stochastic task durations. One method uses resource utilization and the other uses network complexity to determine appropriate feeding buffer sizing. These methods support the use of resource knowledge to build buffer sizing techniques applied to the SRCPSP with STI.

Reactive Procedures

There have been many heuristic solutions proposed, including those that offer a full-rescheduling option, depending on the project objective function (Demeulemeester and Herroelen 2002; Herroelen and Leus 2004b)). Schedule repair includes simple control rules such as a right-shift rule (Sadeh, Otsuka, et al. 1993) which involves moving activities affected by the schedule breakdown forward in time. However, Herroelen and Leus (2004b) warn that this reactive strategy may lead to poor results, since it does not re-sequence activities.

Right and Left Shift Schedule Repair Procedures

Leon, Wu, et al. (1994) cited two advantages of using a right-shift policy. First, its implementation is simple and second, deviation is minimized (where deviation is defined as the difference in activity sequence). Selim (2002, pg. 48-53) described the details of implementation in the STI case as follows:

The schedule is evaluated at each time period and if a stochastic activity occurs at a certain time period it is inserted into the schedule as soon as resources are available and the precedence relations are not violated. The steps are outlined below:

- *Start with the optimistic schedule and create a Gantt chart.*
- *Determine which of the stochastic tasks occur and the sequence of their insertion in the optimistic schedule. The insertion sequence is determined by the sequence of tasks in the list of successors. The order of insertion is as follows:*
- *The stochastic task should be inserted as early as possible after the predecessor activity is finished without violating the resource and precedence constraints. The*

list of successors is used to determine the earliest point at which an activity can be started

- *The sequence of the tasks in the optimistic schedule should be maintained.*
- *If two tasks can be inserted at the same time period, start with the task with the lower sequence number.*

Selim (2002) also provided a detailed implementation description for a left-shift repair of the STI case as follows:

- *Start with the pessimistic schedule and create a Gantt chart.*
- *Remove the stochastic tasks that do not occur from the Gantt chart representing the pessimistic schedule.*
- *Starting from time period 1, determine which of the tasks that do occur can be started earlier, that is, shifted to the left, while keeping track of the precedence and resource constraints. The sequence of tasks in the pessimistic schedule should be maintained as much as possible.*
- *The schedule sequence can be altered only if there are resources available to schedule a task different from the immediate successor of the stochastic task.*
- *The list of successors was used to determine the earliest point at which an activity can be started if one or more of its predecessors have been eliminated.*
- *If two tasks start at the same time period and they can both be shifted to the left in the compressed pessimistic schedule, start with the task with the lower sequence number.*

The reactive procedures used by Grey (2007) assume a left-shift procedure when removing tasks that did not occur and a right-shift procedure when inserting tasks. Both of these procedures maintain the order of tasks as similar as possible to the initial baseline schedule.

Rescheduling Repair

Herroelen and Leus (2001) and Herroelen and Leus (2004b) used a CC/BM buffering approach and evaluated rescheduling based on two techniques for the SRCPSP with stochastic task durations. They defined a schedule update as the time instant at which it becomes known that one or more activities deviate from their estimated duration. A buffer management technique was also examined; this technique takes corrective action when an activity variation consumes a buffer by a pre-determined amount. It was found that regularly updating the baseline schedule and project buffer during execution is beneficial to the re-evaluation of the probability of meeting project due date; i.e., it provides better intermediate estimates of the final project makespan.

This research proposes that project managers re-schedule at some decision point, such as the half-way point. For example, one flag to prompt re-scheduling might be a resource buffer that is consumed by a certain percent. A reactive procedure that allows for the reordering of tasks may produce shorter duration schedules and change the conclusion of which is the best predictive procedure.

Available Tools for Experimental Design

Network Test Sets

There are many resources available to develop networks needed to experiment on factors described above.

Patterson Test Set

The Patterson test set consists of one hundred and ten test problems gathered by Patterson (Patterson 1984) for the purpose of comparing exact procedures for solving a multiple constrained resource project scheduling problem. The number of activities varies between 7 and 50, while the number of resource types required per activity varies between one and three. The problems represente an accumulation of all multi-resource problems that existed in the literature at the time (1984), and had several contributors.

Advantages are that this problem set is readily available on the website http://129.187.106.231/psplib/, although some methods are needed in order to adapt the problem to the STI case. This test set is a widely used test set and the performance of newly developed heuristics on this test set may be of interest to other researchers.

A disadvantage of using this problem set is that it has not been used on the SRCPSP with STI, so the methods of Selim and Grey would need to be duplicated in order to compare results with their methods. Another disadvantage of using this test set is that this test set will not allow for a designed experiment with various factor settings, since it is simply a compilation of test problems with "random" characteristics.

The inference space using this test set is small since there are a limited number of problems with various factor settings. However, it would be informative to see if any new methods developed provide different results than the methods of Grey and Selim across the entire set.

RanGen Network Generator

The RanGen network generator (Demeulemeester, Vanhoucke, et al. 2003) allows for the generation of networks with various settings for network and resource parameters. Resource parameters consist of **resource factors**, defined as the average number of resource types requested by each activity and **resource constrainedness**, defined as resource availability divided by the available number of that resource. Network parameters include **order strength (OS)**, defined as the number of precedence relations divided by the theoretical maximum number of precedence relations (Mastor 1970) and **complexity index (CI)**, defined as: "the minimum number of node reductions sufficient (along with series and parallel reductions) to reduce a two-terminal acyclic network to a single edge"(Demeulemeester, Vanhoucke, et al. 2003).

There is a relationship between the order strength and complexity index of a network. To assist users in understanding this relationship when developing a full factorial experiment, Demeulemeester, Vanhouke, et al. (2003) provided a table describing the range of complexity index values generated in at least 10 instances within one hour of processing for each level of order strength and number of activities.

This type of detailed information about the structure of networks for experimenting is a great advantage when using this tool. Demeulemeester, Vanhoucke, et al. (2003) described how

this can be used in the development of an experiment with these factors. The inference space when using this network generator has the capability to be much larger since a factorial experiment can be designed so that each factor and their interactions are tested for significant effect on the performance measures.

ProGen network generator

The J30, J60, J90 and J120 are standard sets of problems that were generated with the ProGen network generator application (Kolisch and Sprecher 1997), and are available on the website http://129.187.106.231/psplib/. The advantage to using these problem sets is that they are frequently used by other authors to test both predictive and reactive heuristics. Should a new reactive procedure be developed, it can be tested on problem sets to compare performance to other researchers' heuristics.

The J30, J60, and J90 problem sets all have 480 problems that were developed with a full factorial design of the following factors: **Network complexity** (the average number of non-redundant arcs per node – 3 settings), RF (the **resource factor** reflecting the average portion of resources in a category – 4 settings) and RS (**resource strength** is for renewable resources the lowest availability level allowing resource feasibility – 4 settings) and are run for 10 replications (Kolisch and Sprecher 1997). The J120 problem set has 600 problems with 5 setting levels for resource strength (Kolisch and Hartmann 2006).

Experimental Factors

Examples from Literature

There are examples in the literature of other researchers developing experiments to study the effects of heuristics on various networks. An example of a recent study was conducted by Van de Vonder, Demeulemeester et al. (2006b) who provided an "extensive simulation experiment" to investigate the trade-off between quality (project duration) and solution (stability) robustness for the SRCPSP with stochastic task duration. Although the problem focus here is the SRCPSP with stochastic task insertion, ideas for the experimental design technique and factors studied may be gained here.

These researchers used RanGen to develop a set of networks with three factor settings of Low/Medium/High as described below:

- Number of tasks: 10/20/30
- Order Strength: 0.3/0.5/0.7
- Resource Factor: 0.5/0.75/1.0
- Resource Constrainedness: 0.3/0.5/0.7

100 networks are generated for each combination of these factors. Next, weights from 0-4 were applied to each task in a uniform distribution indicating the cost of one time unit of early/lateness; w_p is the weighting parameter between 0-15 as the dummy end weight. Activity durations were simulated with right skewed beta distribution (min=0.5*baseline, mean = baseline, max =2.25*baseline).

A full factorial experiment on the combinations above compared the results of using CC/BM (to minimize project makespan) and the Resource Flow Dependent Float Factor (RFDFF) (to maximize stability). The CC/BM buffer sizing methods included a project buffer as a percent (0%, 30%, 50%) of critical chain length, and feeding buffers as a percent (0%-100%) of critical chain length added to critical chain length. Their reactive heuristic preserved the resource flow between activities and plan as early as possible. The metrics used to evaluate the methods were quality (probability project will end on time) and stability (weighted sum of deviations between planned and actual activity start times).

Experimental Factors for Study of the SRCPSP with STI

Using newly developed robustness measures, Selim (2002) tested the effect of network factors on robustness. The two network topology factors studied were order strength and complexity index. The two resource characteristics were resource factors and resource constrainedness. These network characteristics were then combined with the location of the stochastic occurrence in the network (early or late), and the number of stochastically occurring tasks (high or low). Factors studied by Selim (2002) and Grey (2007) are included in Table 1.

Table 1: Summary of Factors Studied on the STI Case

Studied by Selim (2002)	
Network characteristics	Network topology (high or low) Resource requirements (high or low)
Stochastic task characteristics	Timing of stochastic tasks (early or late) Number stochastic tasks (high or low)
Methods to develop a baseline schedule (predictive)	Optimistic (initially schedule no stochastic tasks) Pessimistic (initially schedule all stochastic tasks)
Studied by Grey (2007) (in addition to all the above)	
Methods to develop a buffered baseline schedule (predictive)	3 fixed sized buffers and 4 incorporating duration, number, and location of stochastic tasks

The experimental process followed by Selim (2002) was to first develop a set of testing networks. The problems that were selected for study had 32 tasks and 2 types of renewable resources, with 10 available of each. RanGen software accepted the network order strength and complexity index as well as resource factor and constrainedness as input parameters. Once RanGen produced 30 networks of each type, Selim selected 5 for study as shown in the following table with a selected identification numbering scheme.

Table 2: Network and Resource Parameters Studied (Selim, 2002)

	Resource Parameter			
Network Parameter	Low	Network No.	High	Network No.
Low	OS = 0.40 CI = 13 RF = 0.40, 0.45, 0.50 RC = 0.25	1004 1010 1015 1020 1028	OS = 0.40 CI = 13 RF = 0.75, 0.80, 0.85 RC = 0.75	1102 1105 1112 1119 1127
High	OS = 0.85 CI = 21 RF = 0.40, 0.45, 0.50 RC = 0.25	1200 1201 1212 1222 1225	OS = 0.85 CI = 21 RF = 0.75, 0.80, 0.85 RC = 0.75	1300 1304 1308 1314 1325

The optimal task order (minimized duration) was determined for each network using the DH algorithm software application (see Chapter Four for additional details on this application). A "stochasticity index" developed by Selim (2002) for each task was then calculated as follows:

$SN_m = 0.5(d_m) + 0.25(r_1) + 0.25(r_2)$

where,

SN_m =stochastic number for task m

d_m = duration of activity m

r_1 = total availability of resource 1

r_2 = total availability of resource 2

Tasks with the highest stochasticity index numbers were considered to be stochastic. Once those potentially stochastic tasks were identified, Selim considered four different variations for each network depending on location and number of stochastic tasks, for a total of (4x5) 20 networks within each network/resource parameter combination:

- Early, low: four stochastic tasks occur in the first half of the network
- Late, low: four stochastic tasks occur in the last half of the network
- Early, high: eight stochastic tasks occur in the first half of the network
- Late, high: eight stochastic tasks occur in the last half of the network

Selim then constructed two different initial baseline schedules for each network variation, called the "optimistic" schedule and the "pessimistic" schedule. The pessimistic schedule contained all of the stochastic tasks and the optimistic contained none, and were solved using the DH algorithm software. Finally, to mimic a real-world scenario, Selim then applied a schedule repair policy by left-shifting (on the pessimistic schedules) and right-shifting (on the optimistic schedules) tasks that occurred or did not occur. These modified base schedules were then compared to the initial baseline schedules and the perfect knowledge schedules.

In order to test new buffering approaches for developing the initial baseline schedules, Grey (2007) replicated Selim's entire study. In addition to employing an optimistic and pessimistic method to develop the initial baseline schedules, Grey developed and tested the following buffer sizing methods:

- Three fixed buffer sizes (10%, 30%, and 50%) were applied to tasks that had been identified as stochastic tasks.

- JG3 = (Duration of Current Stochastic Task)/(Sum of all Potential Stochastic Task Durations)
- JG4 = (Task Stochastic Number) x (JG3)
- JG5 = (Current Stochastic Task Duration) x (1 - % of Total Project Activity Time Remaining)
- JG6 = (Current Stochastic Task Duration) x (1 - % of Total Potential Stochastic Task Activity Time Remaining)

Grey then applied a combined right/left-shift schedule repair policy to the eventuated schedules and compared the results of these buffering methods to Selim's optimistic/pessimistic method of initial baseline development.

The factors for the current research include the above factors in addition to introducing and examining new buffering techniques and the effectiveness of rescheduling polices.

Summary of Research Plan

Chapter Two has demonstrated there is currently a very active research environment in the areas of stochastic scheduling and resource constrained project scheduling, including the complex problems associated with the combination of these two problem types: the stochastic resource constrained project scheduling problem (SRCPSP). The current "state of the art" research concerning this problem and related problems has been outlined in Chapter Three, accompanied by a description of areas where opportunities exists to contribute to the body of knowledge. Specifically, it was demonstrated that there is a need for further research on the stochastic task insertion case of the stochastic resource constrained project scheduling problem

and the justification for proceeding with research on the development of: new metrics associated with resource usage including efficiencies, utilization, idle time, and flow (resource hand-off), new buffering techniques that use information about resource usage or a priori knowledge about the probability of tasks occurrence to determine buffer sizing, and new rescheduling polices. As described in Chapter Four, tools such as SAS can be used to develop an initial study that will guide the direction of research and the development of specific research factors.

CHAPTER FOUR: RESEARCH IMPLEMENTATION

The goal of this research is to expand upon the body of knowledge on the stochastic resource constrained project scheduling problem with stochastic task insertion, and the research findings of Selim (2002) and Grey (2007) on the SRCPS problem with STI. The current "state of the art" research concerning this problem and related problems have been outlined in Chapter Two, followed by additional descriptions of areas where opportunities exists to conduct further research and available tools for implementation in Chapter Three. This chapter describes in detail the process that was used to conduct this research as well as the development of resource metrics.

Tools for Experimentation

The implementation of this research includes extensive use of software, including: the RanGen network generator to generate test cases, the DH procedure application to solve schedules, SAS software v 9.1.3 including SAS/OR, and Excel software for tracking data, formula writing, and chart building. All work was implemented in a Windows environment, which allows for SAS to integrate with other enterprise solutions (SAS Institute. 2004). Base SAS code is written to control the Windowing environment and to work with data sets using basic coding logic. SAS/OR provides a suite of tools within SAS to solve networks, linear programs, and any other optimization problems as needed. SAS is also used at the end of test runs to collect data, compute metrics, and compare schedules. Statistical methods are available, including univariate analysis, analysis of variance, calculation of correlation coefficients, tests of hypothesis, and most other commonly used procedures.

Extending the research of Selim (2002) and Grey (2007) required some automation of a schedule repair policy in order to allow for repeatable processes. In order to investigate the applicability of SAS for this research, replication of the processes used by Selim (2002) and Grey (2007) were established using SAS software. Writing code in the Base SAS environment provides similar capability (including loops, arrays, and function generation) as the C or Microsoft Visual C++ coding language, which has been employed recently by other researchers to implement heuristic testing (Van de Vonder, Demeulemeester, et al. 2007).

In addition to writing code within SAS software, SAS/OR has four procedures for planning, controlling, and monitoring projects. Specifically, the CPM procedure is used for scheduling project activities subject to precedence, time, and resource constraints, allowing the user to choose from a variety of options to control the scheduling process.

Table 3: Relevant SAS Data Sets for Use with PROC CPM

Relevant Input Data Sets for PROC CPM:	
Activity Data Set	contains all activity-related information including activity name, precedence information, calendar, progress information, baseline (or target schedule) information, resource requirements, and time constraints
Resource Data Set	contains resource types, availabilities, priorities, and if any alternate resources exist
Relevant Output Data Sets from PROC CPM:	
Schedule Data Set	contains the early, late, baseline, resource-constrained, and actual schedules
Resource Schedule Data Set	contains the schedules for each resource used by an activity
Usage Data Set	contains each resource's usage

Determining Appropriate Software to Solve Resource Constrained Project Schedules

Before experimentation began, the first step was to determine the appropriate software to conduct experiments on the different predictive and reactive procedures for scheduling the

SRCPSP with STI. Jennifer Grey (2007) and Basma Selim (2002) used an executable DOS application developed by Demeulemeester and Herroelen (1992), referred to as the DH-procedure and is described below. Although this application allows for the capability to solve many problems at once, some limitations include the inability to control the DOS application with Windows commands, because it was only available as an executable file. For example, any iterative processes would have to be done manually (one schedule at a time), which may have become restrictively time consuming, particularly for any simulation experiments. Alternatively, SAS, a commercially available software, can also solve the RCPSP. SAS has a Windows based application that allows for custom coding and relative easy control of the Windows environment. The use of both applications was fully explored, as described below, before finally selecting SAS to proceed with the research.

DH-Procedure Application Scheduling Heuristic

The DH-procedure is a branch-and-bound procedure that employs a "depth-first" solution strategy developed by Demeulemeester and Herroelen. A description of the heuristic used to solve the RCPSP is provided by the researchers (Demeulemeester and Herroelen 1992) and is summarized below.

The nodes of a branch-and-bound search tree correspond to a set of feasible (satisfying both precedence and resource constraints) partial schedules in which finish times have been temporarily assigned to a subset of actives. These subsets include S_m - activities in progress, U_m - unfinished activities, E_m - an eligible set of activities not in the partial schedule and whose predecessor activities have finished. Partial schedules PS_m are considered at every decision point

m which corresponds with the completion of one or more activities. The partial schedules consist of a set of temporarily scheduled activities because they may be delayed as a result of decisions made later in the search process. Partial schedules are constructed by starting at time zero and proceeding systematically throughout the search process by adding subsets of activities at every decision point. The depth-first strategy employed by the DH-procedure does not sort the list of eligible activities. Instead, a delaying set is constructed which contains all the combinations of activities (eligible or in progress) for which delays release enough resources to resolve the resource conflict and combinations are minimal. This generation of minimal delaying alternatives must be exhaustive in order to guarantee optimality.

The DOS application containing the DH-procedure provided by Demeulemeester and Herroelen contains a user option to change maximum computational time. Initial investigation using this application revealed that changing the maximum computational time may affect the final resulting schedule, although increased computation time does not guarantee a better solution (in terms of project duration). In fact, there was a case documented where increasing computational time resulted in a solution with longer project duration than a run with a shorter computational time. Note that the executable DH-procedure code was the first version that was developed. A later version using 32-bit coding is not available.

SAS PROC CPM Scheduling Heuristic

SAS PROC CPM uses a serial-parallel method of scheduling to solve a resource constrained schedule. The name of this heuristic describes itself as being "serial in time and

parallel in activities". A description of the heuristic that SAS PROC CPM uses is provided in SAS documentation (SAS Institute 2006), a summary of which follows.

An initial tentative schedule is determined without considering resource constraints, with each activity scheduled to start as early as possible (*e_start*). To correct for resource constraints, time is set equal to the earliest *e_star*t. All activities with *e_star*t equal to time are sorted in a priority order based on their latest start, which is the latest time the activity can be started based on its successor activities' start times. Starting with the earliest of the latest starts, the activity is scheduled to start if enough resources exist. If not, the activity is postponed. If, or when, all the activities on the waiting list are postponed, their new tentative start time (*e_start*) is set to the next time when there is a change in resource availability. The value of time is then set to the earliest *e_start* of these waiting activities, and the process repeats until all activities are scheduled, or an error occurs.

While there are no options within the SAS system such as stopping criteria or increased processing time that may help improve its solutions, there are user-input priority rules that may be changed (such as longest duration, most work remaining, or most slack). There are also some file size options, such as telling SAS how many predecessor constraints, activities, or resources there are. One may also specify to not use a utility table when memory is too full, or if the number of constraints exceeds the number specified (option NOUTIL). These options may have an effect on the final solution or processing time.

Comparing Results Using DH-Procedure Application and SAS PROC CPM

Before selecting the software for experimentation, a comparison of the results from the DH-procedure application and SAS PROC CPM was created. The comparisons were made by solving several sets of problems with each application separately. The experimental problems sets are the Selim set, the Patterson set, J30, J60, J90, and J120 (see Chapter Three for a full description of these data sets). The DH-procedure application solved the Selim, Patterson, and entire J30 set instantly (in a batch run). However, it was unable to solve the J60, J90, and J120 problems in batch and the majority of several randomly selected ones individually. SAS PROC CPM was able to also very quickly solve the Selim, Patterson, and J30 set. Solutions to the J60, J90, and J120 were provided by SAS in a run that took less than 5 minutes for each set. The project durations resulting from the DH and SAS solutions were then compared for each of the Patterson, Selim, and J30 and summarized in the following sections.

Selim Set

When solving the 20 networks in the Selim set, SAS PROC CPM identified a schedule with the same duration as the DH procedure for 11 of the networks. There were no cases where SAS has found a shorter duration solution than DH. Finally, there are 9 cases where DH finds a better solution than SAS. Of those 9 cases, 7 have high settings for resource parameters, which may indicate an interaction between the resource settings and the ability of DH to find a better solution. Table 4 below summarizes the results and indicates which application has found the best solution.

Table 4: Comparing SAS and DH Solutions for Selim Set

NW	Resource Parameters	Network Parameters	SAS Duration	DH Duration	Diff	% Diff	Best Soln
NW1004	Low	Low	45	44	1	2.2%	DH
NW1010	Low	Low	41	41	0	0.0%	Same
NW1015	Low	Low	39	39	0	0.0%	Same
NW1020	Low	Low	46	40	6	13.0%	DH
NW1028	Low	Low	42	42	0	0.0%	Same
NW1102	High	Low	134	124	10	7.5%	DH
NW1105	High	Low	140	130	10	7.1%	DH
NW1112	High	Low	127	127	0	0.0%	Same
NW1119	High	Low	131	130	1	0.8%	DH
NW1127	High	Low	154	154	0	0.0%	Same
NW1200	Low	High	86	86	0	0.0%	Same
NW1201	Low	High	75	75	0	0.0%	Same
NW1212	Low	High	90	90	0	0.0%	Same
NW1222	Low	High	75	75	0	0.0%	Same
NW1225	Low	High	70	70	0	0.0%	Same
NW1300	High	High	138	136	2	1.4%	DH
NW1304	High	High	142	130	12	8.5%	DH
NW1308	High	High	150	146	4	2.7%	DH
NW1314	High	High	128	122	6	4.7%	DH
NW1325	High	High	149	149	0	0.0%	Same

Patterson Set

When solving the 110 networks in the Patterson set, SAS PROC CPM identified a schedule with the same duration as the DH procedure for 30 of the networks. There were no cases where SAS found a shorter duration solution than DH. Finally, there are 80 cases where DH finds a better solution than SAS, the majority of which are within 10% of the SAS solution duration. Figure 3 displays the frequency histogram of percentage differences between the SAS duration and the DH duration. Note that the x-axis label indicates the top number of the histogram bin. For example there were 35 cases where DH found a better solution than SAS by more than 0% but less than or equal to 5.0%.

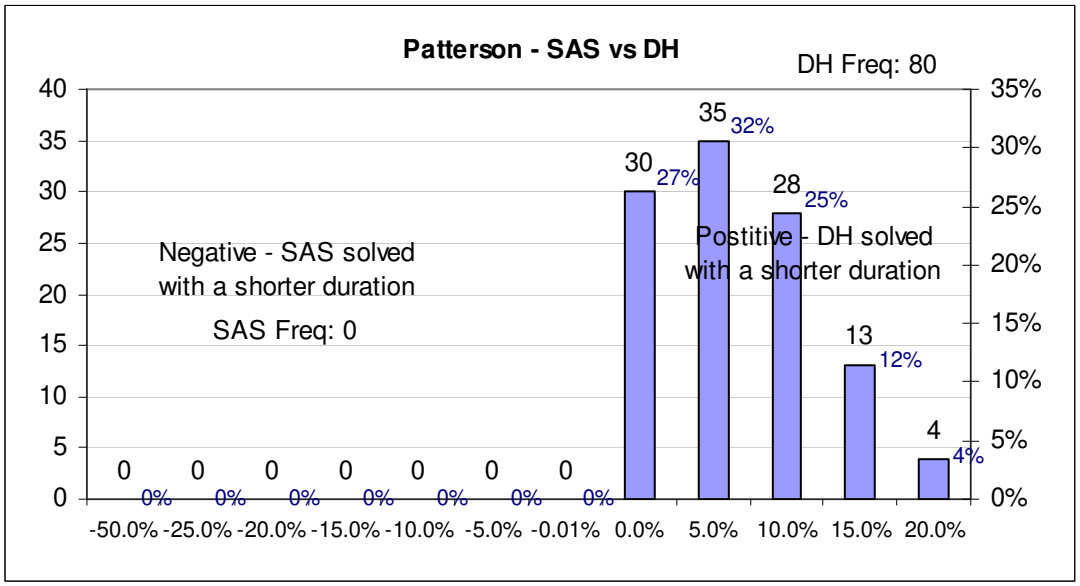


Figure 3: Comparing SAS and DH Solutions for Patterson Set

J30 Set

When solving the 480 networks in the J30 set, SAS PROC CPM identified a schedule with the same duration as the DH procedure for 218 (45%) of the networks. In contrast to the results from the Patterson set test, SAS found better solutions in more cases than DH. There were 164 (34%) cases where SAS found a shorter duration solution than DH, and 80 (20%) cases where DH found a better solution than SAS. Even though there is variation, 70.8% of all cases are within 5% of each other. Figure 4 displays the frequency histogram of percentage difference between the SAS duration and the DH duration for the J30 set.

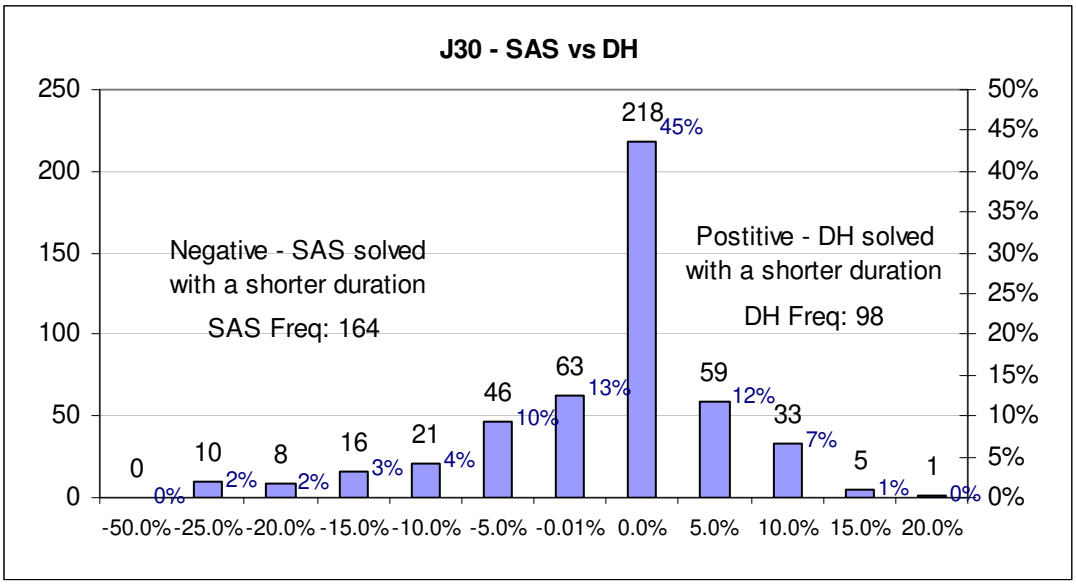


Figure 4: Comparing SAS and DH Solution for J30 Set

There were three factor settings that were provided with the J30 set that may be used in an experimental design to look for effects of these factor settings. These factor settings are: network complexity NC (the average number of non-redundant arcs per node – 3 settings), RF (the resource factor reflecting the average portion of resources in a category – 4 settings) and RS (resource strength is for renewable resources the lowest availability level allowing resource feasibility – 4 settings) (Kolisch and Sprecher 1997). Figure 5 shows that the distribution for the difference between the SAS duration and DH duration is very similar for all the three settings of network complexity.

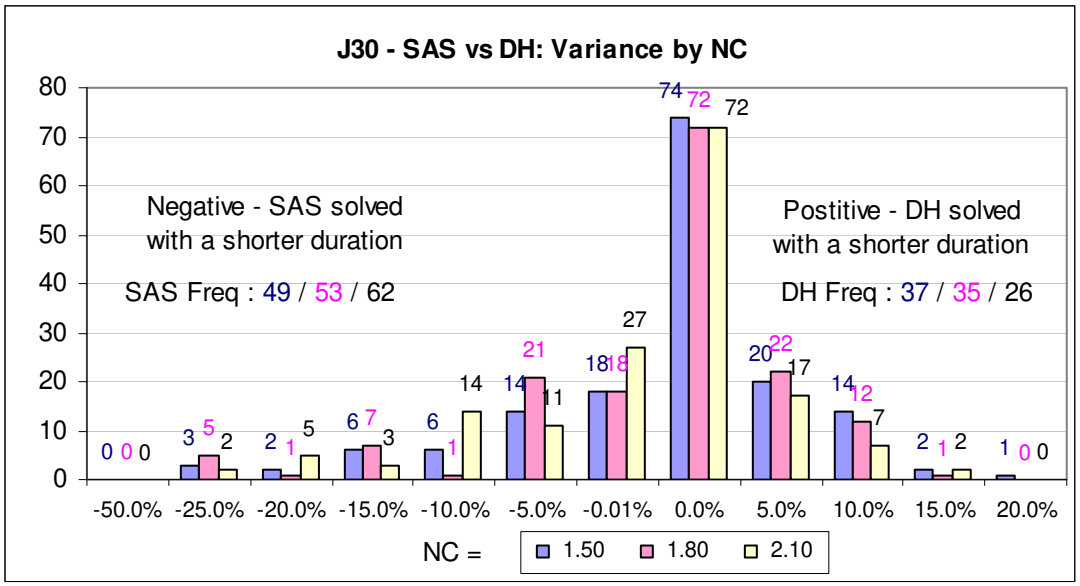


Figure 5: Comparing SAS and DH for J30 Set – Vary by Network Complexity

Figure 6 shows that the distribution for the difference between the SAS duration and DH duration is also similar for all four settings of the resource factors. It appears that when the resource factor setting is at the lowest setting (0.25), that SAS and DH have the highest probability of matching solutions, and the worst chance of matching at the next setting of 0.5. It is noted that at this middle setting of 0.5 is when SAS provides the best solutions. Even with these patterns, there is not clear evidence of a noticeable correlation between the resource factors and the amount of variation between the applications' solutions.

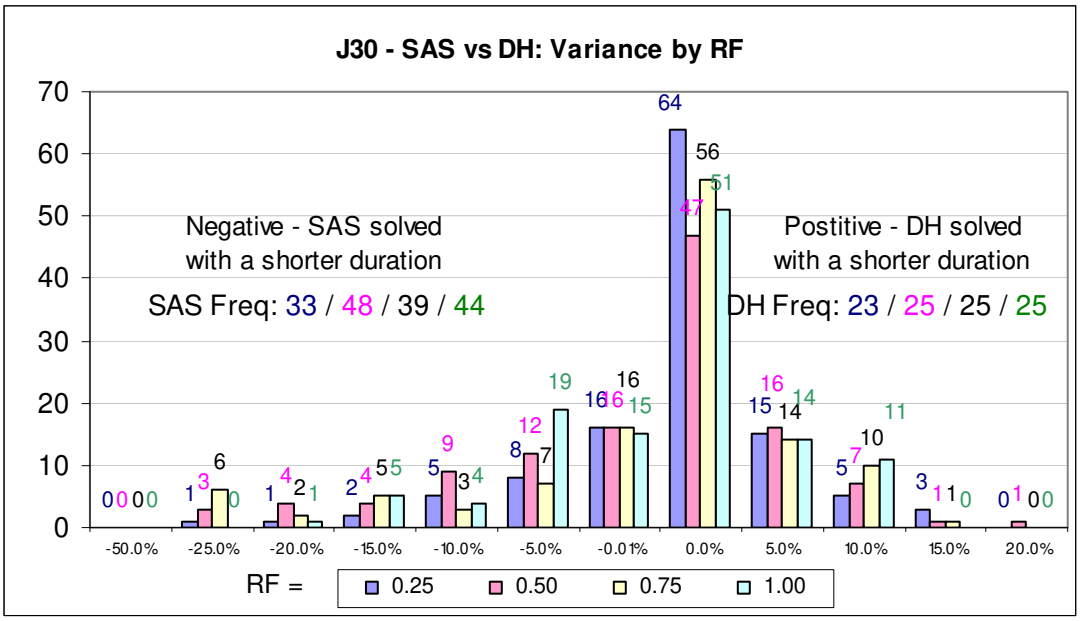


Figure 6: Comparing SAS and DH for J30 Set – Vary by Resource Factors

Figure 7 demonstrates a markedly different distribution between the SAS duration and DH duration for the four settings of resource strength. In 100% of the cases with the highest setting for resource strength (1.0), SAS and DH found the same solution (as shown in Figure 7). Additionally, the number of cases where a match occurs appears to positively correlate with the factor setting.

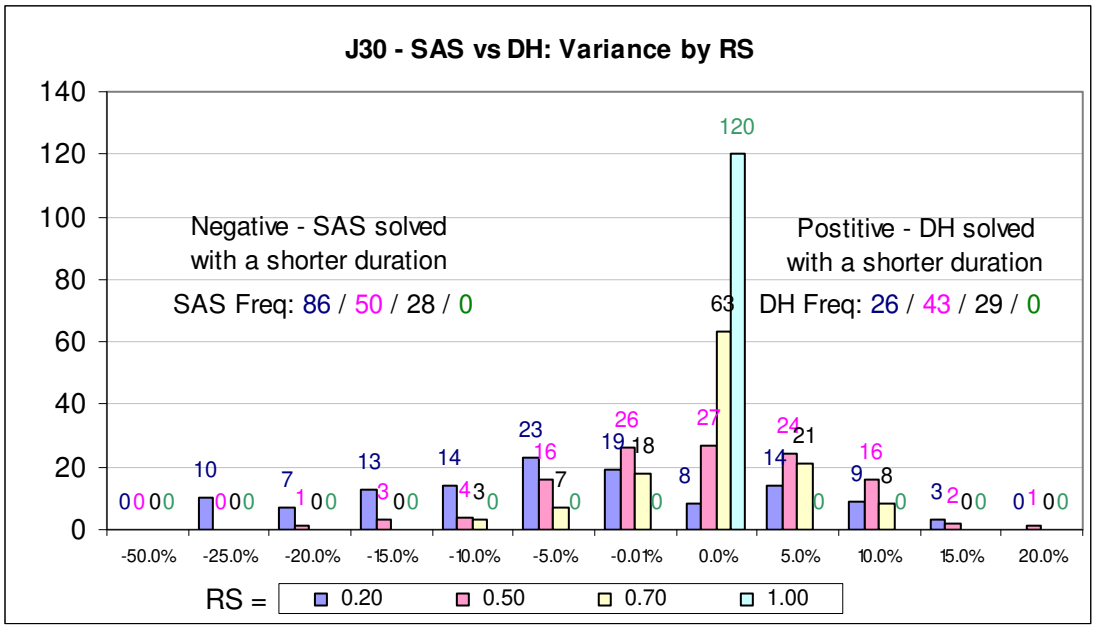


Figure 7: Comparing SAS and DH for J30 Set – Vary by Resource Strength

Software Selection Conclusions

The DH-procedure application performed best in terms of project duration when solving the Patterson set and the Selim set. It is noted that the Demeulemeester and Herroelen research team used the Patterson set in their work to evaluate the effectiveness of their procedure (Demeulemeester and Herroelen 1992). Additionally, the Selim set is created by using the RanGen network generator which was developed by the same research team. The SAS project duration solution was typically within 10% of the project duration provided by the DH.

SAS PROC CPM and the DH-procedure application perform similarly in terms of overall project duration for the J30 problem set, with SAS finding better solutions in 70% more cases than the DH. Although the DH-procedure may in theory be able to solve RCPSP optimally, the apparent time restrictions in the executable code generate an early solution before optimality is

reached. Comparing the frequency histograms of the differences in project duration for each factor setting of network complexity (NC), resource factor (RF), and resource strength (RS) reveals similar distributions for NC and RF, suggesting no interaction of these two factors and the solvers. However, the frequency histogram for RS reveals differing curves for SAS PROC CPM and DH, suggesting a potential interaction of RS factor settings and the performance of each solution heuristic provided by SAS and DH.

SAS clearly outperforms the available DH-procedure application on the J60, J90, and J120 problem sets because SAS was able to generate a solution in every case, while the DH-procedure application was unable to solve the problem sets in batch, and was unable to solve most of the randomly selected individual problems. The performance of the DH-procedure is likely affected by the 16-bit coding. Because of their similar performance, as well as the advantages of using SAS as described above, including the ability to develop code and quickly solve many problems in an iterative process, SAS was selected as the software for use with future experimentation. Since SAS software is commercially available, the conclusions of the experimentation process may be considered relevant to real-world application.

Right/Left-Shift Repair SAS Code Development

In the task insertion problem, the work of Selim (2002) and Grey (2007) focused on the development of initial baseline schedules for a project. After the start of the project, both authors implemented a right-shift policy to react to unscheduled tasks that occurred and a left-shift policy to react to scheduled tasks that did not occur. See Chapter Three (from Selim 2002, pg. 48-53)

for a detailed description of the logic implemented to conduct this repair. It is reasonable that a project manager may implement such policies manually in order to react to schedule changes for a small project with a small number of tasks. However, larger projects will most likely require an automated means by which to reschedule tasks. An additional motivation for developing a coded version of the right and left shift polices are to provide the ability to replicate the work completed by Selim (2002) and Grey (2007) quickly for comparison to newly developed heuristics.

Instead of two separate heuristics, one combined right/left-shift heuristic has been developed to repair any buffered schedule, including the optimistic (0%) and pessimistic (100%) baselines. This has been implemented successfully using SAS code; please see Appendix B for the code itself. The logic for this heuristic follows.

When a task's start time is reached, the stochasticity will eventuate (occurs or does not occur). Any tasks before this time are assumed historical and only tasks ahead may shift to the left or right, with this point in time the minimum time that any future task may shift left to. When a task does not occur, the duration and resource utilization are set to zero. This logic does not require removal of precedence constraints for non-occurring tasks. For example, consider the precedence constraints for tasks: A → B → C. If A is scheduled to end at time period 10 and then we learn that B does not occur, the earliest time C can shift to is 10. Keeping or removing precedence constraints has no effect. Although precedence relationships do not need to be removed, the finish time of all predecessors will need to be updated every time a shifting round is complete before the next stochastic task is removed.

This process is run once for each stochastic task that has been identified. For all study problems, the Selim set has either identified 16 (high stochasticity) or 8 (low stochasticity) stochastic tasks. The steps to repair the modified baseline schedule are as follows:

1. Sort the solved schedule by start time and select the first stochastic task, break ties using activity number lowest to highest.
2. Identify the initial start time of the stochastic task and refer to it as the "shift time" = t_s.
3. Determine this buffered activity's eventuation (occurs or removed/not occur).
4. If the task is to be removed, there is no right-shifting at this time, only left-shifting; skip to step 6.
5. If the task occurs, right shifting must occur to accommodate the additional time this task requires. All tasks that begin after t_s are moved to the right in the schedule. The same large number (currently using 100) is added to each tasks' start and end time.
6. Identify the first left-shifting task to be the task with the earliest start time after t_s that has not yet been left-shifted, breaking ties with a lower activity number. Set the new start time of this left-shifting task to be t_s or the max of the finish times for all its predecessor tasks, whichever is greater.
    a. Check the feasibly of this temporary schedule using SAS PROC CPM for resource constraint violations. If violations exist, increment the start time of this left-shifting task up by one and test again. Repeat incrementing to the right and test until no resource violations occur.

7. Repeat step 6 until all tasks have been shifted to the left and no resource violations occur.
8. Return to step 1, that is, identify the next stochastic task, set the "shift time"(t_s) equal to its start time, determine if the activity eventuates, and continue the rest of the cycle.
9. Note that at every step along the way, a second data set containing each activity's list of predecessor start times is continually updated with the predecessors' constantly changing start times until the process is complete.

Appendix C contains an example result for repairing a buffered schedule using this SAS code. The Gantt chart output is the intermediate result of each loop of the SAS code, one for each of the stochastic tasks. These Gantt charts were created using SAS code that determines the appropriate horizontal and vertical placement of each activity in the resource grid. This is provided as an example to demonstrate the effectiveness of the SAS code implementation.

Resource Flow

Resource handoff, or resource flow network, is a network that describes the number of renewable resources that pass from one task to the next. There may be many possible resource flows for any network, but a minimal cost solution may be formulated assuming some cost associated with resource flow. These assumptions include:

- There is a cost associated with the total number of resources units needed,
    - i.e., it is less costly for one resource unit to complete two tasks than two separate resource units performing each task, and

- costs associated with deploying an additional resource unit may include hiring or training costs (personnel) or transportation costs (equipment).

- There is a cost associated with a resource unit being idle for any length of time.
- There is a cost for resource hand-offs from one task to the next.

With these assumptions, a min cost flow network was formulated to determine a likely flow of resources for an initial baseline schedule to represent the resource plan for a project manager. The costs for this particular example formulation are as follows:

- From supply = $1,000 (representing a new resource unit)
- To demand = $0 (representing a resource that is no longer in use)
- From one activity to another =$1
- Within one activity to the next time pd = $0
- Enter storage = $5 (representing an idle resource)
- Each time unit in storage = $5

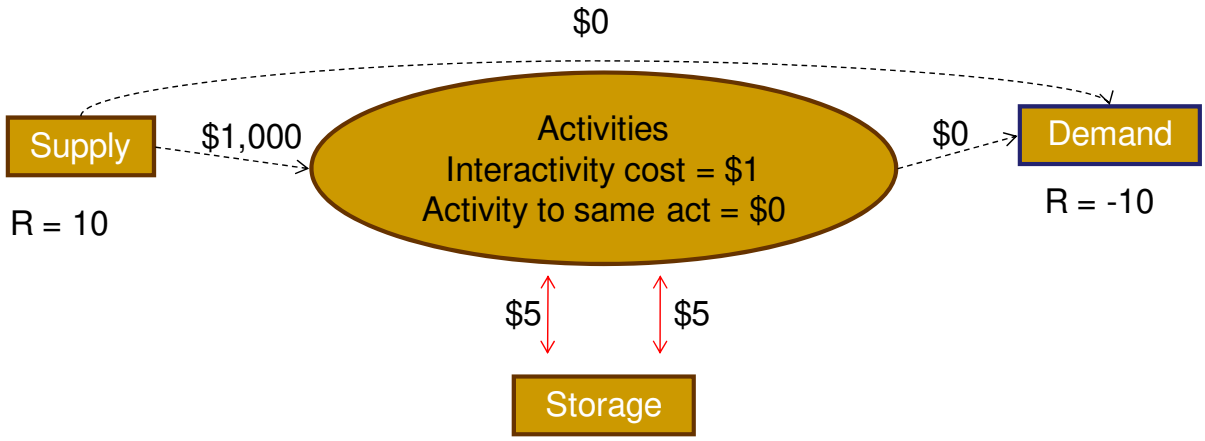


Figure 8: Example of a Min Cost Flow Formulation

The SAS procedure PROC NETFLOW was coded to provide a solution to a network of this formulation and is located in Appendix D. In order to accommodate each task and time

period, each time period/time period represents a node, and the costs are associated with each arc. The following figures provide a visualization of what this problem formulation provides. Figure 9 represents a network flow for one renewable resource (assuming 10 are available) in an initial baseline schedule where task B represents the stochastic task. The initial resource plan in the initial baseline would have included the deployment of a total of 2 resource units total (8 never used), the number of resource hand-offs were 6, and the number of resources planned to be utilized in time periods 1,2,3,4,5 was 2,2,2,2,1, respectively. If task B does not occur, a repaired schedule may actually consist of a modified resource plan with a deployment of 2 resource units, 5 hand-offs, and utilization in time periods 1,2,3,4,5 of 2,2,1,1,1, respectively.

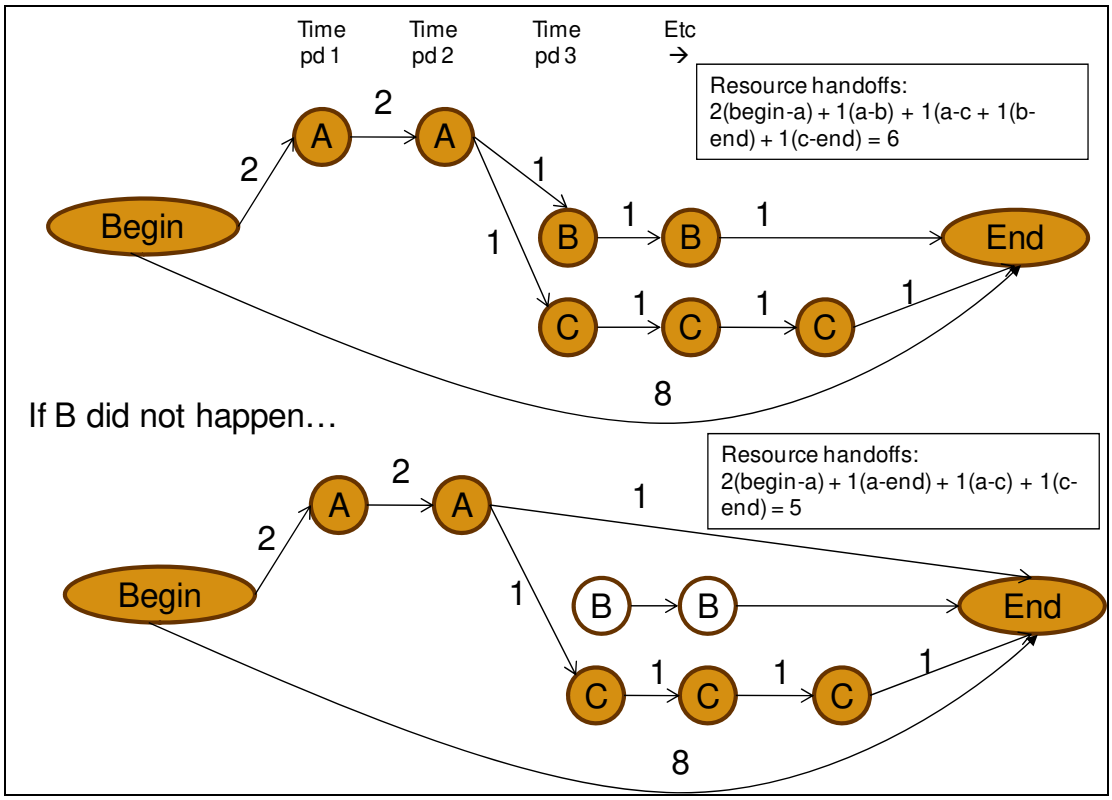


Figure 9: Buffered Initial Baseline to Task Removed

Figures 10, 11, and 12 demonstrate various scenarios of network flows when stochastic tasks eventuate. In Figure 10, we see task B (the stochastic task) has occurred with duration of 3 time units. Notice that the same number of resource hand-offs occur, the same number of resource units are used, but time period 5 now requires 2, instead of 1, resource unit. This change in resource requirements for time period 5 represents the value of a resource plan stability metric.

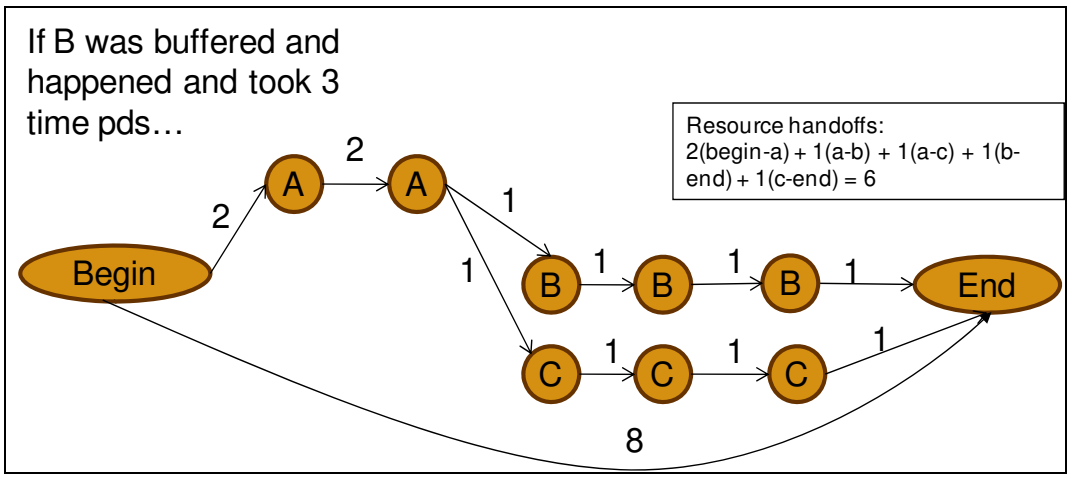


Figure 10: Buffered Initial Baseline to Task Occurs

Figure 11 shows the changes to a resource flow plan if task D is the stochastic task, and the initial baseline was constructed using an optimistic plan (no stochastic tasks were scheduled).

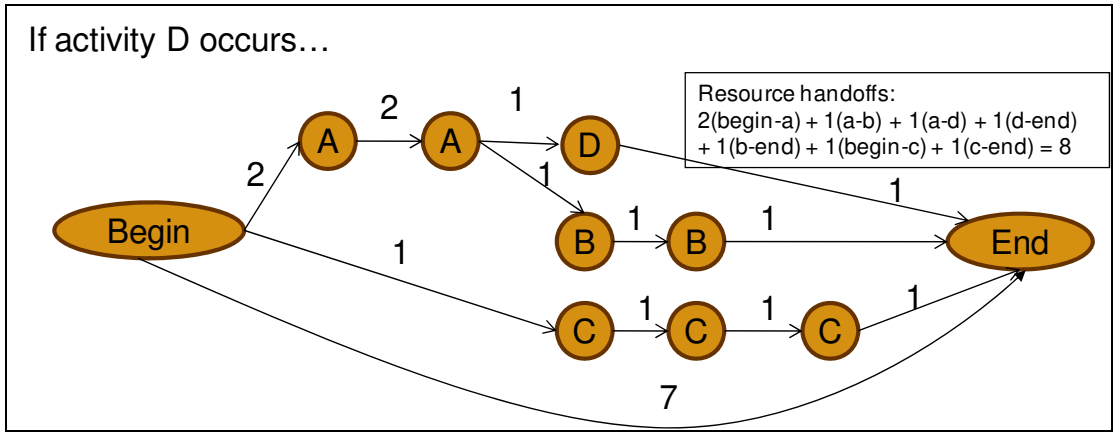


Figure 11: Optimistic to Right-Shifted Repaired

Figure 12 shows the changes to a resource flow plan if again task D is the stochastic task, and the initial baseline was constructed using an optimistic plan, assuming task C begins in time period 2 and task D begins at time period 4 (this may be due to resource constraints on other resources or precedence constraints). In this case, the min cost flow network solution has placed one resource unit used by task A in time period 2 into "storage" (indicated by node S) for one time period until D needs it. This flow was selected because the costs imposed on the arc from storage to a task is less than the costs on the arc from the begin node to a task.

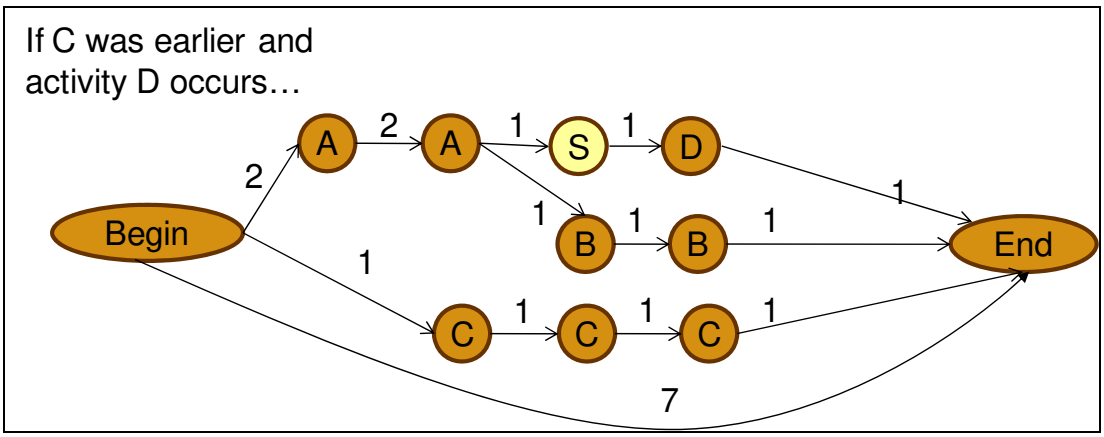


Figure 12: Optimistic to Right-Shifted Repaired with Storage

SAS Implementation for Resource Flow

SAS code, presented in Appendix D, has been created to implement the network flows above. The PROC NETFLOW procedure requires the following data sets as input: the supply and demand data, arc descriptions, and side constraints. Supply and demand data in this case is the simplest data set, only indicating 10 resources at the begin (supply) node, and 10 in the end (demand) node. The arc descriptions data set contains a list of all possible arcs and the associated cost with one unit of resource flow on that arc. A network with 32 tasks and over 44

time periods would result in upwards of 1,408 (32x44) nodes. It would take over 1 million arcs to connect every combination of 2 nodes. However, the problem is quickly reduced when arcs only flow forward in time. Also, only nodes are initialized that will be active during the specified time period. Finally, the side constraints data set contains the requirement that the flow into each node matches the solution. Each activity has a time period assigned when it will be active and requiring resources and is based on the output of PROC CPM.

A "sparse" data set format allows for the same code to be used in a macro when working with networks of various sizes. Once these data sets are created and provided to the SAS NETFLOW procedure, the solution data set contains one record for each arc and the value of the flow on that arc.

The following table in Figure 13 demonstrates how the resource flow model is validated using Excel PivotTables. The resource flow for both Resource 1 and 2 for NW 1004 IB schedule with 50% buffers is output to Excel, along with the SAS PROC CPM solution for the resource utilization for the solved IB schedule. The summary within the PivotTable sums the time-task arc flow value for each time period. This is then compared to the total resource utilization during that time period as per PROC CPM. The "TRUE" values of the cells below validate that the sum of the arcs flowing into each task during that time period is equal to the total resources used during that time.

R1	Time ->																									
Task	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	emand
003	1	1	1																							
005	4	4	4	4	4																					
010				3	3																					
012														1	1	1										
013														3	3	3	3									
015																		1	1							
020														2	2	2	2									
024																								4	4	
027																		3	3	3	3					
029																		3	3							
demand																										10
Tot R1 Usage	5	5	5	7	7									6	6	6	5	7	7	3	3			4	4	10
	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	
R1 Storage																										
storage						7	7	7	7	7	7	7	7	1	1	1	2			1	1	4	4			

R1	Time ->																										
Task	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	emar
003	1	1	1																								
005	2	2	2	2	2																						
008				3																							
009	4	4	4	4	4																						
012														2	2	2											
013														3	3	3	3										
015																		2	2								
016																				4	4	4	4				
018																		2									
021														3	3	3	3	3									
023																						5	5	5	5	5	
026																								2	2	2	
027																		1	1	1	1						
028																	1	1	1	1	1						
demand																											10
Tot R2 Usage	7	7	7	9	6									8	8	8	7	9	4	6	6	9	9	7	7	7	10
	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	
R2 Storage																											
storage					3	9	9	9	9	9	9	9	9	1	1	1	2		5	3	3						

Figure 13: Example Resource Flow Solution

Comparing the above validation PivotTable to the corresponding Gantt chart in Figure 14 further validates the method.

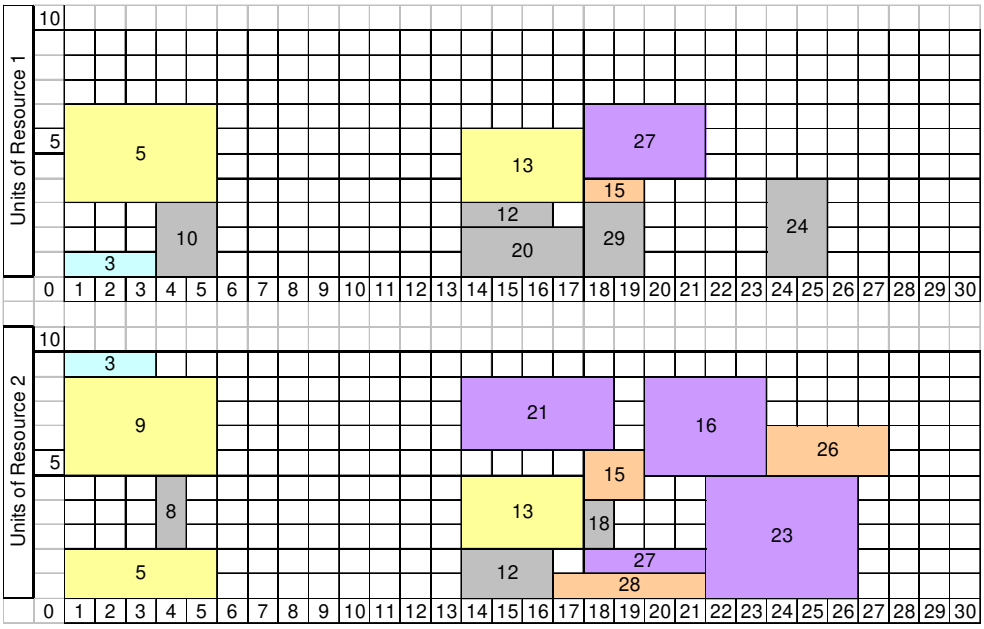


Figure 14: Example Gantt Chart

Finally, additional details in the PivotTable allows for viewing the resource hand-offs from one task to another. For example, examining Figure 15 below reveals that the task 27 received 1 resource unit from task 20 and 2 units from "storage"; task 27 then held onto these three resource units for 4 time periods, before handing off to "storage". The PivotTable also reveals that 3 resource units traveled directly from the supply to demand node, indicating that this IB schedule only utilized 7 out of 10 possible resource units of type 1.

R1	Time ->																										
To Task	From Task	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	Imnc
003	003		1	1																							
	supply	1																									
003 Total		1	1	1																							
005	005		4	4	4	4																					
	supply	4																									
005 Total		4	4	4	4	4																					
010	003				1																						
	010					3																					
	supply				2																						
010 Total					3	3																					
012	012															1	1										
	storage														1												
012 Total															1	1	1										
013	013															3	3	3									
	storage														3												
013 Total															3	3	3	3									
015	015																			1							
	020																		1								
015 Total																			1	1							
020	020															2	2	2									
	storage														2												
020 Total															2	2	2	2									
024	024																									4	
	storage																								4		
024 Total																									4	4	
027	020																		1								
	027																			3	3	3					
	storage																		2								
027 Total																			3	3	3	3					
029	013																		3								
	029																			3							
029 Total																			3	3							
demand	024																										4
	029																										3
	supply																										3
demand Total																											10
Grand Total		5	5	5	7	7									6	6	6	5	7	7	3	3			4	4	10

R1	Time ->																										
To Task	From Task	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	Imnc
storage	005						4																				
	010						3																				
	012																	1									
	015																				1						
	027																						3				
	storage							7	7	7	7	7	7	7	1	1	1	1				1	1	4			
storage Total							7	7	7	7	7	7	7	7	1	1	1	2			1	1	4	4			

Figure 15: Example Resource Hand-Off Solution

There exists the potential to develop new performance metrics that deal with resource utilization and resource flow. Five metrics have been developed, and implemented with SAS code. Resource metric 1 and 2 are related to resource utilization, while resource metrics 3,4, and 5 are related to resource flow.

Utilization Resource Metrics

When SAS PROC CMP solves any schedule, a resource utilization data set may be requested as output from the SAS system. In this case, the resource utilization data sets were stored for later use in computing metric 1 and 2. The SAS code used to calculate resource metric 1 and 2 is located in Appendix E.

Resource Metric 1

Resource metric 1 compares the utilization of resources at every time period from an initial baseline schedule to the modified base schedule. It is calculated as follows using the output from SAS PROC CPM:

- Calculate the absolute difference in the level of resource consumption for the IB and MB schedules for each time period and each resource type.
- For each resource type, sum over all time periods.
- Average the values over all resource types.
- Resource metric 1 = $\dfrac{\sum_{R}\left[\dfrac{\sum_{t}\left|r_{MB}-r_{IB}\right|}{t}\right]}{R}$ where:
    - R = number of resource types.
    - t = max(IB duration, MB duration).
    - r_{MB} = number of resources used in MB schedule during each time pd.
    - r_{IB} = number of resources used in IB schedule during each time pd.

Resource Metric 2

Resource metric 2 compares the total number of resource time unit (e.g., man-hours) for the initial baseline schedule to the modified base schedule. Using the output from SAS PROC CPM, resource metric 2 is calculated as follows:

- Sum over all time periods the total number of resources used for each resource type (total man-hours or equipment-hours).
- Find the absolute difference between the metric for the IB and MB schedules.
- Average the values over all resource types.
- Resource metric 2 = $\dfrac{\sum_{R}\left|\left[\sum_{t} r_{MB}\right]-\left[\sum_{t} r_{IB}\right]\right|}{R}$ where:
    - R = number of resource types.
    - t = max(IB duration, MB duration).
    - r_{MB} = number of resources used in MB schedule during each time pd.
    - r_{IB} = number of resources used in IB schedule during each time pd.

Resource Flow Metrics

Resource flow metrics or resource hand-off metrics compare the resource flow of an initial baseline schedule to the modified base schedule and perfect knowledge schedule. Comparisons to the PK will not be used here, since the PK schedule is not developed to minimize the efficiency of the resource flow in terms of: number of resource units deployed, number of resource hand-offs, or resource idle time. It is more relevant to compare the resource flow initially intended by a project manager in the IB and compare it to the final MB (as-run)

schedule. Please see Appendix F for the SAS code that will uses the resource flow solution to calculate resource metrics 3, 4, and 5.

Resource Metric 3

Resource metric 3 compares the total number of individual resource units needed for each schedule. Using the output from SAS PROC NETFLOW, resource metric 3 is calculated as follows:

- Find the number of non-deployed resource units of each type; this is the value of variable _FLOW_ where _from_ = "supply" and _to_ = "demand".
- Subtract total non-deployed resource units from total available.
- For each resource type, find the absolute difference between the number of resources units used between the MB and IB schedules.
- Average over all resource types.
- Resource metric 3 = $\dfrac{\sum_{R}\left[\left|NRU_{MB} - NRU_{IB}\right|\right]}{R}$ where:
    - NRU_{IB} = total number of individual resource units (NR) needed for the IB schedule.
    - NRU_{MB} = total number of individual resource units (NR) needed for the MB schedule.

Resource Metric 4

Resource metric 4 compares the total number of resource hand-offs needed for each schedule. Using the PROC NETFLOW output, resource metric 4 is calculated as follows:

- Identify the records where the values of the arcs are greater than zero and the "from" node and "to" node represent two different tasks (the SAS variable _FLOW_ contains the value of the arcs).
- Count the number of records identified.
- For each resource type, find the absolute difference between the number of resources hand-offs that occur between the MB and IB schedules.
- Average over all resource types.
- Resource metric 4a = $\dfrac{\sum_{R}\left[\left|NRH_{MB} - NRH_{IB}\right|\right]}{R}$ where:
    - NRH_{IB} = total number of resource hand-offs in the IB schedule.
    - NRH_{MB} = total number of resource handoffs in the MB schedule.

A similar calculation is performed for the volume of resource hand-offs, but the sum of _FLOW_ instead of the count of records is taken.

- Resource metric 4b = $\dfrac{\sum_{R}\left[\left|VRH_{MB} - VRH_{IB}\right|\right]}{R}$ where:
    - VRH_{IB} = total volume of resource hand-offs in the IB schedule (volume = number of hand-offs x number of resource units).
    - VRH_{MB} = total volume of resource handoffs in the MB schedule.

Resource Metric 5

Resource metric 5 compares the number of idle time units (ITU) for deployed resources in two schedules. From PROC NETFLOW output, resource metric 5 is calculated as follows:

- Find the records where the arcs represent resource idle time; this is the arcs that flow "to" idle time node (storage).
- Count the number of records identified.
- For each resource type, find the absolute difference between the number of idle resource time units between the MB and IB.
- Average over all resource types.
- Resource metric 5a = $\dfrac{\sum_{R}\left[\sum\left|ITU_{MB} - ITU_{IB}\right|\right]}{R}$ where:
    - ITU_{IB} = total number idle time units in the IB schedule for all resource units.
    - ITU_{MB} = total number idle time units in the MB schedule for all resource units.

A similar calculation is performed for the volume of idle time, but the sum of _FLOW_ instead of the count of records is taken.

- Resource metric 5b = $\dfrac{\sum_{R}\left[\sum\left|ITV_{MB} - ITV_{IB}\right|\right]}{R}$ where:
    - ITV_{IB} = the idle time volume in the IB schedule (volume = time x resource units).
    - ITV_{MB} = the idle time in the MB schedule.

Robustness Measures

In addition to the newly developed resource metrics established above, the following robustness measures will also be used to evaluate reactive and predictive scheduling heuristics:

From Selim (2002):

- RM1: percentage change in duration from MB to PK = $(|DUR_{MB} - DUR_{PK}|)/DUR_{PK}$ where
  - DUR_{MB} = total project duration of the MB schedule.
  - DUR_{PK} = total project duration of the PK schedule.
  - Note that because PROC CPM heuristic will not always be optimal, the PK duration may be greater than the MB duration.
- RM2: percentage change in duration from IB to MB = $(|DUR_{IB} - DUR_{MB}|)/DUR_{IB}$ where
  - DUR_{MB} = total project duration of the MB schedule.
  - DUR_{IB} = total project duration of the IB schedule.
- RM3: count of tasks with changed start times from MB to PK.
- RM4: count of tasks with a changed preceding tasks from MB to PK ("preceders" in the PK that are missing in MB).
- RM5: count of tasks with additional preceding tasks in the MB than PK.
- RM6: combination of RM4 and RM5. This is the count of tasks that meet both the criteria for RM4 and RM5, namely tasks that have preceders missing in the MB that were in the PK and additional preceding tasks in the MB from the PK.

- RM3, RM4, RM5, and RM6 are modified from Selim to be the count of tasks divided by the total number of tasks (metrics are first calculated then divided by the number of total tasks).

From Grey (2007):

- RM7: percentage change in duration from the IB to PK = $(|DUR_{PK} - DUR_{IB}|)/DUR_{IB}$ where
  - DUR_{PK} = total project duration of the PK schedule.
  - DUR_{IB} = total project duration of the IB schedule.
- RM8: coefficient of variation (for all tasks in the project) of the absolute difference in task start times between the PK and MB. The task start times for the tasks that ultimately did not occur in the perfect knowledge schedules were not included in the computations.
  - Metric 8 = $\dfrac{\sigma\left[\left|S_{PK} - S_{MB}\right|\right]_N}{\mu\left[\left|S_{PK} - S_{MB}\right|\right]_N}$ where:
  - the numerator represents the standard deviation of the differences in start times of all N tasks in the project and
  - the denominators represents the mean of the differences in start times of all N tasks in the project.
  - Note, some of metric 8 were missing because μ was equal to zero. In this case, μ is zero because all of the tasks start in the MB at the same time as the PK, therefore, mark metric 8 as zero.

The following table contains a summary of the metrics, and their comparisons.

Table 5: Summary of Metrics

Robustness Metrics				Comparison	
Selim	Duration	Metric 1	% change in duration	MB	PK
Selim	Duration	Metric 2	% change in duration	MB	IB
Selim	Stability	Metric 3	# tasks with changed start times (rev to %)	MB	PK
Selim	Stability	Metric 4	# tasks with changed preceding tasks (rev to %)	MB	PK
Selim	Stability	Metric 5	# tasks with additional preceding tasks (rev to %)	MB	PK
Selim	Stability	Metric 6	combination of metric 4 & 5	MB	PK
Grey	Duration	Metric 7	% change in duration	IB	PK
Grey	Stability	Metric 8	coef of var for changed start times	MB	PK
Resource Metrics					
Archer	Resource util	RMetric 1	resource consumption for each time pd	MB	IB
Archer	Resource util	RMetric 2	change in "resource-hours"	MB	IB
Archer	Resource flow	RMetric 3	change in number of resource units used	MB	IB
Archer	Resource flow	RMetric 4a	change in number of resource hand-offs	MB	IB
Archer	Resource flow	RMetric 4b	change in volume of resource hand-offs	MB	IB
Archer	Resource flow	RMetric 5a	change in idle time units	MB	IB
Archer	Resource flow	RMetric 5b	change in idle "resource-hours"	MB	IB

Experiment Implementation Plan Summary

This chapter described the tools available for experimenting on the SRCPSP with STI and the development of a new set of metrics dealing with resource flow. SAS/OR software was selected for solving the resource constrained schedules using the PROC CPM procedure, and Base SAS is used to implement a customized right/left-shift repair heuristic for the SRCPSP with STI. In order to develop a set of resource metrics, the problem is formulated as a min cost flow network and a resource flow solution is determined using SAS PROC NETFLOW. From the resource usage information provided by the PROC CPM solutions as well as the resource flow model, a new set of metrics that compare the resource utilization and resource flow from the modified baseline (MB) and initial baseline (IB) were proposed. Chapters Five, Six, and Seven describe the how these metrics, as well as the Selim/Grey robustness metrics, were used to evaluate new predictive and reactive heuristics for the SRCPSP with STI.

CHAPTER FIVE: NEW PREDICTIVE PROCEDURES – USING RESOURCE INFORMATION TO SIZE BUFFERS

The importance of resource availability, utilization, and stability to project managers points to the need for the development of new predictive procedures that provide improved resource performance of project schedules in the presence of the uncertainty. Predictive procedures provide project managers with techniques to develop the initial baseline (IB) schedule before work begins. Selim presented two predictive techniques, the optimistic (O) and pessimistic (P), that buffers each stochastically occurring task with a 0% or 100% buffer, respectively. Grey expanded upon this research with the development of several new buffering strategies which incorporate knowledge about the stochastic tasks' characteristics to determine buffer size, including task duration, the calculated SN number (which incorporates duration and resource usage), and location in the schedule. Additionally, Grey examined a 50% buffering approach, with experimental results suggesting it performed best in many instances such as when applied to high resource parameter networks. This relationship between network resource parameters and the best buffering approach suggests that using resource information in determining buffer sizing or placement may be an advantage.

This chapter presents an initial study for the development of 4 new resource buffers and describes how the initial study summary statistics warranted further experimentation. This is followed by a detailed description of implementation and experimentation results. Throughout the initial study and experiment, the results from the optimistic (O), pessimistic (P), and 50% buffer (B5) are used as benchmarks to compare against the new resource buffers (BR1-BR4). They are chosen for their simplicity of implementation from the perspective of a project manager, and specifically, the buffering techniques' suggested interaction with resource

parameters. The analysis of the experiment results elaborates upon Grey's analysis to prove the existence of interaction effects among buffering techniques, resource parameters, network parameters, location of stochastic tasks (timing), and stochasticity level, for not only the previously studied robustness metrics, but also the newly developed resource metrics.

Research Design to Use Resource Knowledge to Size Buffers

As described in Chapter Three, evidence in the literature suggests the need for the development of new predictive procedures to assist project managers in developing robust initial baseline schedules using resource information as a buffer sizing strategy. The four new resource buffering techniques (labeled as BR1 – BR4 below) proposed here allocate a larger buffer size to tasks with higher levels of resource utilization. This assumes that the stochastic nature of a task with high resource utilization has a more significant impact on its surrounding tasks than those with low resource utilization.

- BR1 = Average ($\%R_1$, $\%R_2$, .., $\%R_N$) where R_N = number of units of resource type N required by that task divided by the total number of resource N units available.
    - For example, task four uses 2 units of resource type one. If there are 10 units of resource one available, BR1 for task four is equal to 2/10 = 20%. If task four required more than one resource, each resource percentage would be calculated separately and averaged.
- BR2 = max(BR1,50% buffer) where 50% buffer is half the duration of the stochastic task.
- BR3 = Average ($\%PU_1$, $\%PU_2$, .., $\%PU_N$) where PU_N is equal to the project level utilization of resource type N at the start time of that task in the pessimistic schedule.

- For example, if task four uses 2 units of resource type one and is scheduled to start at time one in the pessimistic schedule. Also scheduled at time period one in the pessimistic schedule are 3 resources used by another task. If there are 10 units of resource one available, PU_1 for task four is equal to (3+2)/10 = 50%. Similar to BR1, this is calculated for each resource type and averaged.

- BR4 = 70% buffer for networks with high resource parameters, 30% for networks with low resource parameters. Here, high and low resource parameters were defined by Selim. Networks in the 10xx and 12xx sets have low resource parameter settings of RF = 0.40, 0.45, 0.50, and RC = 0.25. Meanwhile, networks in the 11xx and 13xx sets have high resource parameter settings of RF = 0.75, 0.80, 0.85, and RC = 0.75. It is hypothesized that applying a larger buffer on those schedules with high resource parameters may provide better results when comparing the initial base to the modified base (MB) and perfect knowledge schedules (PK).

In each of these buffering strategies outlined above, the buffer is in terms of the percent of task duration. For example, a 50% buffer applied to a task with duration of 10 will schedule that task for duration of 5 in the initial baseline (IB) schedule. During schedule eventuation, the actual task may occur with duration of 10, or will not occur at all, and the surrounding tasks will be shifted to the left or right to repair the schedule in "real time" to create the modified baseline (MB).

Once the values above are calculated, the initial study was conducted to explore the feasibility of these "resource buffers". First, stochastic tasks were identified and initial baseline schedules were created using the pessimistic (P), optimistic (O), 50% (B5), and resource buffers (BR1 – BR4). SAS PROC CPM was invoked to solve the initial baseline buffered networks and

each schedule was "eventuated" using the pre-determined information of which tasks would occur or would not occur using the left/right-shift heuristic described in Chapter Four. The study was conducted using the Selim problem sets used by both Selim and Grey. These steps to carry out the initial study are detailed out in the sections that follow.

Identifying Stochastic Tasks

The following steps were followed to duplicate the procedures of Selim and Grey to identify stochastic tasks. This was applied to the Selim problem set of 20 problems that each contains 32 tasks and 2 resource types.

1. Calculated for each task m: SN = 0.5(d) + 0.25$\left(\sum_{i=1}^{n} r_n\right)$ where:

   SN = stochastic number.

   d = duration of activity.

   r_n = total utilization of resource type n.

   n = the number of resource types.

2. Identified the first half (early tasks) and second half (late tasks) using task start time and breaking ties using lowest activity number.
3. Within the first and second half set of the schedule, identified the tasks with the highest 4 (low stochasticity) SN value and highest 8 (high stochasticity) SN values, breaking ties with start time (ie, sort by timing (early/late), S_N, start time).

Building Buffered Schedules

SAS was used to create the buffered duration sizes for the networks at both the low and high setting. For every network in the Selim set, the following sets of initial baseline (IB) schedules were constructed:

- High stochasticity setting had 16 tasks identified as stochastic in the initial baseline
  - Pessimistic – all tasks at full duration, or 100% buffer.
  - Optimistic – 16 stochastic tasks schedule at zero duration, or 0% buffer.
  - 50% buffer – 16 stochastic tasks scheduled at 50% of their duration.
  - Each of four resource buffers described above applied to the 16 stochastic tasks.
- Low stochasticity setting had 8 tasks identified as stochastic in the initial baseline
  - Pessimistic – all tasks at full duration (note, this is the same as the high stochasticity pessimistic baseline schedule).
  - Optimistic – 8 stochastic tasks scheduled as zero duration, or 0% buffer.
  - 50% buffer – 8 stochastic tasks scheduled at 50% duration.
  - Each of four resource buffers described above applied to the 8 stochastic tasks.

For each of these initial baseline schedules, SAS PROC CPM was used to determine the task order and additional statistics about the schedule was recorded in SAS data sets.

Schedule Eventuation

After the initial baseline buffered schedules were constructed, SAS code was used to implement the eventuation of each schedule into two different results: early and late eventuation. Early eventuation means that the 8 (high stochasticity schedule) or 4 (low stochasticity schedule)

early stochastic tasks occur, and the 8 or 4 late in the schedule do not occur. Similarly, late eventuation means that the early stochastic tasks do not occur, but the late ones do occur. The repair of these schedules used the right/left-shift repair heuristic described in Chapter Four and was implemented with the SAS code found in Appendix B. Appendix G presents a series of 920 Gantt charts that illustrate the initial baseline (IB), repaired (modified base or MB), and perfect knowledge (PK) for each network type and stochasticity level, much like the sample below.

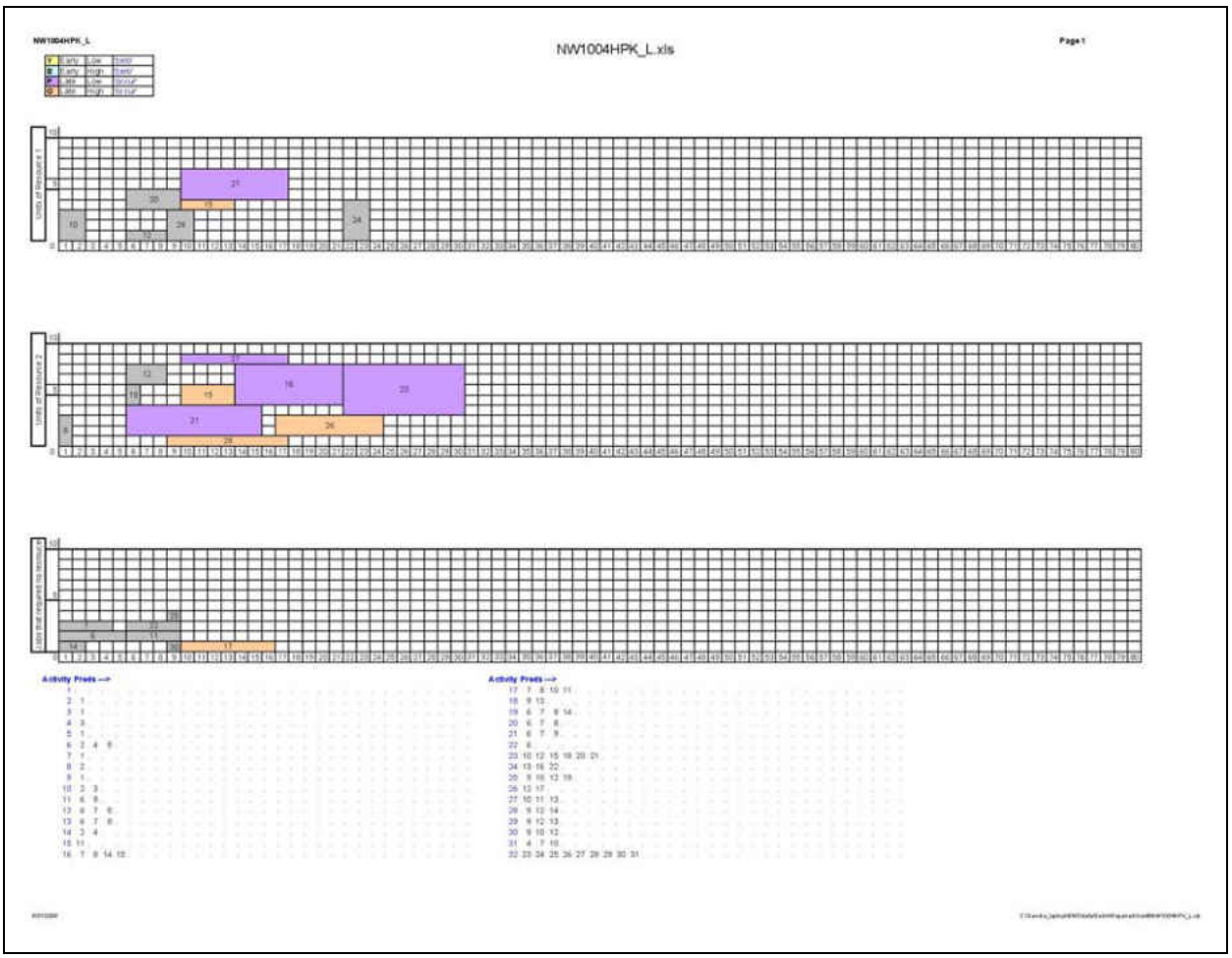


Figure 16: Example Gantt Chart

As shown in the example Gantt charts in Figure 16, the first two charts represent utilization of resource 1 and 2. The third chart represents those tasks with no resource

requirements. Below the charts are the list of activities and their predecessors to demonstrate the precedence constraints. Although the SAS code solved these networks, the Gantt charts are provided here for reference and documentation of the SAS code repair implementation. Similar in the manner of use for the initial baseline schedules, SAS PROC CPM was used once again to collect additional statistics about the modified baselines into SAS data sets. Finally, PROC CPM was invoked once again to develop a perfect knowledge schedule and the data set was stored in SAS.

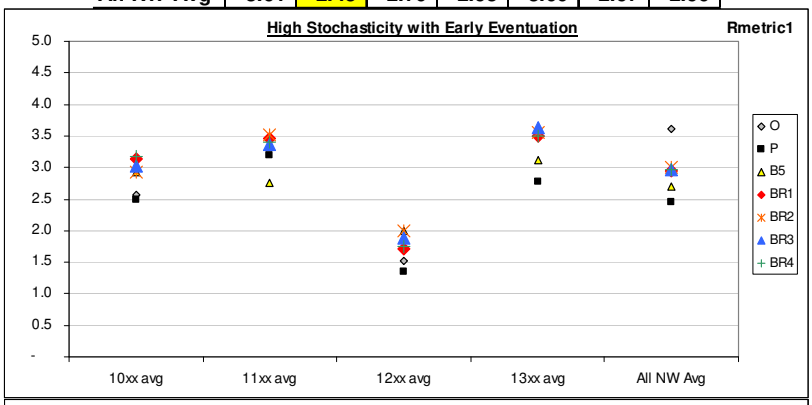
Initial Findings Using Resources to Size Buffers

SAS code was used to compute the Selim/Grey robustness metrics and newly developed resource metrics for each case described above. Summary statistics, scatter plots and histograms were visually inspected to determine where differences may occur between the buffering methods. For example, the below table in Figure 17, scatter plot and histogram is an example of the summary data for resource metric 1. Please see Appendix H for the complete set of initial study summary statistics and results.

Rmetric1

High Stochasticity with Early Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.57	2.49	2.93	3.13	2.93	3.01	3.18
11xx avg	5.24	3.19	2.76	3.46	3.52	3.36	3.41
12xx avg	1.51	1.35	1.99	1.72	1.99	1.88	1.76
13xx avg	5.10	2.77	3.12	3.49	3.55	3.63	3.50
All NW Avg	**3.61**	**2.45**	**2.70**	**2.95**	**3.00**	**2.97**	**2.96**



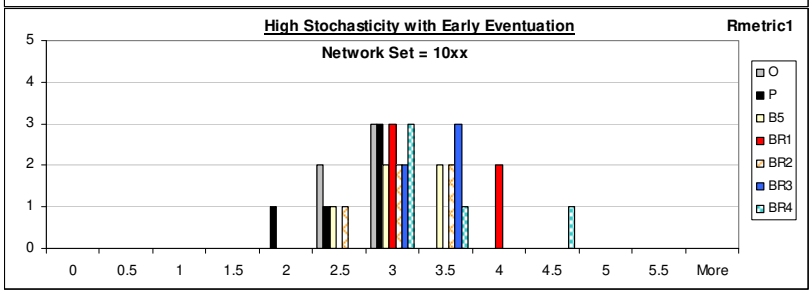


Figure 17: Example Summary Statistics, Scatter Plot, and Histogram

For the set of high stochasticity and early eventuation set of trials, Resource Buffer (BR4) has the best overall average on 3 of the 8 Selim/Grey robustness measures across all networks, namely metric 3, metric 6, and metric 7. However, this comparison is not consistent across all network sets. The only combination where BR1 is better than the rest of the combination is in the 1300's set with metric 8. BR2 appears to performs as well as, but is not exceedingly stronger than the 50% buffer (B5) in the 1000's and 1200's set for metric 2, and the 1200 set on metric 7. The average for BR3 only shows as the best for the 1100 set for metric 5. Overall, BR4 appears to outperform the other buffering schemes for the 1300 set on metric 3, 5 and 6 for the high stochasticity and early eventuation set of trials.

For the set of high stochasticity and late eventuation set of trials, Resource Buffer 1 (BR1) has the best performance for robustness measure 1 in the 1000 set. Also within the 1000 set, BR3 out performs the other buffering schemes on robustness measures 2 and 7. Therefore, the performance of BR1 and BR3 on the 1000 sets using the resource metrics of performance was further examined. In the resource metrics averages within each network set, BR3 appears to perform the best for resource metric 3 in the 1000 set. Closer examination of the histograms for this network set revealed the appearance of better variation in the metric for BR3 over the other buffering schemes, with 4 out of the 5 networks within the 0-0.3 histogram bin. BR1 appeared very strong for the 1000 network set for resource metric 4a. Close examination of the 1000 histogram for BR1 revealed good performance in terms of variation of this metric compared with the rest. Additionally, BR1 appears strong for the 1200 and 1300 set. BR1 was outperformed in the 1000 set in resource metric 4b, with the optimistic and pessimistic performing better. But, BR1 again looks strong here in for the 1200 and 1300 set. BR1 again appears strong in resource metric 5b for the 1300 set.

For the set of low stochasticity and early eventuation set of trials, Resource Buffer 1 has the best overall average value for metric 1, although the specific set does not show RB1 standing out over the optimistic scheduling buffer (the optimistic buffer performs better on the 1000 and 1200 set) and 50% buffer (the 50% buffer performs better on the 1100 and 1300 sets). Resource Buffer 3 has the same overall average value for metric 6 as the optimistic buffering method and performs better than all other buffers for the 1000 set in metric 2. However, resource metrics do not indicate any additional strengths of BR3 over the other buffering schemes for the 1000 set. Resource buffer 4 performs better than all other buffers for the 1100 set for metric 5. In resource metric 1, RB4 performs the best for the 1300 set. In resource metric 2, RB4 performs the best

for the 1000 set. In conclusion, there is little evidence in the initial data to suggest that resource buffers are an improvement over the optimistic or 50% buffer for the low stochastic schedules with early eventuation.

For the set of low stochasticity and late eventuation set of trials, Resource Buffer 1 has the best overall average values for metrics 6 and 8. However, within each of the network sets, the only stand-out performance for BR1 is on metric 6 for the 1000 network set. BR1 also performs best for the 1000 set on resource metric 1. BR1 performs best for the 1200 set for resource metrics 4a and 4b. Additionally, BR4 performs best for the 1100 set in resource metric 4a and 4b. BR1 and BR3 outperform all other buffers in metric 5a in the 1200 set. Meanwhile, in metric 5b, BR1 and BR2 have the best values in the 1100 set, while BR4 stands out for the 1200 set. In general, the low stochasticity problem sets have some cases where the resource buffers look promising, but at this time no conclusive evidence exists to demonstrate that they perform better than the optimistic or 50% buffer in most cases.

The following table contains a very brief summary of the findings from visual inspection of the histograms and summary statistics in the initial study. A note is made for any case in which the resource buffers appear to provide some improvements in the metrics over the other buffering methods. Here, "Metric" refers to the robustness metrics and "RMetric" refers to the resource metrics.

Table 6: Summary of Initial Resource Buffer Findings

	High		Low	
	Early	**Late**	**Early**	**Late**
10xx		BR1 on Metric 1 BR3 on Metric 2 and 7 BR3 on RMetric 3 BR1 on RMetric 4a	BR3 on Metric 2 BR4 on RMetric 2	BR1 on Metric 5 BR1 on RMetric1
11xx	BR3 on Metric 5		BR4 on Metric 5	
12xx				BR1 for RMetric4a & 4b
13xx	BR1 on Metric 8 BR4 on Metric 3, 5, 6		BR4 on RMetric 1	

Initial Study Conclusions and Hypotheses

The conclusion is that the summary statistics, scatter plots, and histograms appear to suggest there are times when the resource buffers produce different results than the other buffering methods. Specifically, this pointed to the need to investigate further if improvement may be found in the metrics by using the four resource buffers over the 50% buffering methods. This led to the following hypothesis:

Hypothesis #1: There are certain instances when improvement may be made in rescheduling metrics (including the Selim and Grey robustness metrics and the newly developed resource metrics) by employing resource information to size buffers over a flat application of a 50% buffer sizing technique. That is, project managers may be able to use information regarding the type of schedule (including network parameters, resource parameters, and the expectation of early or late stochastically occurring tasks) along with information about resources to size their activity buffers (the BR1 – BR4 methods) and find improved stability, duration, and changes in resource plans upon schedule eventuation over applying a 50% buffer (B5 method) to all stochastically occurring tasks.

Additionally, the initial study replicates Grey's results for comparing the use of the optimistic, pessimistic, and 50% buffers by using the Selim and Grey robustness metrics. The analysis in the initial study expands upon Grey's results by also testing the performance of these buffering techniques by using the newly developed resource metrics. Based on the summary statistic results and Grey's conclusions for the network characteristics' effect on robustness metrics, the following hypothesis was formed:

Hypothesis #2: With each of the existing robustness metrics and newly developed resource metrics as dependent variables, interaction effects exist among the buffering methods, network parameters, resource parameters, level of stochasticity, and location (timing) of stochastic tasks.

Finally, in addition to replicating Grey's results for comparing the use of the optimistic, pessimistic, and 50% buffers by using the Selim and Grey robustness metrics, the study expands the analysis of these three buffering techniques on the newly developed resource metrics. This allows us to address the question of whether the findings related to robustness measures would be similar to the findings for resource metrics:

Hypothesis #3: Grey's finding that a 50% buffer is more likely to produce positive results also applies to the newly developed resource metrics. That is, applying a 50% buffer over a 0% (optimistic) or 100% (pessimistic) buffer will produce positive results in the resource metrics in many cases.

Further Study and Conclusions Using Resources to Size Buffers

The initial analysis pointed to areas where resource buffer sizing techniques demonstrate the potential for improvement in robustness and resource metrics. Further statistical testing of the data was then used to first look for interaction effects, significant factors, and any areas of significant improvement.

GLM Model

As demonstrated by Selim, there are interaction effects among the factors: resource parameters, network parameters, location of stochastic tasks (early or late) and the method used to determine the initial baseline (IB) schedule (optimistic or pessimistic). A general linear model (GLM) was constructed to investigate significant factors and interaction effects that explain the variance in the metric values. The general linear model may be expressed for specific element i, $Y_i = \mathbf{x}_i'\boldsymbol{\beta} + \varepsilon = \beta_o + X_{i1}\beta_1 + X_{i2}\beta_2 + \ldots + X_{ip}\beta_p + \varepsilon_i$ where the components of the vector $\mathbf{x}_i'$ are a set of fixed constants associated with element i and the error ε_i is a random variable (Winer, Brown, et al. 1991). For the experimental design, a regression approach to predict a quantitative dependent variable with qualitative independent variables procedures may be used to conduct the analysis of variance (Winer, Brown, et al. 1991). The statistical tests for significance were based on a fixed effects model, since the levels of the factors of study are the only ones assumed to exist. Additionally, normality assumptions (response values at each fixed factor level combination follow a normal distribution and variances of these distributions are the same (Devore and Farnum 2005) were assumed.

H_o = There is no main effect or interaction for factor(s) specified.

H_a = The particular effect or interaction does exist.

The series of GLM results tables, such as the below example, Table 7 for duration, is located in Appendix I. There is one table for each of 16 metrics - duration, 8 robustness metrics, and 7 resource metrics.

Table 7: Example GLM Model Results

Metric	Source	DF	SS Error	F-Val	P-Val
Duration	loc	1	57.857	0.857	0.355
Duration	met*res*net*stoc*loc	6	4.886	0.012	1.000
Duration	meth	6	79.386	0.196	0.978
Duration	meth*loc	6	3.543	0.009	1.000
Duration	meth*net	6	36.643	0.090	0.997
Duration	meth*net*loc	6	46.386	0.114	0.995
Duration	meth*net*stoch	6	19.043	0.047	1.000
Duration	meth*net*stoch*loc	6	3.043	0.008	1.000
Duration	meth*res	6	9.743	0.024	1.000
Duration	meth*res*loc	6	8.900	0.022	1.000
Duration	meth*res*net	6	28.286	0.070	0.999
Duration	meth*res*net*loc	6	62.086	0.153	0.988
Duration	meth*res*net*stoch	6	48.943	0.121	0.994
Duration	meth*res*stoch	6	20.400	0.050	0.999
Duration	meth*res*stoch*loc	6	6.871	0.017	1.000
Duration	meth*stoch	6	14.271	0.035	1.000
Duration	meth*stoch*loc	6	10.486	0.026	1.000
Duration	net	1	36,482.857	540.237	0.000
Duration	net*loc	1	634.314	9.393	0.002
Duration	net*stoch	1	57.857	0.857	0.355
Duration	net*stoch*loc	1	9.257	0.137	0.711
Duration	res	1	387,977.857	5,745.160	0.000
Duration	res*loc	1	12.600	0.187	0.666
Duration	res*net	1	15,645.714	231.681	0.000
Duration	res*net*loc	1	0.714	0.011	0.918
Duration	res*net*stoch	1	333.257	4.935	0.027
Duration	res*net*stoch*loc	1	2.314	0.034	0.853
Duration	res*stoch	1	2,710.400	40.135	0.000
Duration	res*stoch*loc	1	71.429	1.058	0.304
Duration	stoch	1	28,286.429	418.864	0.000
Duration	stoch*loc	1	31.114	0.461	0.498
Duration	ERROR	448	30,254.000	0.000	-

The rows of the ANOVA tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating a significant factor or interaction effect. Table 8 describes the abbreviations are used and factor levels.

Table 8: Factor Settings

Abbreviation	Factor Description	Factor Settings
meth	Method setting	Optimistic (O), Pessimistic (P), 50% Buffer (B5), Resource Buffers 1-4 (BR1-BR1)
loc	Location or Timing	Early (E), Late (L)
net	Network Parameters	High (H), Low (L)
res	Resource Parameters	High (H), Low (L)
stoch	Stochasticity	High (H), Low (L)

The summary in table 9 that follows contains a row for the method and method interaction effects, indicating with a "1" if the effect is significant at $\alpha = 0.05$. For example, method alone explains the variance for 9 out 16 metrics. The only interaction effects including method that do not have any significant effect on any metrics are: meth*net*stoch*loc, meth*res*net*loc, meth*stoch*loc.

Table 9: Summary Table of Significant Effects Involving Method

		Robustness Metrics								Resource Metrics							
Source	Dur	1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Total
met*res*net*stoc*loc																	
meth			1		1			1	1	1	1	1			1	1	9
meth*loc									1	1	1	1	1	1			6
meth*net			1		1	1		1		1							5
meth*net*loc							1				1						2
meth*net*stoch			1					1									2
meth*net*stoch*loc																	
meth*res			1	1	1	1	1	1	1	1			1		1	1	11
meth*res*loc										1	1	1	1				4
meth*res*net			1			1	1	1			1					1	6
meth*res*net*loc																	
meth*res*net*stoch											1						
meth*res*stoch			1					1		1	1						4
meth*res*stoch*loc											1						
meth*stoch			1					1			1	1			1	1	6

Duration is the only metric where method or an interaction with method does not explain some variance. If interaction exists for any given metric, then the interaction with that factor should be examined instead of the main effect for that factor, while factors not involved in significant interaction terms may be interpreted by examination of only the main effects (Devore and Farnum 2005). It is noted that all two-way interactions with method have entered the model for at least some of the metrics.

Practical Application

If a project manager can determine resource parameters, network parameters, stochasticity and location of stochastic events in a project that is to be scheduled, this information can help point the project manager to when it is most important to consider the method of developing the initial baseline schedule. For example, if a project manager is **only** concerned about the final project duration, then there is little reason to pay attention to the initial baseline schedule development method since there is no significant effect involving method for project duration. On the other hand, if resource metric 2 (change in "resource-hours" from the IB to the MB) is very important to a project manager because it is critical for the project to come within the budgeted amount of resource-hours, it would be important to carefully select the method for scheduling the initial baseline schedule since there are many significant factors involving method that affect this metric. Additionally, should a project manager have a very good idea of the resource parameters of the schedule at-hand, this resource information may be used to select a method for initial baseline development, as indicated by the method interaction with resource parameters significantly affecting many metrics, including all robustness metrics

and 4 of the resource metrics. These four resource metrics include those that involve resource consumption (resource metric 1), the number of resource hand-offs (resource metric 4a) and resource waste (resource metric 5a and resource metric 5b).

Table 9 above indicates that, in fact, method and method interactions with other factors have a significant effect on the metric values. The result here is as expected in the robustness metrics as this duplicates the findings of Selim (except that the additional resource buffer methods are now included), while the findings are new for the newly developed resource metrics.

In addition to method, the following Table 10 is a continuation of Table 9. This table indicates (with a 1) where other factors **not** involving initial baseline development method have shown to be significant.

Table 10: Summary Table of Significant Effects Not Involving Method

		Robustness Metrics								Resource Metrics							
Source	**Dur**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**Total**
loc		1		1		1	1		1	1	1	1	1	1			10
net	1	1		1	1	1	1			1	1	1	1	1	1	1	13
net*loc	1	1		1		1	1			1	1						7
net*stoch		1	1	1			1	1		1							6
net*stoch*loc							1										
res	1		1	1	1	1	1	1		1	1	1	1	1	1	1	14
res*loc		1		1			1		1	1	1	1	1	1			9
res*net	1		1	1	1		1	1	1	1	1	1		1	1	1	13
res*net*loc		1					1				1			1			4
res*net*stoch	1			1			1		1	1	1					1	7
res*net*stoch*loc		1					1										2
res*stoch	1		1				1	1				1	1	1	1	1	9
res*stoch*loc						1	1			1	1						4
stoch	1	1	1				1	1		1	1	1	1	1	1	1	12
stoch*loc				1			1			1							3

Based on the GLM model results summarized here and detailed in Appendix I, there is clear evidence in support of Hypothesis #2, that for the existing robustness metrics and newly

developed resource metrics, interaction effects exist among the buffering methods, network parameters, resource parameters, level of stochasticity, and location (timing) of stochastic tasks.

While the GLM model above demonstrates many factors are significant, including method, it does not indicate which of these methods improves the values of the metrics. Therefore, the investigation continued to address the problem presented in Hypothesis #1 and to look for these improvements.

Analysis of Variance (ANOVA)

With the initial GLM model revealing significant interactions with the buffering method used on the value of many metrics, a series of ANOVA tables were constructed for each set of networks. Here, each set of networks represents five networks with the same factor settings for: network parameters, resource parameters, stochasticity, and timing.

H_o = The metric means for each initial baseline buffering method are all equal

H_a = The metric mean for at least one of the initial baseline buffering method is different than the rest

An example ANOVA table is shown here, and the complete ANOVA tables can be found in Appendix I. For all ANOVA table results, the degrees of freedom for the model is 6, error is 28, and the corrected total is 34.

Table 11: Example ANOVA Table for High/Early Settings

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE10	Duration	7.886	222.000	0.166	0.984
HE10	Metric1	0.009	0.030	1.442	0.234
HE10	Metric2	4.275	2.769	7.206	0.000
HE10	Metric3	0.116	0.108	5.011	0.001
HE10	Metric4	0.249	0.192	6.048	0.000
HE10	Metric5	0.091	0.122	3.481	0.011
HE10	Metric6	0.003	0.023	0.585	0.739
HE10	Metric7	4.265	2.751	7.234	0.000
HE10	Metric8	58.817	91.926	2.986	0.022
HE10	RMetric1	2.091	5.395	1.809	0.133
HE10	RMetric2	2.762	9.592	1.344	0.271
HE10	RMetric3	2.546	22.050	0.539	0.774
HE10	RMetric4a	26.600	94.300	1.316	0.283
HE10	RMetric4b	226.061	707.950	1.490	0.218
HE10	RMetric5a	166.061	349.250	2.219	0.071
HE10	RMetric5b	2,174.496	5,363.350	1.892	0.117

The rows of the ANOVA tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating that there is not enough evidence to suggest the means' equality. The following Table 12 summarizes the results of these ANOVA tables, with an indicator (1) located in each cell to represent if the test showed a significant difference among the 7 buffering methods.

Table 12: Summary Table for Significant Differences Among Method

Stoch & Loc		NW	Dur	Robustness Metrics								Resource Metrics							
				1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Total
High	Early	10xx			1	1	1	1		1	1								6
		11xx			1	1		1	1	1	1	1					1	1	9
		12xx		1	1				1	1	1	1	1			1	1	1	10
		13xx			1					1		1	1				1		5
	Late	10xx			1					1		1	1	1					5
		11xx			1		1			1		1				1	1	1	7
		12xx			1	1	1	1	1	1			1	1		1	1		10
		13xx		1	1					1			1				1		5
Low	Early	10xx			1		1			1									3
		11xx			1		1	1		1		1		1			1		7
		12xx			1				1	1		1							4
		13xx			1					1		1		1			1		5
	Late	10xx											1						1
		11xx			1		1	1		1		1		1			1	1	8
		12xx			1				1	1		1	1		1	1			7
		13xx			1					1				1			1	1	5

These results point to the fact that there are, in fact, significant differences among the 7 buffering methods. Because there are several instances where significant differences exist, post-hoc tests were run to determine if a "best" buffering method can be identified.

Tukey Procedure to Test Pairwise Means

For each of the highlighted rows in the ANOVA tables, Tukey's test was used to determine where the means are significantly different, and flag the differences where significant improvement is found by using the 4 buffering strategies over the 50% buffer. The Tukey procedure tests whether the means are equal for each pair of means in the ANOVA by applying the 5% significance level to the entire collection of pairwise hypothesis tests (Devore and Farnum 2005). Therefore, the risk of making a Type I error applies to the comparison of all pairs of means, rather than a single comparison (Mendenhall and Sincich 1995). This test was selected since it requires sample sizes to be equal, which will apply in this case of a factorial designed experiment. For each of the paired comparisons for the 7 buffering strategies (for example, O and P, O and B5, O and BR1, etc.) the following hypotheses were tested:

H_o = The metric means for the two buffering methods are the same.

H_a = The metric means for the two buffering methods are not the same.

The following table is an example of Tukey's test results for the high/early setting test for metric 2, and the complete set of tables are located in Appendix I.

Table 13: Example Tukey Test Results for Metric 2 in High/Early Settings

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE10	Metric2	B		C	0.326	P	1	0	1	1	1	1	1		
HE10	Metric2		A		1.121	O	0	1	0	1	0	0	1	At least one RBuffer differs from B5	B5 better
HE10	Metric2			C	0.164	B5	1	0	1	0	1	1	1		
HE10	Metric2	B	A		0.825	BR1	1	1	0	1	0	0	1	Worse	B5 better
HE10	Metric2			C	0.164	BR2	1	0	1	0	1	1	1		
HE10	Metric2			C	0.170	BR3	1	0	1	0	1	1	1		
HE10	Metric2	B	A	C	0.556	BR4	1	1	1	1	1	1	1		

As shown in Table 13 above, the "Tukey Grouping" columns indicate the significantly different groups with a different letter (A, B, or C). Similarly, a "1" or "0" (highlighted) in the table indicates no significant difference, or significant difference, respectively. (Note that this notation is different than the other tables in this document where "1" indicates significance. Here, "1" indicates not significant). Finally, there are two summary columns to summarize the comparisons to the 50% buffer (B5). The column "B5 vs RBuffers" contains a note if the 50% buffer (B5) is significantly better or worse than any of the 4 resource buffers (BR1 – BR4), and the column "B5 sig better" indicates if the 50% buffer is better than any of the other buffering methods (optimistic, pessimistic, or the four resource buffers). In this case, only the optimistic and resource buffer 1 are significantly different from the 50% buffer, and both produced higher (worse) results.

A review of the Tukey test results revealed that there are **no** instances where significant improvement may be found by using a resource buffer over the 50% buffer. Table 14 summarizes the Tukey tests results, and contains a "1" to indicate the cases where the 50% buffers has a significantly better (lower) mean than the other buffering techniques. That is, a 1 in a resource buffer row indicates that the Tukey test indicated the resource buffer has a significantly worse metric than the 50% buffer. Additionally, an "X" in used to mark any

comparisons where the 50% buffer is significantly worse than the optimistic or pessimistic buffer.

Table 14: Summary of Tukey Results where 50% is Significantly Better (1) or Worse (X)

			Robustness Metrics								Resource Metrics							
Group	Level	Dur	1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Tot
HE10	O			1		X			1	X								2
	P																	
	BR1			1					1									2
	BR2																	
	BR3																	
	BR4																	
HE11	O			1			1		1		1					1	1	6
	P				X											1	1	2
	BR1																	
	BR2																	
	BR3																	
	BR4																	
HE12	O			1					1			X			X	1		3
	P										X					1	1	2
	BR1			1					1									2
	BR2																	
	BR3			1					1									2
	BR4			1					1									2
HE13	O			1					1		1	1				1		5
	P			1					1							1		3
	BR1																	
	BR2																	
	BR3																	
	BR4																	
HL10	O			1					1			1	1					4
	P																	
	BR1			1					1									2
	BR2																	
	BR3																	
	BR4			1														1
HL11	O			1		X			1		1				1	1		5
	P			1					1		1					1		4
	BR1																	
	BR2																	
	BR3																	
	BR4																	

			Robustness Metrics								Resource Metrics							
Group	Level	Dur	1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Tot
HL12	O			1					1			1	1		1			5
	P															1		1
	BR1			1					1									2
	BR2																	
	BR3																	
	BR4			1					1									2
HL13	O			1					1			1				1		4
	P			1	X				1							1		3
	BR1			1														1
	BR2			1														1
	BR3			1					1									2
	BR4			1														1
LE10	O																	
	P																	
	BR1																	
	BR2																	
	BR3																	
	BR4																	
LE11	O			1			1		1		1					1		5
	P			1					1									2
	BR1			1														1
	BR2			1														1
	BR3			1														1
	BR4																	
LE12	O								1									1
	P										X							
	BR1																	
	BR2																	
	BR3																	
	BR4																	
LE13	O			1					1		1	1				1		5
	P			1					1							1		3
	BR1			1														1
	BR2			1														1
	BR3			1					1									2
	BR4																	
LL10	O											1						1
	P																	
	BR1																	
	BR2																	
	BR3																	
	BR4																	

			Robustness Metrics								Resource Metrics							
Group	Level	Dur	1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Tot
LL11	O			1		X	1		1		1							4
	P			1					1		1					1	1	5
	BR1			1					1									2
	BR2			1					1									2
	BR3			1					1		1							3
	BR4																	
LL12	O			1					1			1			1			4
	P										1							1
	BR1			1					1									2
	BR2																	
	BR3																	
	BR4																	
LL13	O			1					1							1	1	4
	P			1			X		1							1		3
	BR1			1					1									2
	BR2			1					1									2
	BR3			1					1									2
	BR4			1														1

The results of Tukey's procedure for multiple comparisons provided the basis for rejecting Hypothesis #1 that there exist instances when improvement may be made in rescheduling metrics by employing resource information to size buffers over a flat application of a 50% buffer sizing technique. In fact, there are instances demonstrated where the resource buffer sizing techniques implemented here is significantly worse than using a 50% rule-of-thumb.

A project manager may use the table above to determine a course of action in determining if a 50% buffer would be important to use. When viewing the table above, recall that the characteristics of each problem set:

- 10xx = Resource parameters = Low; Network parameters = Low.
- 11xx = Resource parameters = High; Network parameters = Low.
- 12xx = Resource parameters = Low; Network parameters = High.
- 13xx = Resource parameters = High; Network parameters = High.

Because the previous section determined that there were several significant interactions among resource and network parameters, and stochasticity level and location, the conclusions of the table results above are impossible to generalize. However, it did provide the basis for concluding Hypothesis #3 is true: applying a 50% buffer over a 0% (optimistic) or 100% (pessimistic) buffer will produce positive results for resource metrics in many cases.

Practical Application

The following example is provided to demonstrate how the information above may be used by a project manager in a real-world application. Assume a project manager is able to identify network characteristics as: Resource parameters = High, Network parameters = High (similar to the Selim set 13xx) and Stochasticity level = Low, Stochasticity location = Late (see the bottom section of Table 14). Also assume that the project manager is mostly concerned about variances between the planned and actual idle time of resources (as indicated by RMetric5a and RMetric5b) because of high holding costs, and duration (Metric2 and Metric7). In this case, it is recommended this project manager utilize the 50% buffering strategy over the optimistic and pessimistic schedule since these metrics are significantly improved by using the 50% over the other strategies. On the other hand, if the project manager is only concerned with the stability robustness metrics, then nothing is gained by implementation of the 50% over the optimistic or pessimistic buffer, which may be preferable for simplicity of implementation.

Resource Buffers Conclusions

If resources are important to a project manager dealing with the resource constrained project scheduling problem with stochastic task insertion (STI), it was hypothesized that this resource information may be used to create a new buffer sizing technique. However, no evidence exists that resource buffers provide project managers with a better way to size buffers. While experimenting to uncover improvements made by resource buffers, the conclusions of Grey's analysis involving interactions with network characteristics for the 50% buffer have been expanded upon using multiple comparison ANOVAs and Tukey's procedure. The newly developed resource metrics were used, in addition to the Selim (2002) and Grey (2007) robustness metrics. While improvements using the resource buffers were not discovered, the conclusions do describe for project managers the interactions that exist and provide recommendations for using the 50% buffering method depending on (1) what is important to the project manager (duration, stability, resource utilization or flow) and (2) what information is available about the network (resource and network parameters, stochasticity level and location) at hand.

Knowing that the 50% buffering method is still the most effective predictive procedure for the SRCPSP with STI, this research was continued to expand upon the use of proportionally sized buffers. Chapter Six discusses the next phase of this research that looks for additional improvements may be made by sizing buffers proportional to the probably of occurrence in initial baseline schedule development. Additionally, new reactive procedures are explored in Chapter Seven.

CHAPTER SIX: NEW PREDICTIVE PROCEDURES – USING PROBABILTY OF TASK OCCURENCE TO SIZE BUFFERS

Chapter Five described a study demonstrating that the simple-to-implement 50% buffering method is the most effective (in many cases) buffering strategy for developing an initial baseline schedule for the resource constrained project scheduling problem with stochastic task insertion, as long as those tasks that are stochastically occurring are identified. The study did not assume any prior knowledge about the actual probability of the stochastic tasks' occurrence. In a real-world application, there are many instances where a project manager may have prior knowledge about the probability of stochastic task occurrence. Wang (2002) noted that information about activity duration may be gained from prior projects and used to predict current activity durations by experienced project managers. The assumption is extended here to assume that project managers may be able to estimate the probability of task occurrence for the STI case.

This chapter describes an initial study that was developed to test the feasibility of applying prior probability knowledge to size buffers. With promising results from the initial study, an experiment was conducted to demonstrate that buffers proportional to the probability of occurrence provide very promising improvements over a flat 50% buffer applied across all stochastic tasks in many cases.

Research Design to Study Buffers Sizing with A Priori Knowledge of Task Occurrence

A subset of the Selim network set was used to conduct an initial study on the feasibility of using a priori knowledge of the occurrence probability in a buffer sizing strategy. A total of 8

out of the total of 20 networks were selected -- two out of each network characteristic sets (1004, 1010, 1102, 1105, 1200, 1201, 1300, and1304). For each network, 8 of the 32 tasks previously identified in the experiments above (also used by Selim and Grey) in the "low stochasticity" experiment (these had the highest SN value) were assigned a 20% chance of occurring. The **next** highest SN set of 8 stochastic tasks previously identified in the "high stochasticity" experiment (which in prior experiments were added to the 8 from the "low stochasticity" experiment to make a total of 16) were assigned 80% chance of occurrence. After 8 tasks were assigned 20% occurrence probability and 8 were assigned 80% occurrence probability, an initial baseline schedule for each of the networks was constructed (buffer method code = B1, also referred to as the "80/20" buffer). The task durations of the 16 potentially stochastically occurring tasks was replaced with duration of either 20% or 80% of their original duration, aligned with their assigned probability. SAS PROC CPM was used to solve the initial baseline (IB) schedules for each network. Additionally, an alternative baseline schedule was developed using the 50% buffering method (buffering method code = B5), applying a 50% buffer to all 16 stochastic tasks.

A simulation was needed to evaluate the effectiveness of the 80/20 buffering strategy and compare its results to the 50% buffering strategy. For each of the 8 networks above, a random number generator was used to establish 100 scenarios where tasks with low probability assignment occur 20% of the time and tasks with high probability assignment occur 80% of the time. If the random number was less than 0.20 or 0.80, respectively for the low and high assignments, then the task was assigned to "occur". Otherwise, the task was assigned to "not occur".

For each of these 16 initial baseline schedules (8 networks x 2 buffering methods), the SAS code to repair a buffered schedule described in Chapter Four was used to repair the

modified baseline schedules upon simulated eventuation (the tasks occur or do not occur) for a total of 1,600 modified baseline schedules. The same tasks assigned to occur or not occur were used for both the buffered initial baseline schedules, providing for 800 dependent pairwise comparisons. Once repaired, the resulting robustness metrics and newly established resource metrics were used to evaluate the proportional buffer's effectiveness by benchmarking against the 50% buffer.

Initial Study Results of Prior Knowledge to Size Buffers

The preliminary results of this simulation were promising when comparing the 80/20 proportional buffer (B1) and 50% buffer (B5). Table 15 below demonstrates the number of instances over 100 replications for 8 networks that had the best metric value in the Selim/Grey robustness and the resource metrics. (Note that high/low stochasticity, and early/late eventuation is not relevant here.) For example, 555 (69.4%) pairwise comparisons for robustness metric 1 out of 800 replications showed the 80/20 proportional buffer out-performing the 50% buffer. The resource metrics were calculated for 50 of the replications and demonstrate a similar pattern, showing promising results for the proportional buffer.

Table 15: Count of the Best Methods for Pairwise Comparisons Over 100 Replications

	Number of Replications	Proportional Buffer	% of reps	50% Buffer	% of reps	Equal	% of reps
Robustness Metrics							
Metric 1	800	555	69.4%	193	24.1%	52	6.5%
Metric 2	800	475	59.4%	325	40.6%	0	0.0%
Metric 3	800	366	45.8%	182	22.8%	252	31.5%
Metric 4	800	274	34.3%	420	52.5%	106	13.3%
Metric 5	800	499	62.4%	200	25.0%	101	12.6%
Metric 6	800	371	46.4%	244	30.5%	185	23.1%
Metric 7	800	560	70.0%	240	30.0%	0	0.0%
Metric 8	800	299	37.4%	497	62.1%	4	0.5%
Resource Metrics							
RMeric1	400	241	60.3%	159	39.8%	0	0.0%
RMeric2	400	360	90.0%	40	10.0%	0	0.0%
RMeric3	400	68	17.0%	99	24.8%	233	58.3%
RMeric4a	400	169	42.3%	198	49.5%	33	8.3%
RMeric4b	400	107	26.8%	284	71.0%	9	2.3%
RMeric5a	400	279	69.8%	105	26.3%	16	4.0%
RMeric5b	400	261	65.3%	139	34.8%	0	0.0%

Appendix J contains a series of tables and histograms that represent all metrics (8 robustness metrics and 7 resource metrics). The tables and histograms in the appendix provide the details of the pairwise comparisons between the proportional 80/20 proportional buffer and the 50% buffer for each type of network. An example of the histograms contained in Appendix J is shown in Figure 18. This example histogram shows that for the 200 pairwise comparisons of networks in the 10xx set, 176 had better performance for robustness metric 1 by using the 80/20 proportional buffer over the 50% buffer. Note that the x-axis label indicates the top number of the histogram bin. Most of the pairwise comparisons showed the value of the metric to be 25% to 100% better when using the proportional buffer.

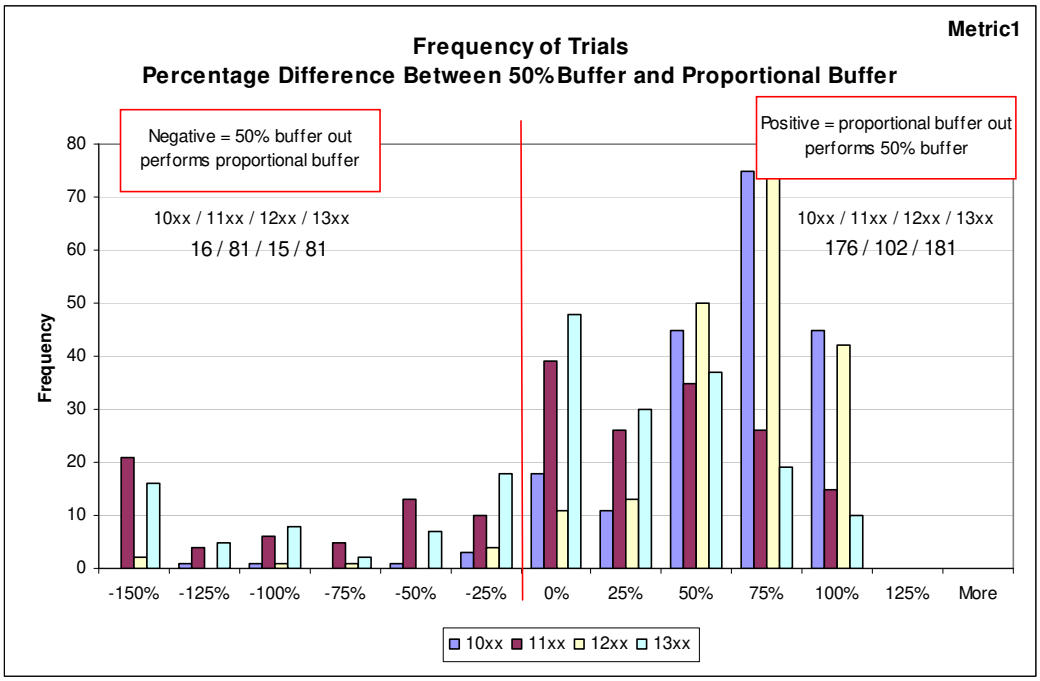


Figure 18: Example Initial Results for Using Proportional Buffers

Examining the results of the table above and the tables in Appendix J indicate that there are several networks for which the proportional buffers provide improvement over the 50% buffer. The initial study led to the following hypothesis:

Hypothesis #4: There are several instances where using a buffer sized proportionally to the probability of occurrence will provide better results than using a 50% buffer on many robustness and resource metrics.

Extension of a Simulation Experiment for Using A Priori Knowledge to Size Buffers

With promising results for using prior knowledge of the occurrence probability to size buffers, an experiment was devised to test if building an initial baseline schedule with buffers proportional to the probability of occurrence provides improved results over 50% buffering. To do this, the 20 networks of the previously studied Selim set were used and a probability was

assigned to all 16 stochastic tasks identified by Selim. Two initial baseline schedules were constructed: one with the buffers sized equal to the probability of occurrence and one with 50% buffers. The simulation experiment eventuated (occurred or did not occur) the tasks at their assigned probability, and each initial baseline was repaired using the previously discussed SAS code to repair a buffered scheduled. There were three separate experiments conducted for the following distinct test sets:

80/20 Buffer Simulation

"80/20 buffer" simulation continued the initial study described above for the remainder of the Selim/Grey set here test. Here, all 16 previously identified stochastic tasks were designated with an 80% or 20% probability of occurring and their buffered duration in the initial baseline was equal to 80% or 20%, respectively.

90/10 Buffer Simulation

"90/10 buffer" simulation assigned a probability of occurrence ranging from 0.10 to 0.90 proportional in value to the previously determined SN value for that task. The first step was to calculate SN. Next, a probability of occurrence was calculated ranging from 0.10 to 0.90, proportional to the SN number of occurring. This probability from 0.10 to 0.90 is calculated as follows for every activity m:

$P_m = P_{min} + [SN_m - SN_{min}]$ * ScaleRatio where:

ScaleRatio = $(P_{max}-P_{min})/(SN_{max}-SN_{min})]$, $P_{min} = 0.1$, $P_{max} = 0.9$.

Next, buffers were created proportional to the computed probability of occurrence and the initial baselines (IB) for each of the 20 buffered schedules was solved using SAS PROC CPM and the predecessor data sets were created. A simulation was replicated 50 times with the probability assignment eventuations. This was accomplished by generating a variable called R_{sm} for each activity (where m = activity number) which follows a uniform random distribution within each replication (where s = simulation replication number). For example, for simulation replication 1 (s = 1): R_{1m} = uniform(0,1). Using the assigned probability of occurrence established above, then if $R1_m <= P_m$ then the task was assigned to "occur". Otherwise, the stochastic task is assigned to "not occur". The clock time is used as a seed for the uniform distribution, ensuring a random simulation for each of the 50 replications.

Uniform Buffer Simulation

"Uniform buffer" simulation ran another simulation experiment where the probability of occurring was a random (uniform) distribution over each of the 16 stochastic tasks. In this case, the probability of occurring was determined using the function in SAS ranuni(1), which produces a random number between 0 and 1. The positive seed of 1 created a duplicate string should the experiment need to be repeated. The proportional buffer was then computed by multiplying the task duration by the resulting random number for each stochastic task. The eventuation and repair of the schedules was conducted similarly to the "80/20" and the "90/10" experiments.

Determining the Number of Replications

There were 100 replications in the initial study of which all 100 had the robustness metrics calculated, and 50 of which had the resource metrics calculated. These replication estimates of each metric, allowed for the comparison of the improvement in metric values.

The confidence interval for expected values for any metric is given as:

$$\bar{x} \pm t_{n-1,1-\alpha/2} \frac{s}{\sqrt{n}} \qquad \text{where:}$$

$\bar{x}$ = mean of metric,

s = standard deviation of metric,

n = number of replications, and

α = confidence level (Kelton, Sadowski, et al. 2007).

Using the average and standard deviation results of the 100 replications for 8 networks and 2 buffering strategies (1,600 runs total) and α = 0.1 allows us to compute the half-width of the confidence interval for each robustness metric estimate for various numbers of replications. The half-widths of the intervals for each network and metric combination are calculated and are divided by the overall average of the each of the 100 replications to provide a perspective. As demonstrated in the chart in Figure 19 below for each of the robustness metrics, the half-width of the confidence interval as a percentage of the estimated value is significantly shorter once the number of replications reaches over 30.

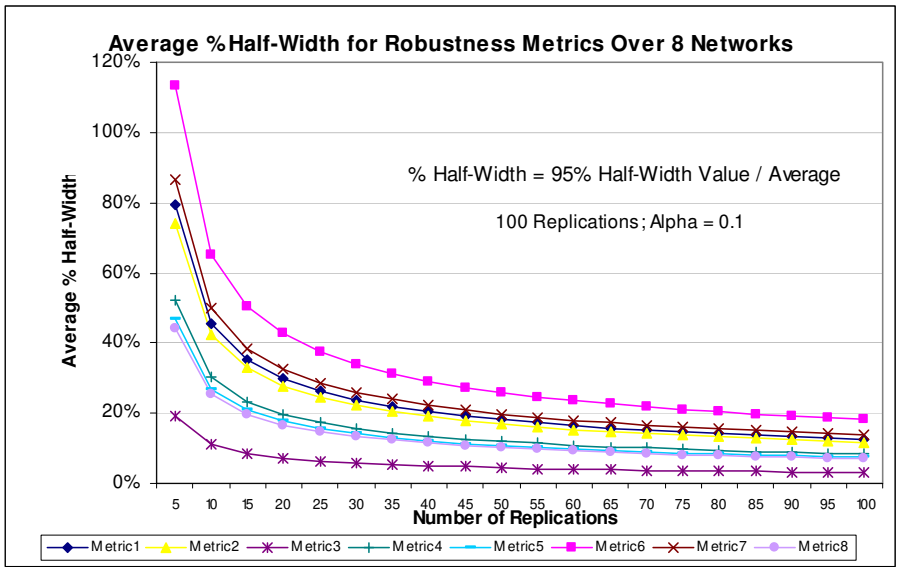


Figure 19: Average Half-Widths for Robustness Metrics

Similarly, the average and standard deviations of 50 replications for 8 networks and 2 buffering strategies provides half-widths for each resource metric estimate as shown in Figure 20.

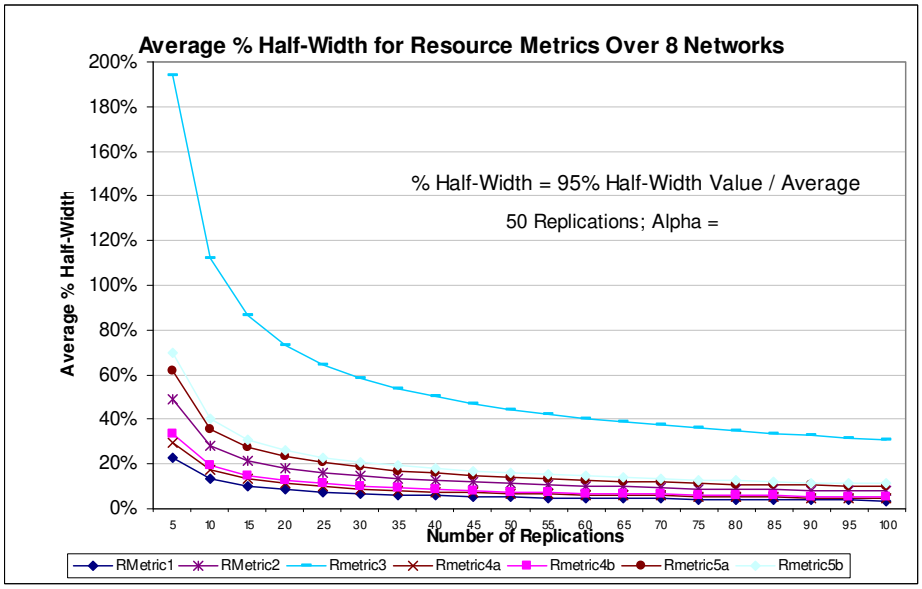


Figure 20: Average Half-Widths for Resource Metrics

The details of the summarized numbers are provided here in Table 16, with each row representing the 100 replications. For example, for NW 1004 with 50% buffer (B5), the average for metric 1 over all 100 replications is 0.493 and standard deviation is 0.416. If we were to use 50 replications, the 95% half-width for the confidence interval is 0.118, or 24% (0.118 divided by 0.493) of the metric estimate summarized in Table 17. In conclusion, 50 replications provide a sufficiently small sized half-width of the confidence interval, and may be used for the remainder of the experiments.

Table 16: Summary Statistics for 100 Replications

		Metric1		Metric2		Metric3		Metric4		Metric5		Metric6		Metric7		Metric8	
		Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Avg	Std
NW1004	B1	0.493	0.416	0.572	0.354	0.753	0.214	0.304	0.152	0.192	0.097	0.105	0.079	0.136	0.103	1.179	0.701
	B5	0.699	0.466	0.853	0.450	0.775	0.204	0.108	0.105	0.263	0.166	0.106	0.143	0.164	0.106	0.674	0.686
NW1010	B1	0.333	0.246	0.378	0.226	0.635	0.178	0.292	0.161	0.151	0.099	0.119	0.096	0.138	0.106	1.129	0.422
	B5	0.686	0.310	1.483	0.426	0.698	0.117	0.239	0.146	0.224	0.123	0.147	0.108	0.499	0.236	0.928	0.220
NW1102	B1	0.194	0.126	0.182	0.134	0.854	0.078	0.336	0.088	0.199	0.075	0.273	0.089	0.148	0.107	0.786	0.221
	B5	0.146	0.090	0.114	0.092	0.906	0.062	0.317	0.103	0.224	0.074	0.309	0.094	0.162	0.115	0.881	0.229
NW1105	B1	0.093	0.071	0.129	0.093	0.806	0.097	0.403	0.106	0.158	0.066	0.392	0.112	0.108	0.083	1.129	0.328
	B5	0.135	0.067	0.098	0.075	0.835	0.073	0.338	0.063	0.158	0.060	0.409	0.084	0.121	0.082	0.955	0.198
NW1200	B1	0.294	0.152	0.414	0.170	0.931	0.071	0.148	0.083	0.211	0.067	0.024	0.035	0.136	0.092	0.590	0.165
	B5	0.692	0.284	0.939	0.235	0.906	0.055	0.172	0.072	0.296	0.075	0.028	0.040	0.183	0.107	0.619	0.121
NW1201	B1	0.320	0.256	0.447	0.281	0.646	0.180	0.152	0.105	0.168	0.067	0.011	0.020	0.146	0.124	1.020	0.391
	B5	0.607	0.249	0.481	0.167	0.771	0.140	0.183	0.094	0.311	0.115	0.044	0.046	0.130	0.079	0.830	0.349
NW1300	B1	0.103	0.067	0.157	0.127	0.723	0.115	0.373	0.065	0.245	0.040	0.043	0.030	0.121	0.091	1.045	0.340
	B5	0.080	0.052	0.136	0.087	0.726	0.137	0.231	0.079	0.183	0.057	0.007	0.014	0.180	0.104	0.979	0.415
NW1304	B1	0.111	0.094	0.158	0.110	0.769	0.086	0.336	0.062	0.283	0.051	0.043	0.032	0.118	0.090	0.946	0.202
	B5	0.147	0.102	0.125	0.086	0.834	0.064	0.364	0.070	0.334	0.065	0.058	0.037	0.109	0.085	0.836	0.177
Grand Total		0.321	0.323	0.417	0.439	0.785	0.154	0.269	0.135	0.225	0.103	0.132	0.152	0.162	0.144	0.908	0.401

Table 17: Half-Widths of Confidence Intervals for α = 0.1

		Metric1		Metric2		Metric3		Metric4		Metric5		Metric6		Metric7		Metric8	
N = 50		% half-width	half-width	% half-width	half-width	% half-width	half-width	% half-width	half-width	% half-width	half-width	% half-width	half-width	% half-width	half-width	% half-width	half-width
NW1004	B1	24.0%	0.118	17.6%	0.101	8.1%	0.061	14.2%	0.043	14.4%	0.028	21.4%	0.022	21.4%	0.029	16.9%	0.199
	B5	19.0%	0.133	15.0%	0.128	7.5%	0.058	27.5%	0.030	18.0%	0.047	38.4%	0.041	18.4%	0.030	28.9%	0.195
NW1010	B1	21.0%	0.070	17.0%	0.064	8.0%	0.051	15.7%	0.046	18.7%	0.028	22.9%	0.027	21.8%	0.030	10.6%	0.120
	B5	12.9%	0.088	8.2%	0.121	4.8%	0.033	17.3%	0.041	15.6%	0.035	20.9%	0.031	13.4%	0.067	6.7%	0.063
NW1102	B1	18.4%	0.036	20.9%	0.038	2.6%	0.022	7.4%	0.025	10.7%	0.021	9.3%	0.025	20.5%	0.030	8.0%	0.063
	B5	17.5%	0.026	23.0%	0.026	1.9%	0.018	9.3%	0.029	9.4%	0.021	8.6%	0.027	20.2%	0.033	7.4%	0.065
NW1105	B1	21.7%	0.020	20.4%	0.026	3.4%	0.028	7.5%	0.030	11.9%	0.019	8.2%	0.032	22.0%	0.024	8.2%	0.093
	B5	14.1%	0.019	21.9%	0.021	2.5%	0.021	5.3%	0.018	10.8%	0.017	5.8%	0.024	19.2%	0.023	5.9%	0.056
NW1200	B1	14.6%	0.043	11.7%	0.048	2.2%	0.020	15.9%	0.023	9.0%	0.019	41.6%	0.010	19.3%	0.026	7.9%	0.047
	B5	11.6%	0.081	7.1%	0.067	1.7%	0.016	12.0%	0.021	7.2%	0.021	39.7%	0.011	16.7%	0.031	5.6%	0.035
NW1201	B1	22.7%	0.073	17.9%	0.080	7.9%	0.051	19.7%	0.030	11.3%	0.019	49.6%	0.006	24.2%	0.035	10.9%	0.111
	B5	11.6%	0.071	9.9%	0.047	5.2%	0.040	14.5%	0.027	10.5%	0.033	29.9%	0.013	17.4%	0.023	11.9%	0.099
NW1300	B1	18.5%	0.019	23.0%	0.036	4.5%	0.033	4.9%	0.018	4.6%	0.011	19.7%	0.008	21.3%	0.026	9.2%	0.097
	B5	18.7%	0.015	18.1%	0.025	5.4%	0.039	9.7%	0.023	8.9%	0.016	59.7%	0.004	16.5%	0.030	12.0%	0.118
NW1304	B1	24.1%	0.027	19.7%	0.031	3.2%	0.024	5.2%	0.018	5.1%	0.014	21.3%	0.009	21.6%	0.025	6.1%	0.057
	B5	19.7%	0.029	19.6%	0.024	2.2%	0.018	5.4%	0.020	5.6%	0.019	18.2%	0.011	22.3%	0.024	6.0%	0.050
Max		24.1%	0.133	23.0%	0.128	8.1%	0.061	27.5%	0.046	18.7%	0.047	59.7%	0.041	24.2%	0.067	28.9%	0.199
Min		11.6%	0.015	7.1%	0.021	1.7%	0.016	4.9%	0.018	4.6%	0.011	5.8%	0.004	13.4%	0.023	5.6%	0.035
Avg		18.1%	0.054	16.9%	0.055	4.4%	0.033	12.0%	0.028	10.7%	0.023	25.9%	0.019	19.8%	0.030	10.2%	0.092

Alternatively, one may set the desired length of the confidence interval and calculate the necessary number of replications to achieve this result. Again using the 100 replications of the initial study on the eight Selim networks and two buffering methods, the method suggested by Winston (1994) was used to determine the number of trials necessary to estimate robustness metrics 1 through 8 in the table below. If the parameter has a standard deviation of σ then the number of trials needed (n) is given by:

$$n = \frac{z_{\alpha/2}^2 \sigma^2}{D^2}$$

where D represents the value for which the estimate is accurate within 100(1-α)% of the time. Assuming estimating the eight robustness metrics within 25% is sufficient provides the following values for n in Table 18 for each combination of networks and buffering methods for each metric:

Table 18: Number of Replications for Robustness Metrics

		Metric 1		Metric 2		Metric 3		Metric 4		Metric 5		Metric 6		Metric 7		Metric 8	
NW		n	half-width	n	half-width	n	half-width	n	half-width	n	half-width	n	half-width	n	half-width	n	half-width
NW1004	B1	48	0.10	26	0.11	5	0.15	17	0.06	17	0.04	38	0.02	38	0.03	24	0.24
	B5	30	0.14	19	0.17	5	0.16	64	0.02	27	0.05	124	0.02	29	0.03	71	0.13
NW1010	B1	37	0.07	24	0.08	5	0.13	21	0.06	29	0.03	44	0.02	40	0.03	10	0.23
	B5	14	0.14	6	0.30	2	0.14	25	0.05	20	0.04	37	0.03	15	0.10	4	0.19
NW1102	B1	28	0.04	37	0.04	1	0.17	5	0.07	10	0.04	7	0.05	36	0.03	5	0.16
	B5	26	0.03	44	0.02	0	0.18	7	0.06	7	0.04	6	0.06	34	0.03	5	0.18
NW1105	B1	40	0.02	35	0.03	1	0.16	5	0.08	12	0.03	6	0.08	41	0.02	6	0.23
	B5	17	0.03	40	0.02	1	0.17	2	0.07	10	0.03	3	0.08	31	0.02	3	0.19
NW1200	B1	18	0.06	11	0.08	0	0.19	21	0.03	7	0.04	145	0.00	31	0.03	5	0.12
	B5	11	0.14	4	0.19	0	0.18	12	0.03	4	0.06	133	0.01	23	0.04	3	0.12
NW1201	B1	43	0.06	27	0.09	5	0.13	33	0.03	11	0.03	207	0.00	49	0.03	10	0.20
	B5	11	0.12	8	0.10	2	0.15	18	0.04	9	0.06	75	0.01	25	0.03	12	0.17
NW1300	B1	29	0.02	45	0.03	2	0.14	2	0.07	2	0.05	33	0.01	38	0.02	7	0.21
	B5	29	0.02	28	0.03	2	0.15	8	0.05	7	0.04	301	0.00	23	0.04	12	0.20
NW1304	B1	49	0.02	33	0.03	1	0.15	2	0.07	2	0.06	38	0.01	39	0.02	3	0.19
	B5	33	0.03	32	0.02	0	0.17	2	0.07	3	0.07	28	0.01	42	0.02	3	0.17
	Max	49		45		5		64		29		301		49		71	

It is noted that 50 replications is sufficient for all cases, except for one case (NW1004 B5) in the metric 4 estimation, one case (NW1004 B5) in metric 8 estimation, and many cases (NW1004 B5, NW1200 B1 and B5, NW1201 B1, and NW1300 B5) for the metric 6 calculation. Closer examination of metric 6 reveals that of the 100 trials, there were many cases where the value of metric 6 was zero (there were no tasks that had both changed precedence relationships and additional preceding tasks in the MB from the PK. Specifically, the number of replications that resulted in zero value for RM6 in the cases mentioned above was 48, 58, 52, 71, and 80, respectively, out of 100 replications. Because of the unusual nature of the value of this metric and non-normal distribution, the standard deviation of the number would be expected to behave unusually.

Similarly, Table 19 is created for the 7 resource metrics to demonstrate the necessary number of replications to estimate the metrics within 20% of the estimate and with $\alpha = 0.1$.

Table 19: Number of Replications for Resource Metrics

		RMetric1		RMetric2		Rmetric3		Rmetric4a		Rmetric4b		Rmetric5a		Rmetric5b	
NW		n	half-width	n	half-width	n	half-width	n	half-width	n	half-width	n	half-width	n	half-width
NW1004	B1	2	0.41	14	0.18	13	0.50	3	1.89	2	4.17	45	1.69	48	7.16
	B5	3	0.46	2	0.52	11	0.44	5	1.43	3	3.55	24	3.18	42	7.98
NW1010	B1	4	0.36	15	0.14	12	0.56	2	1.95	2	4.12	19	1.40	28	4.66
	B5	4	0.44	2	0.57	9	0.61	5	1.38	5	2.48	13	3.69	12	15.24
NW1102	B1	2	0.72	14	0.19	3,403	0.00	4	2.66	5	12.82	19	2.24	29	14.49
	B5	2	0.72	10	0.28	3,403	0.00	3	2.53	8	8.93	16	2.40	13	19.85
NW1105	B1	3	0.66	21	0.15	-	-	3	2.46	3	13.26	26	1.54	14	11.90
	B5	1	0.70	6	0.27	3,403	0.00	3	2.83	4	13.24	16	2.20	12	16.45
NW1200	B1	1	0.33	15	0.09	31	0.31	5	1.52	6	3.13	10	3.80	11	5.64
	B5	2	0.34	3	0.24	11	0.38	5	1.53	8	2.73	9	6.25	16	12.94
NW1201	B1	3	0.28	8	0.13	15	0.39	7	1.18	7	2.40	12	2.72	16	6.61
	B5	2	0.29	8	0.16	27	0.28	5	1.35	7	2.52	10	3.73	20	7.58
NW1300	B1	3	0.59	21	0.14	-	-	3	2.30	7	10.43	22	2.53	30	16.95
	B5	3	0.60	13	0.17	-	-	2	2.89	4	12.32	22	2.08	24	8.66
NW1304	B1	3	0.66	23	0.15	-	-	2	2.67	4	12.06	15	2.24	31	13.98
	B5	2	0.70	9	0.31	-	-	5	1.87	7	9.66	6	2.72	14	16.45
	Max	4		23		3,403		7		8		45		48	

All results, except for a few where non-normality affects the result, demonstrate 50 as a sufficient sample size. This method for determining sample size follows the methods suggested by Law and Kelton (2000) to determine the number of replications when estimating mean with a specified error or precision. Law and Kelton recommend using several successive applications of a fixed-sample-size approach similar to the one above if the precision of the confidence interval is not important (relative error greater than 0.15). Therefore, the remaining trials of the experiment were continued using 50 replications for each experiment on each network. This required the following numbers of schedules to be developed:

Initial baselines: 2 buffers x 20 networks x 3 experiments = 120.

Modified baselines: 2 buffers x 20 networks x 50 replicates x 3 experiments = 6,000.

Perfect knowledge: 20 networks x 50 replicates x 3 experiments = 3,000.

The following section describes the results from running these trials, solving the resource flow networks, and finally calculating the robustness and resource metrics for every network and

calculating the pairwise comparisons between the proportional buffer and its 50% buffer counterpart.

Final Analysis and Results – Using A Priori Knowledge to Size Buffers

A pairwise t-test may be used to compare the response means from two treatments or processes (in this case buffer strategy) (Devore and Farnum 2005). In this case, the experiment produced a resulting metric for the 50% buffered schedule and the proportional buffered baseline schedule for a large number of pairwise replications, which allows the assumption of normality. The hypothesis for the t-test is as follows:

H_o = The means of the pairwise differences are the same.

H_a = The means of the pairwise differences are different.

The following series of tables contains, first, the sample means with highlights to indicate the buffering strategy (proportional buffer (B1, B2, B3) or the 50% buffer (B5)) that produced the smaller mean value of each metric, and second, pairwise differences highlighting significant ($\alpha = 0.05$) pairwise t-tests that indicate an improvement (negative values) when using the proportional buffer (B1, B2, B3) over the 50% buffer (B5).

Table 20: "80/20" Paired Samples Statistics

80/20		Mean	N	Std. Deviation	Error Mean
Pair 1	DurMB_B1	72.9910	1000	23.1766	0.7329
	DurMB_B5	80.7370	1000	21.0136	0.6645
Pair 2	Metric1_B1	0.2436	1000	0.2369	0.0075
	Metric1_B5	0.4353	1000	0.4470	0.0141
Pair 3	Metric2_B1	0.3756	1000	0.3278	0.0104
	Metric2_B5	0.5647	1000	0.5768	0.0182
Pair 4	Metric3_B1	0.7528	1000	0.1576	0.0050
	Metric3_B5	0.7822	1000	0.1793	0.0057
Pair 5	metric4_B1	0.2934	1000	0.1367	0.0043
	metric4_B5	0.2724	1000	0.1302	0.0041
Pair 6	metric5_B1	0.2073	1000	0.0838	0.0026
	metric5_B5	0.2493	1000	0.1106	0.0035
Pair 7	metric6_B1	0.1422	1000	0.1488	0.0047
	metric6_B5	0.1532	1000	0.1564	0.0049
Pair 8	Metric7_B1	0.1558	1000	0.1190	0.0038
	Metric7_B5	0.1683	1000	0.1484	0.0047
Pair 9	Metric8_B1	1.0146	1000	0.4514	0.0143
	Metric8_B5	0.9163	1000	0.4407	0.0139
Pair 10	RMetric1_B1	2.5936	1000	0.8625	0.0273
	RMetric1_B5	2.7767	1000	0.8690	0.0275
Pair 11	RMetric2_B1	0.8839	1000	0.5941	0.0188
	RMetric2_B5	1.5375	1000	0.8773	0.0277
Pair 12	Rmetric3_B1	0.8120	1000	1.1146	0.0352
	Rmetric3_B5	0.8930	1000	1.1523	0.0364
Pair 13	Rmetric4a_B1	10.2065	1000	3.7371	0.1182
	Rmetric4a_B5	9.8690	1000	3.8258	0.1210
Pair 14	Rmetric4b_B1	36.8780	1000	24.8765	0.7867
	Rmetric4b_B5	34.4760	1000	24.2108	0.7656
Pair 15	Rmetric5a_B1	11.1460	1000	7.0877	0.2241
	Rmetric5a_B5	16.7505	1000	12.0789	0.3820
Pair 16	Rmetric5b_B1	55.6160	1000	43.1687	1.3651
	Rmetric5b_B5	78.6120	1000	51.9472	1.6427

Table 21: "80/20" Paired Differences

80/20	Paired Differences	Mean	Std. Dev	St. Er Mean	95% CI of Diff Lower	95% CI of Diff Upper	t	df	Sig. (2-tailed)
Pair 1	DurMB_B1 - DurMB_B5	(7.746)	13.470	0.426	(8.582)	(6.910)	(18.184)	999	0.000
Pair 2	Metric1_B1 - Metric1_B5	(0.192)	0.345	0.011	(0.213)	(0.170)	(17.556)	999	0.000
Pair 3	Metric2_B1 - Metric2_B5	(0.189)	0.455	0.014	(0.217)	(0.161)	(13.134)	999	0.000
Pair 4	Metric3_B1 - Metric3_B5	(0.029)	0.192	0.006	(0.041)	(0.018)	(4.844)	999	0.000
Pair 5	metric4_B1 - metric4_B5	0.021	0.118	0.004	0.014	0.028	5.617	999	0.000
Pair 6	metric5_B1 - metric5_B5	(0.042)	0.107	0.003	(0.049)	(0.035)	(12.408)	999	0.000
Pair 7	metric6_B1 - metric6_B5	(0.011)	0.116	0.004	(0.018)	(0.004)	(3.008)	999	0.003
Pair 8	Metric7_B1 - Metric7_B5	(0.012)	0.139	0.004	(0.021)	(0.004)	(2.838)	999	0.005
Pair 9	Metric8_B1 - Metric8_B5	0.098	0.514	0.016	0.066	0.130	6.042	999	0.000
Pair 10	RMetric1_B1 - RMetric1_B5	(0.183)	0.652	0.021	(0.223)	(0.143)	(8.883)	999	0.000
Pair 11	RMetric2_B1 - RMetric2_B5	(0.654)	0.654	0.021	(0.694)	(0.613)	(31.616)	999	0.000
Pair 12	Rmetric3_B1 - Rmetric3_B5	(0.081)	0.724	0.023	(0.126)	(0.036)	(3.537)	999	0.000
Pair 13	Rmetric4a_B1 - Rmetric4a_B5	0.338	1.968	0.062	0.215	0.460	5.423	999	0.000
Pair 14	Rmetric4b_B1 - Rmetric4b_B5	2.402	8.660	0.274	1.865	2.939	8.771	999	0.000
Pair 15	Rmetric5a_B1 - Rmetric5a_B5	(5.605)	12.186	0.385	(6.361)	(4.848)	(14.543)	999	0.000
Pair 16	Rmetric5b_B1 - Rmetric5b_B5	(22.996)	58.991	1.865	(26.657)	(19.335)	(12.327)	999	0.000

Table 22: "90/10" Paired Samples Statistics

90/10		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	DurMB_B2	81.2420	1000	25.9873	0.8218
	DurMB_B5	89.4470	1000	23.5667	0.7452
Pair 2	Metric1_B2	0.3862	1000	0.4420	0.0140
	Metric1_B5	0.6386	1000	0.8370	0.0265
Pair 3	Metric2_B2	0.4164	1000	0.4779	0.0151
	Metric2_B5	0.6813	1000	0.6965	0.0220
Pair 4	Metric3_B2	0.7855	1000	0.1410	0.0045
	Metric3_B5	0.8090	1000	0.1374	0.0043
Pair 5	metric4_B2	0.3079	1000	0.1252	0.0040
	metric4_B5	0.2786	1000	0.1321	0.0042
Pair 6	metric5_B2	0.2126	1000	0.0874	0.0028
	metric5_B5	0.2361	1000	0.0955	0.0030
Pair 7	metric6_B2	0.2010	1000	0.1841	0.0058
	metric6_B5	0.2170	1000	0.2162	0.0068
Pair 8	Metric7_B2	0.1682	1000	0.1462	0.0046
	Metric7_B5	0.1856	1000	0.1363	0.0043
Pair 9	Metric8_B2	0.9345	1000	0.3495	0.0111
	Metric8_B5	0.8538	1000	0.3310	0.0105
Pair 10	RMetric1_B2	2.7669	1000	0.7803	0.0247
	RMetric1_B5	3.0273	1000	0.9033	0.0286
Pair 11	RMetric2_B2	1.1288	1000	0.8352	0.0264
	RMetric2_B5	1.1110	1000	0.8181	0.0259
Pair 12	Rmetric3_B2	1.3825	1000	1.6795	0.0531
	Rmetric3_B5	0.8280	1000	1.1123	0.0352
Pair 13	Rmetric4a_B2	19.6965	1000	7.5274	0.2380
	Rmetric4a_B5	9.9100	1000	4.3236	0.1367
Pair 14	Rmetric4b_B2	98.3270	1000	65.1631	2.0606
	Rmetric4b_B5	32.2205	1000	25.1534	0.7954
Pair 15	Rmetric5a_B2	18.0285	1000	10.0370	0.3174
	Rmetric5a_B5	18.1695	1000	12.0235	0.3802
Pair 16	Rmetric5b_B2	92.2450	1000	67.8138	2.1445
	Rmetric5b_B5	78.5180	1000	52.1163	1.6481

Table 23: "90/10" Paired Differences

90/10	Paired Differences	Mean	Std. Dev	St. Er Mean	95% CI of Diff Lower	95% CI of Diff Upper	t	df	Sig. (2-tailed)
Pair 1	DurMB_B2 - DurMB_B5	(8.205)	16.271	0.515	(9.215)	(7.195)	(15.946)	999	0.000
Pair 2	Metric1_B2 - Metric1_B5	(0.252)	0.560	0.018	(0.287)	(0.218)	(14.239)	999	0.000
Pair 3	Metric2_B2 - Metric2_B5	(0.265)	0.494	0.016	(0.296)	(0.234)	(16.960)	999	0.000
Pair 4	Metric3_B2 - Metric3_B5	(0.023)	0.121	0.004	(0.031)	(0.016)	(6.147)	999	0.000
Pair 5	metric4_B2 - metric4_B5	0.029	0.126	0.004	0.022	0.037	7.378	999	0.000
Pair 6	metric5_B2 - metric5_B5	(0.024)	0.083	0.003	(0.029)	(0.018)	(8.907)	999	0.000
Pair 7	metric6_B2 - metric6_B5	(0.016)	0.120	0.004	(0.024)	(0.009)	(4.222)	999	0.000
Pair 8	Metric7_B2 - Metric7_B5	(0.017)	0.077	0.002	(0.022)	(0.013)	(7.145)	999	0.000
Pair 9	Metric8_B2 - Metric8_B5	0.081	0.318	0.010	0.061	0.100	8.026	999	0.000
Pair 10	RMetric1_B2 - RMetric1_B5	(0.260)	0.653	0.021	(0.301)	(0.220)	(12.604)	999	0.000
Pair 11	RMetric2_B2 - RMetric2_B5	0.018	0.369	0.012	(0.005)	0.041	1.522	999	0.128
Pair 12	Rmetric3_B2 - Rmetric3_B5	0.555	1.182	0.037	0.481	0.628	14.829	999	0.000
Pair 13	Rmetric4a_B2 - Rmetric4a_B5	9.787	9.698	0.307	9.185	10.388	31.911	999	0.000
Pair 14	Rmetric4b_B2 - Rmetric4b_B5	66.107	85.098	2.691	60.826	71.387	24.566	999	0.000
Pair 15	Rmetric5a_B2 - Rmetric5a_B5	(0.141)	15.309	0.484	(1.091)	0.809	(0.291)	999	0.771
Pair 16	Rmetric5b_B2 - Rmetric5b_B5	13.727	74.073	2.342	9.130	18.324	5.860	999	0.000

Table 24: "Uniform" Paired Samples Statistics

Unif.		Mean	N	Std. Deviation	Std. Error
Pair 1	DurMB_B3	76.7610	1000	26.0341	0.8233
	DurMB_B5	91.3110	1000	21.0040	0.6642
Pair 2	Metric1_B3	0.1836	1000	0.1951	0.0062
	Metric1_B5	0.5140	1000	0.5038	0.0159
Pair 3	Metric2_B3	0.2565	1000	0.2400	0.0076
	Metric2_B5	0.7312	1000	0.6501	0.0206
Pair 4	Metric3_B3	0.7158	1000	0.1728	0.0055
	Metric3_B5	0.8346	1000	0.1240	0.0039
Pair 5	metric4_B3	0.0218	1000	0.0477	0.0015
	metric4_B5	0.0196	1000	0.0448	0.0014
Pair 6	metric5_B3	0.5453	1000	0.2351	0.0074
	metric5_B5	0.5621	1000	0.2111	0.0067
Pair 7	metric6_B3	0.3807	1000	0.2224	0.0070
	metric6_B5	0.3701	1000	0.2021	0.0064
Pair 8	Metric7_B3	0.1096	1000	0.0917	0.0029
	Metric7_B5	0.1740	1000	0.1387	0.0044
Pair 9	Metric8_B3	1.1046	1000	0.4846	0.0153
	Metric8_B5	0.8319	1000	0.3229	0.0102
Pair 10	RMetric1_B3	2.4188	1000	0.7827	0.0248
	RMetric1_B5	2.9105	1000	0.8983	0.0284
Pair 11	RMetric2_B3	0.7284	1000	0.5607	0.0177
	RMetric2_B5	1.4486	1000	0.9077	0.0287
Pair 12	Rmetric3_B3	0.4875	1000	0.7312	0.0231
	Rmetric3_B5	0.9270	1000	1.2044	0.0381
Pair 13	Rmetric4a_B3	5.6250	1000	2.8956	0.0916
	Rmetric4a_B5	9.0945	1000	3.8761	0.1226
Pair 14	Rmetric4b_B3	20.7940	1000	18.4787	0.5843
	Rmetric4b_B5	30.7335	1000	22.6398	0.7159
Pair 15	Rmetric5a_B5	22.4625	1000	14.2402	0.4503
	Rmetric5b_B3	47.5765	1000	34.6393	1.0954
Pair 16	Rmetric5b_B3	47.5765	1000	34.6393	1.0954
	Rmetric5b_B5	95.9310	1000	52.4936	1.6600

Table 25: "Uniform" Paired Differences

Unif.	Paired Differences	Mean	Std. Dev	St. Er Mean	95% CI of Diff Lower	95% CI of Diff Upper	t	df	Sig. (2-tailed)
Pair 1	DurMB_B3 - DurMB_B5	(14.550)	13.652	0.432	(15.397)	(13.703)	(33.703)	999	0.000
Pair 2	Metric1_B3 - Metric1_B5	(0.330)	0.391	0.012	(0.355)	(0.306)	(26.724)	999	0.000
Pair 3	Metric2_B3 - Metric2_B5	(0.475)	0.522	0.016	(0.507)	(0.442)	(28.783)	999	0.000
Pair 4	Metric3_B3 - Metric3_B5	(0.119)	0.191	0.006	(0.131)	(0.107)	(19.671)	999	0.000
Pair 5	metric4_B3 - metric4_B5	0.002	0.016	0.001	0.001	0.003	4.351	999	0.000
Pair 6	metric5_B3 - metric5_B5	(0.017)	0.113	0.004	(0.024)	(0.010)	(4.734)	999	0.000
Pair 7	metric6_B3 - metric6_B5	0.011	0.112	0.004	0.004	0.018	3.012	999	0.003
Pair 8	Metric7_B3 - Metric7_B5	(0.064)	0.114	0.004	(0.071)	(0.057)	(17.885)	999	0.000
Pair 9	Metric8_B3 - Metric8_B5	0.273	0.517	0.016	0.241	0.305	16.681	999	0.000
Pair 10	RMetric1_B3 - RMetric1_B5	(0.492)	0.771	0.024	(0.540)	(0.444)	(20.160)	999	0.000
Pair 11	RMetric2_B3 - RMetric2_B5	(0.720)	0.605	0.019	(0.758)	(0.683)	(37.651)	999	0.000
Pair 12	Rmetric3_B3 - Rmetric3_B5	(0.440)	0.922	0.029	(0.497)	(0.382)	(15.075)	999	0.000
Pair 13	Rmetric4a_B3 - Rmetric4a_B5	(3.470)	2.653	0.084	(3.634)	(3.305)	(41.354)	999	0.000
Pair 14	Rmetric4b_B3 - Rmetric4b_B5	(9.940)	15.323	0.485	(10.890)	(8.989)	(20.512)	999	0.000
Pair 15	Rmetric5a_B5 - Rmetric5b_B3	(25.114)	37.847	1.197	(27.463)	(22.765)	(20.984)	999	0.000
Pair 16	Rmetric5b_B3 - Rmetric5b_B5	(48.355)	55.664	1.760	(51.809)	(44.900)	(27.470)	999	0.000

The tables above indicate that there appears to be a significant effect, over all 1,000 pairwise comparisons (20 networks x 50 replications of each buffering type) for most metrics in all three experiments. This allowed us to reject the null hypothesis and conclude that the pairwise differences are different (and in fact, improved in many cases) when using these proportional buffer assignment techniques over the 50% buffer. Further study was then conducted to understand how the network characteristics may affect this result.

GLM Model

The tables above demonstrated that there is a significant difference (improvement) when using any one of the proportional buffering scenarios on most metrics. With understanding gained in Chapter Five that network characteristics have an effect on many metric values, a GLM model is constructed to test for significant effects and interactions among network and resource characteristics that may affect the paired differences in metrics values among the proportional

buffers. Similar to the application of this method in studying factor effects in Chapter Five, normality is assumed. In this case, our dependent variable is the pairwise differences in the metric between the proportional buffer and the 50% buffer, and there are three proportional buffering schemes to compare.

H_o = There is no main effect or interaction for factor(s) specified.

H_a = The particular effect or interaction does exist.

The GLM results are below with these respective factor settings:

Table 26: Factor Settings

Abbreviation	Factor Description	Factor Settings
Method	Probability assignment	80/20, 90/10, Uniform
Net	Network Parameters	High (H), Low (L)
Res	Resource Parameters	High (H), Low (L)

The complete model results for each of the robustness and resource metrics are located in Appendix K. The following is an example of these results and shows the model results for the total project duration. Here, the dependent variable is the improvement value of the metric over the 50% buffer. Factors and interactions significant at $\alpha = 0.5$ are highlighted.

Table 27: Example GLM Model Results

Metric	Source	DF	SS Error	F-Val	P-Val
Dur	Method	2	28,921.374	98.155	0.000
Dur	Res	1	173,234.403	1,175.862	0.000
Dur	Method*Res	2	2,894.742	9.824	0.000
Dur	Net	1	11,473.896	77.881	0.000
Dur	Method*Net	2	1,033.013	3.506	0.030
Dur	Res*Net	1	806.008	5.471	0.019
Dur	Method*Res*Net	2	2,287.341	7.763	0.000
Dur	ERROR	2988	440,208.556	0.000	-

Since the dependent variable is the improvement in metrics values over the 50% buffer techniques, a negative value of the dependent variable indicates an improvement. All future tables use this improvement value as the dependent variable. Table 28 is a summary of where the model has resulted in significant effects, indicated with a "1". This summary shows that nearly every metric is affected by an interaction factor involving the resource and network parameters.

Table 28: Summary of Significant Model Effects

		Robustness Metrics								Resource Metrics							
Source	**Dur**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**Total**
Method	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
Res	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	15
Method*Res	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	15
Net	1	1	1	1		1	1		1	1	1	1	1	1	1		13
Method*Net	1	1	1	1	1	1	1	1		1	1	1	1	1	1		14
Res*Net	1	1	1	1	1	1		1	1	1	1	1	1	1	1		14
Method*Res*Net	1	1	1	1	1		1	1		1	1	1	1	1	1	1	14
Grand Total	7	7	7	7	6	6	6	6	4	7	7	6	7	7	7	4	101

Since the resource*network*method interaction is significant, the interpretation of the values for the individual factors should consider the level setting of the other two factors. The interaction plots are located in Appendix K. The plots contain the means for the interaction effects for the high and low settings for resource and network factor settings for each method used to test the proportional buffer. Figure 21 is an example of these plots for robustness metric 1.

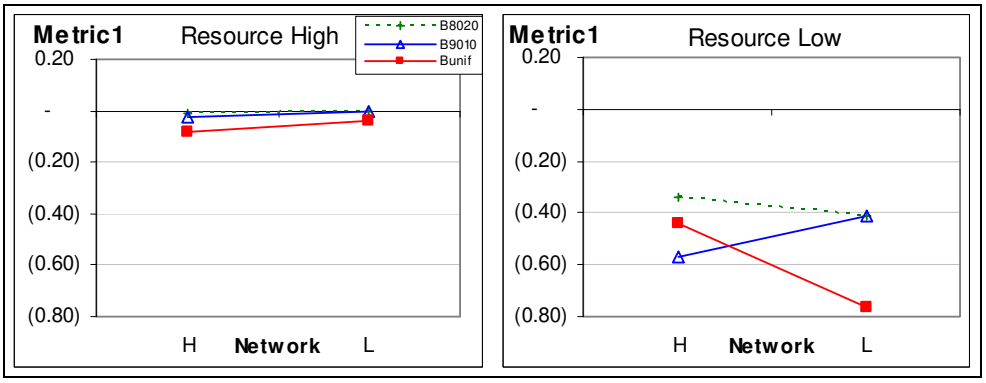


Figure 21: Example Interaction Plot

Since method shows as significant to the final metric value improvement, conclusions of the results for the analysis of proportional buffers must be considered carefully. Recall, the three testing methods determined buffer sizing, but also identified the stochastic tasks, and the eventuation of the schedule (determined the probability of these tasks occurring or not occurring). The 80/20 and 90/10 methods assigned probability related to a calculated (SN) number that incorporated resource information and duration, while the uniform method is based on a uniform distribution across all previously identified stochastic tasks (note, the SN value was used initially to identify this set of stochastic tasks). This indicates that if a project manager believes that stochasticity is related to SN values (for example, planning for a worse-case scenarios since higher SN values indicate a more disruptive task if it occurs stochastically), then it may be more or less helpful to proportionally buffer rather than use a 50% buffer. To determine if it would be more or less helpful in this case, further testing was required.

Paired Differences by Network Type (t-Test Results)

With the knowledge that there are significant interaction effects among the resource and network parameters, a t-test for significant means is once again conducted for each of the three methods **under each factor setting combination**.

H_o = The mean improvement value is zero.

H_a = The mean improvement value is not zero.

This hypothesis test will determine if the mean difference between the metric values using each proportional buffer over the 50% buffer, simulated over 250 replications within the factor settings for resource (high/low) and network (high/low) is different than zero at $\alpha = 0.05$. The t-test results tables are located in Appendix K and an example of these tables follows. Here, each row demonstrates the mean value of the difference between the metric value using the proportional buffer over the 50% buffer, simulated over 250 replications within the factor settings for resource (high/low) and network (high/low). Significant p-values are highlighted in yellow ($\alpha = 0.05$), while significantly improved mean values (negative) are highlighted in green and significantly worsened values (positive) are highlighted in red.

Table 29: Example t-Test Results for Duration

Test Set	Res	Net	Metric	Mean	Std Err	95% CI Lower	95% CI Upper	t	p-val
B8020	H	H	Dur	(1.284)	0.389	(2.051)	(0.517)	(3.297)	0.0011
B9010	H	H	Dur	(2.844)	0.320	(3.474)	(2.214)	(8.887)	0.0000
Bunif	H	H	Dur	(7.888)	0.377	(8.630)	(7.146)	(20.938)	0.0000
B8020	H	L	Dur	(0.360)	0.395	(1.138)	0.418	(0.911)	0.3632
B9010	H	L	Dur	0.204	0.377	(0.538)	0.946	0.542	0.5885
Bunif	H	L	Dur	(3.236)	0.409	(4.041)	(2.431)	(7.915)	0.0000
B8020	L	H	Dur	(17.144)	1.077	(19.265)	(15.023)	(15.917)	0.0000
B9010	L	H	Dur	(19.128)	1.240	(21.570)	(16.686)	(15.430)	0.0000
Bunif	L	H	Dur	(24.448)	0.899	(26.218)	(22.678)	(27.207)	0.0000
B8020	L	L	Dur	(12.196)	0.789	(13.750)	(10.642)	(15.453)	0.0000
B9010	L	L	Dur	(11.052)	1.248	(13.509)	(8.595)	(8.858)	0.0000
Bunif	L	L	Dur	(22.628)	0.726	(24.057)	(21.199)	(31.183)	0.0000

Table 30 below summarizes the results of these paired t-test. The table demonstrates where the mean is significant and there is significant improvement (indicated with a "+") or worsening ("-") by using the proportional buffer over the 50% buffer. A blank indicates no significant difference between that proportional buffering method and the 50% buffer.

Table 30: Summary of Significantly Different Paired Differences

+ imp / - worse				Robustness Metrics								Resource Metrics							Total
Res	**Net**	**Test Set**	**Dur**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**Imp**
H	H	B8020	+	+	-		-	-	-			+	+	-					4
H	H	B9010	+	+	+	-	+	+	+	+		+	-	-	-	+		-	9
H	H	Bunif	+	+	+	+	-			+	-	+	+	-	+	+	+	+	11
Total # Improved			3	3	2	1	1	1	1	2		3	2		1	2	1	1	24
H	L	B8020			-	+		+	-		-	+	+		-	-		+	5
H	L	B9010			+			+	-	+	-	+	-		-	+	-	-	5
H	L	Bunif	+	+	+	+	-	+	-	+	-	+	+	+	+	+	+	+	13
Total # Improved			1	1	2	2		3		2		3	2	1	1	2	1	2	23
L	H	B8020	+	+	+			+	+				+			-	+	+	8
L	H	B9010	+	+	+	+	-	+	+		-	-	+	-	-	-	+	+	9
L	H	Bunif	+	+	+	+	+			+	-	+	+	+	+	+	+	+	13
Total # Improved			3	3	3	2	1	2	2	1		1	3	1	1	1	3	3	30
L	L	B8020	+	+	+	+	-	+	+	+	-	+	+	+	-	-	+	+	12
L	L	B9010	+	+	+	+	-	+		+	-			-	-	-	-	+	7
L	L	Bunif	+	+	+	+	-	+	-	+	-		+	+	+	+	+	+	12
Total # Improved			3	3	3	3		3	1	3		1	2	2	1	1	2	3	31

In addition to the t-test results, a series of confidence intervals for the mean improvement value is located in Appendix K, and an example is shown here for duration.

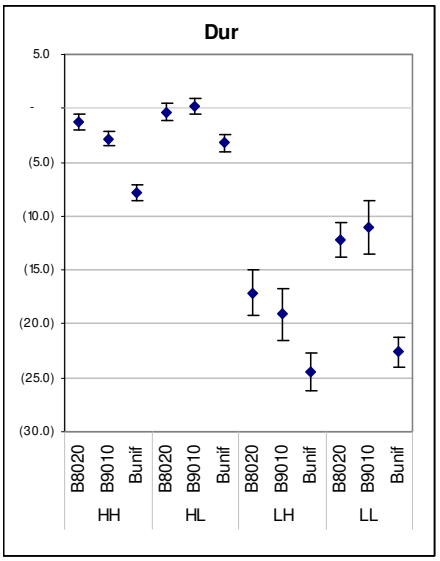


Figure 22: Example Confidence Interval for Improvement

The confidence interval that does not contain zero indicates significant differences. Looking at these confidence intervals and the summary table above suggests that there may be a pattern associated with the buffer used. For example, for the low resource and network parameters setting, 12 of the 16 metrics improved under the uniform buffering test set, while only 7 improved under the 90/10 test set. Also, there are only a few instances where the confidence intervals overlap. The next section will describe how ANOVA was used to test these differences implicitly.

ANOVA Results

With the initial GLM revealing significant interactions with the resource and network parameters, and confidence intervals for the improvement values indicating some differences, a series of ANOVA tables were constructed for each set of networks to determine if the method

used to determine the buffers are statistically different. Here, each set of networks represents five networks with the same factor settings for network and resource parameters.

H_o = The mean pairwise difference for each buffering strategy are all equal.

H_a = At least one of the pairwise difference means for buffering strategy is different than the rest.

The ANOVA results are contained in Appendix K and an example table for the ANOVA with high resource / high network factor settings follows. Here, the degrees of freedom for the model are 2, error is 747, and the corrected total is 749. The highlighted rows indicate where the metric value was statistically different for the three proportional buffering methods at $\alpha = 0.05$. This example table shows that at least one of the buffering strategies produced a significantly different pairwise mean difference in all the metrics for the high resource / high network factor settings.

Table 31: Example ANOVA Results for High Resource / High Network Factors

Res	Net	Metric	SS Model	SS Error	F-Val	P-Val
H	H	Dur	5,957.363	24,652.616	90.257	0.000
H	H	Metric1	0.697	3.097	84.046	0.000
H	H	Metric2	3.527	6.353	207.330	0.000
H	H	Metric3	0.937	13.873	25.224	0.000
H	H	Metric4	0.120	4.260	10.484	0.000
H	H	Metric5	0.070	3.848	6.815	0.001
H	H	Metric6	0.176	2.461	26.752	0.000
H	H	Metric7	0.136	4.507	11.263	0.000
H	H	Metric8	8.072	119.115	25.310	0.000
H	H	RMetric1	66.229	420.891	58.772	0.000
H	H	RMetric2	48.671	92.404	196.731	0.000
H	H	Rmetric3	-	-	-	-
H	H	Rmetric4a	4,477.733	5,456.609	306.497	0.000
H	H	Rmetric4b	78,855.971	196,746.259	149.699	0.000
H	H	Rmetric5a	840.649	44,509.905	7.054	0.001
H	H	Rmetric5b	1,413,397.971	2,149,233.523	245.624	0.000

The following table summarizes the results of the ANOVAs, testing for significantly different metric means under the 3 different methods used to assign a probability of occurrence and modified base eventuation. An indicator (1) is located in each cell to represent if the test

showed a significant difference among the 3 test sets at $\alpha = 0.5$. The majority of the ANOVAs reveal that the average metric value between the three test sets is significantly different within each of the resource (high/low) and network (high/low) parameter settings.

Table 32: Significant Differences Among Three Proportional Buffering Test Sets

			Robustness Metrics								Resource Metrics							
Res	**Net**	**Dur**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**1**	**2**	**3**	**4a**	**4b**	**5a**	**5b**	**Total**
H	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
H	L	1	1	1	1		1		1	1	1	1		1	1	1	1	13
L	H	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
L	L	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16
	Total	4	4	4	4	3	4	3	4	4	4	4	3	4	4	4	4	61

The metrics values that are different depending on the test set indicates that the nature of stochasticity is important for project managers to be aware of, since the amount of improvement over the 50% buffer that may be gained by using proportional buffers varies depending on the distribution of the stochasticity over the network. The amount of expected improvement may be helpful for a project manager to understand as the decision to implement a more complicated buffering method over a simple 50% buffering method.

Tukey's Test

For each of the highlighted rows in the ANOVA tables, Tukey's test was used to determine where the means are significantly different, and look for significant differences among the 3 test sets. For each of the paired comparisons for the 3 test sets (80/20, 90/10, and uniform) the following hypothesis comparing the 50% buffer with a proportional buffer was tested:

H_o = the improvement value means for the two buffering strategies are the same.

H_a = the improvement value means for the two buffering strategies are not the same.

The complete result tables are be located in Appendix K, and an example table follows. In this table, means with the same letter in the columns labeled "Tukey Grouping" are not significantly different. Additionally, a 1 indicates no pair-wise difference significant at $\alpha = 0.05$. Zeros, indicating significant pair-wise differences are highlighted, and a note is made indicating the technique that produced the lowest average improvement metric value. The lowest value indicates the most improvement over the 50% buffering method.

Table 33: Example Tukey Test Results

Res	Net	Metric	Tukey Grouping		Mean	Test Set	Method B8020	Method B9010	Method Bunif	Min Mean
H	H	Dur	A		(1.284)	B8020	1	0	0	
H	H	Dur	B		(2.844)	B9010	0	1	0	
H	H	Dur	C		(7.888)	Bunif	0	0	1	Bunif

The results of the Tukey test results are summarized below in table 34 where it has been demonstrated that significant differences are found at $\alpha = 0.05$. The table contains an indicator (1) of the test set with the lowest mean value of the three techniques if a significant difference was found. For all four combinations settings of resource (High/Low) and network (High/Low) parameters, the uniform probability test set is most likely to have the lowest (best) improvement over the 50% buffer. Table 35 shows the average value of each metric improvement with that test set.

Table 34: Indicators of Best Improvement Over 50% Buffer

Res	Net	Test Set	Dur	Robustness Metrics 1	2	3	4	5	6	7	8	Resource Metrics 1	2	3	4a	4b	5a	5b	Total
H	H	B8020									1								1
H	H	B9010					1	1	1	1						1			5
H	H	Bunif	1	1	1	1						1	1		1		1	1	9
H	L	B8020									1								1
H	L	B9010								1									1
H	L	Bunif	1	1	1	1		1				1	1		1	1	1	1	11
L	H	B8020						1											1
L	H	B9010		1							1								2
L	H	Bunif	1		1	1				1		1	1		1	1	1	1	10
L	L	B8020						1	1			1							3
L	L	B9010									1								1
L	L	Bunif	1	1	1	1	1			1			1	1	1	1	1	1	12
		Total	4	4	4	4	2	4	2	4	4	4	4	1	4	4	4	4	57

Table 35: Average Pairwise Improvement Over 50% Buffer with Highlighted Best

Res	Net	Test Set	Dur	Robustness Metrics 1	2	3	4	5	6	7	8	Resource Metrics 1	2	3	4a	4b	5a	5b
H	H	B8020	(1.28)	(0.01)	0.06	0.01	0.02	0.01	0.02	(0.01)	0.01	(0.19)	(0.41)	-	(0.3)	0.9	0.5	0.43
H	H	B9010	(2.84)	(0.03)	(0.08)	0.02	(0.01)	(0.01)	(0.01)	(0.04)	0.04	(0.54)	0.11	-	0.4	(23.6)	(0.5)	56.5
H	H	Bunif	(7.89)	(0.08)	(0.10)	(0.06)	-	0.00	(0.00)	(0.01)	0.24	(0.92)	(0.45)	-	(5.1)	(16.0)	(2.1)	(49.7)
H	L	B8020	(0.36)	(0.00)	0.06	(0.03)	0.00	(0.03)	0.03	0.00	0.09	(0.17)	(0.34)	(0.00)	0.5	5.2	(0.8)	(14.1)
H	L	B9010	0.20	(0.00)	(0.04)	(0.01)	0.00	(0.01)	0.05	(0.02)	0.10	(0.57)	0.04	(0.00)	0.8	(12.7)	4.3	49.0
H	L	Bunif	(3.24)	(0.04)	(0.04)	(0.05)	0.01	(0.04)	0.03	(0.02)	0.23	(0.84)	(0.38)	(0.02)	(4.7)	(19.0)	(2.5)	(28.0)
L	H	B8020	(17.1)	(0.34)	(0.33)	0.02	0.00	(0.07)	(0.01)	0.00	0.04	(0.01)	(0.59)	(0.08)	0.1	1.2	(12.3)	(44.9)
L	H	B9010	(19.1)	(0.57)	(0.50)	(0.07)	0.11	(0.04)	(0.10)	0.00	0.04	0.06	(0.10)	1.87	19.9	150.6	(8.3)	(33.4)
L	H	Bunif	(24.4)	(0.44)	(0.71)	(0.15)	(0.00)	(0.00)	(0.00)	(0.13)	0.21	(0.14)	(0.64)	(0.89)	(2.5)	(3.6)	(21.8)	(45.6)
L	L	B8020	(12.2)	(0.42)	(0.55)	(0.12)	0.06	(0.08)	(0.08)	(0.05)	0.25	(0.37)	(1.27)	(0.24)	1.1	2.2	(9.8)	(33.4)
L	L	B9010	(11.1)	(0.41)	(0.44)	(0.03)	0.02	(0.03)	(0.00)	(0.01)	0.14	0.00	0.03	0.36	18.1	150.1	3.9	(17.2)
L	L	Bunif	(22.6)	(0.76)	(1.06)	(0.21)	0.00	(0.03)	0.02	(0.10)	0.41	(0.07)	(1.41)	(0.85)	(1.5)	(1.2)	(21.0)	(70.1)

The table patterns reveal the interaction effects between the methods and network characteristics, as indicated in the previous section. The highlighted values in the table describe to a project manager the average improvement one may expect over the 50% buffer, and can compare this to other types of methods. This information is not necessarily intended to be directly applied by a project manager; however, it is provided here for reference to other researchers to demonstrate that the methods we have implemented have produced different results. Therefore, the information that a project manager may apply directly (that is the

information in Table 30) would have varying results based on the type of network on which this information was applied.

Practical Application

There is evidence that resource and network characteristics interact with the nature of the stochasticity of the network (and our method to assign stochastic probabilities). Therefore, it is recommended that a project manager pay careful attention to the characteristics of the project network before determining if buffers proportional to the probability of occurrence is appropriate. The proportional buffer in the 80/20, 90/10, and uniform test sets is proven to produce statistically different improvement values over the 50% buffer, so a project manager should use the information about the stochasticity of the network to determine if proportional buffers should be implemented over the 50%.

A project manager may use the information in the above tables to determine if proportional buffers are appropriate, and gain an understanding how much relative improvement one may gain if the stochastic tasks are distributed in a manner that aligns with the testing strategies presented here. If a project manager thinks that the probability of occurrence is not correlated to SN values (similar to the uniform testing methods) and the network is high resource and low network parameters, then Table 30, Summary of Significantly Different Paired Differences, demonstrates that all resource metrics will be improved by implementing a proportional buffer over the 50% method. Therefore, if resource metrics are important for the project manager and there is knowledge about the probability of occurrence, proportional buffers are recommended.

Proportional Buffers Conclusions

The above results provided strong evidence to conclude that Hypothesis #4 is true, that is, applying a buffer proportional to the probability of occurrence will produce significantly improved results over applying a 50% buffer to stochastically occurring tasks in the development of the initial baseline schedule. Overall, all three test sets (80/20, 90/10, and uniform) showed that proportional buffer sizes generally provided significant improvement over the 50% buffer. Table 30 may be used as a reference by project managers to determine if proportional buffers should be applied to the project at hand. This decision would depend on the network characteristics (resource and network parameters) and what is important to the project manager.

The three test sets described here assumed perfect knowledge of stochastic task occurrence probability, so further study may determine the tolerance level of how accurate a project manager must be in projecting these probabilities to maintain the effectiveness of this strategy.

Chapter Five has investigated sizing buffers using resource information, and Chapter Six has examined sizing buffers proportional to the probability of occurrence. Both of these experiments looked at these "predictive" methods while repairing the eventuated schedules using the same right/left-shift policy initially described by Selim, modified by Grey for various sized buffers, and implemented here using SAS code. Thus far, there has been no research conducted on revising the repair heuristic for the SRCPSP with STI. Chapter Seven describes the first study of its kind to determine if a modification of the right/left-shift policy that incorporates a rescheduling point will improve overall performance of the repair heuristic.

CHAPTER SEVEN: NEW REATIVE SCHEDULING PROCEDURE

The previous experiments described in Chapters Five and Six utilized a combined right/left-shift repair heuristic that was used by Grey and may be considered a modification of the left and right shift repair heuristic described by Selim for the SRCPSP with STI. For this research, this right/left-shift repair was implemented in SAS for automation (see Chapter Four for a detailed description). Other researchers have also described a simple control rules such as a right-shift rule (Sadeh, Otsuka, et al. 1993) which involves moving activities affected by the schedule breakdown forward in time. However, Herroelen and Leus (2004b) warn that this reactive strategy may lead to poor results, since it does not re-sequence activities. There have been many heuristic solutions proposed in the literature for the SRCPSP with stochastic activity durations, including those that offer a full-rescheduling option. The recommended reactive procedure will often depend on the objective, which may be different than the objective used for developing the initial baseline, because it may now include ex post stability (Demeulemeester and Herroelen 2002; Herroelen and Leus 2004b).

This chapter describes an experiment that was developed and implemented to test if a revised repair heuristic that involves a reschedule at some point will improve schedule repair performance. This was tested on the Selim problem set with 50% buffers for high and low stochasticity and early and late eventuation. In order to maintain some stability, the rescheduling was done only one point during the scheduling. Three different repair heuristics determine a rescheduling point for when the right/left-shifting will be stopped and a new solution for the later half of the schedule is established with SAS PROC CPM.

Research Design for Studying New Reactive Scheduling Procedures

Three methods were developed to test if a complete rescheduling during schedule repair will improve schedule repair performance. These three methods each used different criteria to determine a point during schedule repair that may be considered a rescheduling point. A revised repair heuristic using this rescheduling point begins repair using the right/left-shift repair heuristic until this rescheduling point is reached. At that point, a complete rescheduling would occur on the latter half of the schedule that has not yet occurred. Finally, the repair of the remainder of the schedule continues with the right/left-shift heuristic as the reminder of the schedule eventuates. The three methods for determining this rescheduling point for rescheduling are described here, along with a diagram depicting an example scenario for clarification's sake.

Half of the "Max" Project Buffer Rescheduling Point

The "max" project buffer rescheduling point is defined as the point in time during scheduling repair that half of the "max" project buffer is used by the stochastically occurring tasks. The size of "max" project buffer is equal to the sum of the buffered duration of all stochastic tasks in the initial baseline schedule. During schedule eventuation, right/left-shifting repair begins, until the cumulative sum of the eventuated stochastic tasks durations is equal to half of the "max" project buffer. In other words, if a stochastic task does not occur, it will not "use" any of the "max" project buffer. If a stochastic task does occur, its duration is subtracted from the value of the "max" project buffer. At the point in time during project eventuation when the "max" project buffer reaches half of its original value, SAS PROC CPM is called to

reschedule the remaining tasks in the schedule that have not yet started or eventuated. This process is illustrated in Figure 23.

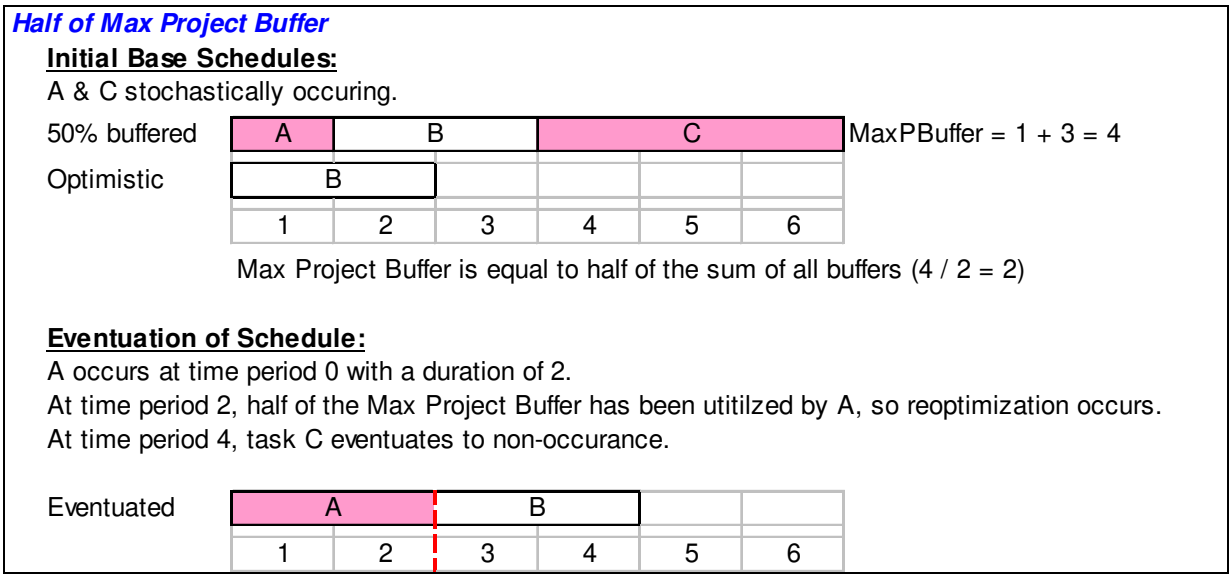


Figure 23: Half of "Max" Project Buffer Rescheduling Point Example

Half of the "Effective" Project Buffer Rescheduling Point

The "effective" project buffer rescheduling point is defined as the point in time during scheduling repair that half of the "effective" project buffer is used by the stochastically occurring tasks. The size of the "effective" project buffer is equal to the difference in duration of the buffered initial baseline (IB) and optimistic IB schedule (no stochastic tasks are scheduled). This is implemented in a similar fashion as the "max" project buffer, with right/left-shifting repair during eventuation, until the cumulative sum of the eventuated stochastic tasks durations is equal to half of the "effective" project buffer. Durations of the occurring stochastic tasks are subtracted from the "effective" project buffer until the point in time when the buffer reaches half

its original value. At that time, SAS PROC CPM is called to reschedule the remaining tasks in the schedule that have not yet started or eventuated.

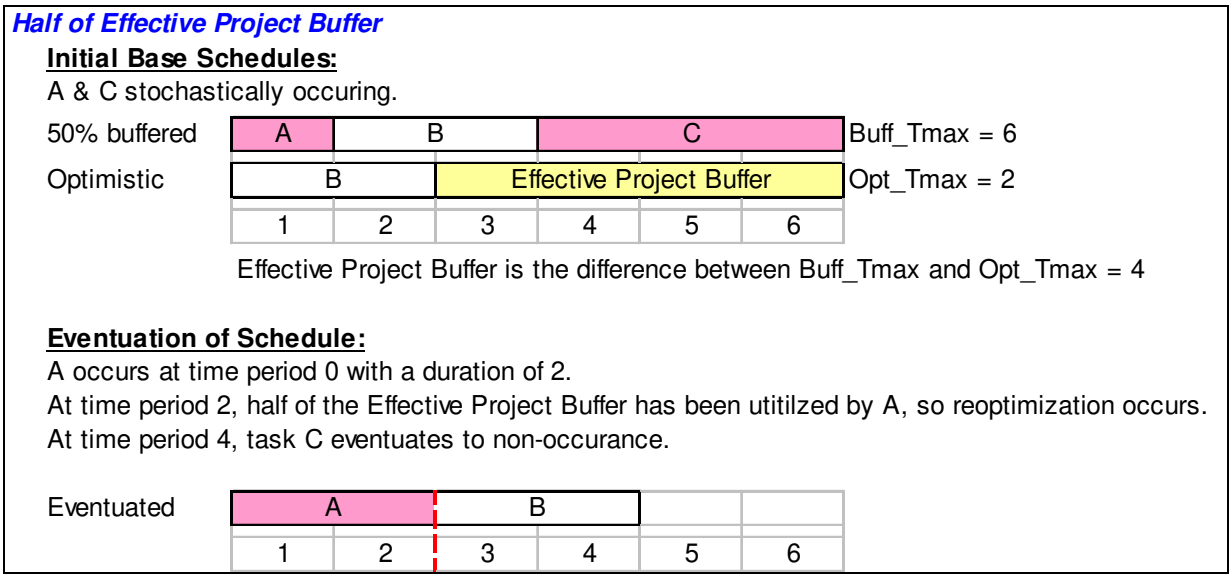


Figure 24: Half of "Effective" Project Buffer Rescheduling Point Example

Half-Time Rescheduling Point

The "half-time" rescheduling point is different from the previously described methods to determine a rescheduling point in that a project buffer value is not established. Rather, the "half-time" rescheduling point is equal to the value of the initial baseline (IB) scheduled duration divided by two. This exact clock-time is established before schedule eventuation even begins. During schedule eventuation, right-left-shifting repair is used, until this point in time when SAS PROC CPM is called to reschedule the remaining tasks in the later half of the schedule that have not yet started or eventuated.

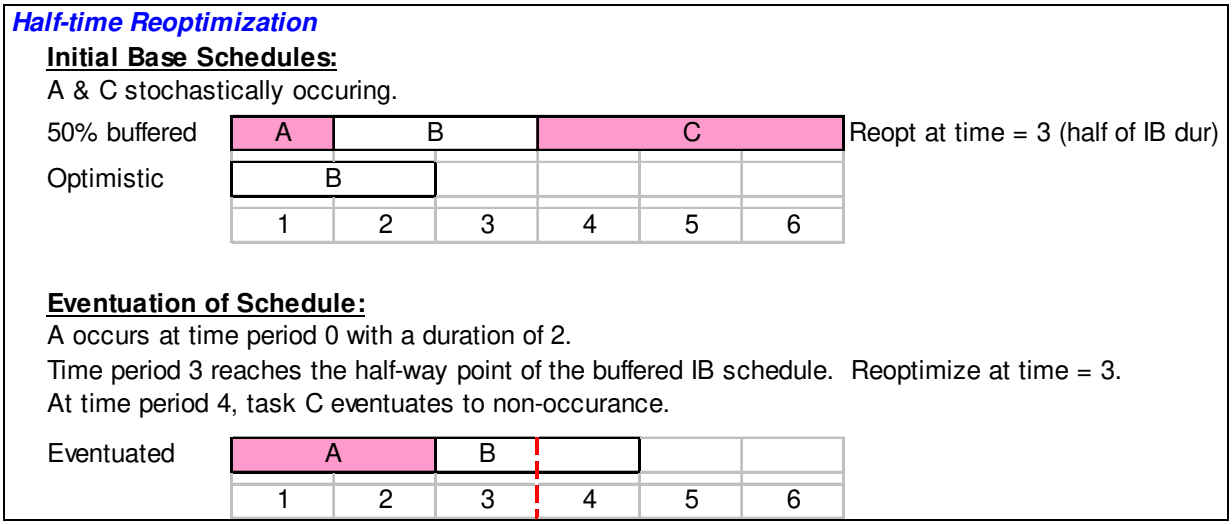


Figure 25: Half-Time Rescheduling Point Example

SAS code was developed to implement each of these three rescheduling methods. Please see Appendix L for the SAS code associated with completing this process. This SAS code starts with the previously solved 50% buffered and eventuated Selim set of schedules used in Chapters Six and Seven. The rescheduling point is established by using one of the three methods described above. At that rescheduling point, the first half of the schedule is considered to be in the past and any task that has already begun is unaffected. The second half of the schedule is considered to be in the future and all stochastic tasks are returned to their buffered duration. PROC CPM reschedules the reminder of the tasks in the second half of the schedule, and then right/left-shifting resumes to repair the remainder of the schedule as eventuation continues.

Initial Study for Studying New Reactive Procedures

The initial study examined the resulting rescheduling time as a percentage of overall projection duration for the final modified base schedule. The goal of this initial analysis was to ensure that, in fact, each of the methods used to determine a rescheduling point did determine a

point in time or location in the project that would be reasonable for a project manager to consider rescheduling. For example, a method that sets the rescheduling point almost immediately after the project begins, or is about to end would probably not have practical application. Also, it is of interest to see if each of these three methods generally produces three **different** rescheduling points.

Each cell in Table 36 below represents one network that has been repaired using one of three methods to determine the time for rescheduling and contains the calculated value of rescheduling time divided by the duration of the modified base schedule. For example, when repairing the second network in the 10xx Selim set (network 1010) under the high stochasticity and late occurrence settings, the "half of maximum project buffer" rescheduling time was 6 for the modified base with a total duration of 24 (6/24 = 25.0%). Meanwhile for the same network, the "half of effective project buffer" rescheduling time was 4 for the modified base with a total duration of 23 (4/23 = 17.4%) and the "half time" rescheduling time was 11 for the modified base with a total duration of 23 (11/23 = 47.8%). The lowest percentage of each of the three methods is highlighted here. Note the highlights here are not intended to indicate benefits over the other methods; it is simply intended to highlight the methods that caused the earliest rescheduling time.

Table 36: Rescheduling Time as a Percentage of Modified Base Duration

			NW 10xx Set			NW 11xx Set			NW 12xx Set			NW 13xx Set		
			Max	Eff	Time	Max	Eff	Time	Max	Eff	Time	Max	Eff	Time
High	Early	1	0.0%	0.0%	43.3%	26.3%	15.0%	48.8%	43.1%	0.0%	41.5%	17.2%	17.2%	47.3%
		2	0.0%	0.0%	34.4%	22.5%	22.5%	55.0%	38.3%	0.0%	48.9%	33.7%	11.6%	47.4%
		3	0.0%	0.0%	42.9%	34.9%	14.0%	47.7%	30.6%	0.0%	40.3%	31.6%	31.6%	45.6%
		4	25.9%	0.0%	48.1%	32.0%	32.0%	54.7%	30.0%	0.0%	42.0%	26.3%	26.3%	51.3%
		5	0.0%	0.0%	54.2%	29.9%	29.9%	50.5%	19.2%	0.0%	36.5%	28.7%	26.4%	56.3%
	Late	1	30.0%	16.7%	43.3%	64.9%	47.3%	52.7%	56.6%	26.4%	50.9%	57.3%	57.3%	49.4%
		2	25.0%	17.4%	47.8%	44.8%	44.8%	45.8%	41.2%	21.6%	45.1%	67.0%	56.4%	47.9%
		3	31.0%	18.5%	41.4%	46.1%	46.1%	53.9%	56.1%	29.8%	43.9%	57.9%	57.9%	54.7%
		4	33.3%	20.0%	43.3%	45.1%	45.1%	45.1%	50.0%	25.0%	40.4%	55.4%	53.0%	49.4%
		5	25.7%	22.9%	37.1%	54.0%	54.0%	49.0%	56.5%	26.1%	41.3%	58.5%	50.9%	46.2%
Low	Early	1	0.0%	0.0%	46.2%	60.4%	60.4%	48.1%	37.3%	0.0%	48.0%	36.9%	36.9%	49.5%
		2	0.0%	0.0%	48.8%	23.1%	23.1%	50.0%	0.0%	0.0%	46.6%	35.1%	9.6%	48.2%
		3	0.0%	0.0%	43.3%	51.5%	51.5%	48.5%	26.3%	0.0%	40.8%	33.6%	33.6%	49.6%
		4	23.5%	0.0%	47.1%	30.9%	20.6%	51.5%	23.8%	0.0%	44.4%	30.3%	30.3%	49.5%
		5	0.0%	0.0%	45.7%	35.9%	8.5%	50.4%	18.8%	0.0%	42.2%	21.9%	21.9%	50.9%
	Late	1	41.7%	30.6%	50.0%	75.5%	75.5%	53.1%	78.9%	38.2%	47.4%	64.0%	64.0%	51.0%
		2	43.9%	43.9%	48.8%	67.3%	67.3%	49.1%	21.1%	21.1%	47.4%	67.0%	67.0%	50.5%
		3	51.4%	37.1%	37.1%	67.4%	67.4%	50.5%	62.1%	30.3%	47.0%	54.2%	54.2%	51.7%
		4	44.4%	38.9%	44.4%	64.4%	64.4%	49.5%	59.4%	48.4%	43.8%	61.5%	61.5%	51.0%
		5	31.6%	28.9%	42.1%	38.5%	38.5%	48.4%	64.9%	33.3%	47.4%	67.5%	67.5%	49.6%

The highlighting in the table suggests that there is some interaction between the method to determine rescheduling time and characteristics of the schedule. For example, the effective project buffer method most frequently causes the earliest reschedule time for networks in the 12xx set. The above table validates that each of the three rescheduling methods determines a "reasonable" mid-point for rescheduling, and the time does vary across all three methods. Further summary statistics of rescheduling times is located in Appendix L.

Initial Study Results and Conclusions

A total of 16 metrics (duration, 8 robustness metrics, and 7 resource metrics) were calculated for each of the repaired schedules using the three different rescheduling techniques

and compared to the schedule repaired with right/left-shift only (no rescheduling). Appendix L contains a series of tables with the resulting metric values and highlights where improvements are shown with a rescheduling technique. The following Table 37 for duration is shown as an example.

Table 37: Example duration

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	30.00	30.00	30.00	30.00	78.00	80.00	80.00	80.00	65.00	65.00	65.00	65.00	93.00	93.00	93.00	93.00
		2	32.00	32.00	32.00	32.00	82.00	80.00	80.00	80.00	47.00	47.00	47.00	47.00	95.00	95.00	95.00	95.00
		3	28.00	28.00	28.00	28.00	86.00	86.00	86.00	86.00	62.00	62.00	62.00	62.00	115.00	114.00	114.00	114.00
		4	27.00	27.00	27.00	27.00	76.00	75.00	75.00	75.00	50.00	50.00	50.00	50.00	80.00	80.00	80.00	80.00
		5	24.00	24.00	24.00	24.00	97.00	97.00	97.00	97.00	52.00	52.00	52.00	52.00	87.00	87.00	87.00	87.00
	Late	1	30.00	30.00	30.00	30.00	74.00	74.00	74.00	74.00	53.00	53.00	53.00	53.00	89.00	89.00	89.00	89.00
		2	23.00	24.00	23.00	23.00	96.00	96.00	96.00	96.00	51.00	51.00	51.00	51.00	94.00	94.00	94.00	94.00
		3	29.00	29.00	27.00	29.00	76.00	76.00	76.00	76.00	57.00	57.00	57.00	57.00	95.00	95.00	95.00	95.00
		4	30.00	30.00	30.00	30.00	91.00	91.00	91.00	91.00	52.00	52.00	52.00	52.00	83.00	83.00	83.00	83.00
		5	35.00	35.00	35.00	35.00	100.00	100.00	100.00	100.00	46.00	46.00	46.00	46.00	106.00	106.00	106.00	106.00
Low	Early	1	39.00	39.00	39.00	39.00	106.00	106.00	106.00	106.00	75.00	75.00	75.00	75.00	103.00	103.00	103.00	103.00
		2	41.00	41.00	41.00	41.00	108.00	108.00	108.00	108.00	58.00	58.00	58.00	58.00	114.00	114.00	114.00	114.00
		3	30.00	30.00	30.00	30.00	99.00	99.00	99.00	99.00	76.00	76.00	76.00	76.00	125.00	125.00	125.00	125.00
		4	34.00	34.00	34.00	34.00	97.00	97.00	97.00	97.00	63.00	63.00	63.00	63.00	99.00	99.00	99.00	99.00
		5	35.00	35.00	35.00	35.00	117.00	117.00	117.00	117.00	64.00	64.00	64.00	64.00	114.00	114.00	114.00	114.00
	Late	1	36.00	36.00	36.00	36.00	98.00	98.00	98.00	96.00	76.00	76.00	76.00	76.00	100.00	100.00	100.00	100.00
		2	41.00	41.00	41.00	41.00	110.00	110.00	110.00	110.00	57.00	57.00	57.00	57.00	109.00	109.00	109.00	109.00
		3	35.00	35.00	35.00	35.00	95.00	95.00	95.00	95.00	66.00	66.00	66.00	66.00	120.00	120.00	120.00	120.00
		4	36.00	36.00	36.00	36.00	101.00	101.00	101.00	101.00	64.00	64.00	64.00	64.00	96.00	96.00	96.00	96.00
		5	38.00	38.00	38.00	38.00	122.00	122.00	122.00	122.00	57.00	57.00	57.00	57.00	117.00	117.00	117.00	117.00

Visual inspection of these values and highlighted areas of improvement demonstrate some potential patterns that may suggest some interactions with network characteristics and improvement when using rescheduling techniques for some metrics, while other metrics appear to have no improvement. These preliminary results led to the following hypothesis:

Hypothesis #5: There are instances where a rescheduling may be beneficial to project manager during schedule eventuation. These cases may vary depending on the network types and the goals of the project manager.

Rescheduling Results

It was established in the section above that the three described methods to determine a rescheduling point provide varying times of rescheduling, and these rescheduling points as a proportion of total project duration may have an interaction effect with network and resource parameters, as well as the location/timing of stochastic tasks. Initial summaries of data reveal that there are cases where the method appears to provide some improvement in some metrics. Further study investigated whether the rescheduling at a mid-point of schedule eventuation is beneficial to a project manager and in which cases.

GLM Model

To determine when rescheduling may be beneficial to a project manager, an analytical approach similar to that presented in Chapter Five to examine new buffering techniques was followed. First, a general linear model (GLM) is constructed to determine which factors and interaction of factors explain the metric values studied. In this case, the dependent variable is the metric value.

H_o = There is no main effect or interaction for factor(s) specified.

H_a = The particular effect or interaction does exist.

A model for each metric is constructed with the following independent factors:

Table 38: GLM Model Factor Abbreviations

Abbreviation	Factor Description	Factor Settings
reopt	Rescheduling method	None, Max, Effective, Time
loc	Location or Timing	Early (E), Late (L)
net	Network Parameters	High (H), Low (L)
res	Resource Parameters	High (H), Low (L)
stoch	Stochasticity	High (H), Low (L)

Appendix M contains the GLM model results for each metric, and an example table is shown below. Here, the dependent variable is the value of duration and factors and interactions significant at $\alpha = 0.5$ are highlighted.

Table 39: GLM Model Example for Duration

Metric	Source	DF	SS Error	F-Val	P-Val
Duration	reopt	3	0.159	0.001	1.000
Duration	res	1	219,922.878	3,204.705	0.000
Duration	reopt*res	3	0.159	0.001	1.000
Duration	net	1	22,028.203	320.994	0.000
Duration	reopt*net	3	0.084	0.000	1.000
Duration	res*net	1	8,518.128	124.126	0.000
Duration	reopt*res*net	3	0.109	0.001	1.000
Duration	stoch	1	15,470.703	225.438	0.000
Duration	reopt*stoch	3	0.134	0.001	1.000
Duration	res*stoch	1	1,276.003	18.594	0.000
Duration	reopt*res*stoch	3	0.084	0.000	1.000
Duration	net*stoch	1	2.628	0.038	0.845
Duration	reopt*net*stoch	3	0.109	0.001	1.000
Duration	res*net*stoch	1	322.003	4.692	0.031
Duration	reopt*res*net*stoch	3	0.084	0.000	1.000
Duration	loc	1	16.653	0.243	0.623
Duration	reopt*loc	3	0.084	0.000	1.000
Duration	res*loc	1	24.753	0.361	0.549
Duration	reopt*res*loc	3	0.134	0.001	1.000
Duration	net*loc	1	306.153	4.461	0.036
Duration	reopt*net*loc	3	0.084	0.000	1.000
Duration	res*net*loc	1	8.778	0.128	0.721
Duration	reopt*res*net*loc	3	0.109	0.001	1.000
Duration	stoch*loc	1	41.328	0.602	0.438
Duration	reopt*stoch*loc	3	0.159	0.001	1.000
Duration	res*stoch*loc	1	55.278	0.806	0.370
Duration	reopt*res*stoch*loc	3	0.159	0.001	1.000
Duration	net*stoch*loc	1	4.278	0.062	0.803
Duration	reopt*net*stoch*loc	3	0.109	0.001	1.000
Duration	res*net*stoch*loc	1	4.753	0.069	0.793
Duration	reo*res*net*stoc*loc	3	0.084	0.000	1.000
Duration	ERROR	256	17,568.000	0.000	-

The full set of tables for all metrics is located in Appendix M with highlights to indicate a significant effect at $\alpha = 0.05$. Table 40, below, reflects a summary of the GLM models for those factors that involve the rescheduling factor (variable = "reopt").

Table 40: Rescheduling GLM Model Summary

		Robustness Metrics								Resource Metrics							
Source	Dur	1	2	3	4	5	6	7	8	1	2	3	4a	4b	5a	5b	Total
reo*res*net*stoc*loc																	
reopt							1										1
reopt*loc							1										1
reopt*net							1										1
reopt*net*loc																	
reopt*net*stoch																	
reopt*net*stoch*loc																	
reopt*res							1										1
reopt*res*loc																	
reopt*res*net						1	1										2
reopt*res*net*loc																	
reopt*res*net*stoch																	
reopt*res*stoch																	
reopt*res*stoch*loc																	
reopt*stoch																	

The table above indicates that only robustness metrics 5 and 6 are affected by the method used to determine rescheduling time (recall that "none" was included as a factor setting). These two metrics are stability metrics associated with counting the number of tasks with additional preceding tasks. Even though not many metrics' variations are explained by the rescheduling methods, there are several interaction effects that do explain the variance of robustness metric 6. Additional testing within each of these factors that may reveal additional information was then conducted to determine which of these cases indicate that rescheduling may improve the metric over no rescheduling.

Analysis of Variance (ANOVA)

With the initial GLM revealing significant interactions with the method used on at least two metrics, a series of ANOVA tables was constructed for each set of networks. Here, each set

of networks represents five networks with the same factor settings for: network parameters, resource parameters, stochasticity, and timing.

H_o = The mean metric value for each rescheduling method (including none) are all equal.

H_a = At least one of the mean metric values for each rescheduling method (including none) is different than the rest.

The complete set of ANOVA tables is contained in Appendix M and an example is shown below. For all ANOVA tables, the degrees of freedom for the model are 3, error is 16, and the corrected total is 19. The rows of the ANOVA tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating a significant factor or interaction effect.

Table 41: Example ANOVA Results

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE10	Duration	-	147.200	-	1.000
HE10	Metric1	(0.000)	0.004	-	1.000
HE10	Metric2	0.000	0.292	0.000	1.000
HE10	Metric3	0.018	0.045	2.091	0.142
HE10	Metric4	0.084	0.129	3.481	0.041
HE10	Metric5	0.012	0.024	2.673	0.082
HE10	Metric6	0.001	0.001	2.667	0.083
HE10	Metric7	0.000	0.312	0.000	1.000
HE10	Metric8	9.424	69.948	0.719	0.555
HE10	RMetric1	(0.000)	2.320	-	1.000
HE10	RMetric2	-	4.231	-	1.000
HE10	RMetric3	0.038	14.600	0.014	0.998
HE10	RMetric4a	3.384	43.100	0.419	0.742
HE10	RMetric4b	10.838	531.400	0.109	0.954
HE10	RMetric5a	0.938	116.800	0.043	0.988
HE10	RMetric5b	33.750	2,052.200	0.088	0.966

The following table summarizes the results of the ANOVAs, testing for significantly different metric means under the 3 different rescheduling methods used repair a schedule and left-right shifting repairs with no rescheduling. An indicator is located in each cell to represent if the test showed a significant difference among the 4 repair techniques.

Table 42: Rescheduling ANOVA Summary

Stoch & Loc		NW	Dur	Robustness Metrics 1	2	3	4	5	6	7	8	Resource Metrics 1	2	3	4a	4b	5a	5b	Total
High	Early	10xx					1												1
		11xx							1					1					2
		12xx							1										1
		13xx												1					1
	Late	10xx																	
		11xx												1					1
		12xx							1										1
		13xx												1					1
Low	Early	10xx		1		1	1	1											4
		11xx												1					1
		12xx							1										1
		13xx												1					1
	Late	10xx																	
		11xx												1					1
		12xx							1										1
		13xx												1					1

As shown by the summary table above, robustness metric 6 and resource metric 3 seem to be the most sensitive to using the different types of reactive scheduling policies. Additionally, the low stochasticity / early / 10xx network seems to be the most sensitive for several robustness metrics.

Tukey's Test

For each of the highlighted rows in the ANOVA tables, Tukey's test is used to determine where the means are significantly different, and to look for significant improvement by using the 3 rescheduling strategies over repairing with the left-right shift without rescheduling. For each of the paired comparisons for the 4 buffering strategies (for example, none and "max", none and "effective", etc.) the following hypothesis was tested:

H_o = the means for the two rescheduling strategies are the same.

H_a = the means for the two rescheduling strategies are not the same.

The complete result tables are located in Appendix M and an example Table 42 follows. In the tables located in the appendix, means with the same letter in the columns labeled "Tukey Grouping" are not significantly different. Additionally, a "1" indicates no pair-wise difference. Zeros, indicating significant pair-wise differences are highlighted, and a note is made if at least one of the rescheduling methods shows improvement over repairing a schedule using right/left-shift with no rescheduling. This example table shows that each of the three rescheduling methods has a significant improvement over no rescheduling. However, each of the three rescheduling methods are not significantly different from one another.

Table 43: Example Tukey Test Results

Group	Metric	Tukey Grouping		Mean	Reopt Meth	None	Re-Scheduling Max	Eff	Time	None vs Reopt
HE11	Metric6	A		0.300	None	1	0	0	0	At least one Reopt differs from None
HE11	Metric6	B		0.113	max	0	1	1	1	Improvement
HE11	Metric6	B		0.113	eff	0	1	1	1	Improvement
HE11	Metric6	B		0.131	time	0	1	1	1	Improvement

Table 43 summarizes the Tukey tests where it has been demonstrated that significant differences are found at $\alpha = 0.05$. A "1" indicates the method with the lowest mean value of the three techniques if a significant difference was found. The summary table demonstrates that rescheduling produces a significantly lower mean (better) values for robustness metric 3,4,5, and 6. There are no instances where a rescheduling technique shows a significantly higher (worse) mean than no rescheduling.

Table 44: Tukey Test Results Summary

Group	Buffer	Metric3	Metric4	Metric5	Metric6	Total
HE11	eff				1	1
	max				1	1
	time				1	1
LE10	eff	1	1	1		3
	max	1	1	1		3
	time		1	1		2
Total		2	3	3	3	11

There are only a few cases where rescheduling has produced improvement over not rescheduling. Specifically, improvement is found only in the metrics 3, 4 and 5 for networks in the 10xx set (recall this set had low resource and network parameters) with low and early stochastic task occurrence. Additionally, improvement is found in metric 6 for networks in the 11xx set (high resource and low network parameters) with high and early stochastic task eventuation. Metrics 3, 4, 5, and 6 are all stability metrics related to the counts of changed start times and preceding tasks.

Rescheduling Conclusions

Chapters Five and Six presented a study on two experiments that were conducted to determine if a new predictive technique may be used to improve results in developing an initial baseline schedule before a project begins when it is known that some tasks will occur stochastically. The work of Selim and Grey also tested different initial baseline development methods. This chapter provided the first attempt to test for improvement that may be gained in schedule performance with a new reactive technique that may be implemented in real-time during schedule eventuation. So far, the only reactive procedure used to repair a resource constrained schedule with stochastic task insertion was the right/left-shift heuristic initially

described by Selim and implemented by Grey for buffered schedules. This chapter provides a revision to this technique by determining a mid-point during schedule eventuation that reschedules the second half of the schedule.

It was hypothesized that there are instances where a rescheduling may be beneficial to a project manager during schedule eventuation, depending on network parameters and the goals (such as duration or stability) of the project. There are only a few cases where evidence exists for improvement in rescheduling over no rescheduling. This improvement only occurred in the 10xx and 11xx problem sets and only for a few stability metrics. These problem sets describe the least restrictive types of networks. For example, the 10xx network set has low resource and network parameters, which may explain why there was a difference found here. There was no improvement found in any duration-related metrics or any resource metrics. Therefore, it is not recommended to project managers to reschedule unless the schedule fits these few specific cases. At the same time, there were no cases where rescheduling causes any significantly worse metric values. If there is no cost associated with implementing the rescheduling, then there would be no "harm" done if a project manager rescheduled at a specified rescheduling time during schedule repair. In general, this study has shown that the right/left-shift repair heuristic initially described by Selim and implemented in this research with SAS code has been shown to be an effective strategy to repair the resource constrained project scheduling problem with stochastic task insertion.

CHAPTER EIGHT: CONCLUSIONS AND FURTHER RESEARCH

The area of focus for this research is the Stochastic Resource Constrained Project Scheduling Problem (SRCPSP) with Stochastic Task Insertion (STI). The STI problem is a specific form of the SRCPSP, which may be considered to be a cross between two types of problems in the general form: the Stochastic Project Scheduling Problem, and the Resource Constrained Project Scheduling Problem. The stochastic nature of this problem is in the occurrence/non-occurrence of tasks with deterministic duration. Researchers Selim (2002) and Grey (2007) laid the groundwork for the research on this problem. Selim (2002) provided a set of robustness metrics and used these to evaluate two initial baseline (predictive) scheduling techniques, optimistic (0% buffer) and pessimistic (100% buffer), where none or all of the stochastic tasks were scheduled, respectively. Grey (2007) expanded the research by developing a new partial buffering strategy for the initial base development for this problem and found superior results to Selim's "extreme" buffering approach. The current research continued the work on this problem by focusing in on the resource aspects of the problem, a new buffering approach, and new reactive scheduling. If resource usage is important to project managers, then a set of metrics that describes changes to the resource flow would be important to measure differences between the initial baseline schedule and the final "as-run" schedule. Two new sets of resource metrics were constructed regarding resource utilization and resource flow. In order to solve for resource flow, the problem was formulated as a min cost flow problem. Using these new metrics, as well as the Selim/Grey metrics, a new buffering approach was developed that used resource information to size the buffers. The resource-sized buffers did not show to have significant improvement over the 50% buffer used as a benchmark, and in fact, was worse in

some cases. During the course of this study, however, the new resource metrics were used to validate that the 50% buffering strategy is superior to the 0% or 100% buffering strategy in many cases based on the previously developed Selim and Grey robustness measures as well as newly developed resource measures.

Recognizing that partial buffers appear to be the most promising initial baseline development approach for the STI case, and understanding that experienced project managers may be able to predict stochastic probabilities based on prior projects, led to the next phase of the research that developed a new set of buffering strategies proportional to the probability of occurrence. The results of this proportional buffering strategy were very positive, with the majority of the metrics (both robustness and resource), except for several stability metrics, improved by using the proportional buffer.

Finally, it was recognized that all research thus far for the SRCPSP with STI focused solely on the development of predictive schedules. Therefore, the final phase of this research developed a new reactive strategy that determined a rescheduling point during schedule eventuation when a complete rescheduling of the latter part of the schedule would occur. The results of this new reactive technique indicate that rescheduling improves the schedule performance in only a few metrics under very specific factor settings (those with the least restrictive parameters).

Practical Application

Table 44 summarizes practical guidance for the project manager planning a resource constrained project with stochastic task insertion (unplanned work). Table 44 part A describes

the recommended initial baseline development approach if the project manager has a good idea of the level and location of the stochasticity for the network, and highlights two cases where rescheduling during schedule eventuation may be beneficial. Blank cells indicate that no initial baseline buffering method stood out as the best approach for this case. Table 44 part B shows when buffering proportional to the probably of occurrence is recommended, or not recommended, or the cases where the evidence is inconclusive.

Table 44 may be read as a decision tree from left to right. The table is arranged in two parts (A and B) depending on the project manager's knowledge of the stability characteristics of the STI tasks. Step one for using Table 44 is to determine the network and resource parameters for the current project and identify the set of rows associated with this set of factor settings. Step two is to describe the stochasticity of the network. If the network stochasticity can be described as high level (in this case this was half of the tasks occurred stochastically) or low level (one quarter of the tasks occurred stochastically) and the location of the stochastically occurring tasks is known (early or late), then the project manager may use part A to determine the best course of action in developing the predictive (initial baseline) and reactive schedule. For example, if the project manager has the following parameters Network = Low, Resource = Low, Level = High, Location = Early, and a goal of overall project stability, then the optimistic schedule is recommended for the initial baseline with right/left-shift schedule repair during schedule eventuation.

If instead of the high/low and early/late characterization, the project manager has a good sense for the probability of stochastic task occurrence, then he or she may look at part B. In this example with Network = Low, Resource = Low, part B of the table shows that the results for using proportional buffers are inconclusive. In other words, some stability metrics showed good

results for proportional buffers, while others showed the 50% buffer as better. Therefore, the project manager would be recommended to stay with the 50% buffer in this case.

Table 45: Table of Recommendations for Project Managers

PART A: If Stochasticity Level and Location are Known							
Network Parameters		**Stochasticity**		**Project Manager Goals**			
				Robustness		Resource	
Network	Resource	Level	Loc	Stability	Duration	Util	Flow
L	L	H	E	O	B5		
L	L	H	L		B5	B5	B5
L	L	L	E	*			
L	L	L	L			B5	
L	H	H	E	B5 */ P	B5	B5	B5
L	H	H	L	O	B5	B5	B5
L	H	L	E	O	B5	B5	B5
L	H	L	L	B5 / O	B5	B5	B5
H	L	H	E		B5	O / P	B5
H	L	H	L		B5	B5	B5
H	L	L	E		B5	P	
H	L	L	L		B5	B5	B5
H	H	H	E		B5	B5	B5
H	H	H	L	P	B5	B5	B5
H	H	L	E		B5	B5	B5
H	H	L	L	P	B5		B5

PART B: If Prior Knowledge of Occurrence Probability is Known						
Network Parameters		**Stochasticity**	**Project Manager Goals**			
			Robustness		Resource	
Network	Resource	Related to SN	Stability	Duration	Util	Flow
L	L	Related		PB	PB	
L	L	Not Related		PB	PB	PB
L	H	Related			PB	
L	H	Not Related		PB	PB	PB
H	L	Related		PB		
H	L	Not Related		PB	PB	PB
H	H	Related		PB	PB	B5
H	H	Not Related		PB	PB	PB

P = Pessimistic (100% buffer) PB = Proportional buffer
O = Optimistic (0% buffer) B5 = 50% buffer
** cases when rescheduling the B5 may be beneficial*

Note, there are only two cases when a project manager is recommended to reschedule during project eventuation, and they are indicated with an asterisk. When using the recommendation to reschedule, it is important to note that the testing in this research began with

the 50% buffered initial baseline. Therefore, the same recommendation may not hold if the initial baseline was developed with another buffering approach. Testing the combinations of initial baseline development strategies and rescheduling decisions may be an area for future research. The remainder of this chapter describes this and other areas recommended for further research.

Other Predictive Scheduling Procedures for the STI Case

Grey suggested that buffering concepts from the CC/BM method may be incorporated, including the use of project, feeding and resource buffers (Grey 2007). These methods of buffering may be further explored for application to the SRCPSP with STI. Tavares, Ferreira et al.(1998) have applied the concept of using buffers to protect the schedule by adding time buffers throughout a baseline schedule, and this method was then developed into an adapted float factor heuristic (ADFF) by Leus (2003) and Van de Vonder, Demeulemeester et al. (2005b). ADFF adopts an activity-dependent float factor that is calculated as $\alpha_i = \beta_i / (\beta_i + \delta_i)$ where β_i is the sum of the weight of activity i and the weights of all its transitive predecessors, while δ_i is the sum of the weights of all transitive successors. This causes the ADFF method to insert longer time buffers into activities that would incur a high cost if started later than originally planned (Van de Vonder, Demeulemeester, et al. 2005b), while no activity may begin earlier than originally scheduled. Additional research demonstrates that the heuristic can be extended for the resource-constrained case by adding additional precedence constraints that correspond to resource network flows (Van de Vonder, Demeulemeester, et al. 2004) and is referred to as the resource flow-dependent float factor (RFDFF). This problem is applied to the general form of the

SRCPSP where activity durations are uncertain. This method is tested on a set of problems generated using the RanGen project scheduling instances generator developed by Demeulemeester, Vanhoucke, et al. (2003). Activity durations are simulated using a right-skewed beta-distribution (min = RanGen duration/2, max = RanGen duration*2.25) and activity weights are drawn from a normal distribution (μ=3, σ=2) with negatives replaced by zeros. This concept of buffering with the objective of minimizing a cost associated with the tasks' late start times could be applied to the STI case with deterministic durations.

Additionally, Van de Vonder, Demeulemeester et al. (2005a; 2006a) introduced multiple heuristics to include time buffers in a given schedule while a predefined project due date remains respected. These heuristics construct buffers using additional information about the activities' duration probability density functions. The heuristics were tested on the J30 instance set of PSPLIB (Kolisch and Sprecher 1997) as well as those developed using the RanGen project scheduling network instances generator (Demeulemeester, Vanhoucke, et al. 2003). Van de Vonder, Demeulemeester et al. (2006b) tested additional buffering heuristic algorithms along with an improvement algorithm on the J30, J60 and J120 PSPLIB data sets with three settings for activity duration variability: high, medium, and low. These buffering schemes make use of knowledge of the tasks' duration variability. This concept may be applied to the STI problem case with deterministic durations where knowledge of a task's probability of occurrence helps determine its (or its successors') buffer size.

An additional area of future research for the STI case of the SRCPSP is the development of initial baseline schedules with various objectives studied by other researchers for the general problem. For example, additional objectives include the minimization of weighted tardiness time and the minimization of weighted resource consumption costs (Ozdamar and Ulusoy 1995).

Additionally, heuristics for the RCPSP with the objective of cost minimization have recently been developed (Liu and Wang 2006).

Other Reactive Scheduling Procedures for the STI Case

This research provided the first look at a variation from the right/left-shift repair heuristic, and tested one possible method with little success. However, there are numerous examples in the literature where various reactive procedures have proven to be very effective, often with different objectives than the initial predictive procedure. Concepts from these other strategies for reactive procedures could be tested on the STI case. Different reactive procedures that are possible and have been suggested in the literature include those reactive procedures that:

- implement an optimal rescheduling policy every time an interruption occurs (Grey 2007);
- anticipate future disruptions (Van de Vonder, Ballestín, et al. 2007);
- builds priority lists to support a selection of the projected schedule with minimum makespan at every decision time (Van de Vonder, Ballestín, et al. 2007);
- is solution robust (activity time stable) and provides good makespan performance with improved computational requirements than heuristics that have been developed (Van de Vonder, Demeulemeester, et al. 2007);
- incorporate activity-dependent cost weights to reschedule with a cost minimization objective function (Van de Vonder, Demeulemeester, et al. 2006b); or
- apply network flow models such as those used by the Resource Flow Dependent Float Factor (RFDFF) heuristic for the general SRCPSP by Van de Vonder,

Demeulemeester et al. (2006b) where a resource network flow model is used to add additional constraints regarding resource hand-off among tasks into the model in order to retain some stability. In this case, the objective of the reactive procedure may be to a minimize resource flow disruptions when stochastic tasks eventuate.

The research presented here only studied if rescheduling as a part of reactive procedures was beneficial when developing the initial baseline for the 50% buffered IB. Testing the combinations of initial baseline development strategies and other reactive procedures, including rescheduling, is an area for future research. In this case, the objective of the reactive procedure may be different than the objective of the development of the initial baseline development. It may be appropriate to develop a new set of metrics to evaluate these new objectives.

Network Characteristics and Size

The work of Selim (2002) and Grey (2007) was restricted to networks with 32 tasks. However, it may be useful to examine methods on problems of various sizes as they occur in real-world applications. Selim and Grey were able to provide a set of recommendations to project managers for their specific set of tested problems. However, should a larger problem arise, it is unclear if the same recommendations would hold. Examples of evidence for real-world problem sizes variation follow.

In a 2001 survey (Liberatore, Pollack-Johnson, et al. 2001) of 688 project management professionals, more than two-thirds of the 240 respondents indicated typical project sizes over 50 activities. Additionally, 18% of respondents were in the construction industry and reported a median project size of about 300 activities. This indicates that projects are likely to be larger

than 30 tasks in real-world applications, and also that specific areas of application, such as construction, are very likely to encounter larger projects.

Commonly used project management software allows for projects of larger sizes and advertises it as such: MS project allows up to 400,000 tasks per project (source: http://office.microsoft.com/en-us/project/HP101065651033.aspx). Primavera Project Planner (P3®) software promises up to 100,000 activities per project (source: http://www.primavera.com/files/brochures/ProjectPlanner_low.pdf).

The need for testing newly developed proactive heuristic procedures on project of different sizes has been recognized by Van de Vonder, Demeulemeester, et al. (2006a) where their buffering techniques for the SRCPSP with stochastic durations was tested on the J30, J60 and J120 PSPLIB data sets (Kolisch and Sprecher 1997) with projects of size of 30, 60, and 120, respectively, and in their work to study the trade-off between stability and duration metrics (Van de Vonder, Demeulemeester, et al. 2006b), networks examined were sized 10, 20, and 30.

A study of larger networks may produce different results than the smaller ones. For example, a low stochasticity experiment may show that a longer schedule with high network parameters (and perhaps low resource parameters), may have more time to "recover" from network interruptions than a shorter schedule, particularly if comparing the duration of a modified base (MB) to the initial baseline (IB) schedule. This may be of particular importance when investigating reactive procedures.

Other Techniques Involving Project Manager Knowledge

This research presented a strategy to size stochastic task buffers that are proportional to the probability of occurrence. It was assumed for this experiment that a project manager would have perfect knowledge of the probability of occurrence (this probability was applied over the set of 500 replications). However, in real application, a project manager may not have perfect knowledge of the probabilities. Other researchers have studied variations of the general form of the problem that includes fuzzy resource-constrained project scheduling. Fuzzy set scheduling is used when activity durations are modeled with vague or imprecise information, rather than probability distributions (Herroelen and Leus 2005). Further study on the STI case may determine the tolerance level of how accurate a project manager must be in projecting these probabilities to maintain the effectiveness of this strategy.

Pollack-Johnson and Liberatore (2006) applied concepts from the analytic hierarchy process (AHP) to develop a method for project managers to develop quality level curves to illustrate the tradeoffs between the timely completion of the project, cost, and quality. These concepts of applying decision maker preference and management judgment into the scheduling process for the STI may be further studied.

New metrics for STI Case

As previously mentioned, the development of new scheduling procedures or variations of the problem would require the development of new ways to measure the success of these procedures. In this research, a new set of resource metrics was developed and implemented in order to evaluate the effectiveness of resource-related buffering strategies. Additional concepts

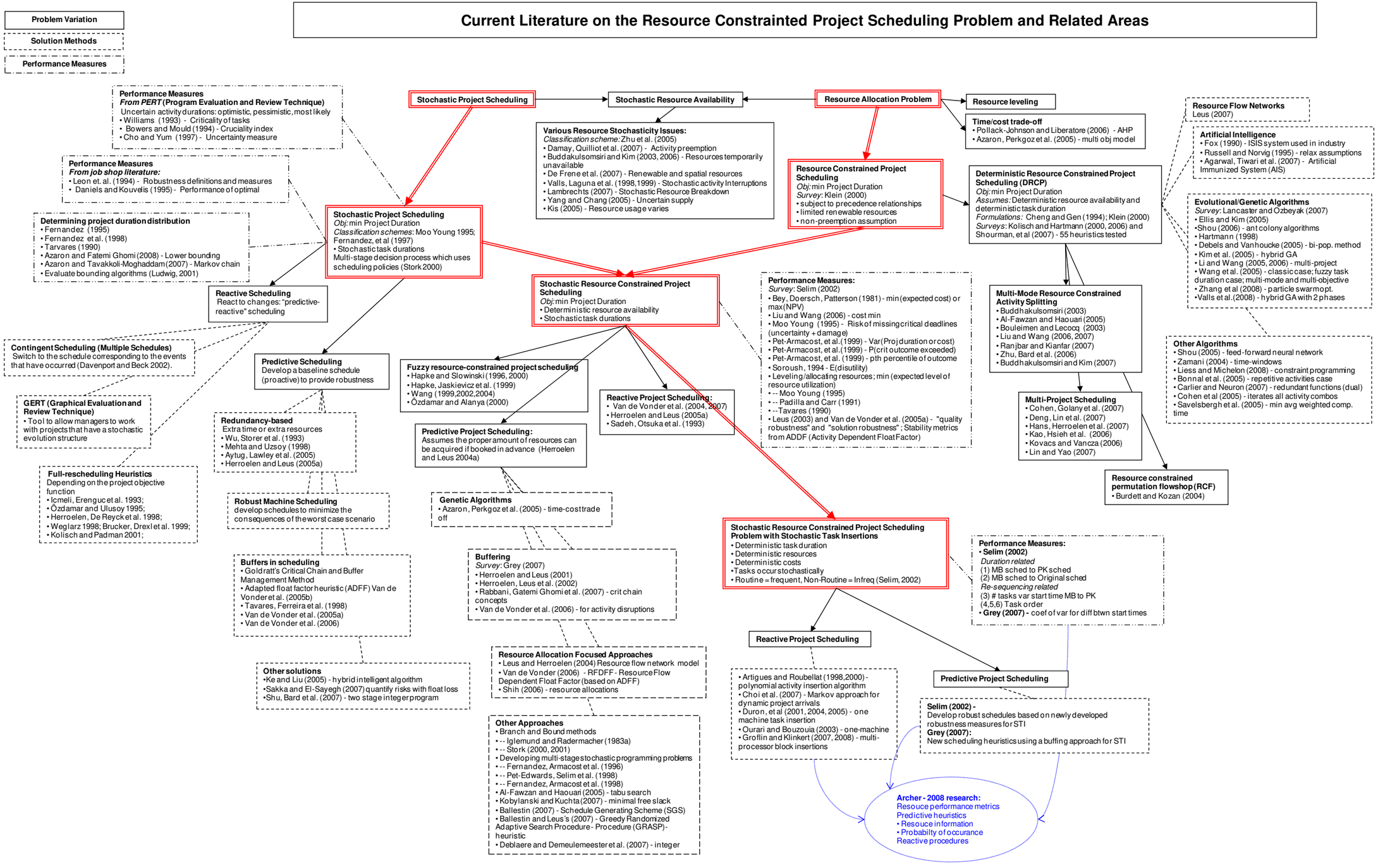
from the literature that may be applied to the STI case include a recent study that was conducted by (Van de Vonder, Demeulemeester, et al. 2006b), who provided an "extensive simulation experiment" to investigate the trade-off between quality (project duration) and solution (stability) robustness for the SRCPSP with stochastic task duration. The metrics used to evaluate the methods were quality (probability project will end on time) and stability (weighted sum of deviations between planned and actual activity start times).

Conclusion

The stream of research that began with Basma Selim (2002) and Jennifer Grey (2007) has been continued here, and when combined, constitutes a comprehensive look at the stochastic resource constrained project scheduling problem with stochastic task insertion. Overall, the current bodies of research provide some basic guidance for project managers who are faced with the challenge of scheduling projects that involve unplanned work. As outlined above, there are opportunities for further research on this and related problems and it is anticipated that this research will continue.

APPENDIX A: LITERATURE REVIEW DIAGRAM

Current Literature on the Resource Constrainted Project Scheduling Problem and Related Areas



APPENDIX B: SAS CODE TO REPAIR A BUFFERED SCHEDULE

Note, the following code is presented to provide the logical steps necessary to complete schedule repair. Preliminary data clean-up and code is needed to construct the necessary input data sets to run the code.

```
*****************************************************************************************;
* Repairing a buffered schedule                                                         ;
* This code requires "Solved NW1.sas" to run first in order to load the work directory  ;
* Input: NW_soln.&NW._optimal_stats from running "Solved NW1.sas"                       ;
*        NW_Soln.&NW._preds from running "build pred data.sas"                          ;
* and Calculate SN.sas to add the timing and stoch columns to the optimal stats data set ;
* and Create and solve buffered schedules to find the solved buffered schedule(IB)      ;
* Output:  Repaired Modified Baseline schedule - prob.&NW.&S.&B._&T.                     ;
*          Resource usage of the final repaired schedule - prob.&NW.&S.&B._&T._rout      ;
*****************************************************************************************;

*****************************************************************************************;
*problem set-up;
*****************************************************************************************;
*Select the buffer label and formula for this run;
/*%let B = O;                                                  *optimistic;*/
/*%let B = P;                                                  *pessimistic;*/
/*%let B = B5;                                                 *50% buffer;*/
/*%let B = BR1;  %let Bduration = "N/A";                       *Resource Buffer 1;*/
/*%let B = BR2;  %let Bduration = "N/A";                       *Resource Buffer 2;*/
/*%let B = BR3;  %let Bduration = "N/A";                       *Resource Buffer 3;*/
/*%let B = BR4;  %let Bduration = "N/A";                       *Resource Buffer 4;*/

* Select the stochasticity level for this run - these are the tasks that DO occur;
/*%let stoch = "Low"; %let S = L;                      *Low;*/
/*%let stoch = "Low","High"; %let S = H;        *High;*/

* Select the timing setting this run - these are the stoch tasks that DO occur;
/*%let timing = "Late"; %let T = L;                                    *Late;*/
/*%let timing = "Early"; %let T = E;                                   *Early;*/

%let path = C:\Sandra_laptop\IEMS\data\selim; *run for each prob type;
libname NW_soln "&path.\Non-optimal SAS Solutions";
/*libname NW "&path.\SAS Solutions";*/
%let outpath = C:\Sandra_laptop\IEMS\data\Selim\Repaired;
libname prob "&outpath.";
*****************************************************************************************;
*end problem set-up;
*****************************************************************************************;
```

```
%macro merge_soln(NW);

*****************************************************************************************************;
*initialize datasets;
*****************************************************************************************************;
*get number of successors;
      data work.succ;   set NW_soln.&NW._optimal_stats;     keep succ:;run;
      data work._null_;
          %let dsid=%sysfunc(open(work.succ));
          %let num_succ=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activity types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The max number of successors are: &num_succ.; *create global macro var;

*get number of resource types;
      data work.R; set NW_soln.&NW._resources_avail;  keep R:;run;
      data work._null_;
          %let dsid=%sysfunc(open(work.R));
          %let num_R=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activity types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of resource types are: &num_R.; *create global macro var;

*get number of preds - from running "build pred data.sas";
      data work._null_;
          %let dsid=%sysfunc(open(NW_Soln.&NW._preds));
          %let num_vars=%sysfunc(attrn(&dsid,nvars)); *contains the number of vars in the data set pred;
            %let num_preds = %eval(%sysfunc(sum(&num_vars.,-3))/2);
            %let rc=%sysfunc(close(&dsid));
      run;
      %put &num_vars.;
      %put the highest number of predecessors for any activity is: &num_preds.;

*create a copy of the optimal data set into work ;
      data work.&NW.&S.&B._optimal_stats;
          set NW_soln.&NW.&S.&B._optimal_stats; *from running "create and solve buffered schedules.sas";
            PDuration = Bduration;
            *this "planning dur" will be a mix of actual (zero or full) for stoch tasks in the past ;
            *and buffered durations in the future;
            *identify stochastic tasks;
```

```
            format remove $20.;
            if stoch not in (&stoch.) then remove = "occur"; *set all non-stoch tasks to occur;
            if stoch in (&stoch.) and timing in (&timing.) then remove = "occur";
            if remove = '' then remove = "remove";
            keep activity_num succ1-succ&num_succ. duration Bduration Pduration R1 R2 s_start s_finish SN
                 timing stoch remove;
      run;

*create a copy of the pred data set into work ;
      data work.pred_data; *pred data from running "build pred data.sas";
          set NW_soln.&NW.&S.&B._preds;
            Pduration = Bduration; *initialize Bdur;
      run;

*****************************************************************************************************;
*end initialize datasets;
*****************************************************************************************************;

*identify shifting tasks
data work.stoch; *stochastically occurring tasks -> either will not occur or happen at great than plan;
      set work.&NW.&S.&B._optimal_stats;
      if stoch not in (&stoch.) then delete;
run;

*get number of stochastic activities;
      data work._null_;
          %let dsid=%sysfunc(open(work.stoch));
          %let num_stoch=%sysfunc(attrn(&dsid,nobs)); *num_stoch contains the number of stochastic tasks;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of stochastic activites is: &num_stoch.;

*****************************************************************************************************;
*Begin Exterior Loop**Begin Exterior Loop**Begin Exterior Loop**Begin Exterior Loop**Begin Exterior Loop* ;
*****************************************************************************************************;
%let k = 1;
%macro exterior(); *run once for each stochastic task;

%if &num_stoch. = 0 %then %do; *if there are not stoch tasks, do not execute this - create a copy and exit;
      %put NO STOCH TASKS;
      %goto exit1;
```

```
%end;

%do k = 1 %to &num_stoch.;
      %put the value of k is &k.;

data work.stoch; *the chronological order of stoch tasks has the potential to re-order before eventuates;
      set work.&NW.&S.&B._optimal_stats;
      if stoch not in (&stoch.) then delete;
      if Kloop = "eventuated" then delete; *remove the stochastic tasks we have already looped on;
                                           *prevents accidentally looping the same task twice;
run;

proc sort data=work.stoch; by s_start; run;
data work.check;
      set work.stoch (firstobs=1 obs=1);
      call symput('shift_time',s_start); *puts the start time of the removed activity to this global macro;
      call symput('act_to_remove',activity_num); *puts start time of removed task to global macro;
      call symput('shiftype',remove); *shift type to this global macro;
run;
%put the shift time is now: &shift_time.;
%put the stochastic activity is: &act_to_remove.;
%put the shift-type of this loop is: &shiftype.;

*set duration and resource util of removed task to zero - solution file;
data work.step1; *overwrite file;
      set work.&NW.&S.&B._optimal_stats;
      if activity_num = &act_to_remove. and %index(&shiftype.,remove) > 0 then do; * removed task ;
            call symput("flag","REMOVING TASK"); *make a flag to test this logic;
            call symput("rightshift",0); *if there will be no right-shifting, only left-shifting;
            Pduration = 0; *set planning duration of removed task to zero;
                  call symput("Pduration",0); *duration for fixing pred data;
            s_finish = s_start; *make the finish time equal to the start time;
            call symput("shift_time_f",s_finish); *store the new finish time for pred use;
            array r{&num_r.} r1-r&num_r.; *make resource usage equal to zero;
            do i=1 to &num_r.;
                  r{i} = 0;
            end;
            Kloop = "eventuated"; *add a flag in the data for stochastic tasks that have been eventuated;
      end;
      if activity_num = &act_to_remove. and %index(&shiftype.,occur) > 0 then do; *inserted or expanded;
            call symput("flag","INSERTING OR EXPANDING TASK"); *make a flag to test this logic;
```

```
            call symput("rightshift",sum(duration, -Bduration)); *tasks after ts shift right this amount;
            Pduration = duration; *make the planning duration of the task now known to full duration;
                  call symput("Pduration",duration); *duration for fixing pred data;
            s_finish = s_start + duration; *make the finish time equal to the start time;
            call symput("shift_time_f",s_finish); *store the new finish time for pred use;
            Kloop = "eventuated"; *add a flag in the data for the eventuated stochastic tasks;
      end;
      drop i;
run;
%put Before left-shifting, everything after time &shift_time. will be right shifted by: &rightshift.;
%put &flag.;
%put The finish time of this &shiftype. task is: &shift_time_f.;
%put The task that is shifting now has an eventuated duration of &Pduration. ;

data work.step2;
      set work.step1;
      if s_start >= &shift_time. and activity_num ne &act_to_remove. then do; *tasks after the stoch task;
            s_start = s_start + 100;
            s_finish = s_finish + 100;
      end;
run;

data work.&NW.&S.&B._optimal_stats; *overwrite file;
      set work.step2;
run;
*update the pred list start time for the stoch task start=finish times;
data work.pred_data;
      set work.pred_data;
      array Apred_num{&num_preds.} pred1-pred&num_preds.;
      array Apred_finish{&num_preds.} pred_finish1-pred_finish&num_preds.;
      do i=1 to &num_preds.;
            if Apred_num{i} = &act_to_remove. then Apred_finish{i} = &shift_time_f.;
            *creates the earliest point to shift left for successors;
      end;
      drop i;
      pred_finish_max = max(of pred_finish1-pred_finish&num_preds.);
      if activity_num = &act_to_remove. then Pduration = &Pduration.; *update the Pduration;
run;

/*initializing data set of "shifted" tasks - those in their final timeslot;*/
data work.shifted_tasks;
```

```
      set work.&NW.&S.&B._optimal_stats;

      where s_start < &shift_time.;*any task that starts before the stoch task - none at the same time;
      keep activity_num succ1-succ&num_succ. r1-r&num_r. duration Bduration Pduration s_start s_finish
Kloop ;
run;

*****************************************************************************************************;
*Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer    ;
*****************************************************************************************************;
%let i=1;
%macro outer(); *identify the next task after the shifting time and move left;
%do %while (&i.>0); %put the value of i is &i.;

*Create shift;
proc sort data=work.shifted_tasks; by activity_num; run;
proc sort data=work.&NW.&S.&B._optimal_stats; by activity_num; run;

data work.remaining_tasks;
      merge work.shifted_tasks (in=a)
              work.&NW.&S.&B._optimal_stats (in=b)
      ; by activity_num; if b and not a;
      keep s_start activity_num succ1-succ&num_succ. ;
run;
proc sort data=work.remaining_tasks; by s_start activity_num; run;
data work.task_to_shift;
      set work.remaining_tasks (obs = 1);
      call symput('task_to_shift',activity_num); *finds the first activity to shift;
run;
%put the task to shift is: &task_to_shift.; *write task to shift to the log;

*find max of pred finish time for this shift;
data work.test;
      set work.pred_data;
      where activity_num = &task_to_shift.;
*finding the max pred_finish time;
      newstart = pred_finish_max;
      if newstart < &shift_time. then newstart = &shift_time.; *ensure shifting start time is not past;
      if newstart = . then newstart = 0;
      newfinish = sum(newstart, Pduration);
      call symput ('shifted_start',newstart); *put the max pred start time to shifted start global var;
```

```
      call symput ('shifted_finish',newfinish); *put the max pred finish time to shifted start global var;
run;
%put the new start time for activity &task_to_shift. is: &shifted_start.; *log new start time of shifter;
%put the new finish time for activity &task_to_shift. is: &shifted_finish.; *log finish time of shifter ;

*****************************************************************************************************;
*Inner Loop**Inner Loop**Inner Loop**Inner Loop**Inner Loop**Inner Loop**Inner Loop**Inner Loop**Inner *;
*****************************************************************************************************;
%let j=1;
%macro inner();  *check the location of the shifting task and increment by one to the right if needed;
%do %while (&j.>0); %put the value of j is &j.;

data work.test;
      set work.pred_data;
      where activity_num = &task_to_shift.;
      newfinish = sum(&shifted_start., Pduration); *anything shifting is still in the future;
      call symput ('shifted_finish',newfinish); *recalc the shifted finish time;
run;
%put new start time of shifter: &shifted_start.; *write new start time of shifter to the log;
%put  new finish time of shifter: &shifted_finish.; *write new finish time of shifter to the log;

*with new start time of shifting activity, send to proc cpm to check if there are any resource violations;
data work.&NW.&S.&B._shift1;
      set work.&NW.&S.&B._optimal_stats;
      if activity_num = &task_to_shift. then s_finish = &shifted_finish.;
      keep activity_num succ1-succ&num_succ. r1-r&num_r. s_finish Pduration;
run;

*Call PROC CPM;
proc cpm data=work.&NW.&S.&B._shift1
out=work.&NW.&S.&B._shift1_check
resourceout = work.&NW.&S.&B._rout_check
ressched = work.&NW.&S.&B._ressched_check
resin = NW_Soln.&NW._resources_avail
;
activity activity_num;
duration Pduration;
successor succ1-succ&num_succ.;
resource R1-R&num_R. /  period=date obstype=obstype;
actual / A_finish = s_finish; *set the actual end time of the tasks to be the optimal end times;
```

```
run;

*if resource violations, increment start time by 1 and go to inner loop;
data work.check_for_r_violation;
      set work.&NW.&S.&B._rout_check;
      where AR1 < 0 or AR2 < 0 ;
run;

data work._null_;
      %let dsid=%sysfunc(open(work.check_for_r_violation));
      %let num=%sysfunc(attrn(&dsid,nobs));
      %let rc=%sysfunc(close(&dsid));
run;

%put There are &num. observations in dataset work.check_for_r_violation.;
data work._null_;
      if &num. > 0 then do;
            newstart = sum(&shifted_start., 1); *add one to the shifted start time;
            call symput ('shifted_start',newstart); *put this new shifted start global var;
            CALL SYMPUT('j',%eval(&j.+1));
      end;
      if &num. = 0 then do;
            CALL SYMPUT('j',0);
      end;
run;
%put the value of j is &j.;
%end;
%put start time of &task_to_shift. is &shifted_start.; *write new start time of shifter to the log;
%mend inner;
%inner();

*****************************************************************************************************;
*End Inner Loop**End Inner Loop**End Inner Loop**End Inner Loop**End Inner Loop**End Inner Loop**End Inner;
*****************************************************************************************************;

*if no resource violations, loop to outer loop to shift the remaining tasks;
data work.&NW.&S.&B._optimal_stats;
      merge work.&NW.&S.&B._shift1_check
            work.&NW.&S.&B._optimal_stats (keep = activity_num Bduration duration timing stoch remove
Kloop);
run;
```

```
data work.find_shifter;
      set work.&NW.&S.&B._optimal_stats;
      where activity_num = &task_to_shift. ;
      if activity_num = &task_to_shift. then do; *this was the task just shifted;

      if %index(&shiftype.,remove) > 0 then do; *removed task ;
            call symput('shift_time',s_start); * changes shift time to the start of the task just shifted;
      end;
      if %index(&shiftype.,occur) > 0 then do; * inserted or expanded task;
            %put do not update the shift time; *this may be removed;
      end;

      end;
      keep activity_num succ1-succ&num_succ. r1-r&num_r. Pduration s_start s_finish duration Bduration
           Kloop;
run;
%put task just shifted: &task_to_shift.;
%put start time of &task_to_shift. is &shifted_start.; *write new start time of shifter to the log;
%put shifting point in time is currently: &shift_time.;

*update the pred list start times based on preds new start times;
data work.pred_data;
      set work.pred_data;
      array Apred_num{&num_preds.} pred1-pred&num_preds.;
      array Apred_finish{&num_preds.} pred_finish1-pred_finish&num_preds.;
      do i=1 to &num_preds.;
            if Apred_num{i} = &task_to_shift. then Apred_finish{i} = &shifted_finish.;
      end;
      pred_finish_max = max(of pred_finish1-pred_finish&num_preds.);
run;

*update data set of shifted tasks;
proc datasets nolist;
     append base=work.shifted_tasks
       data=work.find_shifter force;
run;
%put start time of &task_to_shift. is &shifted_start.; *write new start time of shifter to the log;

data work._null_;
      if &task_to_shift. < 32 then do;
            CALL SYMPUT('i',%eval(&i.+1));
```

```
      end;
      if &task_to_shift. = 32 then do;
            CALL SYMPUT('i',0);
      end;
run;
%end;
%mend outer;
%outer();
*****************************************************************************************;
*End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End Outer;
*****************************************************************************************;

%exit1:
%if &num_stoch. = 0 %then %do; *if there are not stoch tasks, do not execute this - create a copy and exit;
%put THIS EXCEPTION CODE JUST RAN!;
data prob.&NW.&S.&B._&T.;
    set NW_soln.&NW.&S.&B._optimal_stats; *comment out for testing only;
run;
%end;

%end;
%mend exterior;

dm "log;clear;"; *clear the log;
%exterior();
*****************************************************************************************;
*End Exterior Loop**End Exterior Loop**End Exterior Loop**End Exterior Loop**End Exterior Loop*   ;
*****************************************************************************************;

%macro wrapup();
%if &num_stoch. = 0 %then %do; *if there are not stoch tasks, do not execute this - create a copy and exit;
      %put NO STOCH TASKS;
      %goto exit2;
%end;

data work.solution;
      set work.shifted_tasks;
run;

proc sort data=work.solution; by activity_num; run;
proc sort data=work.&NW.&S.&B._optimal_stats; by activity_num; run;
```

```
proc sort data=work.pred_data; by activity_num; run;

data work.output;
      merge work.solution (keep = activity_num s_start s_finish)
            work.&NW.&S.&B._optimal_stats (keep = activity_num duration Bduration Pduration succ1-
succ&num_succ. r1-r&num_r. timing stoch remove)
              work.pred_data (keep = activity_num pred1-pred&num_preds. pred_finish_max)
      ; by activity_num;
run;

data prob.&NW.&S.&B._&T.;
      set work.output;
run;

data prob.&NW.&S.&B._&T._rout;
      set work.&NW.&S.&B._rout_check; *output last round of this schedule - correct resource usage ;
run;

%exit2:
%mend wrapup;
%wrapup();

%mend merge_soln;

%inc "&path.\RCP\macro_calls.txt";*
```

APPENDIX C: EXAMPLE REPAIR OF A BUFFERED SCHEDULE

The following 17 Gantt charts demonstrate the results of SAS code implementation for repairing a buffered schedule. The first Gantt chart (Figure 27) contains the initial baseline schedule. The sections of each Gantt chart represent the two resource types, with 10 units available each, as well as a third section with no resource utilization. The yellow and purple tasks are those that have been initially scheduled in the initial baseline schedule with 20% of their actual duration. Similarly, blue and orange shaded tasks are those with an 80% buffer. The 16 Gantt charts in Figure 28 through Figure 43 show state of the repaired schedule as each of the stochastic tasks eventuate (either occur or do not occur). In the case of a task occurring, all tasks are shifted towards the right to make room for this "expanding" task and then shifted back to the left, one at a time. In the case of a task that does not occur, the task is removed and all tasks are shifted to the left, one at a time. When left shifting, a task is temporarily assigned a new start time that is equal to the current system time, or the latest finish time of its predecessors, which ever is later. If a resource violation occurs, the start time is incremented by one until it starts at a time when no resource violations occur.

Y	Early	Low	'20%'
B	Early	High	'80%'
P	Late	Low	'20%'
O	Late	High	'80%'

Figure 26: Color Codes for Buffers in Appendix C

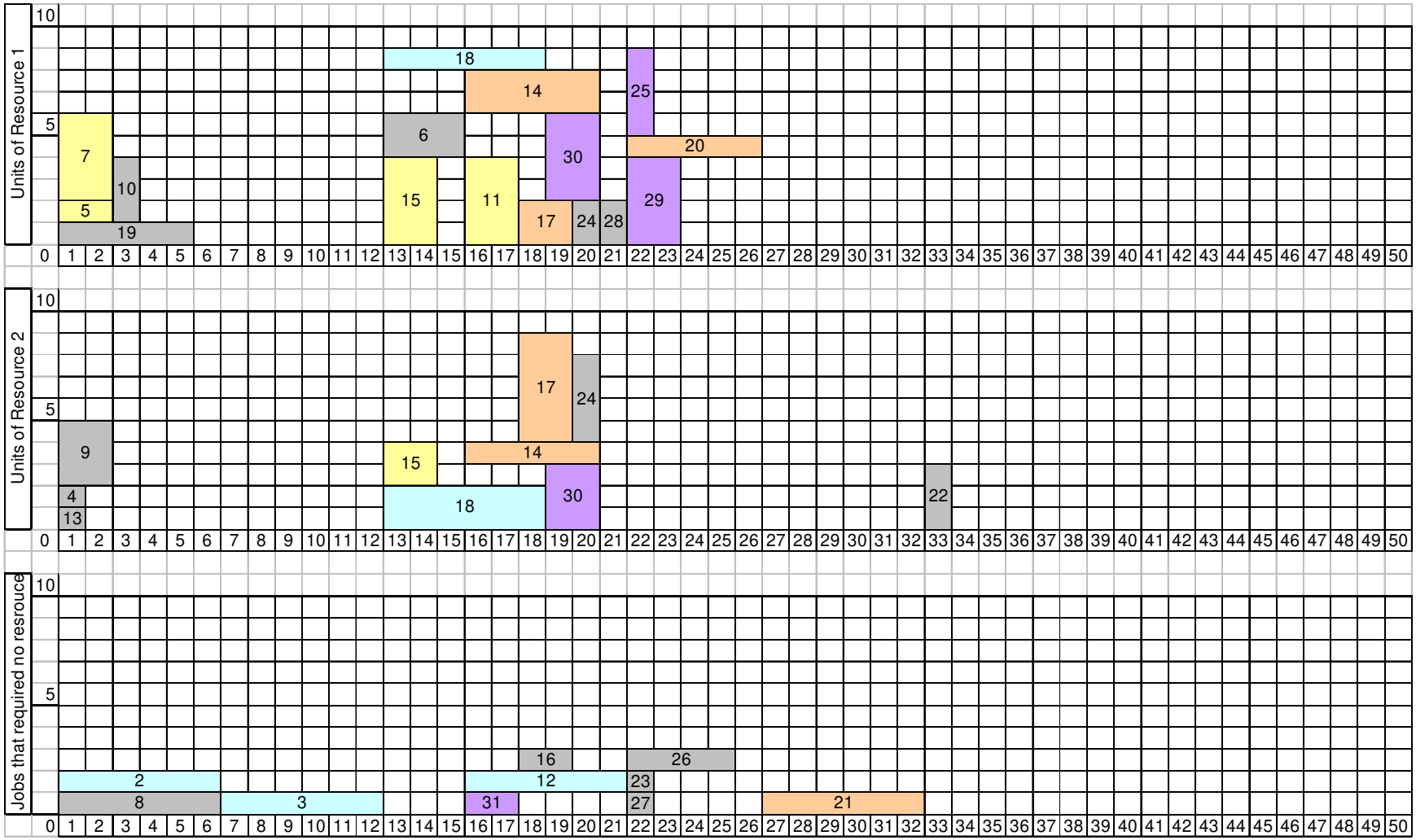


Figure 27: Initial baseline schedule – 80/20 Buffers on Stochastically Occurring Tasks

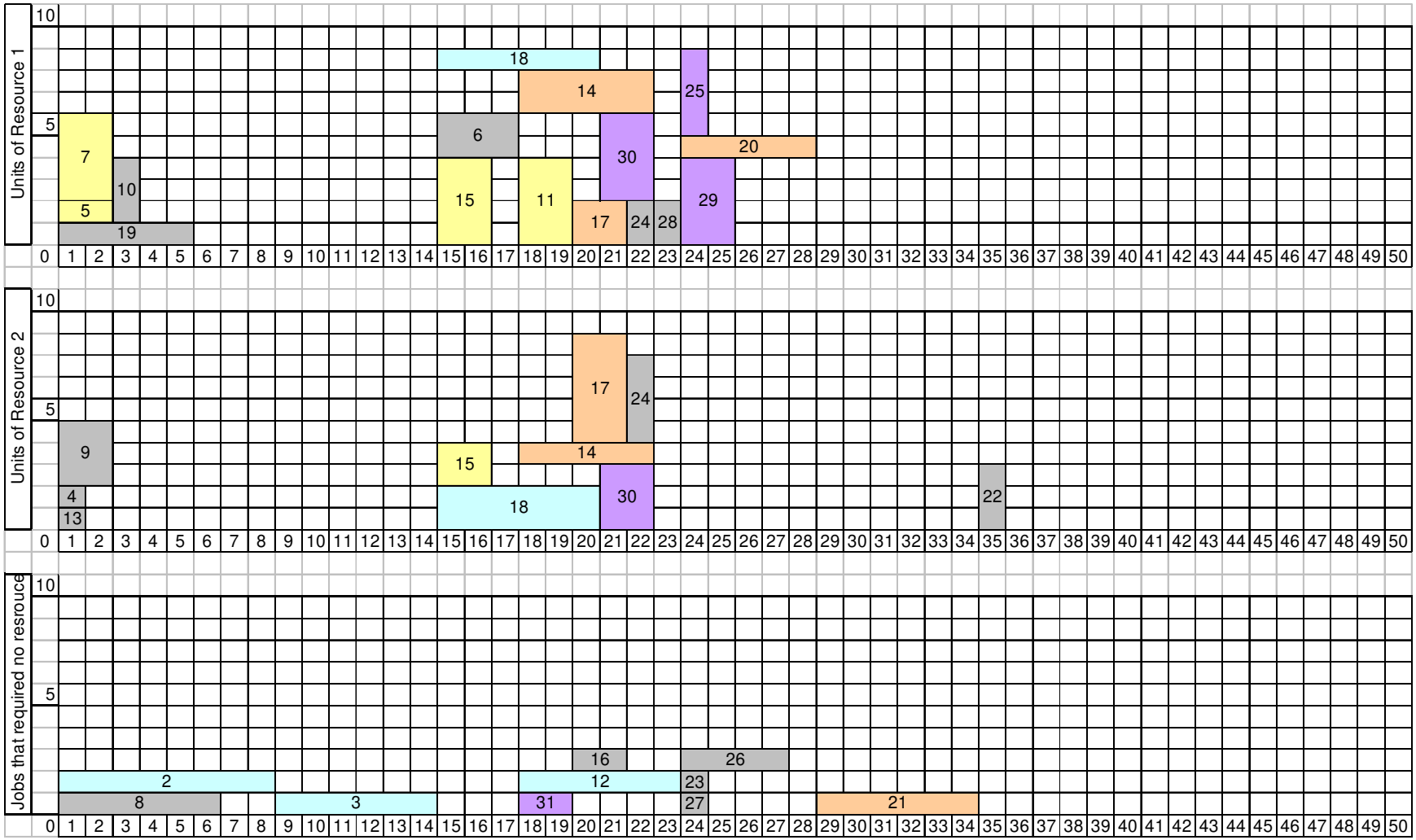


Figure 28: Task 2 Eventuation - Occurs

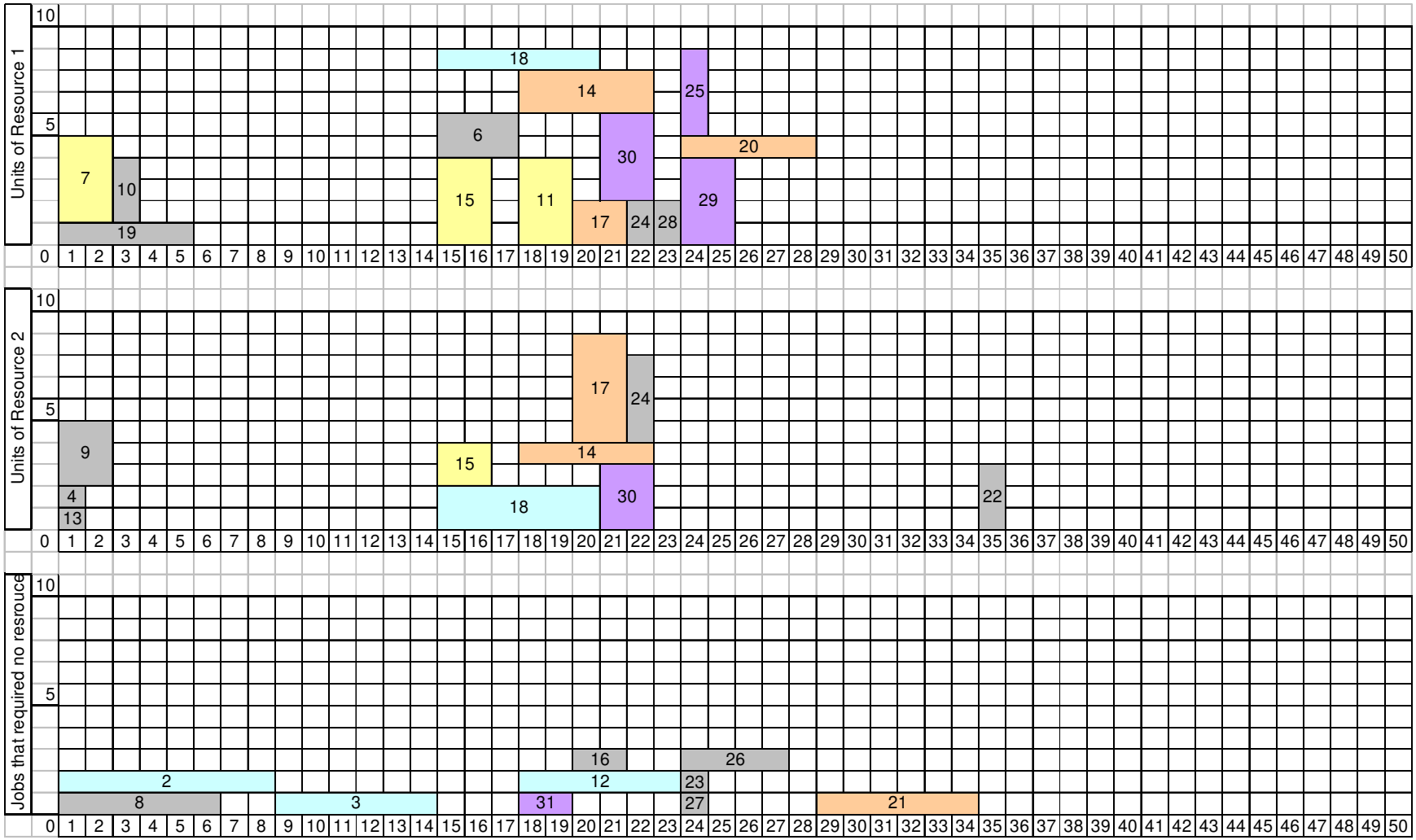


Figure 29: Task 5 Eventuation – Does not occur

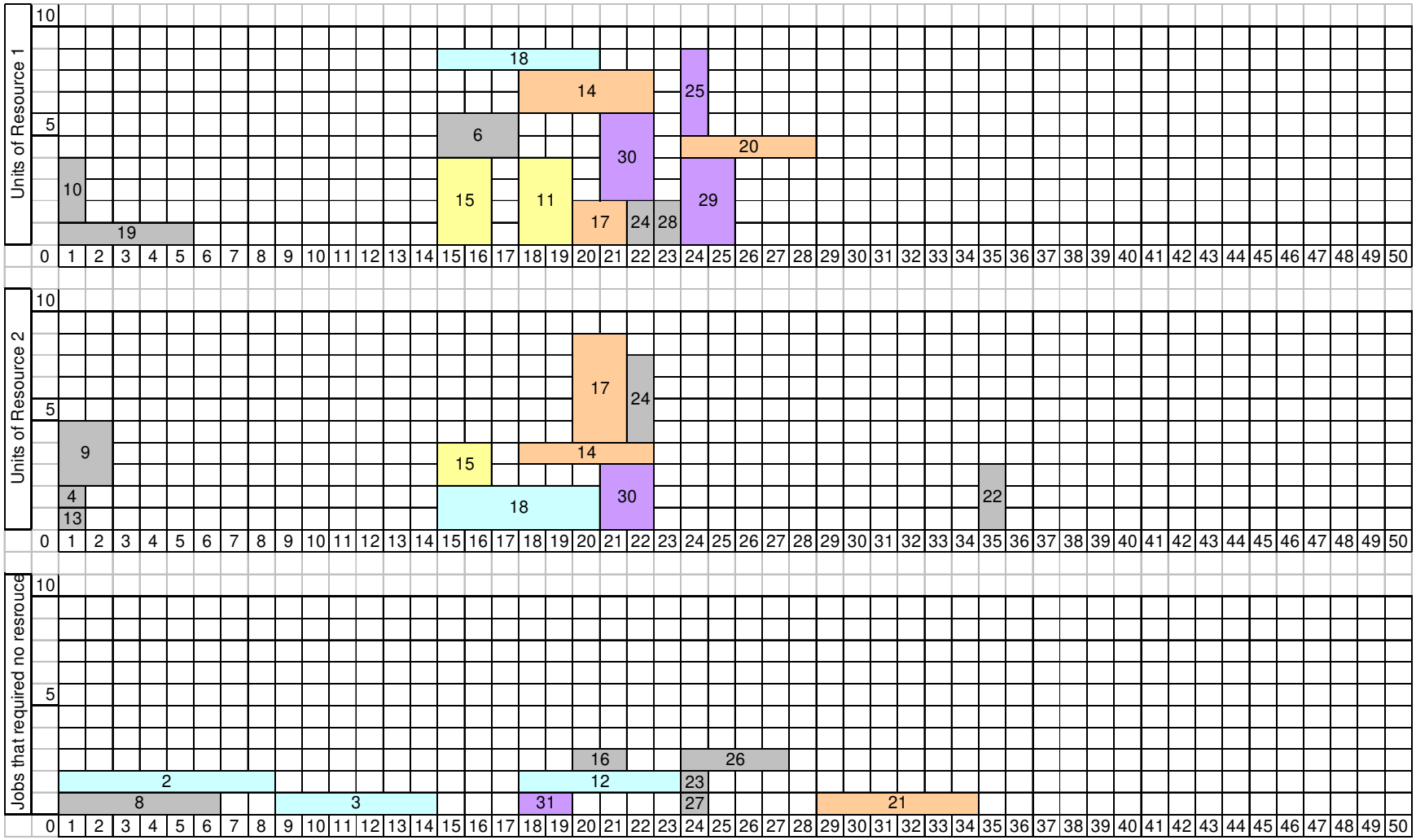


Figure 30: Task 7 Eventuation – Does not occur

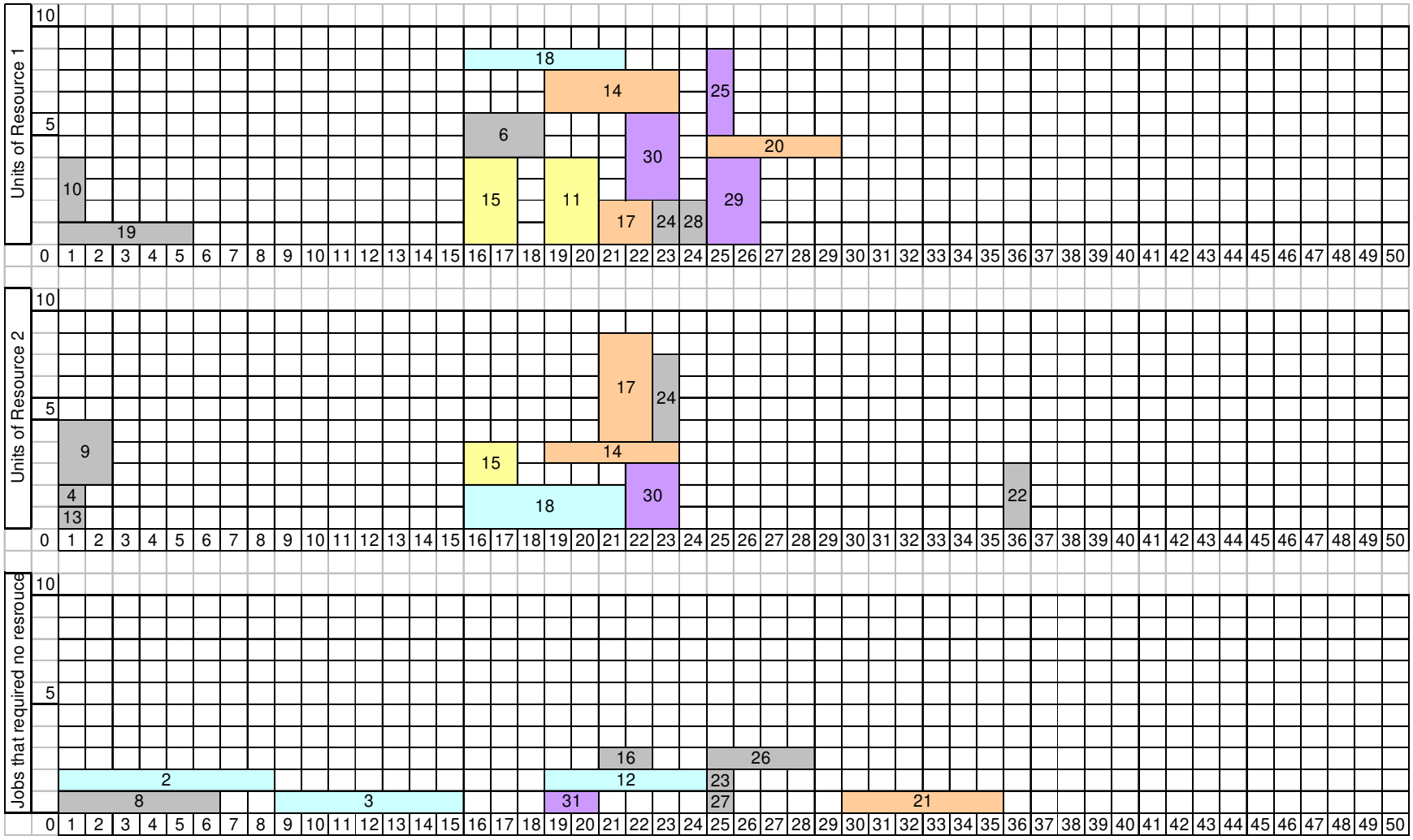


Figure 31: Task 3 Eventuation - Occurs

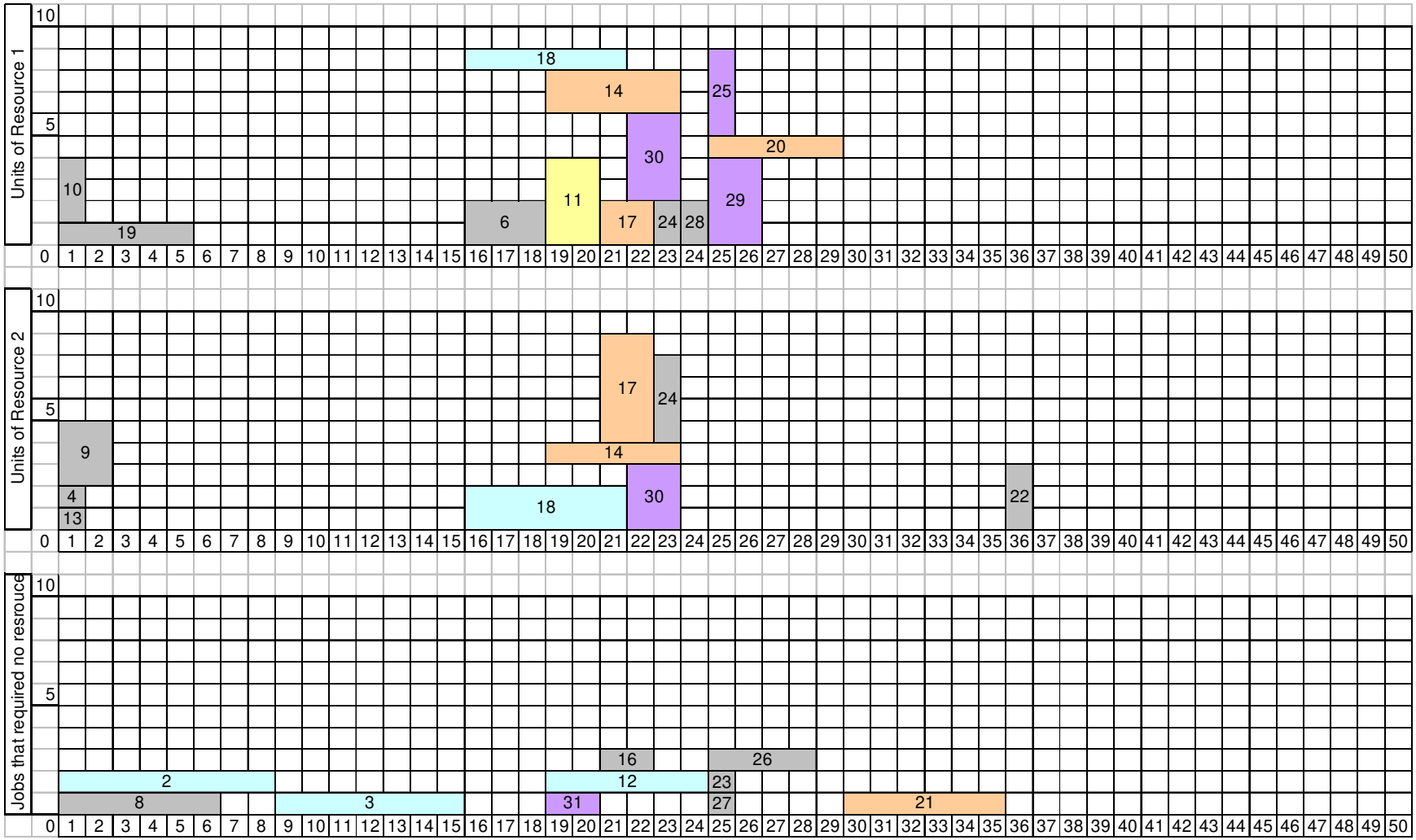


Figure 32: Task 15 Eventuation – Does not occur

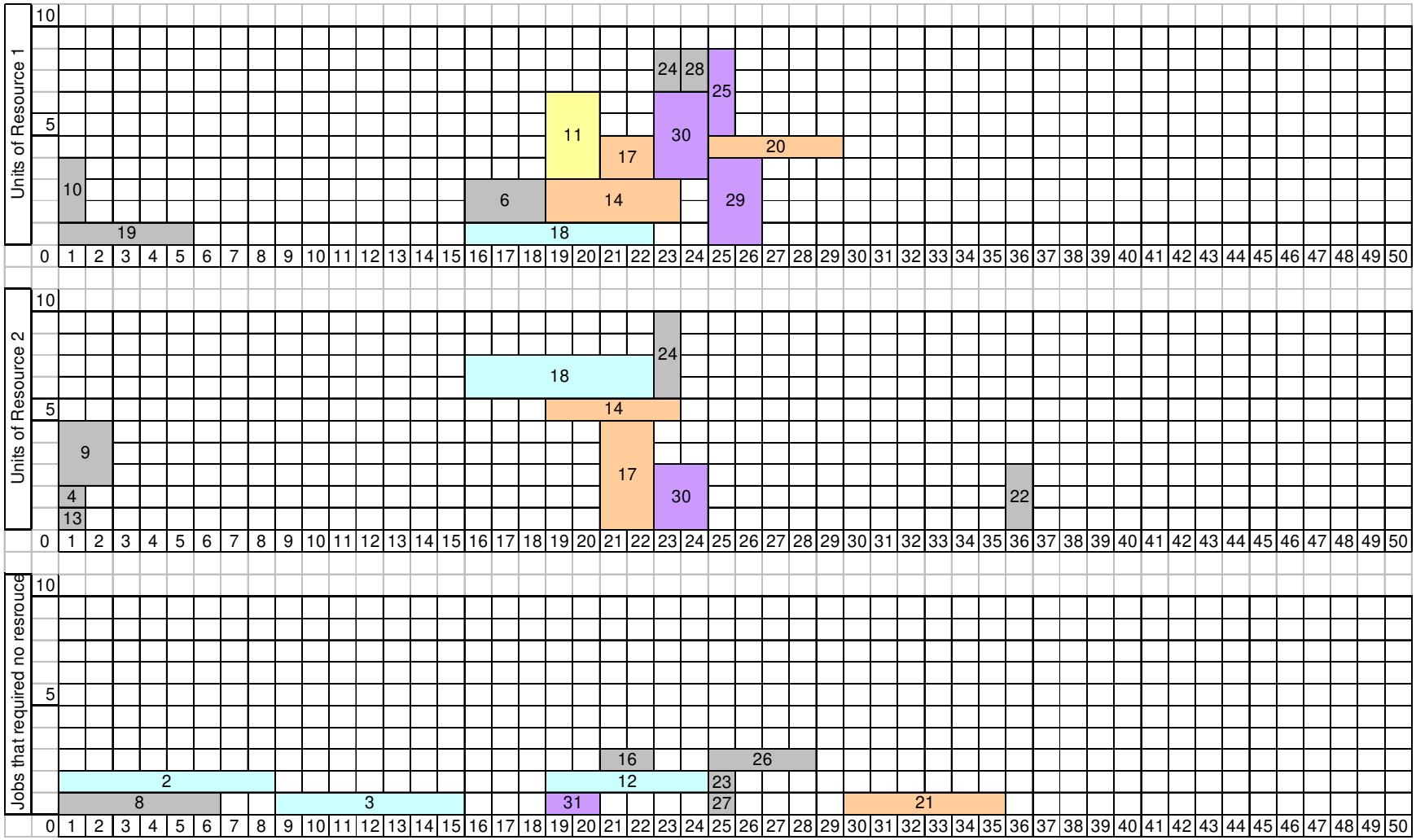


Figure 33: Task 18 Eventuation - Occurs

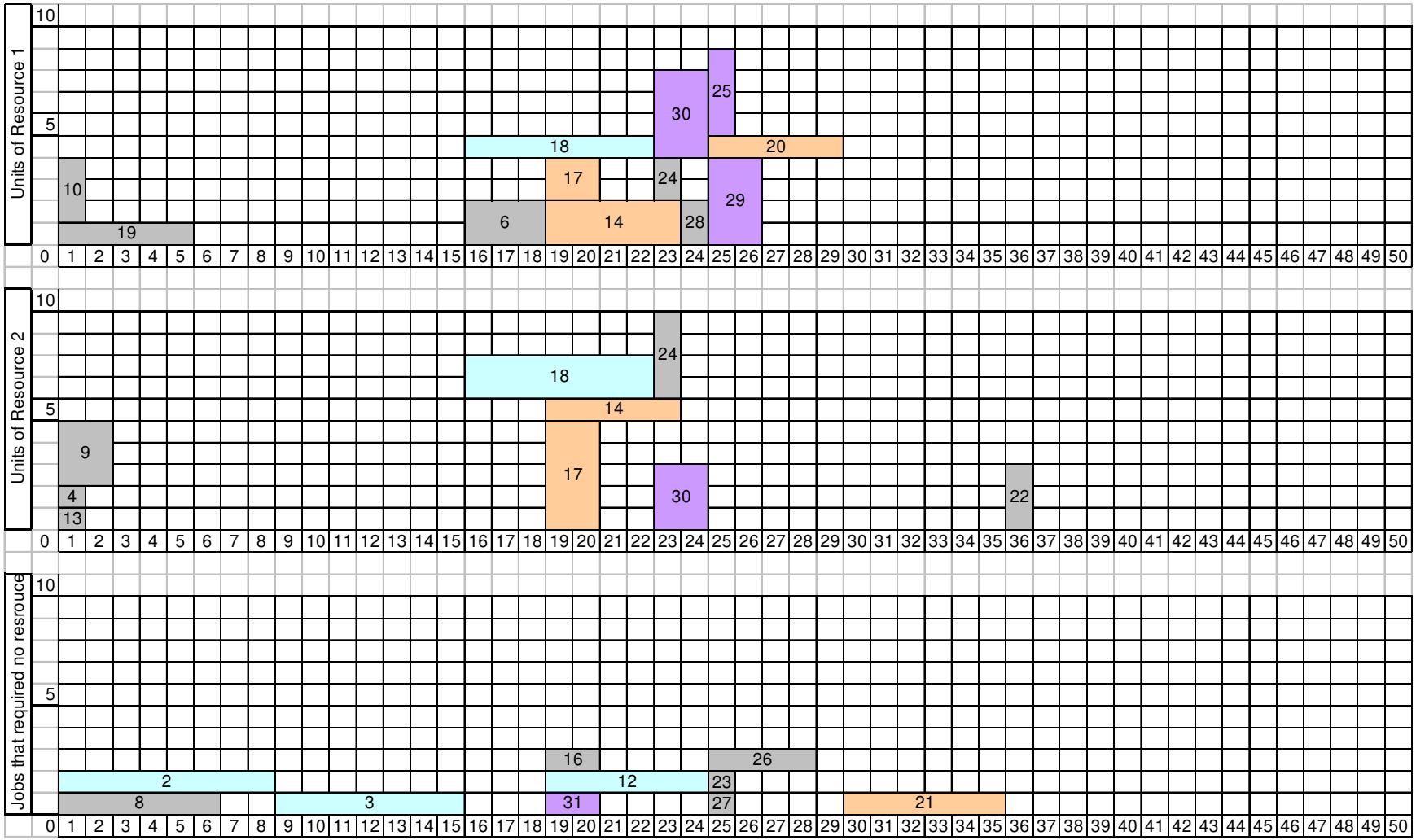


Figure 34: Task 11 Eventuation – Does not occur

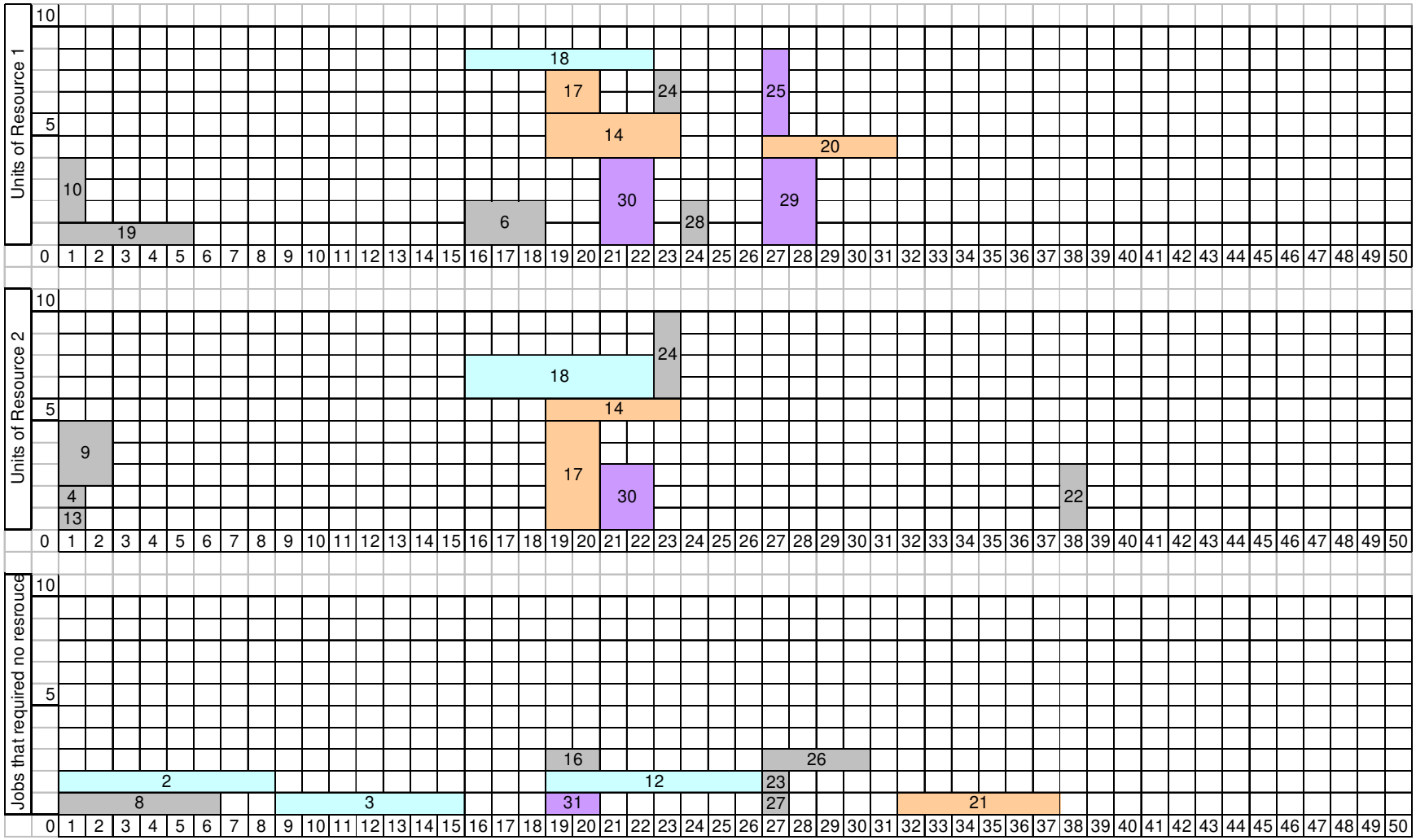


Figure 35: Task 12 Eventuation - Occurs

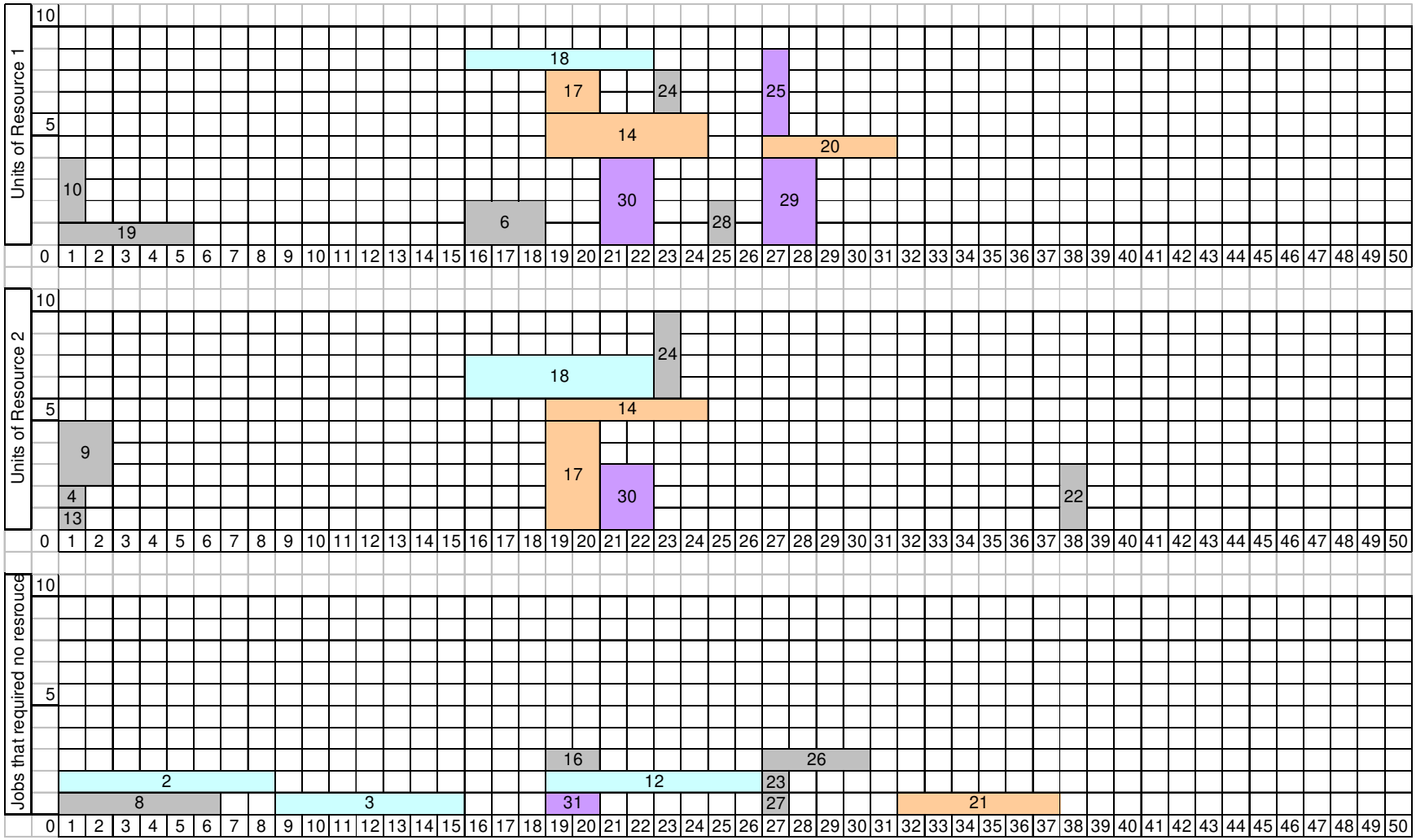


Figure 36: Task 14 Eventuation - Occurs

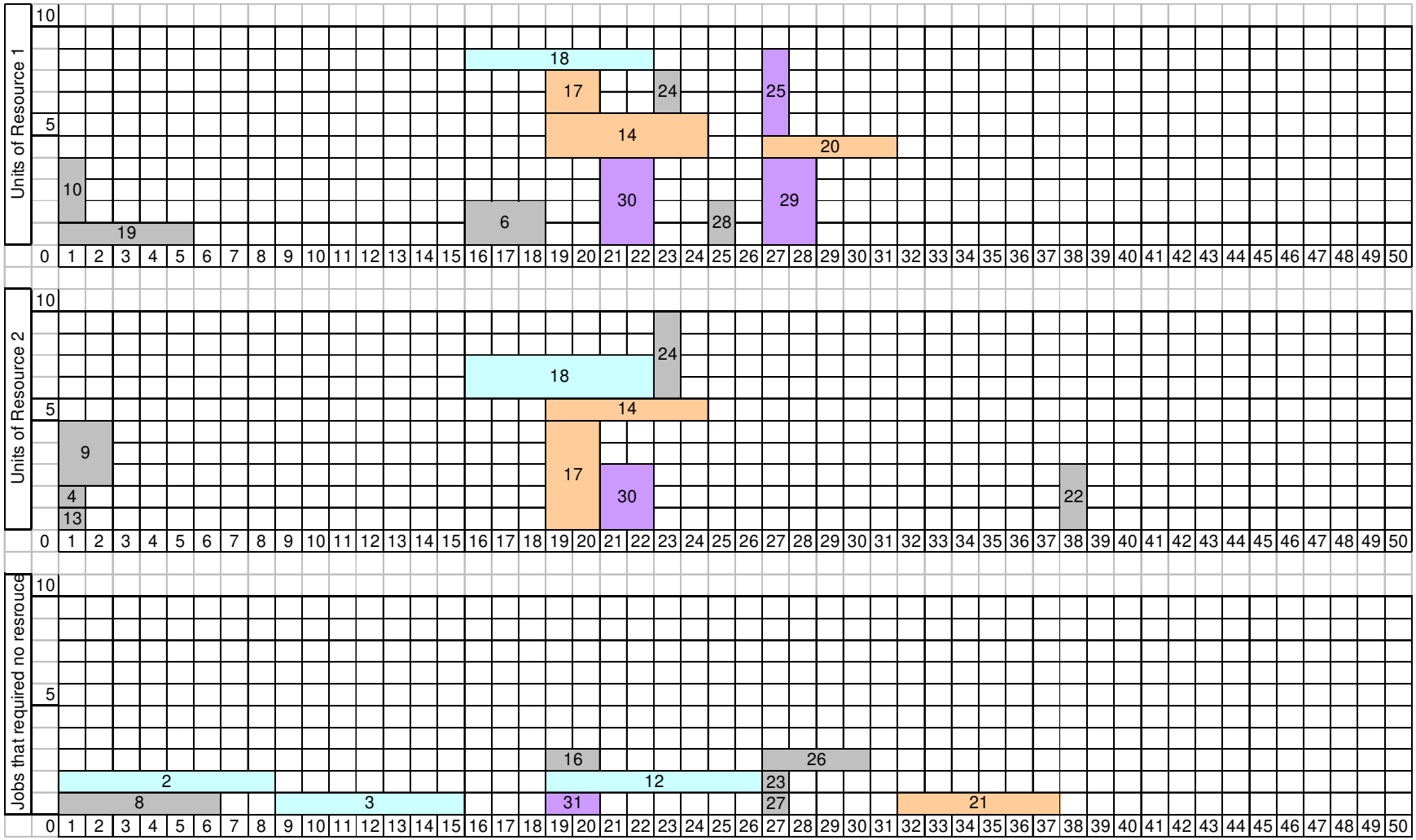


Figure 37: Task 17 Eventuation - Occurs

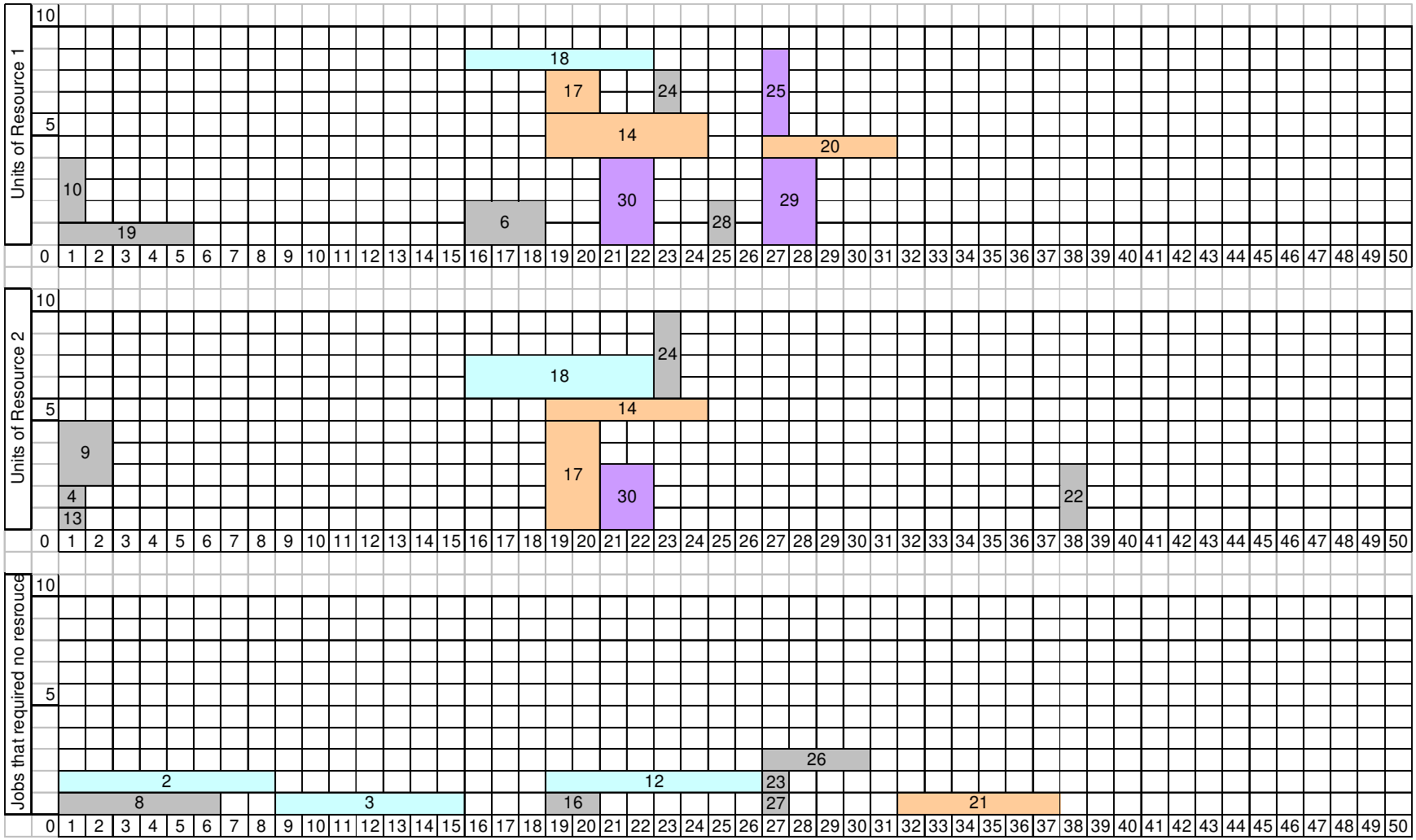


Figure 38: Task 31 Eventuation - Removed

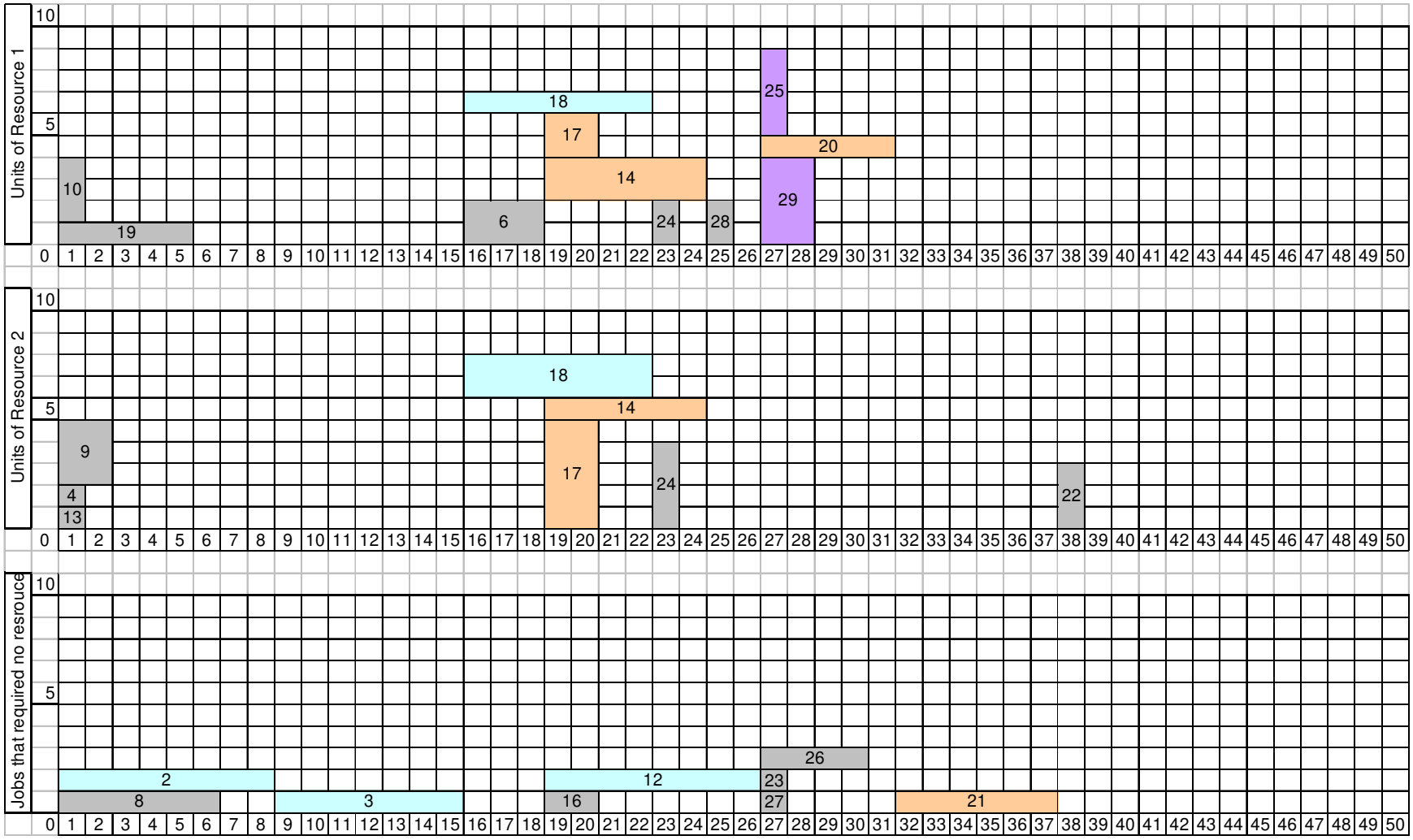


Figure 39: Task 30 Eventuation – Does not occur

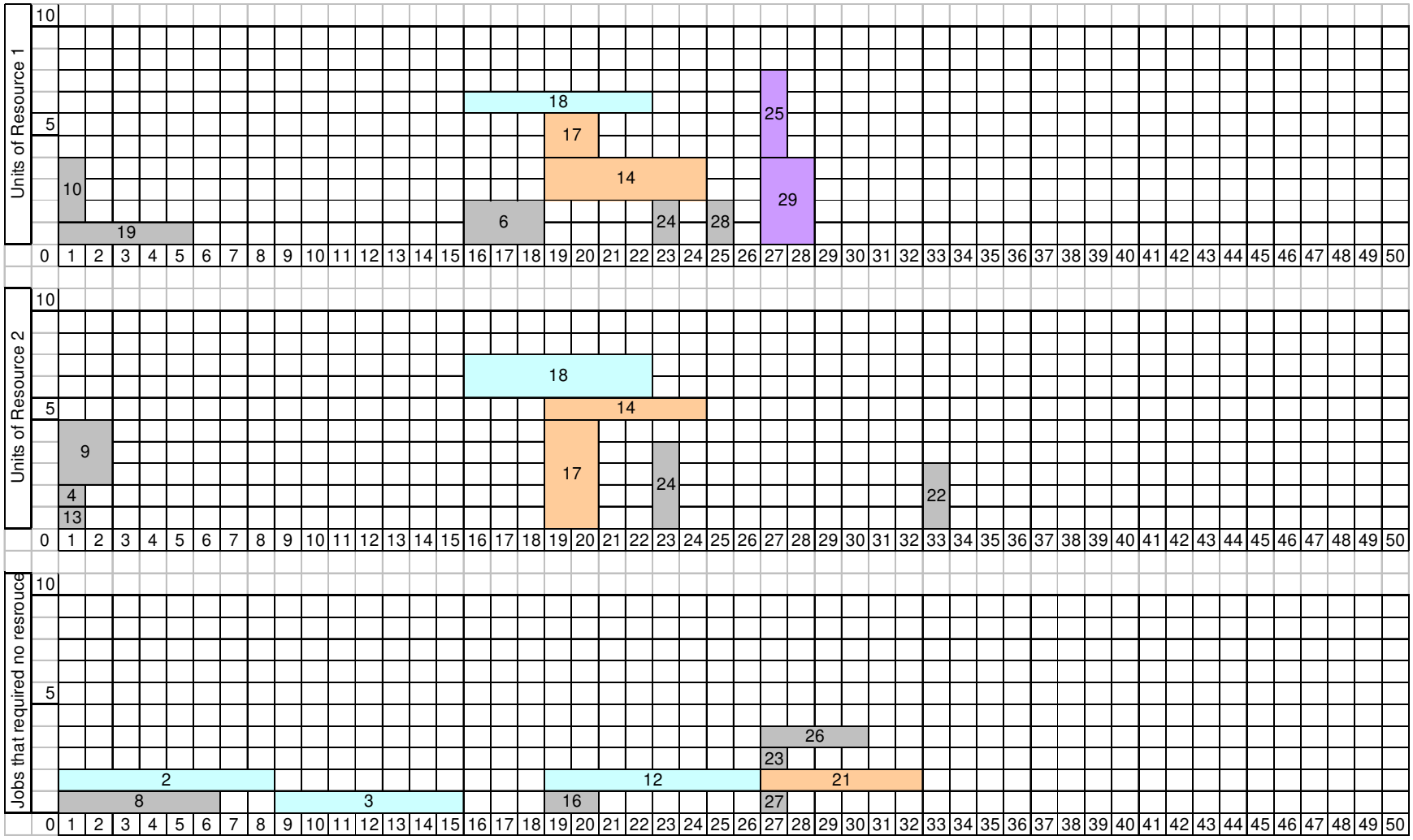


Figure 40: Task 20 Eventuation – Does not occur

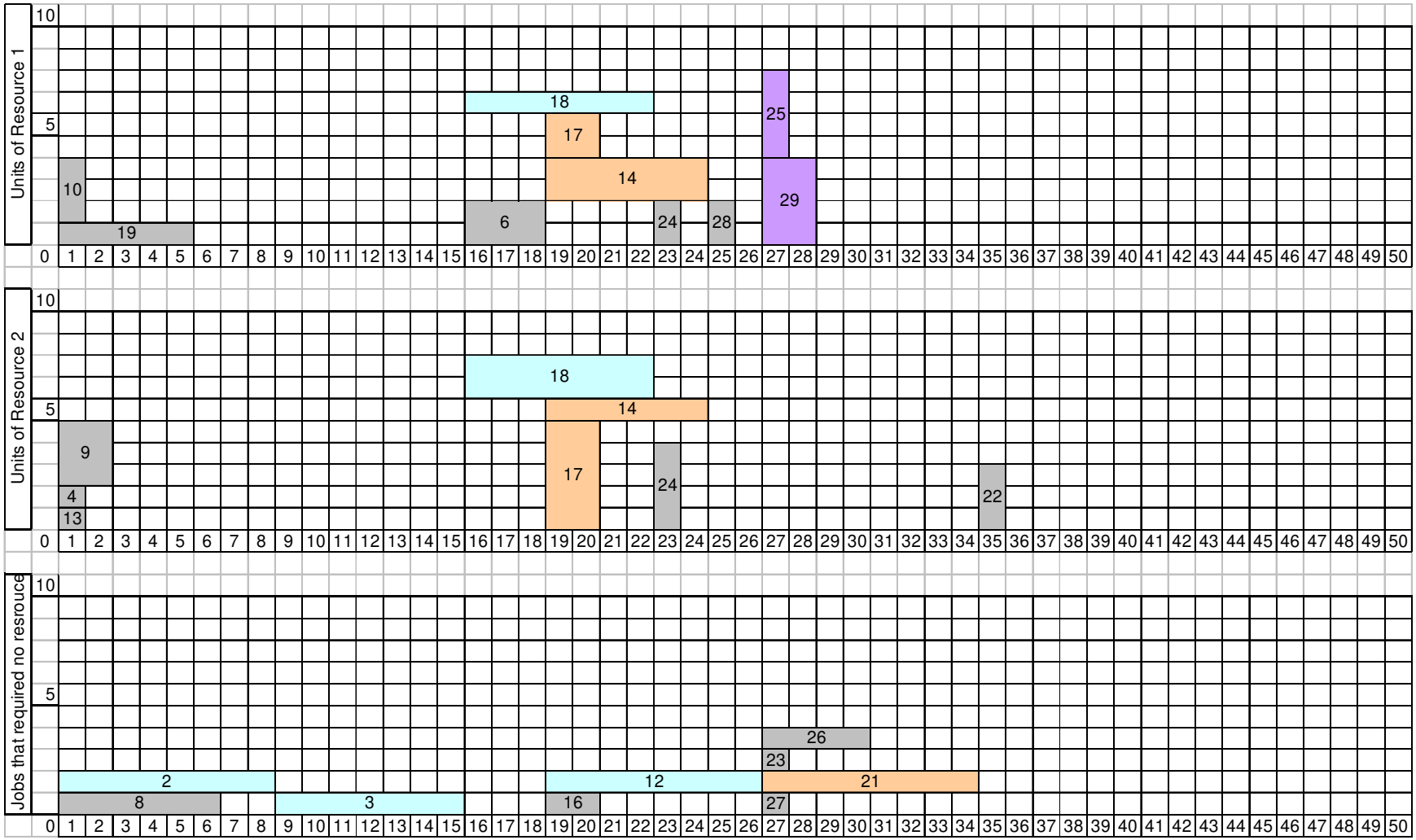


Figure 41: Task 21 Eventuation – Occurs

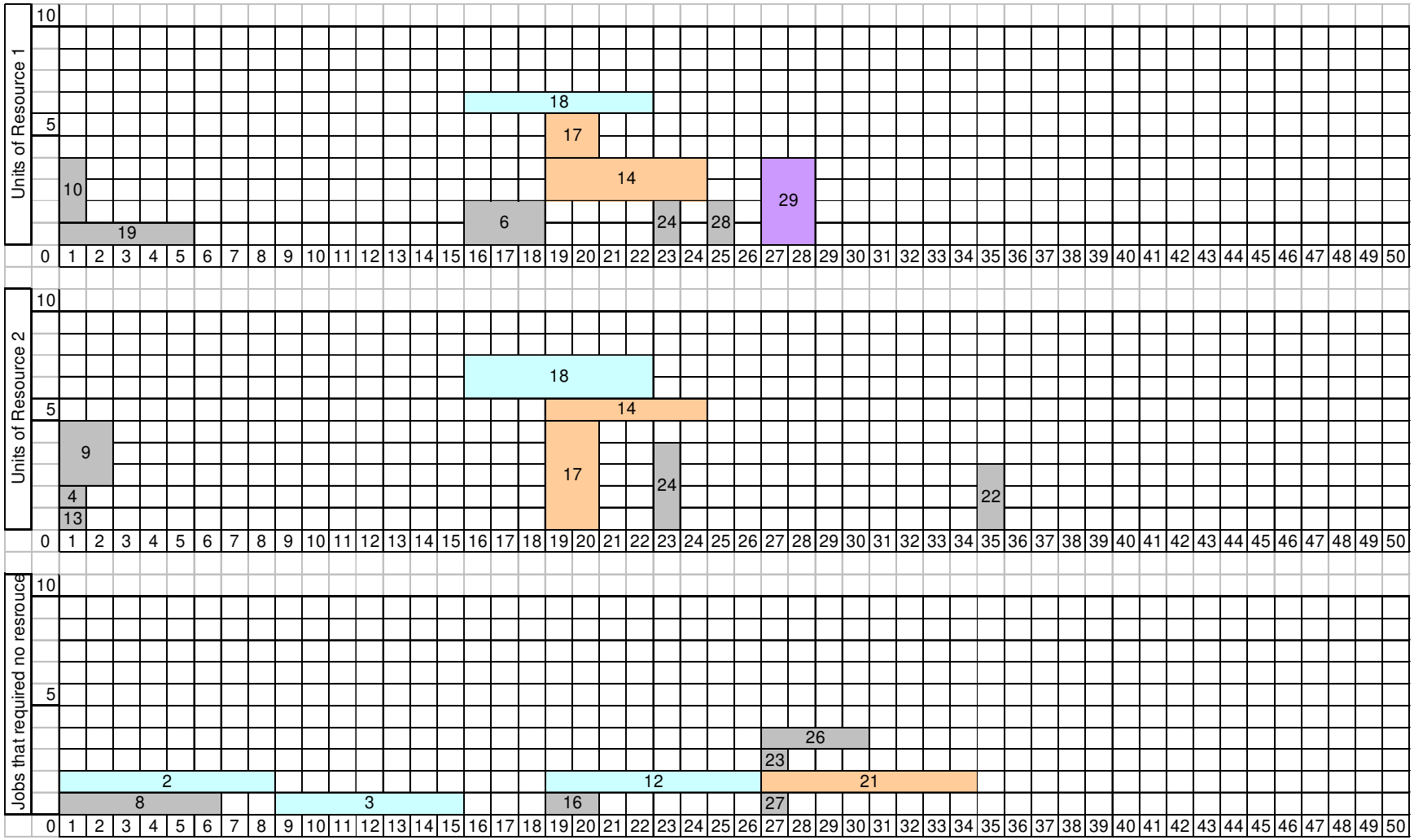


Figure 42: Task 25 Eventuation – Does not occur

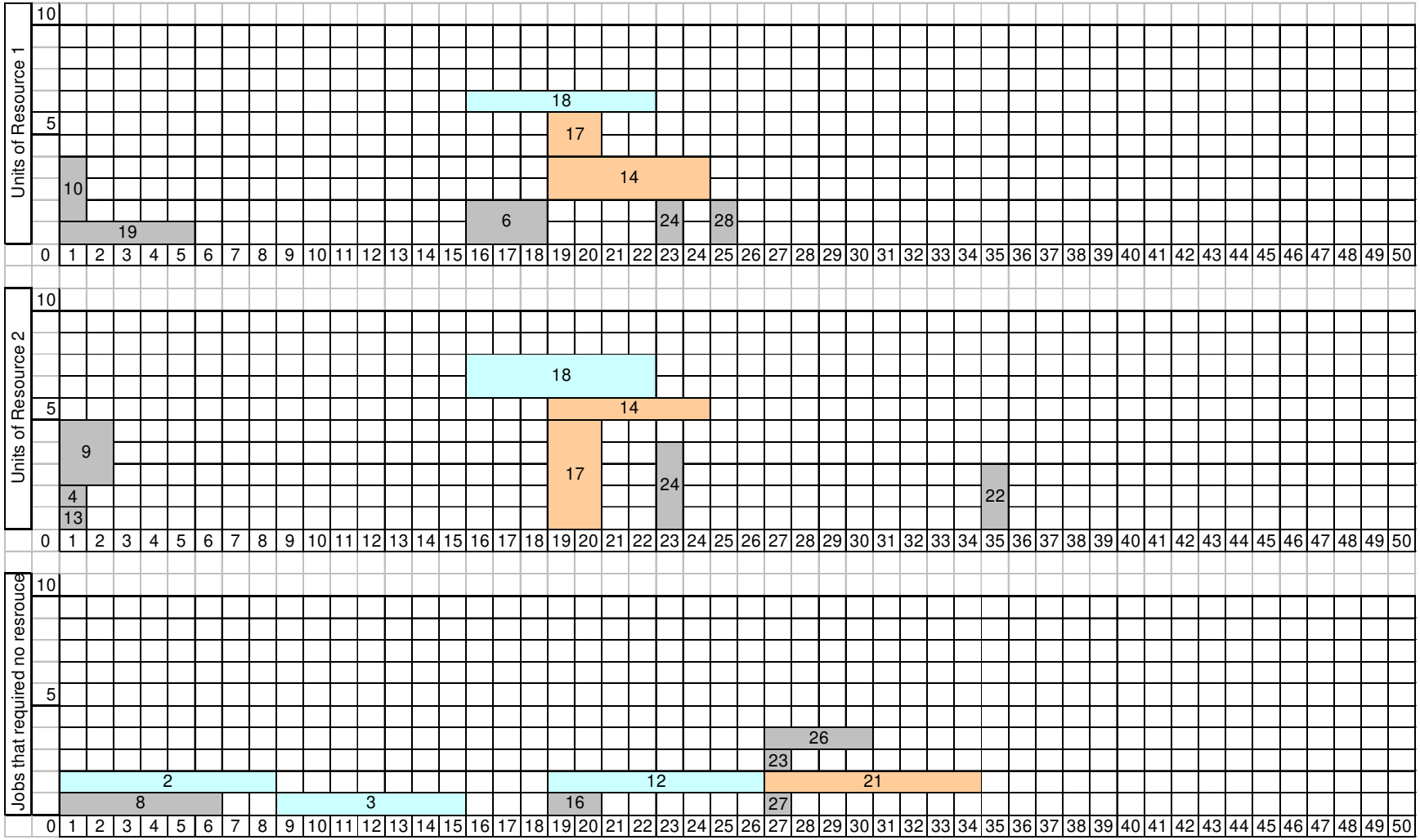


Figure 43: Task 29 Eventuation – Does not occur

APPENDIX D: SAS CODE FOR SOLVING RESOURCE FLOW

```
*****************************************************************************************;
* Resource flow v4.sas                                                                  ;
*     Input: solved or repaired NW - prob.&NW.&S.&B._&T. -                              ;
*     Output: the resource flow of this NW - R_soln.&NW.&S.&B._&T._&R.                  ;
*****************************************************************************************;

*****************************************************************************************;
*problem set-up;
*****************************************************************************************;
*Select the buffer lable and formula for this run;
/*%let B = O;                                                *optimistic;*/
/*%let B = P;                                                *pessimistic;*/
/*%let B = B5;                                               *50% buffer;*/
/*%let B = B2;                                               *90/10% buffer;*/
/*%let B = B1;                                               *80/20% buffer;*/

* Select the stochasticity level for this run - here these are the tasks that DO occur;
/*%let stoch = "Low"; %let S = L;                            *Low;*/
/*%let stoch = "Low","High"; %let S = H;                     *High;*/
/*%let stoch = "Low","High"; %let S = A;                     *90/10 and 80/20; */

* Select the timing setting this run - here these are the stoch tasks that DO occur;
/*%let timing = "Late"; %let T = L;                          *Late;*/
/*%let timing = "Early"; %let T = E;                         *Early;*/
/*%let timing = "Early", "Late"; %let T = Optimal_stats;     *Initial Base; */

%let path = C:\Sandra_laptop\IEMS\data\Selim; *run for each prob type: pat, RCP files;
libname NW_soln "&path.\Non-optimal SAS Solutions";
libname prob "&path.\Non-optimal SAS solutions"; *Non-optimal SAS solutions (IB) or repaired (MB or PK);
libname resource "&path.\Resource metrics";
libname R_Soln "&path.\R Solutions";
*****************************************************************************************;
*end problem set-up;
*****************************************************************************************;

*****************************************************************************************;
*initialize datasets;
*****************************************************************************************;

* create a set of storage nodes with a 1 for the utilization - establish arcs to connect to other nodes;
data work.storage;  *may be used for all NW;
```

```
input id $; format id $9.;cards;
storage
;
run;

*create supply to demand arc;
data work.supply_to_demand;   *may be used for all NW;
length begin_id $20. end_id $20. _from_ $20. _to_ $20. _cost_ 8. _name_ $50.;
infile cards dlm=',';
input begin_id $ end_id $ _from_ $ _to_ $ _cost_ _name_ $ ;
cards;
supply, demand, supply, demand, 0, supply_demand
;
run;

* Build the supply and demand nodes;
data work.supply_and_demand_template; *values of the number of avail resources will be filled in the loop;
infile cards dlm=',';
input _node_ $ _sd_ ;
cards;
supply, 0,
demand, 0,
;
run;

%macro merge_soln(NW);

*get number of resource types;
      data work.R; set NW_soln.&NW._resources_avail;  keep R:;run;
      data work._null_;
          %let dsid=%sysfunc(open(work.R));
          %let num_R=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activity types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of resource types are: &num_R.; *create this global macro var;

*****************************************************************************************;
*end initialize datasets;
*****************************************************************************************;

%do nr = 1 %to &num_R.; *r flows are not relevant for R0, so start with 1;
```

```
%let R = r&nr.;
%put We are now working on &NW. resource: &r.;

      data work.R_avail;
      set NW_soln.&NW._resources_avail;
            CALL SYMPUT('avail',&r.);
      run;
      %put There are &avail. resources of type &r. available;

*****************************************************************************************************;
* Build sparse constraint data for use in PROC NETFLOW  ;
*****************************************************************************************************;
*note, solving for R1 and R2 can be done separately - they have no effect on one another;

*STEP 1: Build a data set that can be used to build the constraint data ;
data work.data;
      set prob.&NW.&S.&B._&T.;
run;

proc sort data=work.data; by descending S_finish; run;

data work.test ;
      set work.data (obs = 1);
      call symput('TimeMax',put(S_finish,Z3.)); *time pds of this activity;
run;
%put &TimeMax.;

data work.NW_&R.;
      set work.data;
      where &R. ne 0 and Pduration ne 0; *duration for the IB schedules;
      zero_activity_num = put(activity_num,z3.);
      drop activity_num;
run;

data work.NW_a;
      set work.NW_&R.;
      n = _n_;
      activity_num = zero_activity_num;
      drop zero_activity_num;
run;
```

```
data work._null_;
    %let dsid=%sysfunc(open(work.NW_a));
    %let num_obs=%sysfunc(attrn(&dsid,nobs)); *num_vars contains the number of obs in the data set NW_a;
      %let rc=%sysfunc(close(&dsid));
run;
%put There are &num_obs. activities in &NW. that use resource &r.;

* create a set of storage nodes with a 1 for the utilization - establish arcs to connect to other nodes;
proc datasets nolist nodetails library = work; delete base; run;
data base1; format id $9. Time001-Time&TimeMax. 15.;run;

data work.base;
      set work.base1
            work.storage;
      array TimePds{&TimeMax.} Time001-Time&TimeMax.;
      where id ne '';
      if id = 'storage' then %do m = 1 %to &TimeMax.;  TimePds{&m.} = 1; %end;
run;

* create a base for the RHS constraint building;
proc datasets  nolist nodetails library = work; delete rhs_base; run;
data rhs_base; format _col_ $50. _row_ $20._coef_ 10. ; run;

*Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer Loop**Begin Outer *;
%macro outer();
      %do n = 1 %to &num_obs.;
      %put the value of n is &n.;

data work.NW_b;
      set work.NW_a;
      where n = &n.;
      call symput('pds',sum(S_finish, -S_start, 0)); *time pds of this activity;
      call symput('start',put(S_start+1,z3.)); *End of first time pd;
      call symput('end',put(S_finish,z3.)); *End of last time pd;
      call symput('Act',activity_num);

      call symput('Resource',&R.); *Resource utilization of this activity;
run;

%put Time periods are: &pds.;
```

```
%put Start time is: &start.;
%put End time is: &end.;
%put &R. Level is: &Resource.;

data work.NW_&n.;
      set work.NW_b;
      id = "Task&act.";
      array TimePds{&pds.} Time&start.-Time&end.; *use 100 time periods for all tasks;

      do i = 1 to &pds.;
            TimePds{i} = &Resource.;
      end;
      keep id Time&start.-Time&end.;
run;

proc datasets nolist nodetails ; append base=work.base data=work.NW_&n. force; run;
data work.all1;   set work.base; run;

proc transpose data=work.NW_&n. out=work.NW_trans&n.; *id id; run;
data work.NW_trans&n.;
      set work.NW_trans&n.;
      _col_ = "_rhs_";
      _row_ = "Con_"||trim(_name_)||"Task&act.";
      _coef_ = Col1;
      keep _col_ _row_ _coef_;
run;
proc datasets nolist nodetails ; append base=work.rhs_base data=work.NW_trans&n. force; run;
data work.RHS;    set work.rhs_base; where _col_ ne '' and _row_ ne '' and _coef_ ne .; run;

%end;
%mend outer;
%outer();
*End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End Outer Loop**End;

proc transpose data=work.all1 out=work.all2; id id; run;

* STEP 2:  Build a data set that builds the possible arcs;
* 2 - 1: Pull all time-task cells with R > 0;
* 2 - 2: Permutate;
* 2 - 3: Only t -> t+1 are the possible arcs;
```

```
data outerbase; format begin_id $20. end_id $20._from_ $20. _to_ $20.  _cost_ 15. _name_ $50. ; run;

%macro outer_permutate ;
%do tempj = 1 %to &TimeMax.;
%let j = %sysfunc(putn(&tempj.,z3.)); *put is not available with %sysfunc - use putn (pg 287 macro docs);

data innerbase&j.; format begin_id $20. end_id $20._from_ $20. _to_ $20.  _cost_ 15. _name_ $50. ; run;

data work.time&j.;
      set work.all1;
      where time&j. > 0;
      begin_node = "Time&j."||id;
      merge = 1;
      begin_id = id;
      keep merge begin_id begin_node time&j.;
run;

data work._null_;
    %let dsid=%sysfunc(open(Time&j.));
    %let num_obs=%sysfunc(attrn(&dsid,nobs)); *num_vars contains the number of obs data set;
      %let rc=%sysfunc(close(&dsid));
      call symput("tempk",&j.+1);
run;
%let k = %sysfunc(putn(&tempk.,z3.));
%put The number of obs in the data set Time&j. is: &num_obs.;
%put j is now: &j.;
%put k is now: &k.;

data work.time&k.; *this gives an error on the last time period - but it is ok;
      set work.all1;
      where time&k. > 0;
      end_node = "Time&k."||id;
      merge = 1;
      end_id = id;
      keep merge end_id end_node time&k.;
run;

%macro inner_permutate;
%do i = 1 %to &num_obs.;
data work.time&j._&i.;
   set work.time&j. (firstobs=&i. obs=&i.);
```

```
run;
data work.merge&i.;
      merge work.time&j._&i.
              work.time&k.
      ; by merge;
      _to_ = end_node;
      _from_ = begin_node;
      if begin_id  = end_id then _cost_ = 0;
      if begin_id ne end_id then _cost_ = 1;
      if end_id  = "storage" then _cost_ = 5;
      _name_ = trim(_from_)||"_"||trim(_to_);
      keep _to_ _from_ _cost_ _name_ begin_id end_id;
run;

proc datasets nolist nodetails; append base=work.innerbase&j. data=work.merge&i. force; run;

%end;
%mend;
%inner_permutate;

proc datasets nolist nodetails; append base=work.outerbase data=work.innerbase&j. force; run;

%end;
%mend;
%outer_permutate ;

data work.arcs;
      set work.outerbase;
      if    _to_ = '' and _from_ = '' and _cost_ = . and _name_ = '' then delete;
run;

*create supply and demand arcs - use begin list of nodes as a complete list ;
proc sort data=work.arcs; by _from_; run;
data work.supply;
      set work.arcs;
      by _from_;
      if first._from_;
      _to_ = _from_;
      _from_ = "supply";
      _cost_ = 1000; *cost to release new resource unit;
      _name_ = trim(_from_)||"_"||trim(_to_);
```

```
      end_id = begin_id;
      begin_id = _from_;
run;
proc sort data=work.supply; by _to_; run;

proc sort data=work.arcs; by _from_; run;
data work.demand;
      set work.arcs;
      by _from_;
      if first._from_;
      _to_ = "demand";
      _cost_ = 0;
      _name_ = trim(_from_)||"_"||trim(_to_);

      end_id = _to_;
run;

data work.all_arcs;
      set work.supply_to_demand
            work.arcs
            work.supply
            work.demand
      ;
run;
data work.final_arcs;
      set work.all_arcs;
      where _to_ ne '';
      keep _from_ _to_ _cost_ _name_;
run;

* STEP 3:  Build a data set that contains the constraints coef row, RHS already created;
data work.coefs;
      set work.all_arcs;
      where end_id ne '';
            _col_ = _name_;
            _coef_ = 1;
            _row_ = "Con_"||_to_;
            _type_ = "EQ";
      keep _col_ _coef_ _row_ _type_;
run;
data work.rhs_list;
```

```
      set work.rhs;
      keep _row_;
run;
proc sort data = work.RHS_list; by _row_; run;
proc sort data = work.coefs; by _row_; run;
data work.coef1;
      merge work.coefs
            work.RHS_list (in=a)
      ; by _row_; if a;
run;

data work.constraints;  set work.coef1 work.RHS; run;

* STEP 4:  Build the supply and demand nodes;
data work.supply_and_demand;
      set work.supply_and_demand_template;
      if _node_ = "supply" then _sd_ = &avail.;
      if _node_ = "demand" then _sd_ = -&avail.;
run;

proc netflow
      sparsecondata
      nodedata = work.supply_and_demand /* the supply and demand data */
      arcdata = work.final_arcs /* the arc descriptions */
      condata = work.constraints /* the side constraints */
      conout = work.&NW._&R._soln; /* the solution data set */
run;

proc print data=work.&NW._&R._soln;
var _from_ _to_ _name_ _cost_ _supply_ _demand_ _flow_;
run;

proc sort data=work.&NW._&R._soln; by _name_; run ;
data r_soln.&NW.&S.&B._&T._&R.;
      set work.&NW._&R._soln;
      where _flow_ > 0 or _name_ ='supply_demand';
run;

%end;
%mend merge_soln;
%inc "&path.\RCP\macro_calls.txt";
```

APPENDIX E: SAS CODE TO COMPUTE RESOURCE METRIC 1 AND 2

```
*****************************************************************************************;
* R Metric 1&2.sas - only run for the repaired (MB) set                                  ;
* Resource usage metrics:                                                                ;
*     Input: &NW.&S.&B._&T._rout - from running       "repair a buffered scheudle.sas" for the MB       ;
*                                                     "PK generation.sas" for the PK                    ;
*                                                     "Create and solve buffered schedules" for the IB  ;
*     Output:                                                                            ;
*     Resource Metric 1: compare the utilization of resources at every time period from an IB to MB     ;
*     Resource Metric 2: compare the total number of resource time unit (man-hours) for the IB to MB    ;
*****************************************************************************************;

*****************************************************************************************;
*problem set-up;
*****************************************************************************************;

*Select the buffer lable and formula for this run here;
/*%let B = O;                                          *optimistic;*/
/*%let B = P;                                          *pessimistic;*/
/*%let B = B5;                                         *50% buffer;*/
/*%let B = BR1;  %let Bduration = "N/A";               *Resource Buffer 1;*/
/*%let B = BR2;  %let Bduration = "N/A";               *Resource Buffer 2;*/
/*%let B = BR3;  %let Bduration = "N/A";               *Resource Buffer 3;*/
/*%let B = BR4;  %let Bduration = "N/A";               *Resource Buffer 4;*/

* Select the stochasticity level for this run here - here these are the tasks that DO occur;
/*%let stoch = "Low"; %let S = L;                      *Low;*/
/*%let stoch = "Low","High"; %let S = H;               *High;*/

* Select the timing setting this run here - here these are the stoch tasks that DO occur;
/*%let timing = "Late"; %let T = L;                    *Late;*/
/*%let timing = "Early"; %let T = E;                   *Early;*/

%let path = C:\Sandra_laptop\IEMS\data\selim; *run for each prob type: pat, RCP files;
libname NW_soln "&path.\Non-optimal SAS Solutions";
libname prob "&path.\repaired";
libname Rmetrics "&path.\Resource metrics";

*****************************************************************************************;
*end problem set-up;
*****************************************************************************************;
```

```
proc datasets nolist nodetails library = work; delete M1base; run;
proc datasets nolist nodetails library = work; delete M2base; run;

%macro merge_soln(NW);

*****************************************************************************************************;
*initialize datasets;
*****************************************************************************************************;
*get number of resource types;
      data work.R; set NW_soln.&NW._resources_avail;  keep R:;run;
      data work._null_;
          %let dsid=%sysfunc(open(work.R));
          %let num_R=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activities types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of resource types are: &num_R.; *re-create this global macro var for use here;

*****************************************************************************************************;
*end initialize datasets;
*****************************************************************************************************;
*Resource Metric 1;
data work.MB;
      set prob.&NW.&S.&B._&T._rout;
      array Ruse{&num_R.} RR1-RR&num_R.;
      array MBRuse{&num_R.} MBR1-MBR&num_R.;
      do i=1 to &num_R.;
            MBRuse{i} = Ruse{i};
      end;
      keep _TIME_ MBR1-MBR&num_R.;
run;
data work.IB;
      set NW_Soln.&NW.&S.&B._rout;
      array Ruse{&num_R.} RR1-RR&num_R.;
      array IBRuse{&num_R.} IBR1-IBR&num_R.;
      do i=1 to &num_R.;
            IBRuse{i} = Ruse{i};
      end;
      keep _TIME_ IBR1-IBR&num_R.;
run;

proc sort data=work.MB; by _time_; run;
```

```
proc sort data=work.IB; by _time_; run;
data work.merge;
      merge work.MB
              work.IB
      ; by _time_;
run;

data work.metric1;
      set work.merge;
      array MBRuse{&num_R.} MBR1-MBR&num_R.;
      array IBRuse{&num_R.} IBR1-IBR&num_R.;
      array RDiff{&num_R.} RDiff1-RDiff&num_R.;
      array RPDiff{&num_R.} RpDiff1-RpDiff&num_R.;
      array RabsDiff{&num_R.} RabsDiff1 - RabsDiff&num_R.;
      do i=1 to &num_R.;
            if IBRuse{i} = . then IBRuse{i} = 0;
            if MBRuse{i} = . then MBRuse{i} = 0;
            RDiff{i} = MBRuse{i}-IBRuse{i}; *increase in resources this time pd from IB to MB is pos;
            if IBRuse{i} ne 0 then RpDiff{i} = RDiff{i}/IBRuse{i}; else RpDiff{i} = .;
            RabsDiff{i} = abs(RDiff{i});
      end;
run;

proc univariate data=work.metric1;
      var RabsDiff1-RabsDiff&num_R.;
      output out=work.avg mean=RabsDiff1-RabsDiff&num_R.;
run;

data work.output;
      set work.avg;
      format label stoch_lvl buffer timing $50.;
      label = "&NW.&S.&B._&T.";
      NW = "&NW.";
      stoch_lvl = "&S.";
      buffer = "&B.";
      timing = "&T.";
      Metric1 = sum(of RabsDiff1-RabsDiff&num_R.)/&num_R.;
run;

proc datasets nolist nodetails;
    append base=work.M1Base
```

```
      data=work.output force ;
run;

*Resource Metric 2;
proc univariate data=work.merge;
      var MBR1-MBR&num_R. IBR1-IBR&num_R.;
      output out=work.sum mean=MBR1-MBR&num_R. IBR1-IBR&num_R.;
run;
data work.metric2;
      set work.sum;
      array MBRuse{&num_R.} MBR1-MBR&num_R.;
      array IBRuse{&num_R.} IBR1-IBR&num_R.;
      array RDiff{&num_R.} RDiff1-RDiff&num_R.;
      array RPDiff{&num_R.} RpDiff1-RpDiff&num_R.;
      array RabsDiff{&num_R.} RabsDiff1 - RabsDiff&num_R.;
      do i=1 to &num_R.;
            if IBRuse{i} = . then IBRuse{i} = 0;
            if MBRuse{i} = . then MBRuse{i} = 0;
            RDiff{i} = MBRuse{i}-IBRuse{i}; *increase in resources this time pd from IB to MB is pos;
            if IBRuse{i} ne 0 then RpDiff{i} = RDiff{i}/IBRuse{i}; else RpDiff{i} = .;
            RabsDiff{i} = abs(RDiff{i});
      end;
run;
data work.metric2a;
      set work.metric2;
      format label stoch_lvl buffer timing $50.;
      label = "&NW.&S.&B._&T.";
      NW = "&NW.";
      stoch_lvl = "&S.";
      buffer = "&B.";
      timing = "&T.";
      Metric2 = sum(of RabsDiff1-RabsDiff&num_R.)/&num_R.;
run;

proc datasets nolist nodetails;
    append base=work.M2Base
      data=work.metric2a force ;
run;

%mend merge_soln;
```

APPENDIX F: SAS CODE TO COMPUTE RESOURCE METRIC 3, 4, 5

```
*****************************************************************************************;
* R Metric 3-5.sas                                                                      ;
* Resource flow metrics: compare the resource flow of IB to MB and PK                   ;
*     Input: R_solns.NW&NW._&R._soln_flow - from running    "Resource flow v5.sas"      ;
*     Output:                                                                           ;
*     Resource Metric 3: compare the total number of individual resource units needed for each schedule  ;
*     Resource Metric 4: compare the total number of resource hand-offs needed for each schedule         ;
*     Resource Metric 5: compare the number of time units a deployed resource is idle                    ;
*****************************************************************************************;

*****************************************************************************************;
*problem set-up;
*****************************************************************************************;
*Select the buffer lable and formula for this run here;
/*%let B = O;                                          *optimistic;*/
/*%let B = P;                                          *pessimistic;*/
/*%let B = B5;                                         *50% buffer;*/

* Select the stochasticity level for this run here - here these are the tasks that DO occur;
/*%let stoch = "Low"; %let S = L;                      *Low;*/
/*%let stoch = "Low","High"; %let S = H;               *High;*/

* Select the timing setting this run here - here these are the stoch tasks that DO occur;
/*%let timing = "Late"; %let T = L;                    *Late;*/
/*%let timing = "Early"; %let T = E;                   *Early;*/
/*%let timing = "Early", "Late"; %let T = IB;          *Initial Base;*/

%let path = C:\Sandra_laptop\IEMS\Dissertation\data\selim; *run for each prob type: pat, RCP files;
libname NW_soln "&path.\Non-optimal SAS Solutions";
libname prob "&path.\Non-optimal SAS solutions"; *change to Non-optimal SAS solutions(IB) or repaired (MB);
libname Rmetrics "&path.\Resource metrics";
libname R_Soln "&path.\R Solutions";
*****************************************************************************************;
*end problem set-up;
*****************************************************************************************;

proc datasets nolist nodetails library = work; delete base; run;
%macro merge_soln(NW);

*****************************************************************************************;
*initialize NW specific datasets;
```

```
*****************************************************************************************;
*get number of resource types;
      data work.R; set NW_soln.&NW._resources_avail;  keep R:;run; *changed source 17may;
      data work._null_;
          %let dsid=%sysfunc(open(work.R));
          %let num_R=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activity types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of resource types are: &num_R.; *create global macro var ;
*****************************************************************************************;
*end initialize NW specific datasets;
*****************************************************************************************;

%do nr = 1 %to &num_R.; *this one; *r flows are not relevant for R0, so start with 1;

%let R = r&nr.;
%put We are now working on &NW. resource: &r.;

      data work.R_avail;
      set NW_soln.&NW._resources_avail;
            CALL SYMPUT('avail',&r.);
      run;
      %put There are &avail. resources of type &r. available;

data work.flow;
      set r_soln.&NW.&S.&B._&T._&R.;
      format from_time from_task to_time to_task $30.;
      format temp1 temp2 z3.;
      *splitting the _from_ time and tasks;
      if find(_from_,'Time')= 1 and find(_from_,'Task') = 8 then do;
            from_time = substr(_from_,5,3);
            from_task = substr(_from_,12,3);
      end;
      if find(_from_,'Time')= 1 and find(_from_,'storage') = 8 then do;
            from_time = substr(_from_,5,3);
            from_task = 'storage';
      end;
      if find(_from_,'supply')= 1 then do;
            temp1 = put(substr(_to_,5,3),3.)-1;
            from_time = put(temp1,z3.);
            from_task = 'supply';
```

```
      end;

      *splitting the _to_ time and tasks;
      if find(_to_,'Time')= 1 and find(_to_,'Task') = 8 then do;
            to_time = substr(_to_,5,3);
            to_task = substr(_to_,12,3);
      end;
      if find(_to_,'Time')= 1 and find(_to_,'storage') = 8 then do;
            to_time = substr(_to_,5,3);
            to_task = 'storage';
      end;
      if find(_to_,'demand')= 1 then do;
            temp2 = put(substr(_from_,5,3),3.)+1;
            to_time = put(temp2,z3.);
            to_task = 'demand';
      end;
      drop temp1 temp2;

      *flag resource hand-offs;
      if to_task ne from_task then hand_off = _flow_;
run;

*Resource Metric 4: compare the total number of resource hand-offs needed for each schedule;
data work.hand_off;
      set work.flow;
      where hand_off not in (0,.);
      NW = "&NW.&R.";
run;
proc summary data=work.hand_off;
      var hand_off;
      id NW;
      output out=work.num_r_handoffs n=count_of_r_handoffs sum=volume_of_r_handoffs;
run;

*Resource Metric 3: compare the total number of individual resource units needed for each schedule;
data work.total_used;
      set work.flow;
      where _name_ = 'supply_demand';
      used = -sum(_flow_,-&avail.);
      NW = "&NW.&R.";
      keep _name_ used NW;
```

```
run;

*Resource Metric 5: compare the number of idle time units (ITU) for deployed resources in two schedules;
data work.storage;
      set work.flow;
      where to_task = 'storage';
      NW = "&NW.&R.";
run;
proc summary data=work.storage;
      var _flow_;
      id NW;
      output out=work.num_storage_units n=count_of_storage_units sum=volume_of_storage_units;
run;

data work.R_metrics_&NW.&R.;
      merge work.num_r_handoffs
              work.num_storage_units
              work.total_used
      ; by NW;
      format label stoch_lvl buffer timing $50.;
      label = "&NW.&S.&B._&T.";
      NW = "&NW.";
      stoch_lvl = "&S.";
      buffer = "&B.";
      timing = "&T.";
      resource = "&r.";
      drop _type_ _freq_ _name_;
run;

proc datasets nolist nodetails;
    append base=work.base
      data=work.R_metrics_&NW.&R. force ;
run;
%end;
%mend merge_soln;

%inc "&path.\RCP\macro_calls.txt";
```

Note, additional code was run to calculate the metrics

APPENDIX G: GANTT CHARTS

A series of Gantt charts was constructed to validate the right/left-shift repair heuristic implemented with SAS code. There are a total of 920 files, as indicated in the following two tables, and presented here as hyperlinks to PDF formatted files. The column and row headers indicate the type of network. Click on the "X" to launch the corresponding Gantt chart.

	Optimistic						Pessimistic						50% Buffer						Perfect Knowledge			
	High			Low			High			Low			High			Low			High		Low	
NW	IB	Early	Late	IB	Early	Late	IB	E	L	IB	E	L	IB	E	L	IB	E	L	E	L	E	L
NW1004	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1010	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1015	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1020	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1028	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1102	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1105	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1112	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1119	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1127	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1200	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1201	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1212	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1222	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1225	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1300	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1304	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1308	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1314	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1325	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total #	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

	Resource Buffer 1 (BR1)						Resource Buffer 2 (BR2)						Resource Buffer 3 (BR3)						Resource Buffer 4 (BR4)					
	High			Low			High			Low			High			Low			High			Low		
NW	IB	Early	Late	IB	E	L	IB	E	L	IB	E	L	IB	E	L	IB	E	L	IB	E	L	IB	E	L
NW1004	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1010	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1015	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1020	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1028	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1102	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1105	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1112	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1119	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1127	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1200	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1201	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1212	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1222	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1225	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1300	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1304	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1308	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1314	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
NW1325	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20

APPENDIX H: INITIAL STUDY RESULTS - EVALUATING USING RESOURCE INFORMATION TO SIZE BUFFERS

Selim/Grey Robustness Measures

The following 5 tables provide an initial summary of the performance of the resource buffers using the eight robustness metrics.

Each cell in the below table represents the average of 20 trials. For example, in the 10xx set, there are a total of 5 networks, with four separate eventuations of stochasticity: high/early, high/late, low/early, and low/late. The number in each cell represents the average of the specified robustness measure for each of the 20 trials using the 7 different methods to develop the initial baseline schedule: O = optimistic, P = Pessimistic, B5 = 50% buffer, BR1 – BR4 = Resource Buffer 1 – Resource Buffer 4. The highlighted cells indicate the initial baseline development method(s) that produced the minimum average for that metric (minimum of row). The detailed tables for each eventuation of stochasticity: high/early, high/late, low/early, and low/late immediately follows this overall table.

All Stochasticity with All Eventuation

		O	P	B5	BR1	BR2	BR3	BR4
Average of Metric1	10xx avg	0.024	0.060	0.023	0.027	0.039	0.054	0.041
	11xx avg	0.031	0.037	0.032	0.040	0.031	0.041	0.032
	12xx avg	-	0.022	0.012	0.001	0.012	0.011	0.006
	13xx avg	0.028	0.006	0.017	0.015	0.012	0.010	0.008
Average of Metric2	10xx avg	0.686	0.208	0.124	0.493	0.121	0.093	0.360
	11xx avg	1.130	0.291	0.038	0.164	0.173	0.194	0.138
	12xx avg	0.666	0.241	0.126	0.514	0.126	0.332	0.378
	13xx avg	0.788	0.284	0.036	0.180	0.184	0.198	0.130
Average of Metric3	10xx avg	0.105	0.250	0.191	0.158	0.266	0.278	0.192
	11xx avg	0.752	0.578	0.716	0.702	0.702	0.666	0.661
	12xx avg	-	0.197	0.178	0.031	0.178	0.120	0.119
	13xx avg	0.383	0.244	0.419	0.380	0.363	0.336	0.313
Average of Metric4	10xx avg	0.028	0.217	0.181	0.103	0.188	0.177	0.141
	11xx avg	0.164	0.378	0.408	0.391	0.386	0.400	0.416
	12xx avg	-	0.085	0.063	0.016	0.063	0.031	0.036
	13xx avg	0.096	0.149	0.244	0.206	0.199	0.195	0.194
Average of Metric5	10xx avg	0.053	0.128	0.089	0.125	0.160	0.163	0.147
	11xx avg	0.383	0.167	0.195	0.199	0.206	0.191	0.214
	12xx avg	-	0.078	0.058	0.016	0.058	0.041	0.038
	13xx avg	0.131	0.103	0.213	0.175	0.167	0.163	0.158
Average of Metric6	10xx avg	0.028	0.036	0.017	0.009	0.022	0.028	0.028
	11xx avg	0.142	0.131	0.199	0.191	0.174	0.169	0.138
	12xx avg	-	-	-	-	-	-	-
	13xx avg	0.011	0.008	0.019	0.008	0.006	0.006	0.011
Average of Metric7	10xx avg	0.650	0.246	0.114	0.535	0.141	0.112	0.379
	11xx avg	1.093	0.314	0.053	0.179	0.182	0.215	0.147
	12xx avg	0.666	0.257	0.113	0.513	0.113	0.319	0.371
	13xx avg	0.786	0.283	0.047	0.175	0.183	0.198	0.131
Average of Metric8	10xx avg	0.784	2.364	1.672	1.713	1.756	2.092	1.864
	11xx avg	1.020	1.379	1.162	1.271	1.249	1.390	1.401
	12xx avg	-	2.355	1.867	0.521	1.867	1.748	1.307
	13xx avg	1.576	1.616	1.670	1.503	1.552	1.664	1.831
Total Average of Metric1		0.021	0.031	0.021	0.021	0.023	0.029	0.022
Total Average of Metric2		0.818	0.256	0.081	0.337	0.151	0.204	0.251
Total Average of Metric3		0.310	0.317	0.376	0.318	0.377	0.350	0.321
Total Average of Metric4		0.072	0.207	0.224	0.179	0.209	0.201	0.197
Total Average of Metric5		0.142	0.119	0.139	0.129	0.148	0.139	0.139
Total Average of Metric6		0.045	0.044	0.059	0.052	0.050	0.051	0.044
Total Average of Metric7		0.799	0.275	0.081	0.350	0.155	0.211	0.257
Total Average of Metric8		0.845	1.928	1.593	1.252	1.606	1.723	1.601

Each of the follow four tables that follow represents the average of 5 networks, with a separate table for each of the four eventuations of stochasticity: high/early, high/late, low/early, and low/late.

High Stochasticity with Early Eventuation

		O	P	B5	BR1	BR2	BR3	BR4
Average of Metric1	10xx avg	-	0.023	0.007	0.013	0.006	0.053	0.013
	11xx avg	0.061	0.038	0.059	0.067	0.054	0.040	0.049
	12xx avg	-	0.039	0.016	0.003	0.016	0.012	0.003
	13xx avg	0.018	-	0.008	0.015	0.015	0.009	-
Average of Metric2	10xx avg	1.121	0.326	0.164	0.825	0.164	0.170	0.556
	11xx avg	1.795	0.370	0.042	0.209	0.225	0.258	0.197
	12xx avg	1.065	0.289	0.188	0.799	0.188	0.495	0.583
	13xx avg	1.130	0.333	0.066	0.187	0.201	0.222	0.146
Average of Metric3	10xx avg	-	0.144	0.119	0.063	0.119	0.194	0.081
	11xx avg	0.906	0.500	0.769	0.763	0.763	0.663	0.662
	12xx avg	-	0.225	0.181	0.100	0.181	0.156	0.113
	13xx avg	0.475	0.238	0.400	0.438	0.438	0.344	0.188
Average of Metric4	10xx avg	-	0.238	0.250	0.094	0.219	0.169	0.113
	11xx avg	0.231	0.450	0.400	0.344	0.356	0.425	0.431
	12xx avg	-	0.088	0.056	0.044	0.056	0.050	0.031
	13xx avg	0.106	0.188	0.231	0.219	0.219	0.219	0.194
Average of Metric5	10xx avg	-	0.094	0.094	0.075	0.131	0.181	0.094
	11xx avg	0.382	0.144	0.125	0.138	0.144	0.119	0.162
	12xx avg	-	0.094	0.069	0.038	0.069	0.056	0.050
	13xx avg	0.125	0.113	0.188	0.169	0.169	0.150	0.107
Average of Metric6	10xx avg	-	0.031	0.012	0.019	0.019	0.025	0.019
	11xx avg	0.207	0.213	0.300	0.363	0.319	0.294	0.225
	12xx avg	-	-	-	-	-	-	-
	13xx avg	0.012	0.006	0.019	0.006	0.006	0.006	-
Average of Metric7	10xx avg	1.121	0.340	0.156	0.848	0.171	0.201	0.577
	11xx avg	1.691	0.392	0.087	0.217	0.223	0.255	0.191
	12xx avg	1.065	0.314	0.170	0.794	0.170	0.479	0.578
	13xx avg	1.174	0.333	0.071	0.174	0.188	0.214	0.146
Average of Metric8	10xx avg	-	3.907	4.039	1.876	3.101	2.660	1.876
	11xx avg	0.873	1.644	1.022	1.099	1.065	1.387	1.271
	12xx avg	-	3.555	2.663	1.063	2.663	1.725	1.063
	13xx avg	1.743	1.889	1.942	1.178	1.196	1.436	1.407
Total Average of Metric1		0.020	0.025	0.022	0.025	0.023	0.028	0.016
Total Average of Metric2		1.278	0.330	0.115	0.505	0.194	0.286	0.370
Total Average of Metric3		0.345	0.277	0.367	0.341	0.375	0.339	0.261
Total Average of Metric4		0.084	0.241	0.235	0.175	0.213	0.216	0.192
Total Average of Metric5		0.127	0.111	0.119	0.105	0.128	0.127	0.103
Total Average of Metric6		0.055	0.063	0.083	0.097	0.086	0.081	0.061
Total Average of Metric7		1.263	0.345	0.121	0.508	0.188	0.287	0.373
Total Average of Metric8		0.654	2.749	2.416	1.304	2.006	1.802	1.404

High Stochasticity with Late Eventuation

		O	P	B5	BR1	BR2	BR3	BR4
Average of Metric1	10xx avg	0.063	0.137	0.069	0.046	0.102	0.118	0.101
	11xx avg	0.020	0.049	0.032	0.051	0.032	0.048	0.030
	12xx avg	-	0.004	0.004	-	0.004	-	-
	13xx avg	0.047	-	0.024	0.014	-	-	0.008
Average of Metric2	10xx avg	1.176	0.274	0.154	0.757	0.154	0.072	0.573
	11xx avg	1.750	0.353	0.066	0.168	0.190	0.210	0.159
	12xx avg	0.982	0.344	0.126	0.725	0.126	0.420	0.508
	13xx avg	1.138	0.355	0.043	0.214	0.216	0.240	0.166
Average of Metric3	10xx avg	0.231	0.400	0.313	0.250	0.469	0.450	0.288
	11xx avg	0.694	0.706	0.794	0.781	0.781	0.800	0.794
	12xx avg	-	0.225	0.181	-	0.181	0.013	0.025
	13xx avg	0.319	0.113	0.406	0.281	0.213	0.219	0.313
Average of Metric4	10xx avg	0.063	0.238	0.156	0.069	0.181	0.188	0.150
	11xx avg	0.150	0.244	0.375	0.450	0.419	0.375	0.356
	12xx avg	-	0.169	0.131	-	0.131	0.038	0.069
	13xx avg	0.094	0.163	0.288	0.194	0.163	0.169	0.213
Average of Metric5	10xx avg	0.131	0.175	0.106	0.162	0.206	0.194	0.194
	11xx avg	0.375	0.219	0.269	0.269	0.294	0.263	0.313
	12xx avg	-	0.094	0.069	-	0.069	0.013	0.025
	13xx avg	0.175	0.100	0.238	0.194	0.163	0.175	0.182
Average of Metric6	10xx avg	0.044	0.050	0.006	0.006	0.006	0.006	0.037
	11xx avg	0.169	0.100	0.163	0.131	0.106	0.150	0.125
	12xx avg	-	-	-	-	-	-	-
	13xx avg	-	-	0.019	0.019	0.013	0.013	0.006
Average of Metric7	10xx avg	1.060	0.348	0.139	0.829	0.183	0.073	0.562
	11xx avg	1.694	0.384	0.067	0.208	0.215	0.246	0.183
	12xx avg	0.982	0.346	0.122	0.725	0.122	0.420	0.508
	13xx avg	1.110	0.355	0.048	0.202	0.216	0.240	0.173
Average of Metric8	10xx avg	1.230	0.931	1.206	1.861	1.251	1.820	2.262
	11xx avg	1.063	0.597	1.026	1.121	1.069	1.051	1.315
	12xx avg	-	0.913	0.536	-	0.536	0.938	0.938
	13xx avg	1.562	1.143	1.568	1.404	1.582	1.636	1.945
Total Average of Metric1		0.033	0.047	0.032	0.028	0.034	0.041	0.035
Total Average of Metric2		1.262	0.331	0.097	0.466	0.171	0.236	0.351
Total Average of Metric3		0.311	0.361	0.424	0.328	0.411	0.370	0.355
Total Average of Metric4		0.077	0.203	0.238	0.178	0.224	0.192	0.197
Total Average of Metric5		0.170	0.147	0.171	0.156	0.183	0.161	0.178
Total Average of Metric6		0.053	0.038	0.047	0.039	0.031	0.042	0.042
Total Average of Metric7		1.211	0.358	0.094	0.491	0.184	0.245	0.356
Total Average of Metric8		0.964	0.896	1.084	1.096	1.109	1.361	1.615

Low Stochasticity with Early Eventuation

		O	P	B5	BR1	BR2	BR3	BR4
Average of Metric1	10xx avg	-	0.012	-	-	-	-	-
	11xx avg	0.035	0.006	0.004	0.007	0.007	0.012	0.007
	12xx avg	-	0.021	0.021	-	0.021	0.010	0.010
	13xx avg	0.021	0.018	0.011	0.025	0.025	0.025	0.018
Average of Metric2	10xx avg	0.194	0.150	0.064	0.184	0.064	0.059	0.144
	11xx avg	0.498	0.224	0.023	0.138	0.138	0.157	0.101
	12xx avg	0.335	0.151	0.122	0.291	0.122	0.224	0.236
	13xx avg	0.448	0.210	0.014	0.144	0.145	0.150	0.087
Average of Metric3	10xx avg	0.019	0.125	0.075	0.069	0.082	0.088	0.075
	11xx avg	0.794	0.450	0.594	0.563	0.563	0.469	0.550
	12xx avg	-	0.113	0.106	0.019	0.106	0.106	0.106
	13xx avg	0.425	0.300	0.381	0.406	0.406	0.400	0.325
Average of Metric4	10xx avg	0.013	0.175	0.194	0.175	0.200	0.200	0.175
	11xx avg	0.144	0.462	0.394	0.369	0.369	0.419	0.431
	12xx avg	-	0.031	0.025	-	0.025	0.025	0.025
	13xx avg	0.113	0.169	0.244	0.256	0.256	0.244	0.200
Average of Metric5	10xx avg	0.013	0.094	0.063	0.094	0.107	0.094	0.100
	11xx avg	0.381	0.175	0.188	0.175	0.175	0.188	0.169
	12xx avg	-	0.063	0.050	0.019	0.050	0.050	0.050
	13xx avg	0.106	0.113	0.200	0.169	0.169	0.163	0.156
Average of Metric6	10xx avg	-	0.006	0.006	0.006	0.006	0.019	0.006
	11xx avg	0.125	0.125	0.156	0.163	0.163	0.113	0.113
	12xx avg	-	-	-	-	-	-	-
	13xx avg	0.013	0.019	0.025	0.006	0.006	0.006	0.025
Average of Metric7	10xx avg	0.194	0.158	0.064	0.184	0.064	0.059	0.144
	11xx avg	0.521	0.228	0.024	0.131	0.131	0.167	0.094
	12xx avg	0.335	0.168	0.100	0.291	0.100	0.212	0.224
	13xx avg	0.460	0.207	0.025	0.145	0.147	0.152	0.086
Average of Metric8	10xx avg	0.632	2.953	0.571	1.591	1.591	1.543	1.591
	11xx avg	0.952	1.765	1.414	1.563	1.563	1.883	1.656
	12xx avg	-	2.936	2.929	1.020	2.929	2.929	2.929
	13xx avg	1.183	2.164	1.702	2.052	2.052	2.052	2.141
Total Average of Metric1		0.014	0.014	0.009	0.008	0.013	0.012	0.009
Total Average of Metric2		0.369	0.184	0.056	0.189	0.117	0.148	0.142
Total Average of Metric3		0.309	0.247	0.289	0.264	0.289	0.266	0.264
Total Average of Metric4		0.067	0.209	0.214	0.200	0.213	0.222	0.208
Total Average of Metric5		0.125	0.111	0.125	0.114	0.125	0.124	0.119
Total Average of Metric6		0.034	0.038	0.047	0.044	0.044	0.034	0.036
Total Average of Metric7		0.378	0.190	0.053	0.188	0.111	0.147	0.137
Total Average of Metric8		0.692	2.455	1.654	1.556	2.034	2.102	2.079

Low Stochasticity with Late Eventuation

		O	P	B5	BR1	BR2	BR3	BR4
Average of Metric1	10xx avg	0.033	0.067	0.017	0.050	0.046	0.046	0.050
	11xx avg	0.009	0.056	0.034	0.032	0.032	0.063	0.042
	12xx avg	-	0.024	0.009	-	0.009	0.024	0.009
	13xx avg	0.025	0.007	0.027	0.007	0.007	0.007	0.007
Average of Metric2	10xx avg	0.255	0.084	0.115	0.204	0.102	0.072	0.167
	11xx avg	0.478	0.217	0.021	0.139	0.139	0.150	0.094
	12xx avg	0.282	0.178	0.067	0.240	0.067	0.189	0.186
	13xx avg	0.436	0.238	0.020	0.174	0.175	0.181	0.119
Average of Metric3	10xx avg	0.169	0.331	0.256	0.250	0.394	0.381	0.325
	11xx avg	0.613	0.656	0.706	0.700	0.700	0.731	0.638
	12xx avg	-	0.225	0.244	0.006	0.244	0.206	0.231
	13xx avg	0.313	0.325	0.488	0.394	0.394	0.381	0.425
Average of Metric4	10xx avg	0.038	0.219	0.125	0.075	0.150	0.150	0.125
	11xx avg	0.131	0.356	0.463	0.400	0.400	0.381	0.444
	12xx avg	-	0.050	0.038	0.019	0.038	0.013	0.019
	13xx avg	0.069	0.075	0.213	0.156	0.156	0.150	0.169
Average of Metric5	10xx avg	0.069	0.150	0.094	0.169	0.194	0.181	0.200
	11xx avg	0.394	0.131	0.200	0.213	0.213	0.194	0.213
	12xx avg	-	0.063	0.044	0.006	0.044	0.044	0.025
	13xx avg	0.119	0.088	0.225	0.169	0.169	0.163	0.188
Average of Metric6	10xx avg	0.069	0.056	0.044	0.006	0.056	0.063	0.050
	11xx avg	0.069	0.088	0.175	0.106	0.106	0.119	0.088
	12xx avg	-	-	-	-	-	-	-
	13xx avg	0.019	0.006	0.012	-	-	-	0.012
Average of Metric7	10xx avg	0.227	0.137	0.096	0.278	0.146	0.115	0.234
	11xx avg	0.466	0.253	0.035	0.159	0.159	0.193	0.122
	12xx avg	0.282	0.198	0.058	0.240	0.058	0.163	0.175
	13xx avg	0.402	0.238	0.042	0.179	0.181	0.186	0.119
Average of Metric8	10xx avg	1.275	1.663	0.874	1.524	1.080	2.345	1.726
	11xx avg	1.191	1.509	1.185	1.300	1.300	1.241	1.360
	12xx avg	-	2.015	1.341	-	1.341	1.399	0.297
	13xx avg	1.816	1.269	1.468	1.379	1.379	1.531	1.832
Total Average of Metric1		0.017	0.039	0.022	0.022	0.024	0.035	0.027
Total Average of Metric2		0.363	0.179	0.056	0.189	0.121	0.148	0.141
Total Average of Metric3		0.273	0.385	0.424	0.338	0.433	0.425	0.405
Total Average of Metric4		0.060	0.175	0.210	0.163	0.186	0.174	0.189
Total Average of Metric5		0.145	0.108	0.141	0.139	0.155	0.145	0.156
Total Average of Metric6		0.039	0.038	0.058	0.028	0.041	0.045	0.038
Total Average of Metric7		0.344	0.207	0.058	0.214	0.136	0.165	0.163
Total Average of Metric8		1.071	1.614	1.217	1.051	1.275	1.629	1.304

Resource Metrics

The following tables, scatter plots, and histograms provide an initial summary of the performance of the resource buffers using the seven resource metrics.

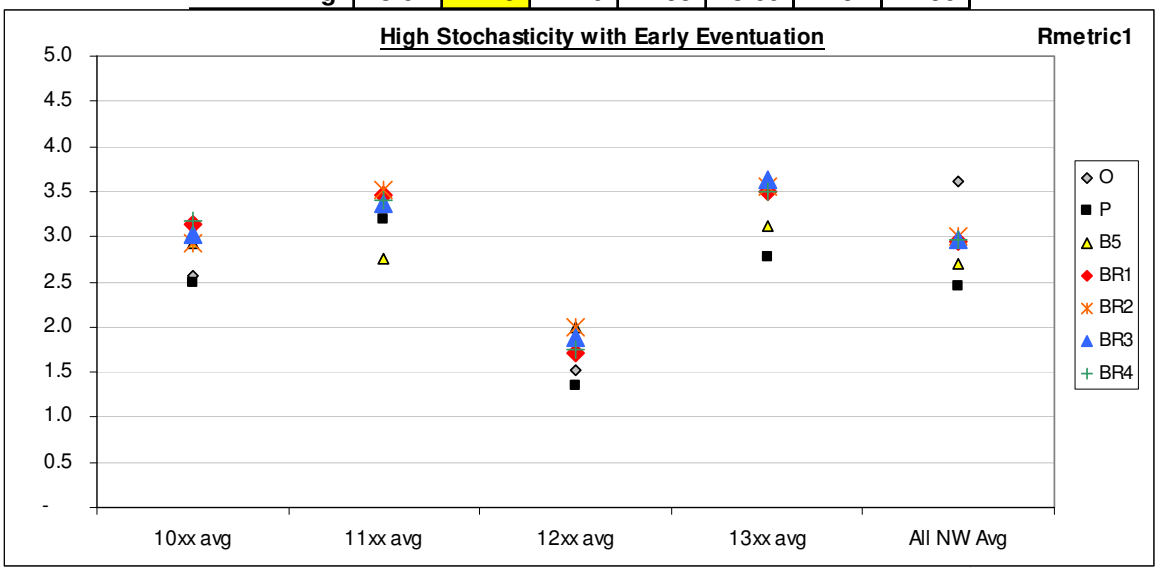
Each cell and data point on the following set of four tables and scatter plots represent the average of five trials for the four eventuations of stochasticity: high/early, high/late, low/early, and low/late. Immediately following the four tables and scatter plots are histograms plotting out the same data. The histograms provide a more detailed look at the distribution of the resource metrics. Each set of tables, scatter plots, and histograms is then repeated for each resource metric. Each of the cells in the following tables represents the average of 5 values for the specified metric for all networks within the network set. For example, there are 5 networks in the 10xx set. For each the 7 resource metric (resource metrics 1, 2, 3, 4a, 4b, 5a, and 5b) there are four tables: one for each of the 4 eventuations of stochasticity: high/early, high/late, low/early, and low/late. The formatting highlights the lowest value of each row, that is the initial baseline development method that provided the lowest average value of that metric for the network set. The scatter plot below is only provided as a visualization of the data contained in the table that is immediately above it.

Finally, a set of histograms are provided immediately following the tables and scatterplots for this resource metric analysis. The histograms demonstrate the spread of the data values for each of the network trials, providing more detailed information on the averages plotted in the scatterplots and allowing for a visualization of the spread of data values.

Rmetric1

High Stochasticity with Early Eventuation

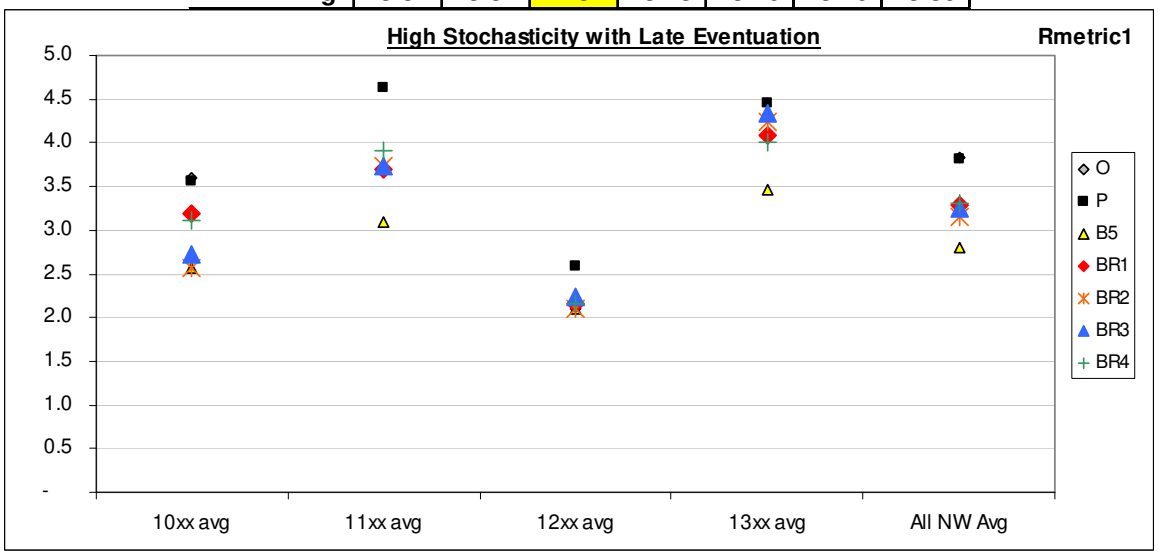
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.57	2.49	2.93	3.13	2.93	3.01	3.18
11xx avg	5.24	3.19	2.76	3.46	3.52	3.36	3.41
12xx avg	1.51	1.35	1.99	1.72	1.99	1.88	1.76
13xx avg	5.10	2.77	3.12	3.49	3.55	3.63	3.50
All NW Avg	**3.61**	**2.45**	**2.70**	**2.95**	**3.00**	**2.97**	**2.96**



Rmetric1

High Stochasticity with Late Eventuation

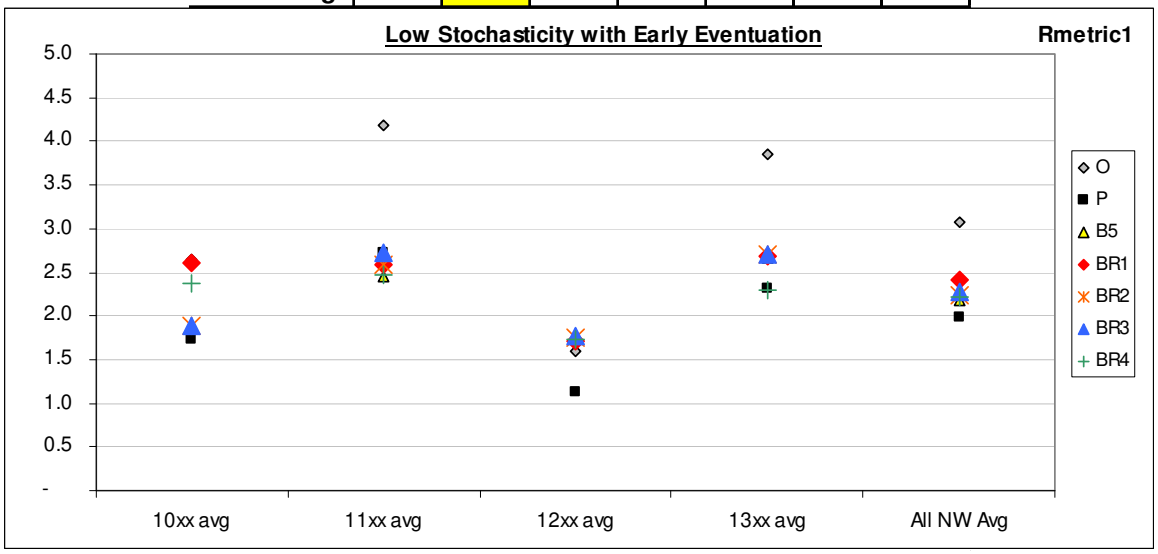
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	3.60	3.56	2.56	3.19	2.56	2.73	3.12
11xx avg	5.34	4.63	3.10	3.70	3.74	3.73	3.91
12xx avg	2.10	2.60	2.10	2.16	2.10	2.23	2.16
13xx avg	4.32	4.46	3.47	4.09	4.24	4.34	4.00
All NW Avg	**3.84**	**3.81**	**2.81**	**3.28**	**3.16**	**3.26**	**3.30**



Rmetric1

Low Stochasticity with Early Eventuation

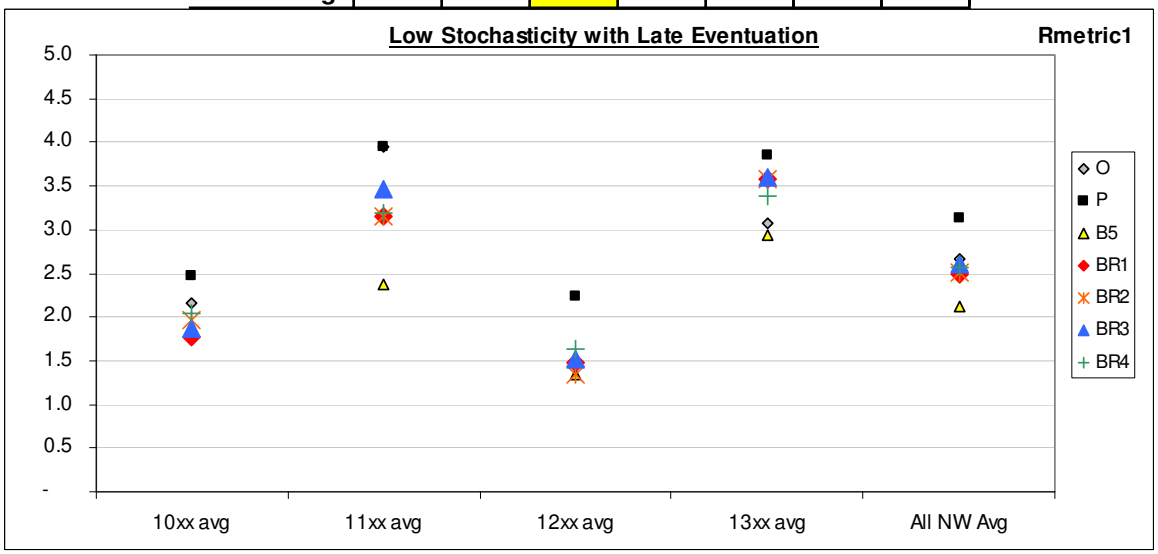
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.64	1.73	1.88	2.61	1.88	1.89	2.38
11xx avg	4.19	2.73	2.45	2.59	2.59	2.73	2.47
12xx avg	1.59	1.14	1.75	1.72	1.75	1.77	1.73
13xx avg	3.85	2.32	2.67	2.69	2.70	2.71	2.29
All NW Avg	**3.07**	**1.98**	**2.19**	**2.40**	**2.23**	**2.28**	**2.22**

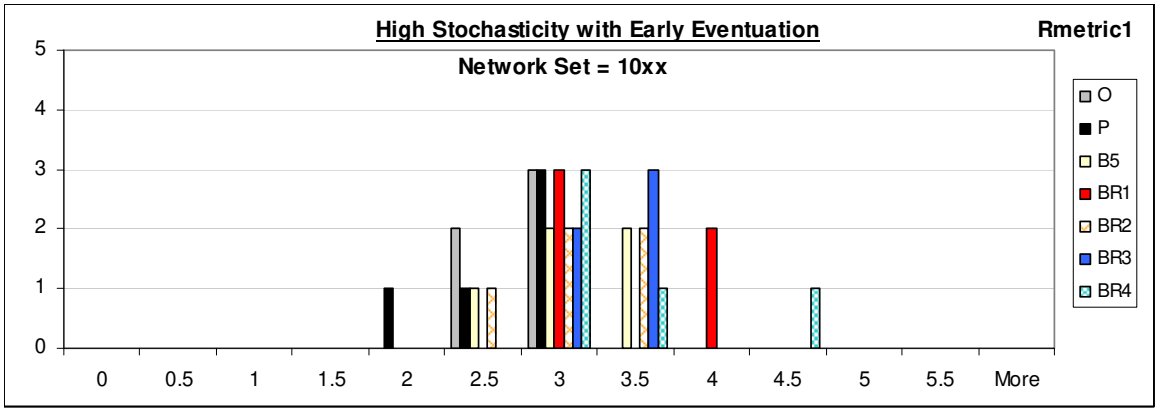


Rmetric1

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.15	2.47	1.84	1.77	1.96	1.87	2.04
11xx avg	3.95	3.95	2.37	3.14	3.14	3.47	3.20
12xx avg	1.45	2.24	1.34	1.48	1.34	1.53	1.63
13xx avg	3.08	3.85	2.93	3.57	3.57	3.59	3.38
All NW Avg	**2.66**	**3.13**	**2.12**	**2.49**	**2.50**	**2.61**	**2.56**




High Stochasticity with Early Eventuation
Rmetric1
Network Set = 10xx
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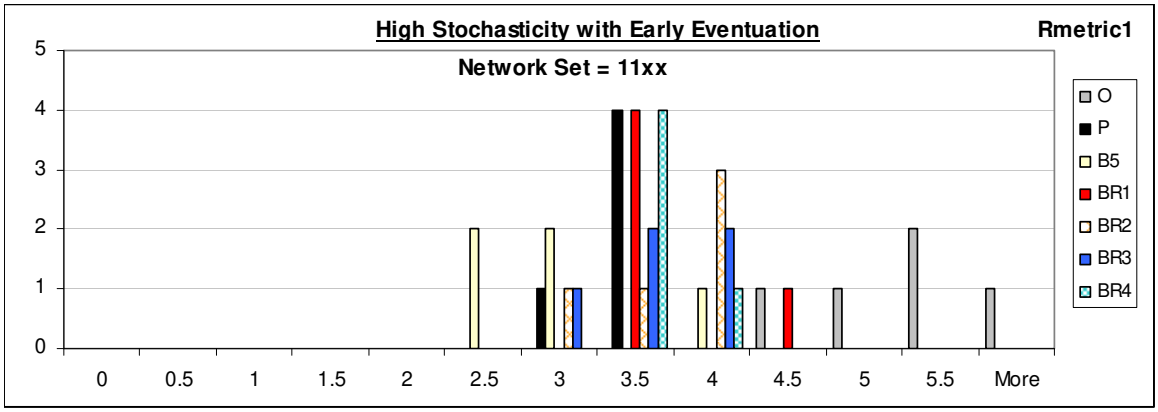
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Network Set = 11xx
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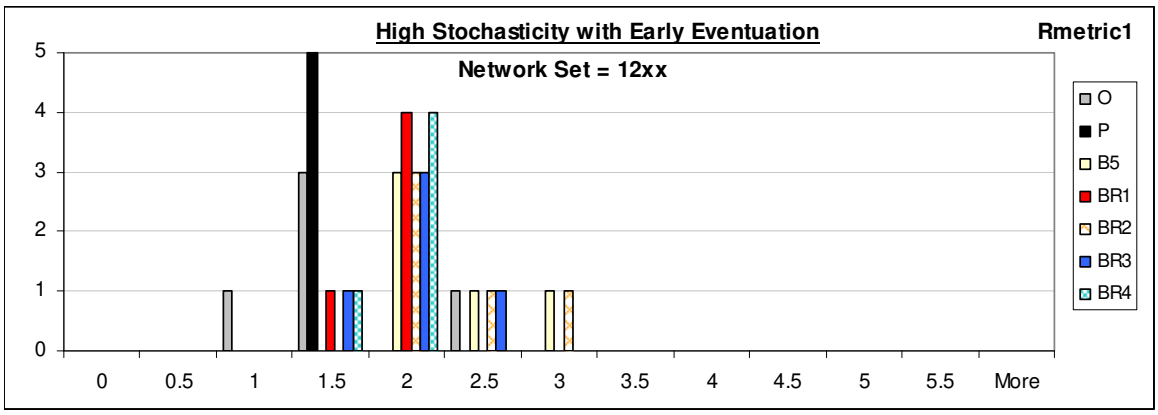
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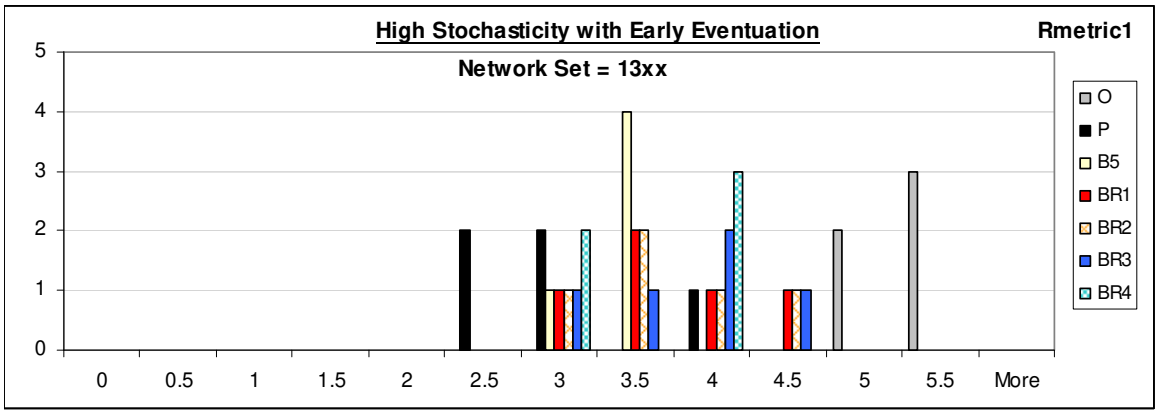
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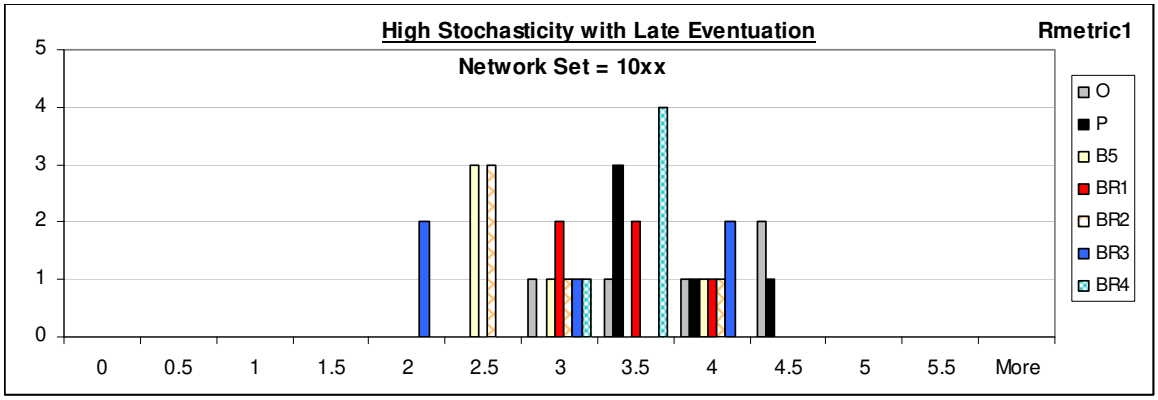
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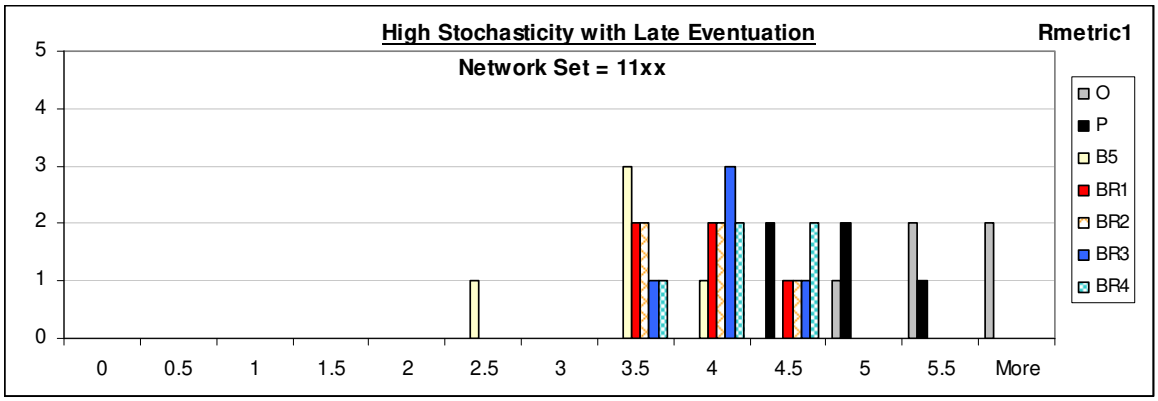
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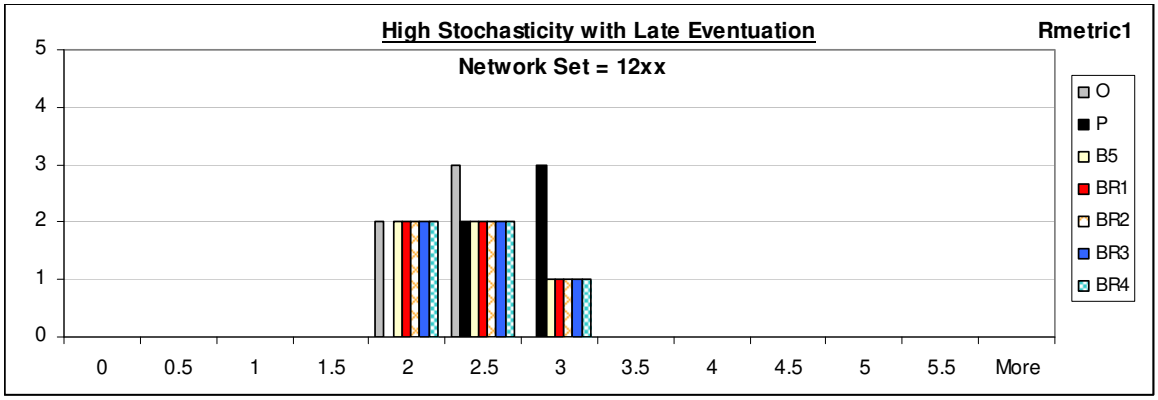
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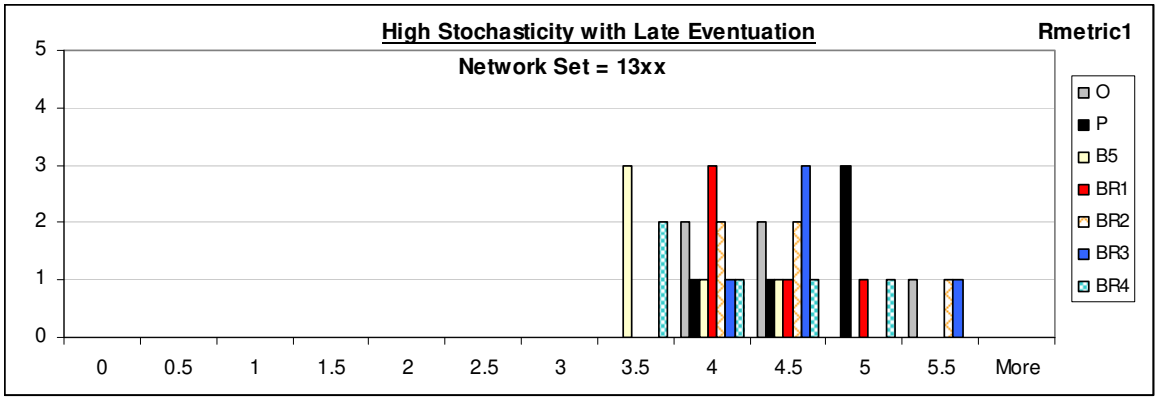
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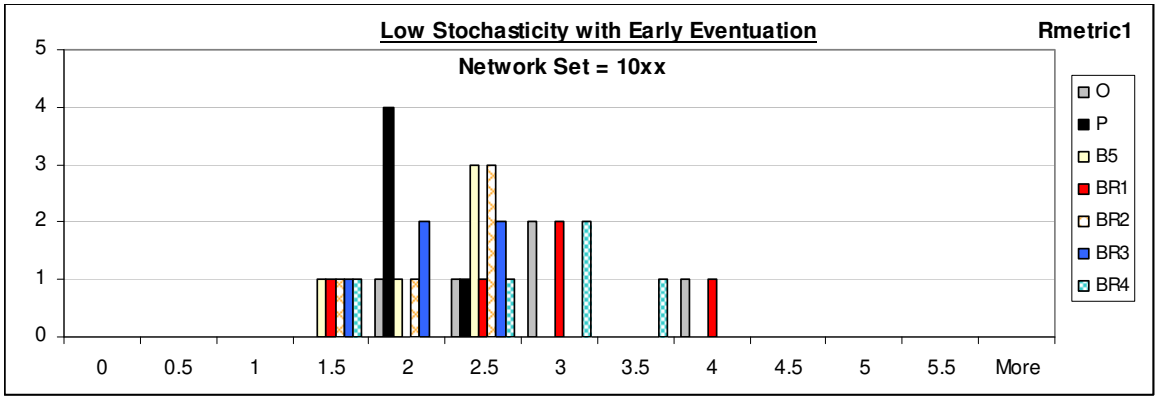
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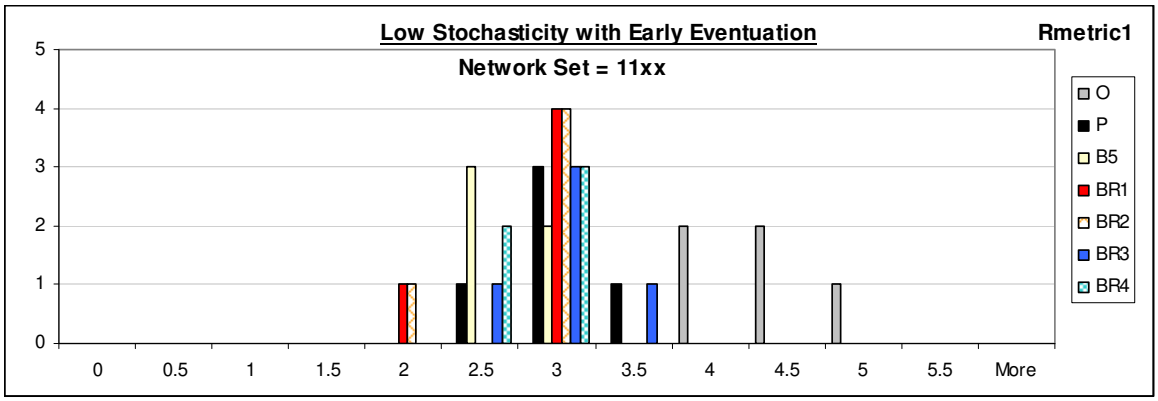
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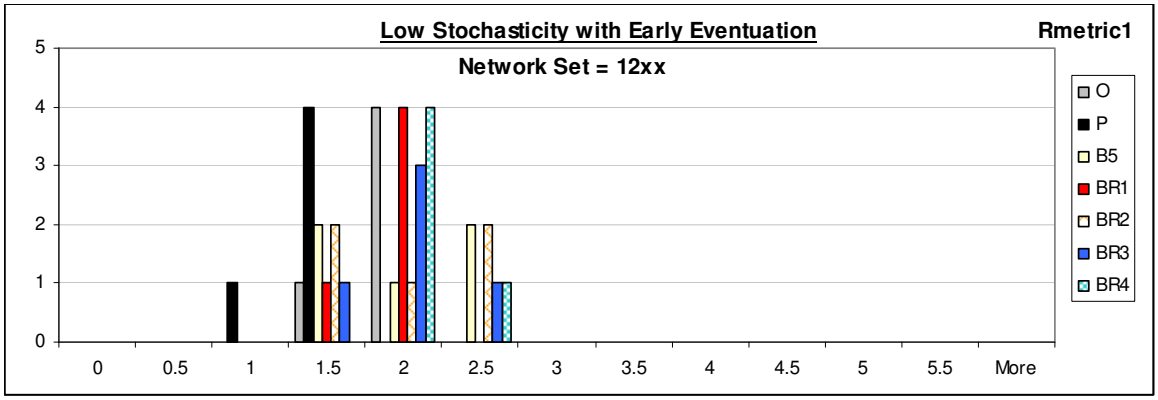
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Network Set = 12xx
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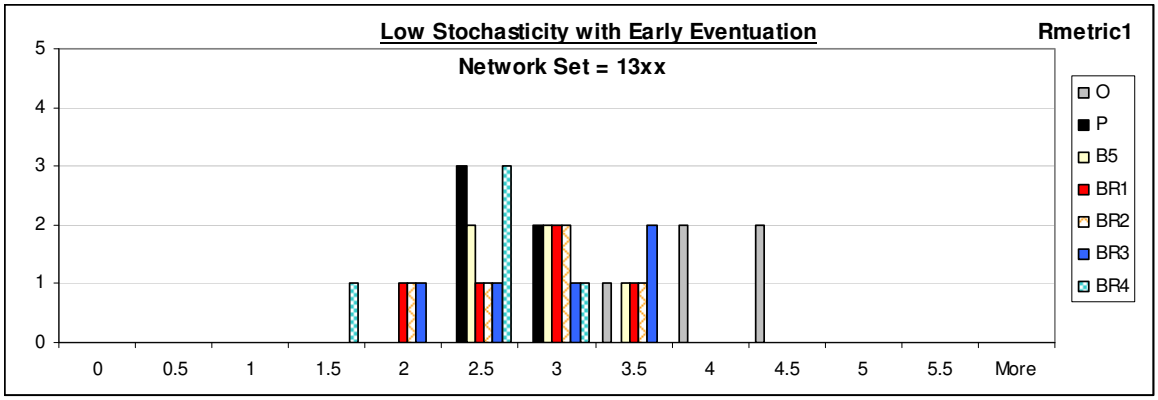
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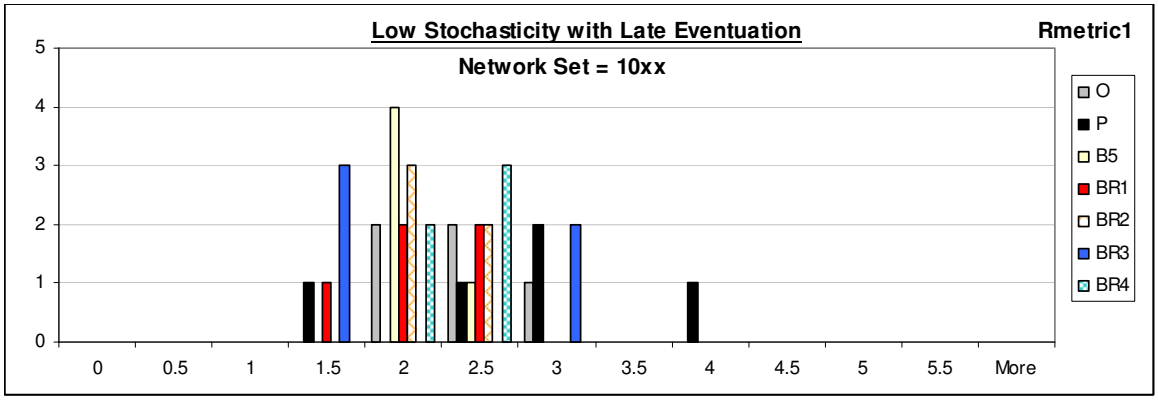
Low Stochasticity with Late Eventuation
Rmetric1
Network Set = 10xx
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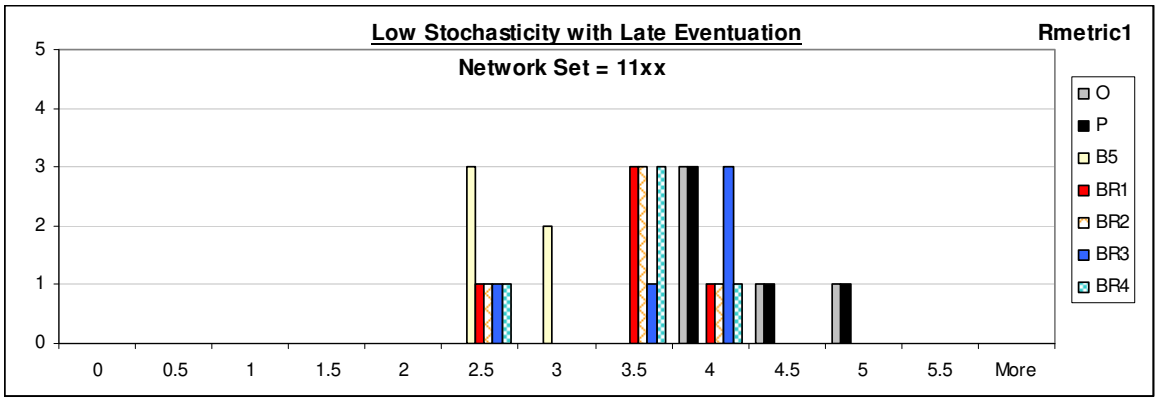
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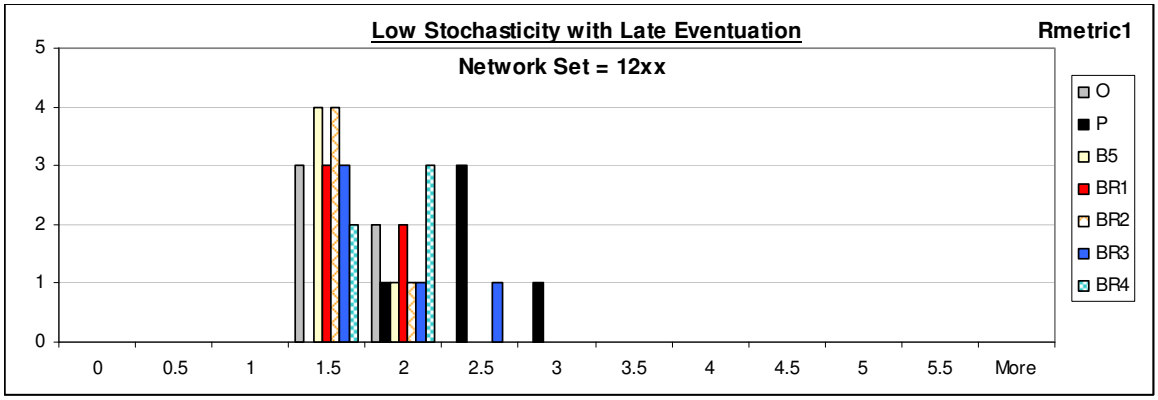
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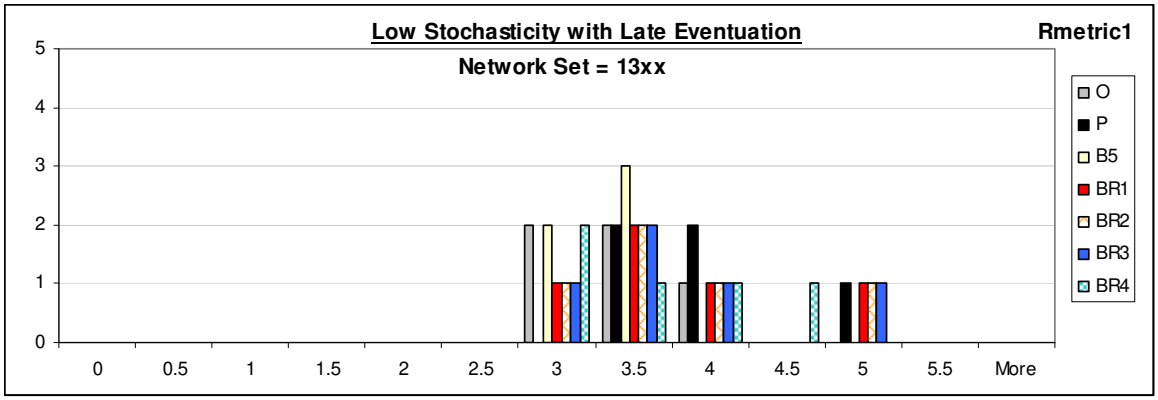
Low Stochasticity with Late Eventuation
Rmetric1
Network Set = 13xx
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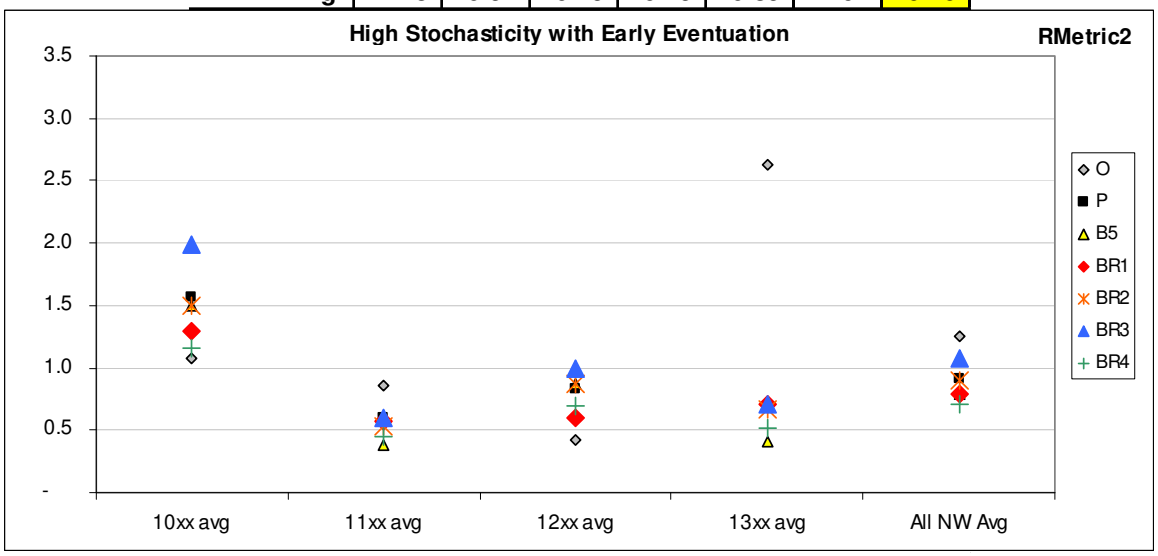
RMetric2

High Stochasticity with Early Eventuation

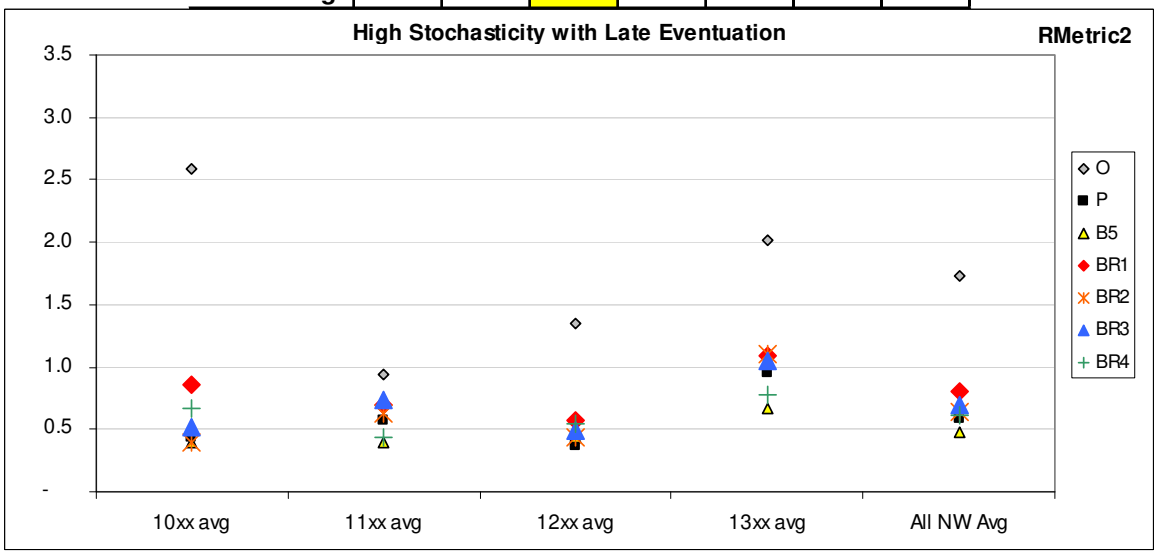
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	1.07	1.56	1.50	1.29	1.50	1.98	1.16
11xx avg	0.86	0.60	0.39	0.57	0.53	0.60	0.45
12xx avg	0.42	0.83	0.88	0.60	0.88	1.00	0.69
13xx avg	2.63	0.68	0.40	0.71	0.67	0.70	0.51
All NW Avg	**1.25**	**0.92**	**0.79**	**0.79**	**0.89**	**1.07**	**0.70**



RMetric2

High Stochasticity with Late Eventuation

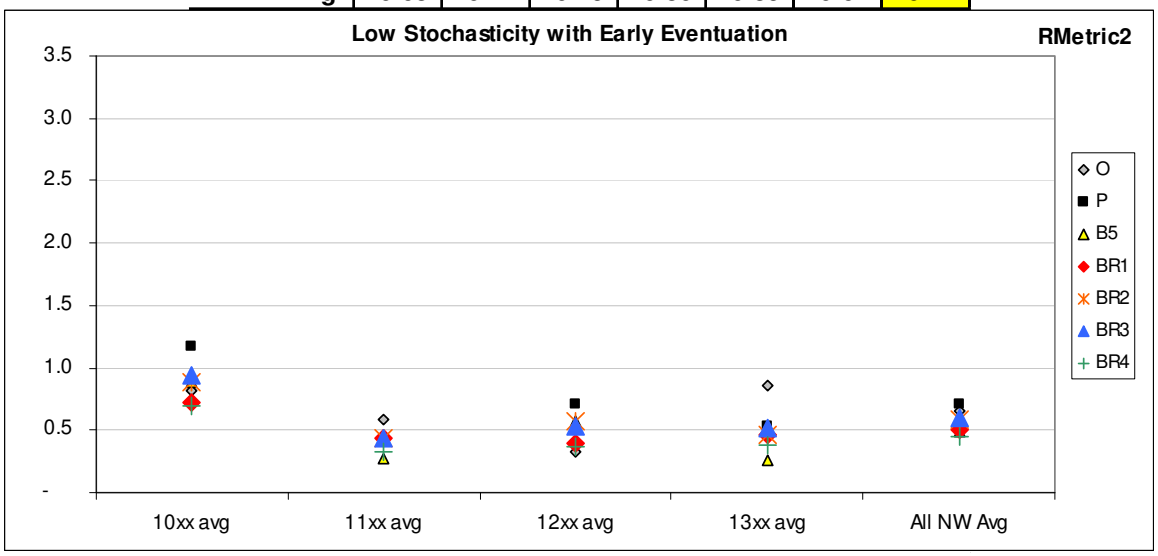
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.59	0.44	0.39	0.85	0.39	0.52	0.67
11xx avg	0.94	0.57	0.39	0.69	0.63	0.73	0.44
12xx avg	1.35	0.37	0.44	0.57	0.44	0.49	0.55
13xx avg	2.02	0.95	0.67	1.09	1.10	1.04	0.78
All NW Avg	**1.73**	**0.58**	**0.47**	**0.80**	**0.64**	**0.69**	**0.61**



RMetric2

Low Stochasticity with Early Eventuation

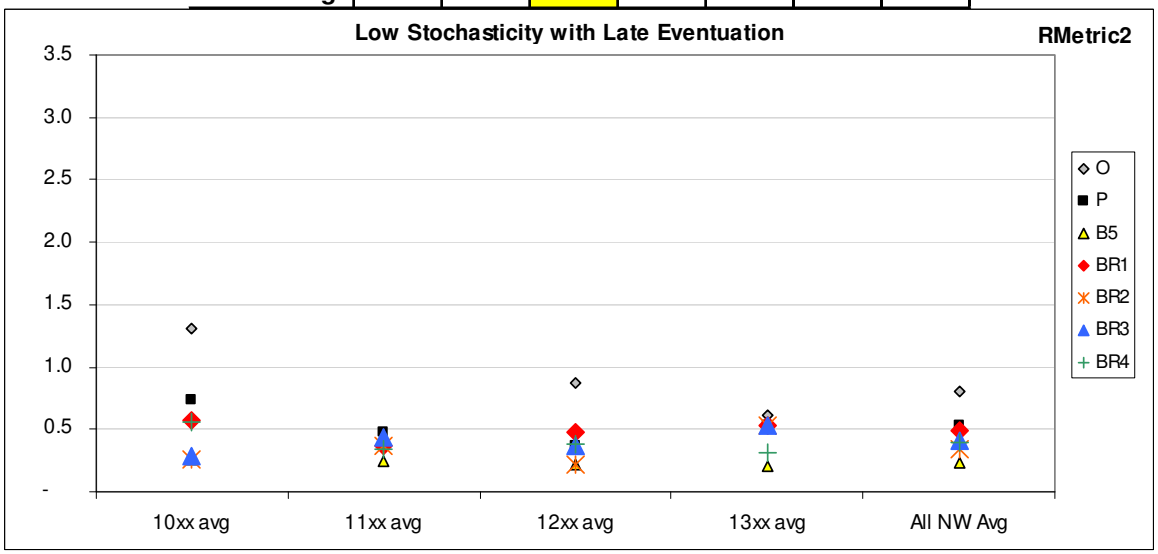
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	0.82	1.18	0.88	0.72	0.88	0.94	0.70
11xx avg	0.59	0.41	0.27	0.43	0.43	0.43	0.33
12xx avg	0.33	0.71	0.58	0.39	0.58	0.54	0.36
13xx avg	0.86	0.53	0.25	0.46	0.46	0.52	0.38
All NW Avg	**0.65**	**0.71**	**0.49**	**0.50**	**0.59**	**0.61**	**0.44**

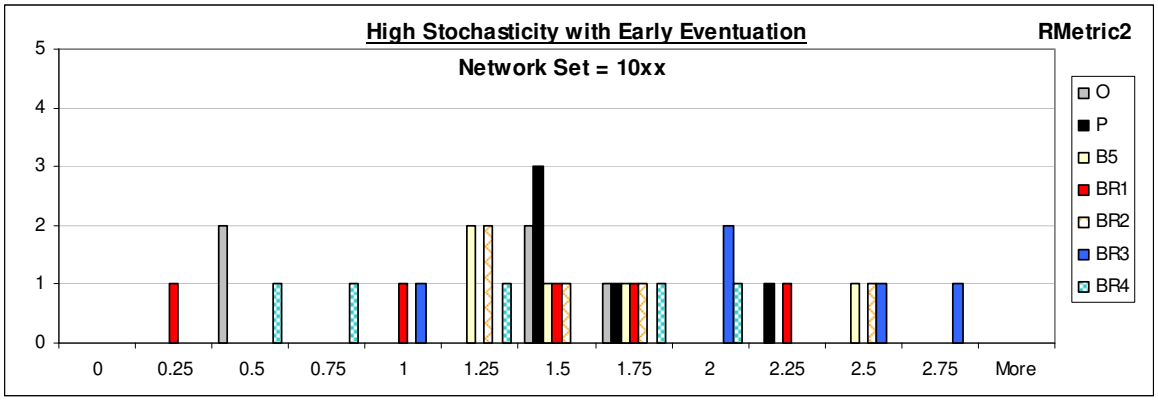


RMetric2

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	1.31	0.73	0.25	0.58	0.26	0.28	0.55
11xx avg	0.41	0.48	0.25	0.37	0.37	0.44	0.34
12xx avg	0.88	0.37	0.22	0.47	0.22	0.37	0.38
13xx avg	0.61	0.53	0.21	0.53	0.53	0.53	0.31
All NW Avg	**0.80**	**0.53**	**0.23**	**0.49**	**0.34**	**0.41**	**0.40**




High Stochasticity with Early Eventuation
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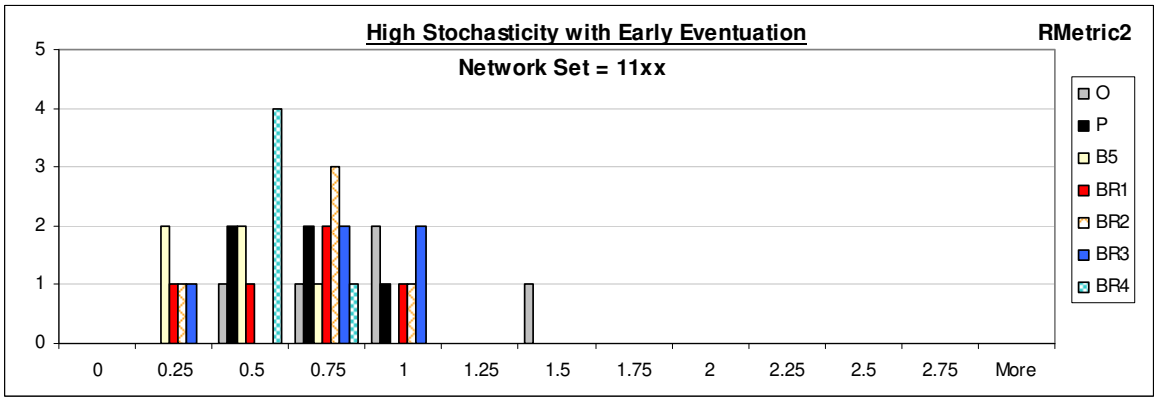
High Stochasticity with Early Eventuation
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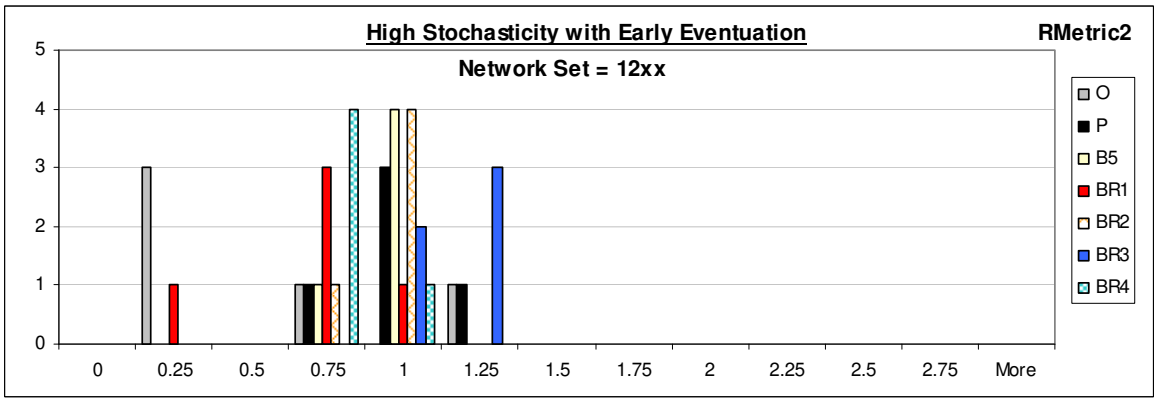
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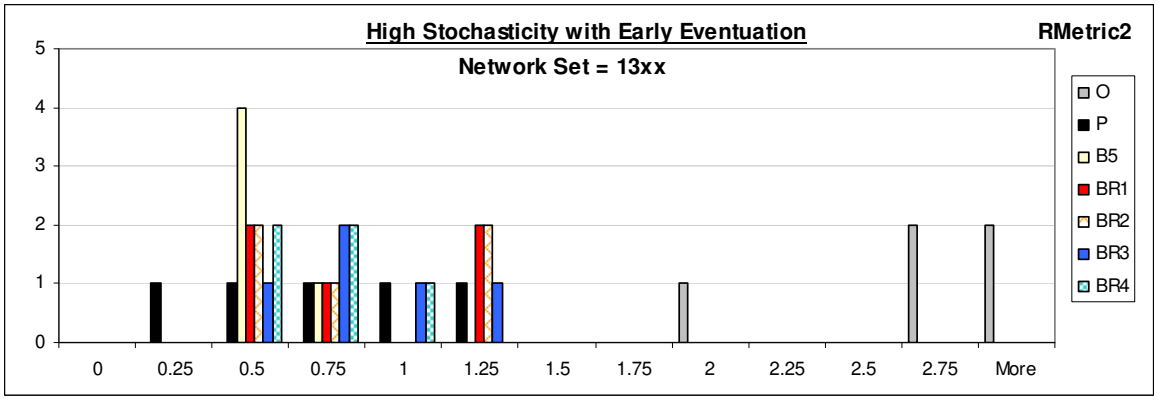
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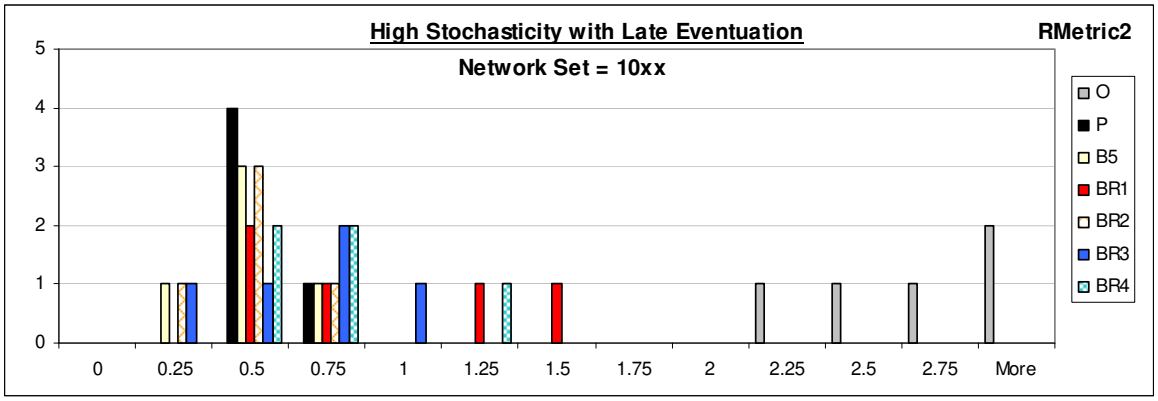
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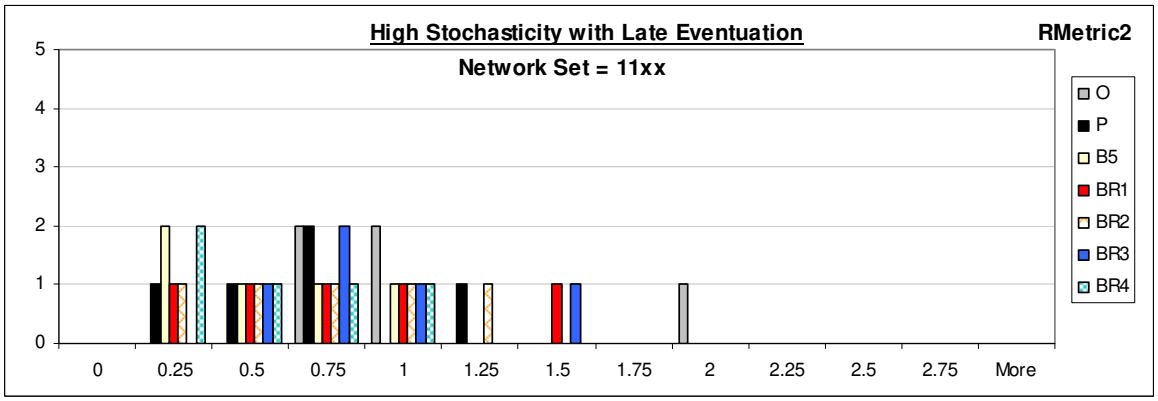
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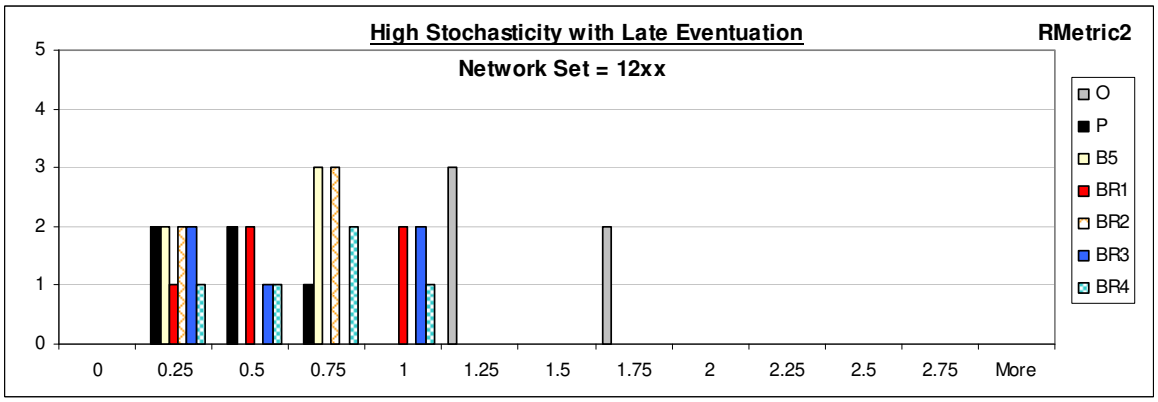
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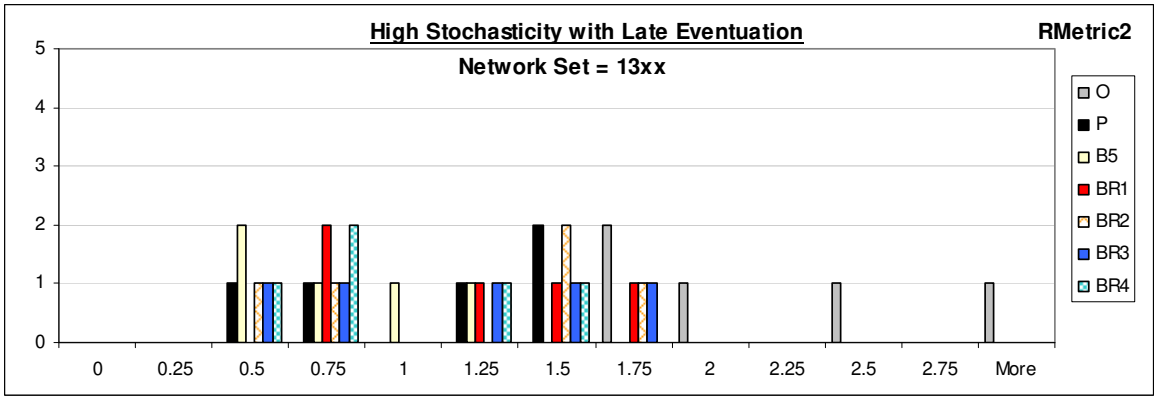
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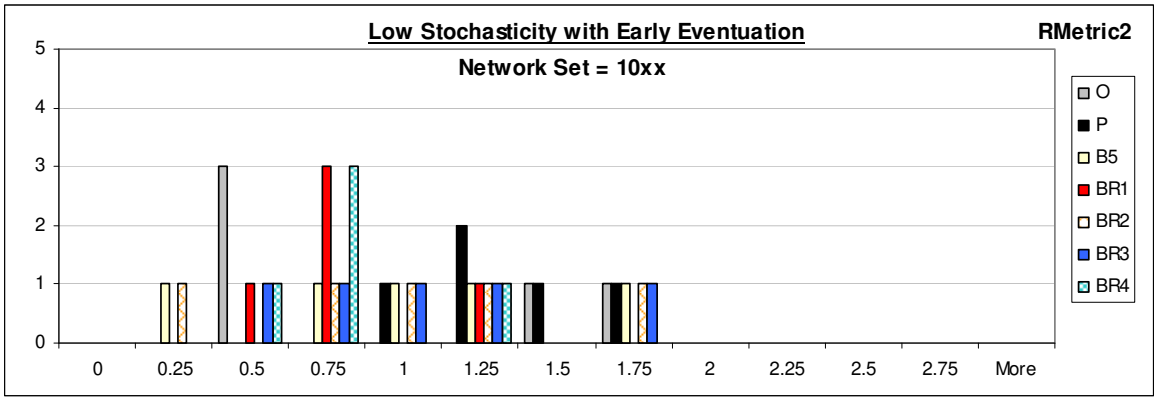
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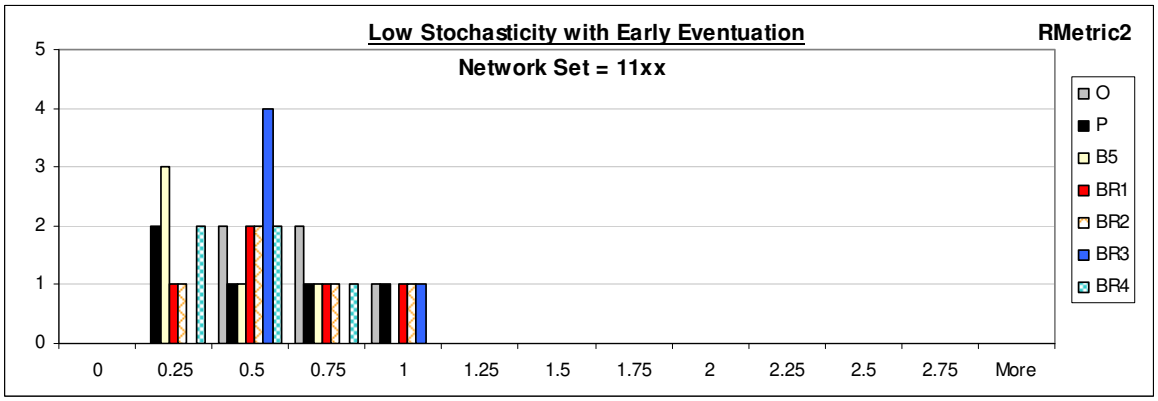
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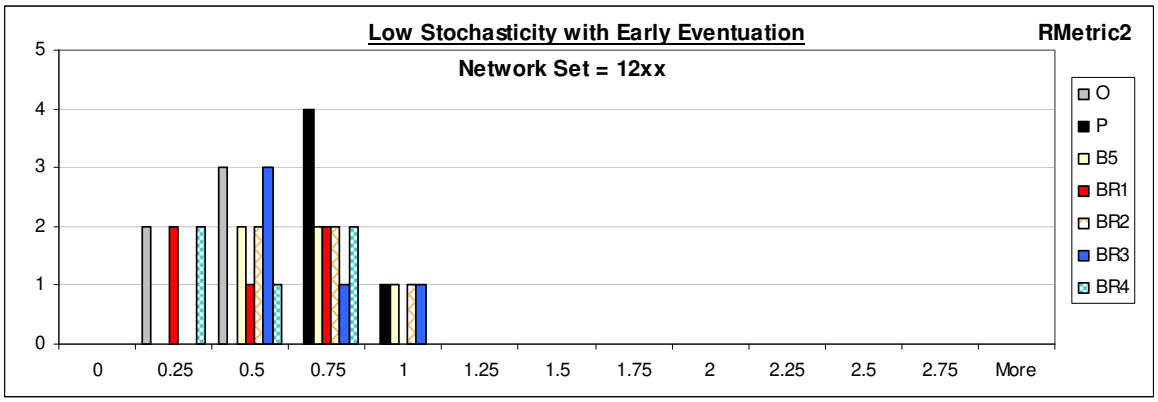
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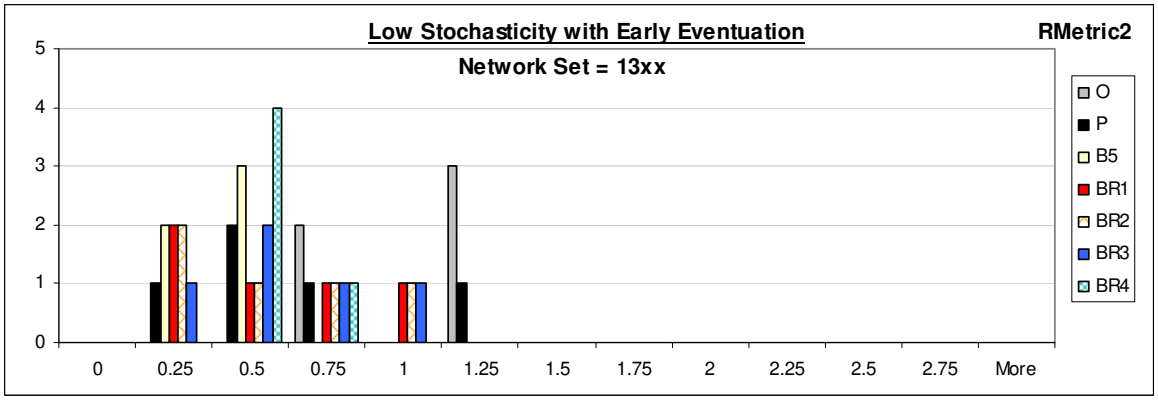
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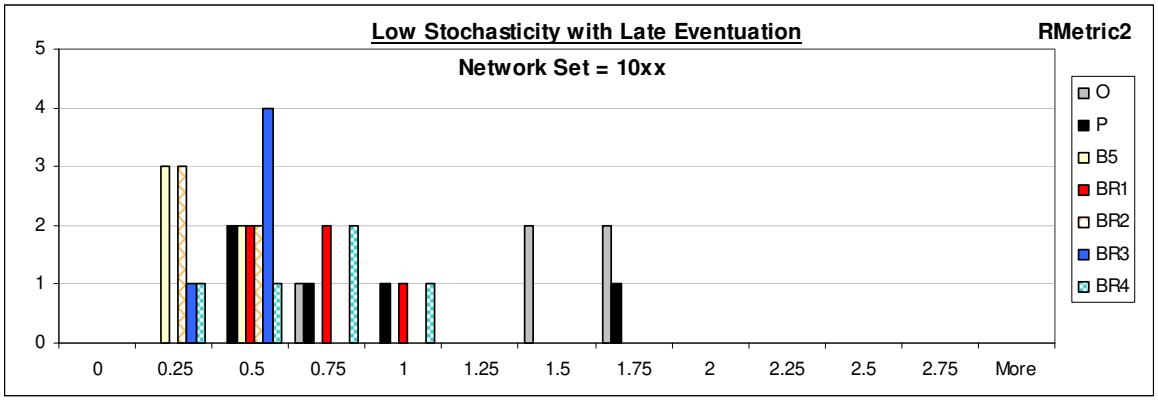
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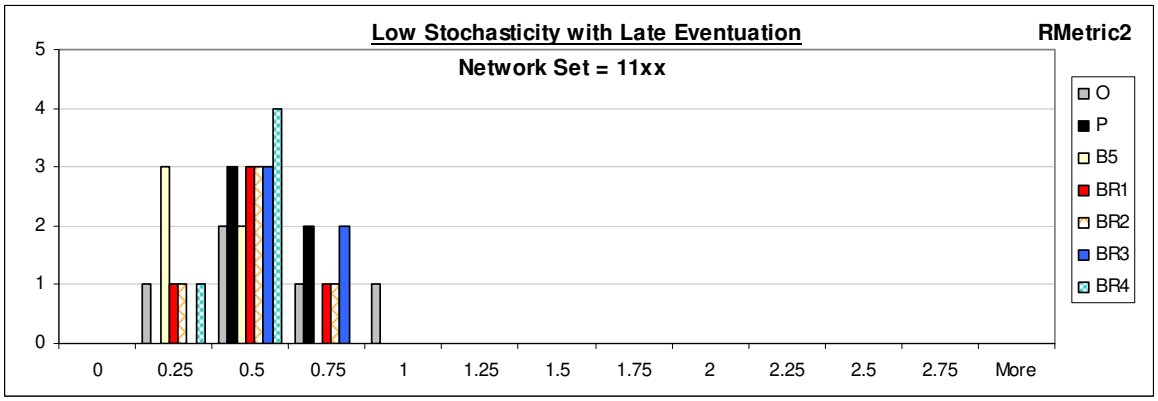
Low Stochasticity with Late Eventuation
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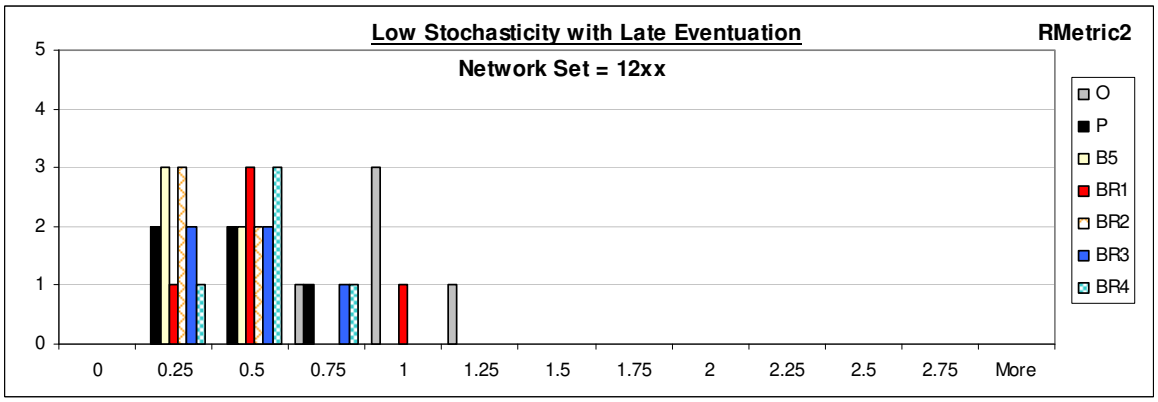
Low Stochasticity with Late Eventuation
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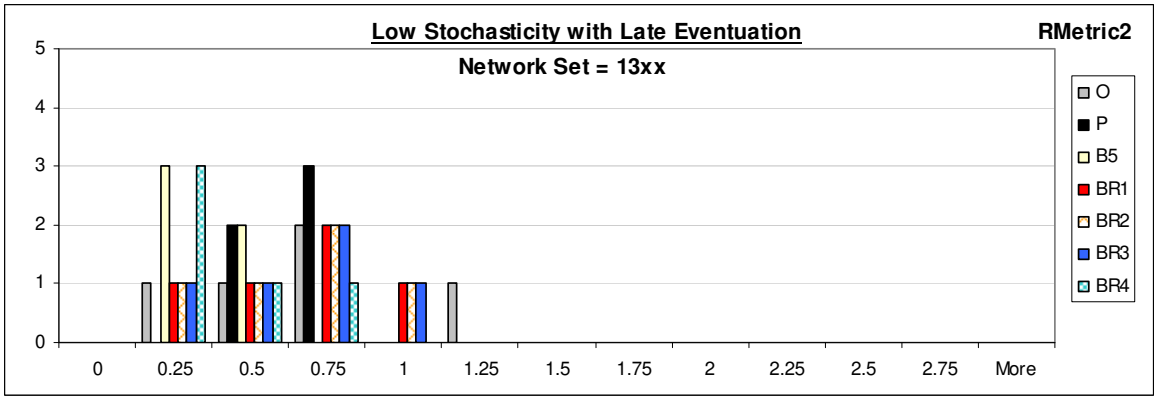
Low Stochasticity with Late Eventuation
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Network Set = 13xx
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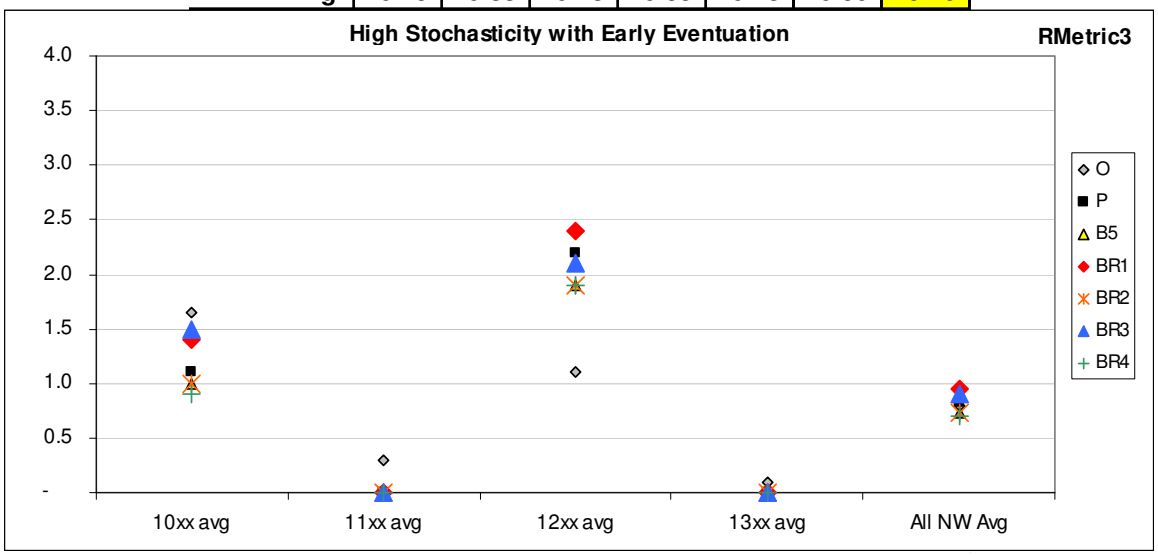
More

RMetric3

High Stochasticity with Early Eventuation

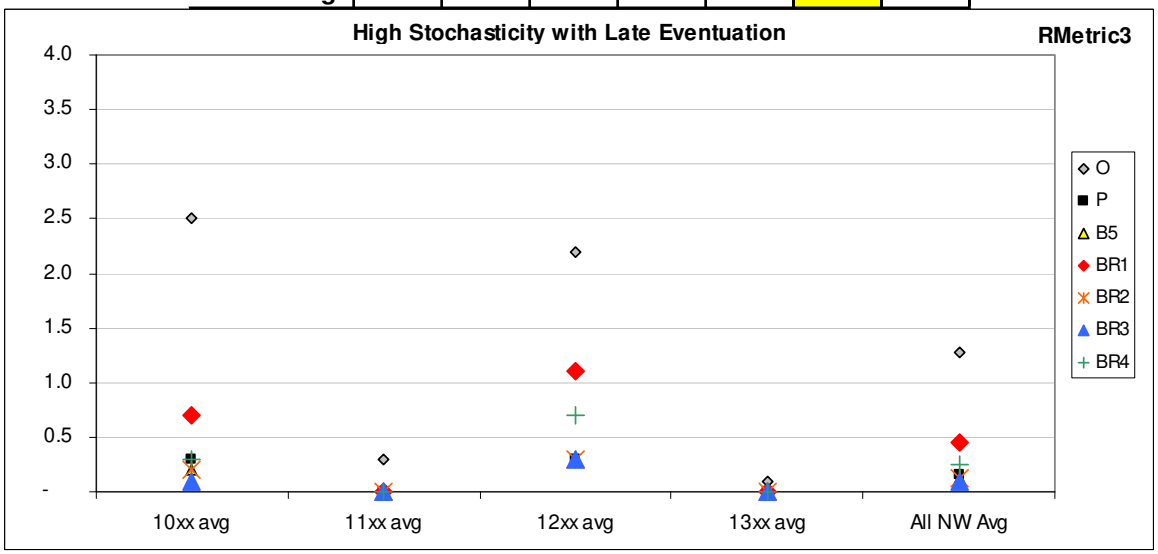
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	1.65	1.10	1.00	1.40	1.00	1.50	0.90
11xx avg	0.30	-	-	-	-	-	-
12xx avg	1.10	2.20	1.90	2.40	1.90	2.10	1.90
13xx avg	0.10	-	-	-	-	-	-
All NW Avg	**0.79**	**0.83**	**0.73**	**0.95**	**0.73**	**0.90**	**0.70**



RMetric3

High Stochasticity with Late Eventuation

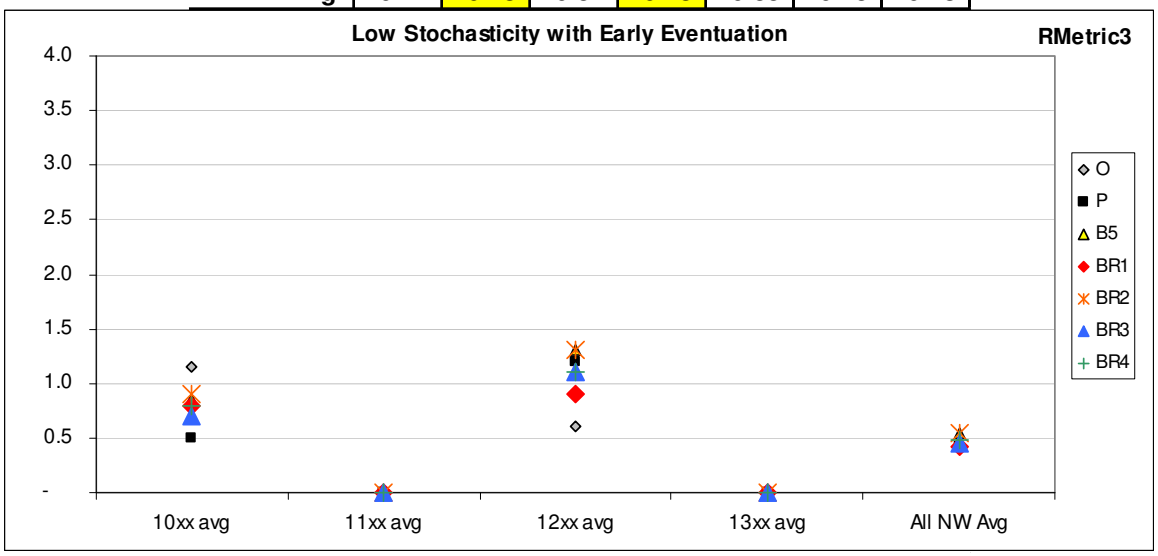
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.50	0.30	0.20	0.70	0.20	0.10	0.30
11xx avg	0.30	-	-	-	-	-	-
12xx avg	2.20	0.30	0.30	1.10	0.30	0.30	0.70
13xx avg	0.10	-	-	-	-	-	-
All NW Avg	**1.28**	**0.15**	**0.13**	**0.45**	**0.13**	**0.10**	**0.25**



RMetric3

Low Stochasticity with Early Eventuation

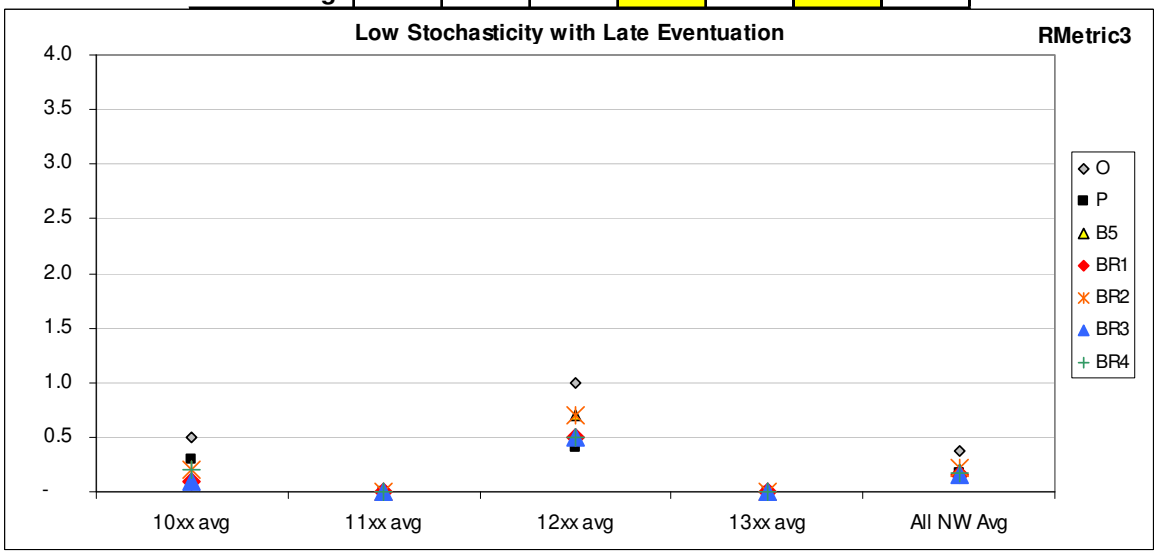
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	1.15	0.50	0.85	0.80	0.90	0.70	0.80
11xx avg	-	-	-	-	-	-	-
12xx avg	0.60	1.20	1.30	0.90	1.30	1.10	1.10
13xx avg	-	-	-	-	-	-	-
All NW Avg	**0.44**	**0.43**	**0.54**	**0.43**	**0.55**	**0.45**	**0.48**

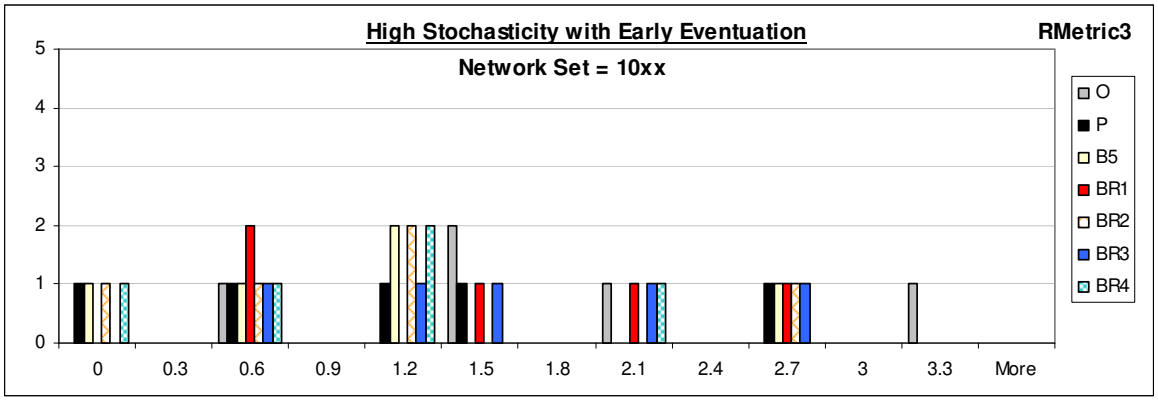


RMetric3

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	0.50	0.30	0.10	0.10	0.20	0.10	0.20
11xx avg	-	-	-	-	-	-	-
12xx avg	1.00	0.40	0.70	0.50	0.70	0.50	0.50
13xx avg	-	-	-	-	-	-	-
All NW Avg	**0.38**	**0.18**	**0.20**	**0.15**	**0.23**	**0.15**	**0.18**




High Stochasticity with Early Eventuation
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Network Set = 10xx
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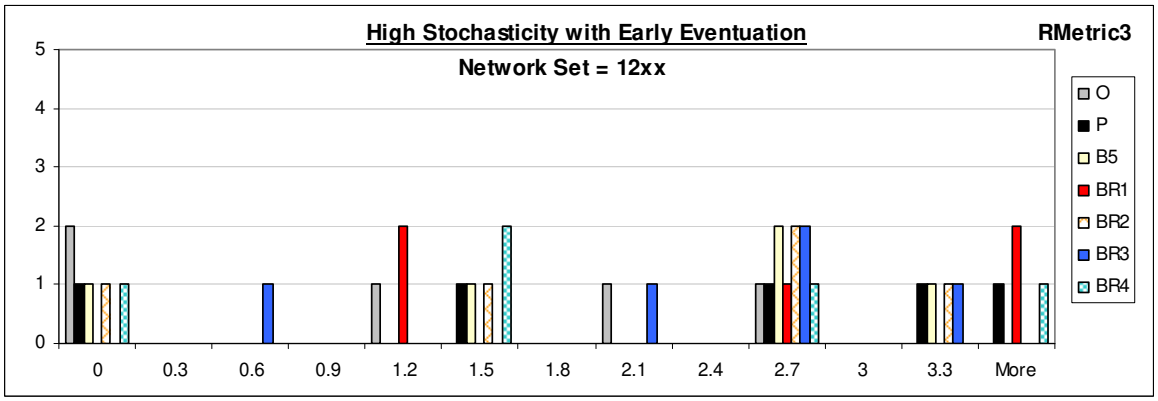
High Stochasticity with Early Eventuation
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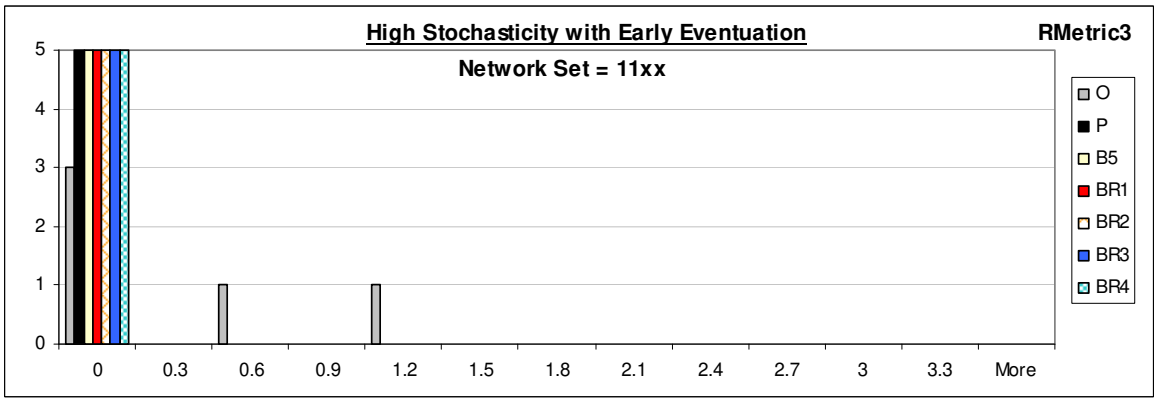
High Stochasticity with Early Eventuation
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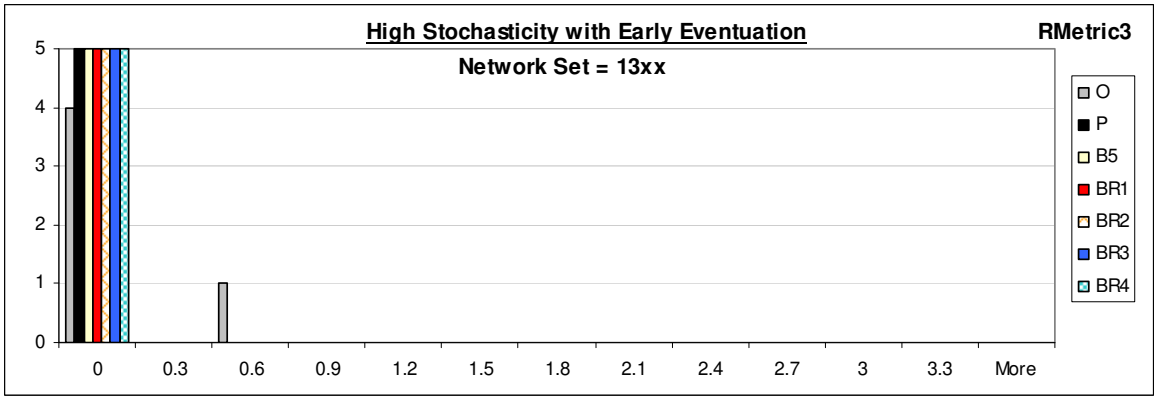
High Stochasticity with Early Eventuation
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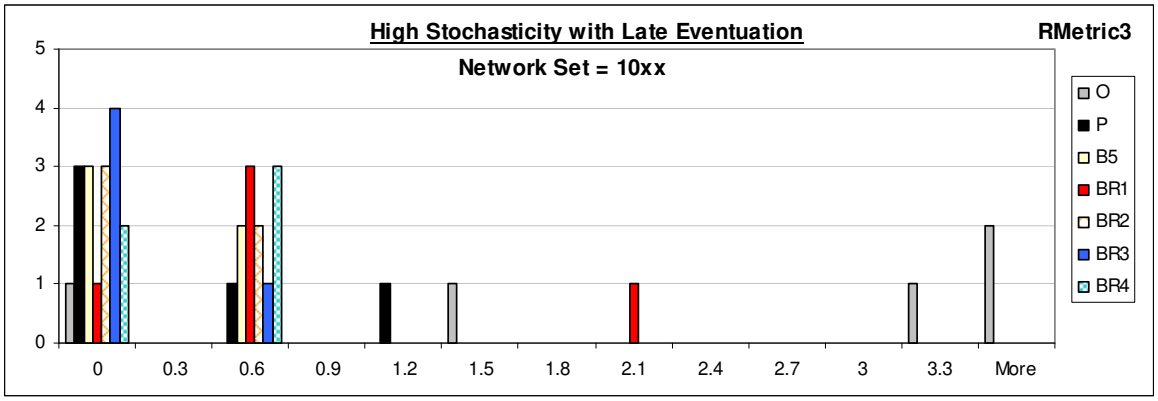
High Stochasticity with Late Eventuation
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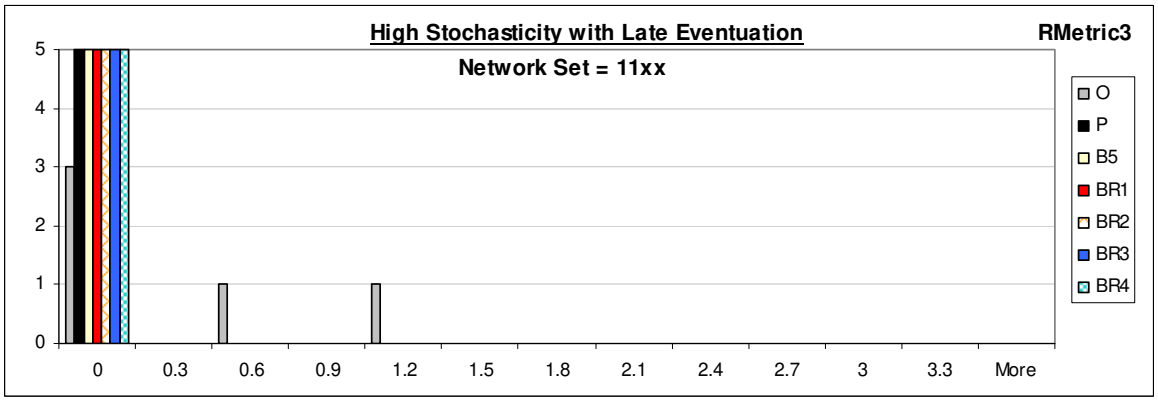
High Stochasticity with Late Eventuation
RMetric3
Network Set = 11xx
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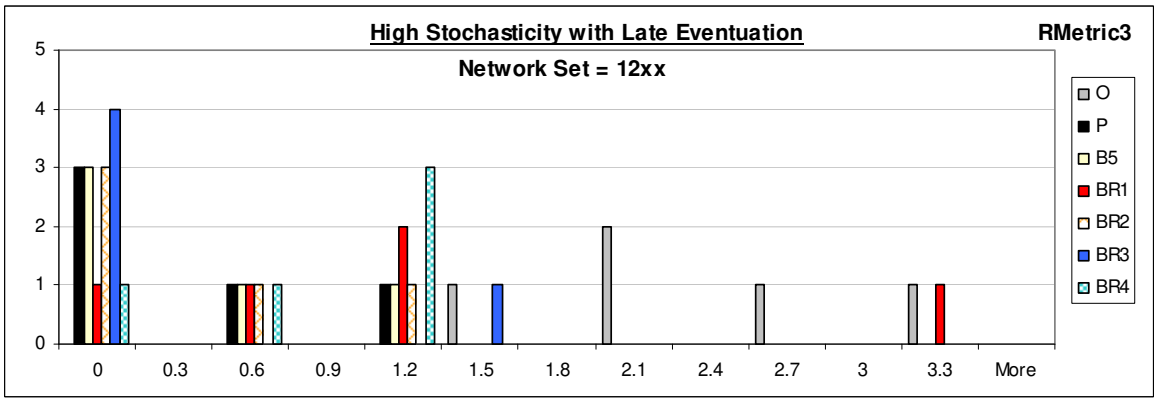
High Stochasticity with Late Eventuation
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Network Set = 12xx
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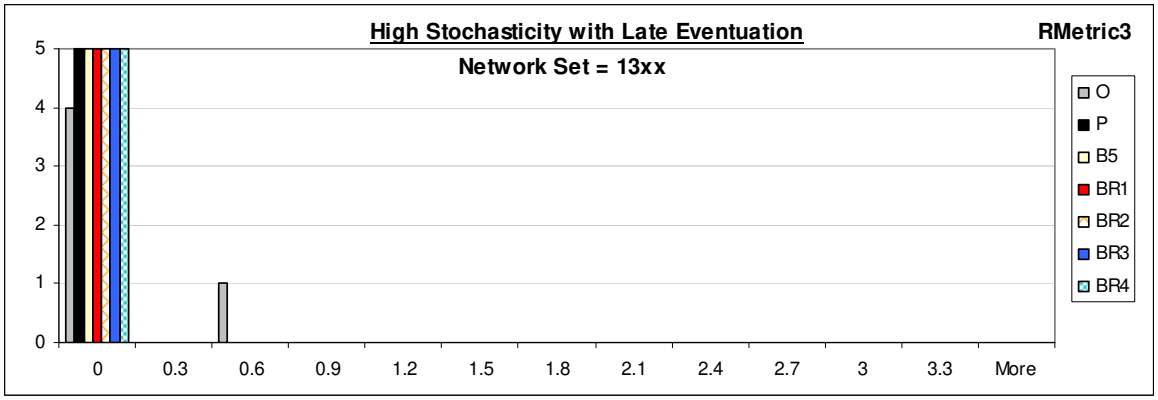
High Stochasticity with Late Eventuation
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Network Set = 13xx
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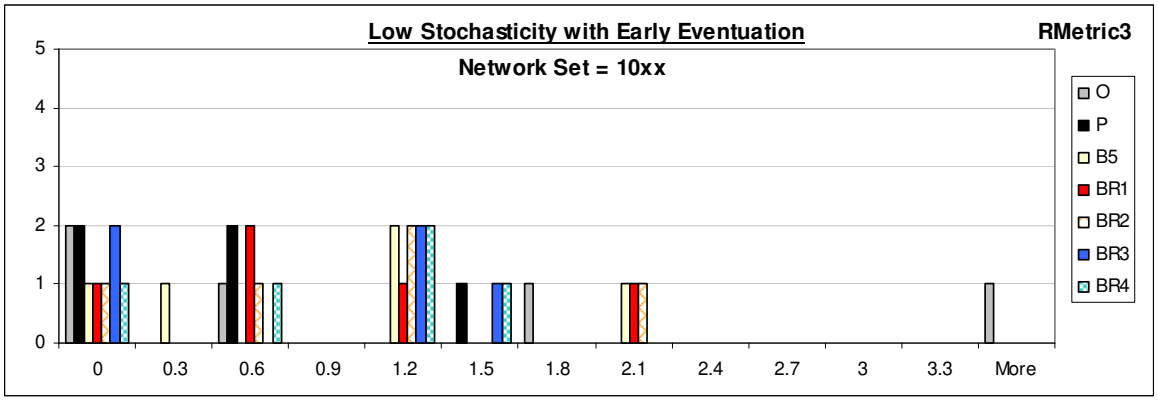
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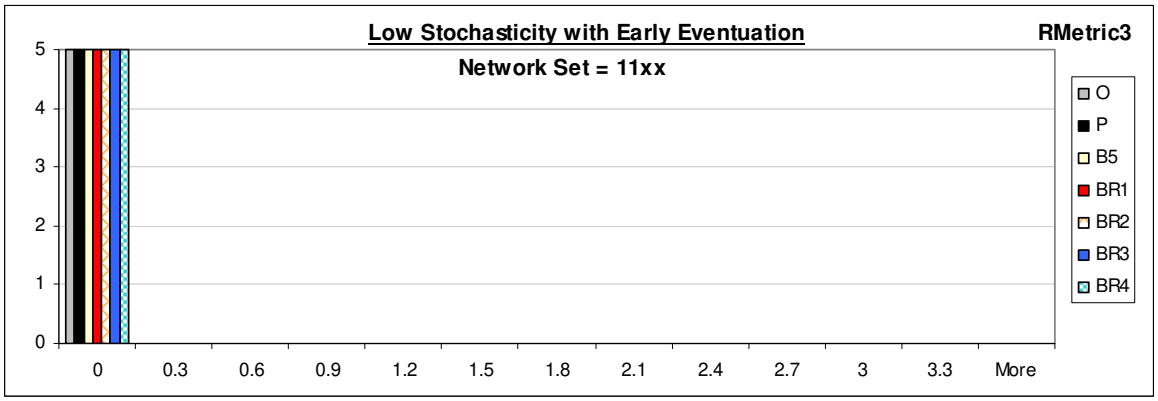
BR3
BR4


Low Stochasticity with Early Eventuation
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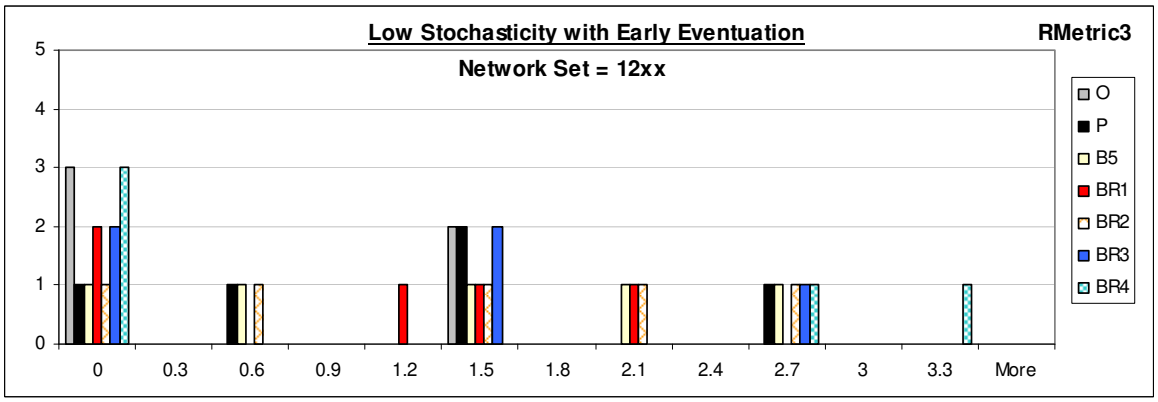
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O
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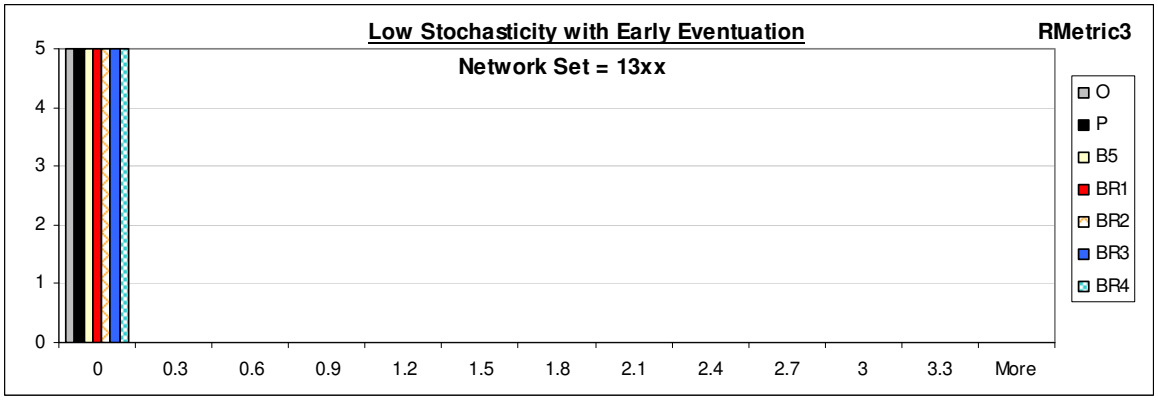
B5
BR1
BR2
BR3
BR4


Low Stochasticity with Early Eventuation
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Network Set = 13xx
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3.3
More
O
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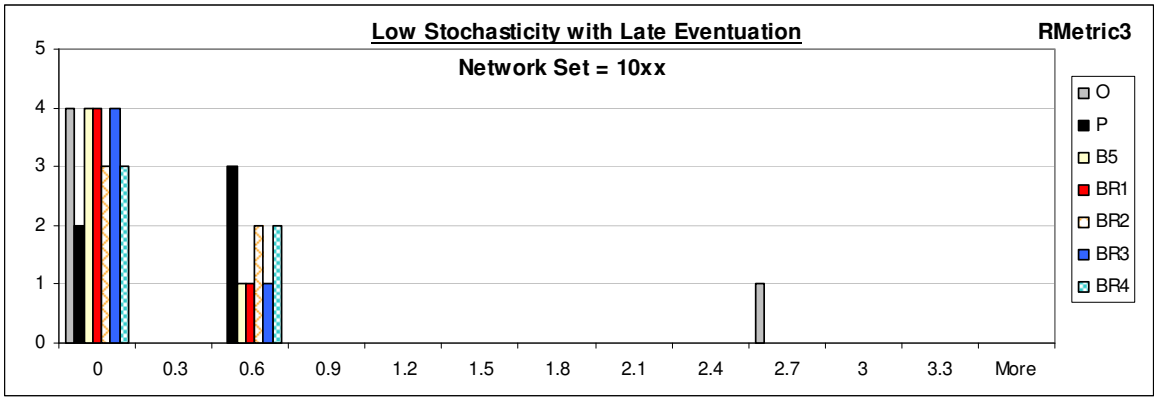
B5
BR1
BR2
BR3
BR4


Low Stochasticity with Late Eventuation
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Network Set = 10xx
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BR1
BR2
BR3
BR4
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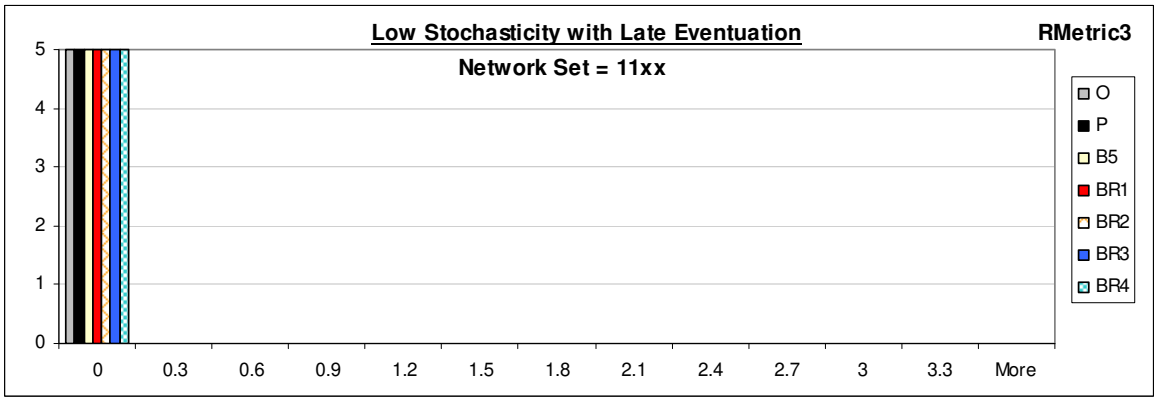
More


Low Stochasticity with Late Eventuation
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BR1
BR2
BR3
BR4
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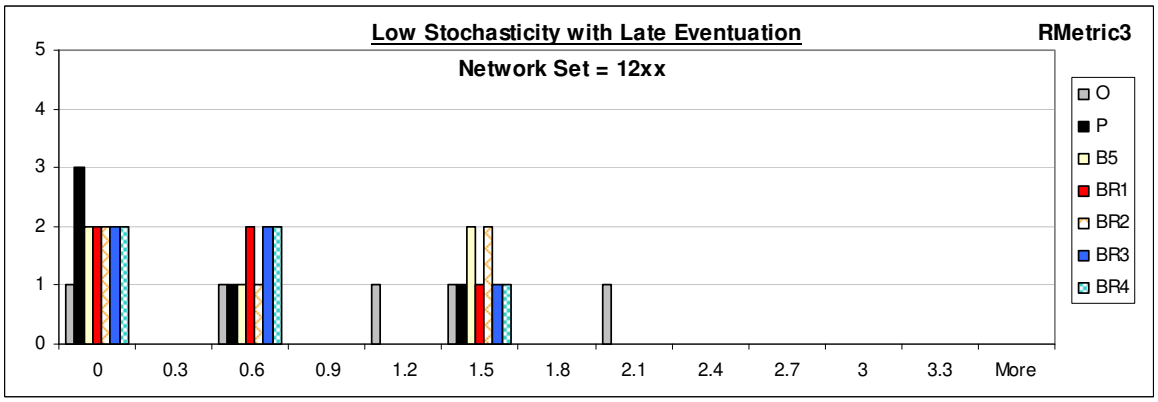
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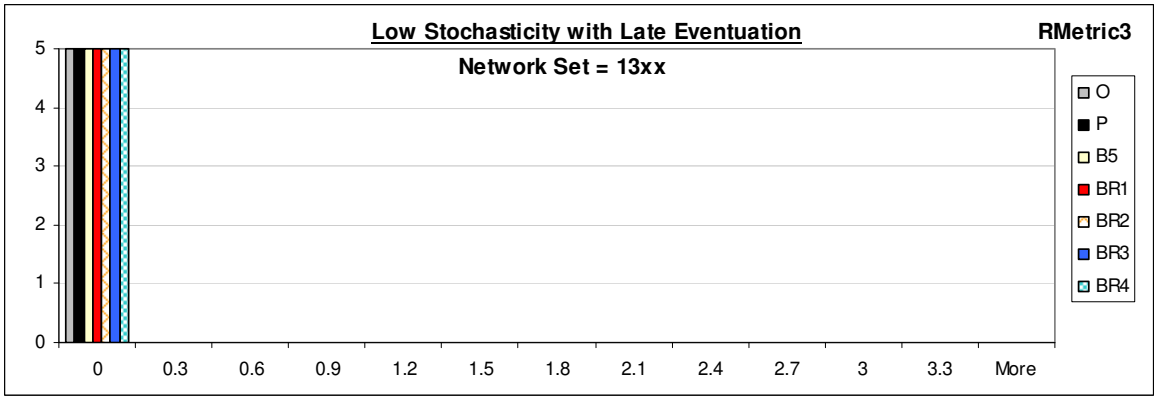
3
3.3
More


Low Stochasticity with Late Eventuation
RMetric3
Network Set = 13xx
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B5
BR1
BR2
BR3
BR4
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2.4
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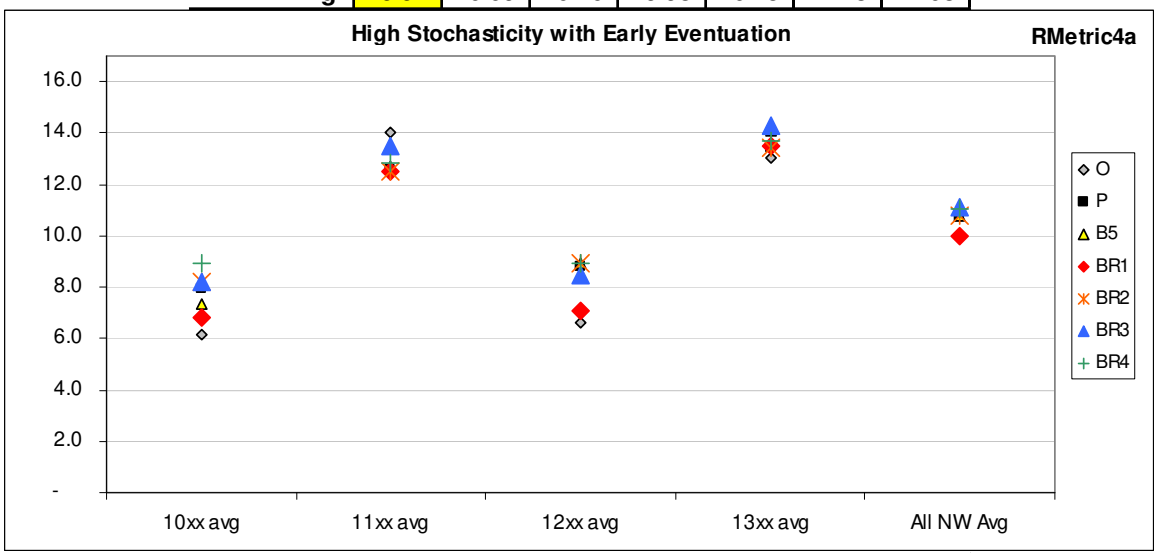
3.3
More

RMetric4a

High Stochasticity with Early Eventuation

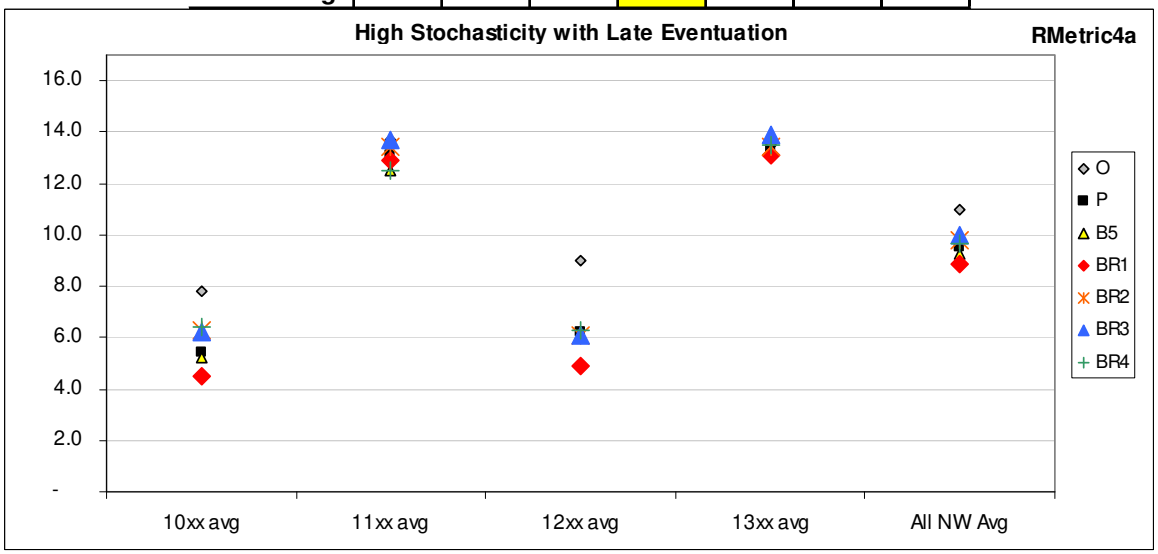
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	6.15	7.95	7.35	6.80	8.20	8.20	8.90
11xx avg	14.00	12.60	12.70	12.50	12.50	13.50	12.80
12xx avg	6.60	8.80	8.90	7.10	8.90	8.50	8.90
13xx avg	13.00	13.40	14.10	13.50	13.40	14.30	13.70
All NW Avg	**9.94**	**10.69**	**10.76**	**9.98**	**10.75**	**11.13**	**11.08**



RMetric4a

High Stochasticity with Late Eventuation

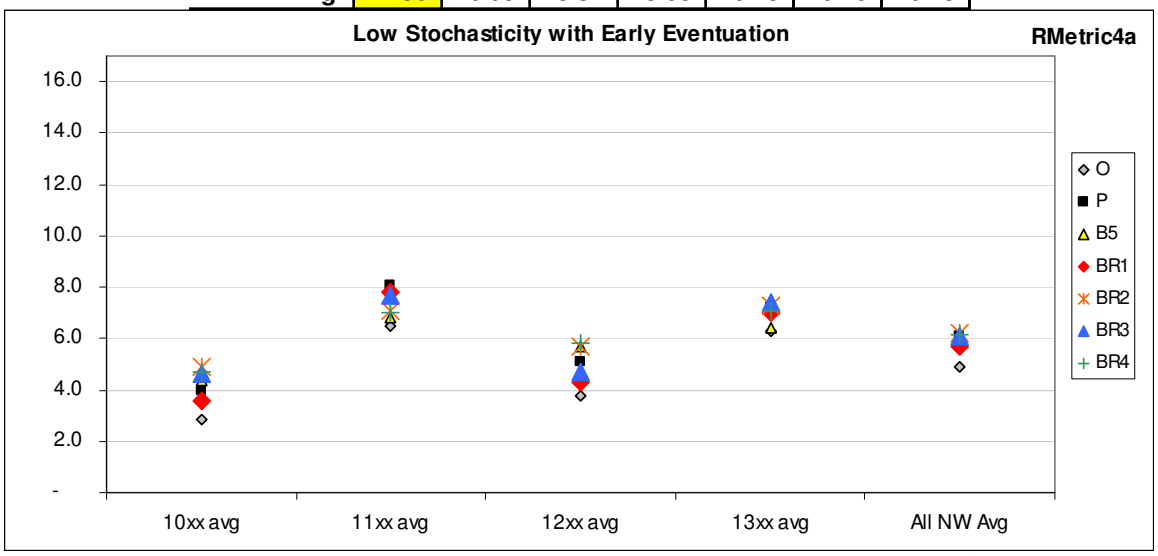
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	7.80	5.40	5.20	4.50	6.30	6.20	6.40
11xx avg	13.70	13.10	12.50	12.90	13.40	13.70	12.50
12xx avg	9.00	6.20	6.10	4.90	6.10	6.10	6.30
13xx avg	13.50	13.30	13.30	13.10	13.40	13.90	13.50
All NW Avg	**11.00**	**9.50**	**9.28**	**8.85**	**9.80**	**9.98**	**9.68**



RMetric4a

Low Stochasticity with Early Eventuation

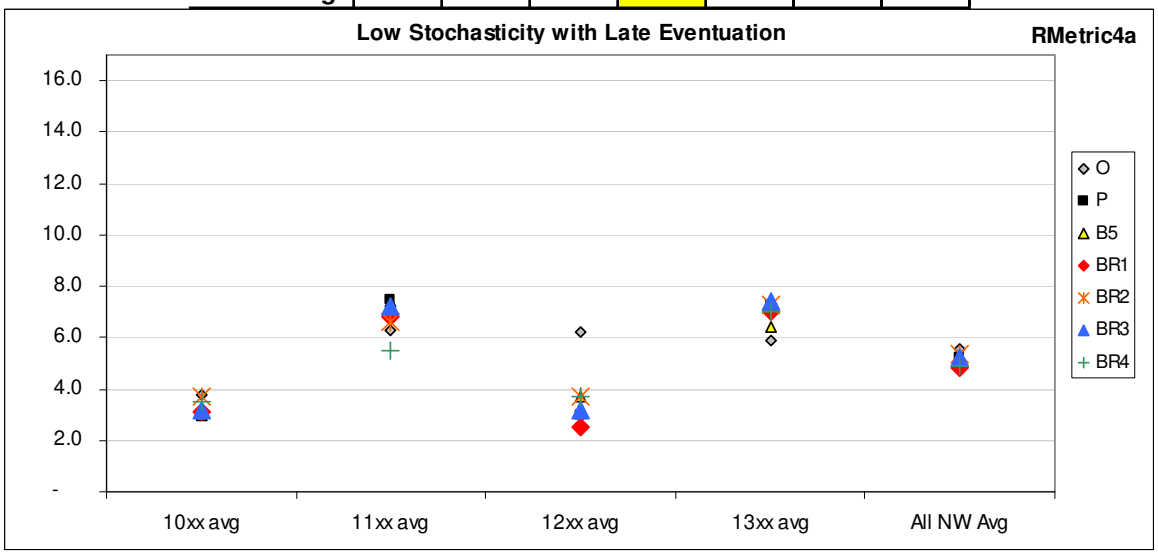
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	2.85	3.95	4.35	3.60	4.90	4.60	4.70
11xx avg	6.50	8.10	6.80	7.80	7.10	7.70	7.00
12xx avg	3.80	5.10	5.70	4.30	5.70	4.70	5.80
13xx avg	6.30	7.20	6.40	7.00	7.30	7.40	7.10
All NW Avg	**4.86**	**6.09**	**5.81**	**5.68**	**6.25**	**6.10**	**6.15**

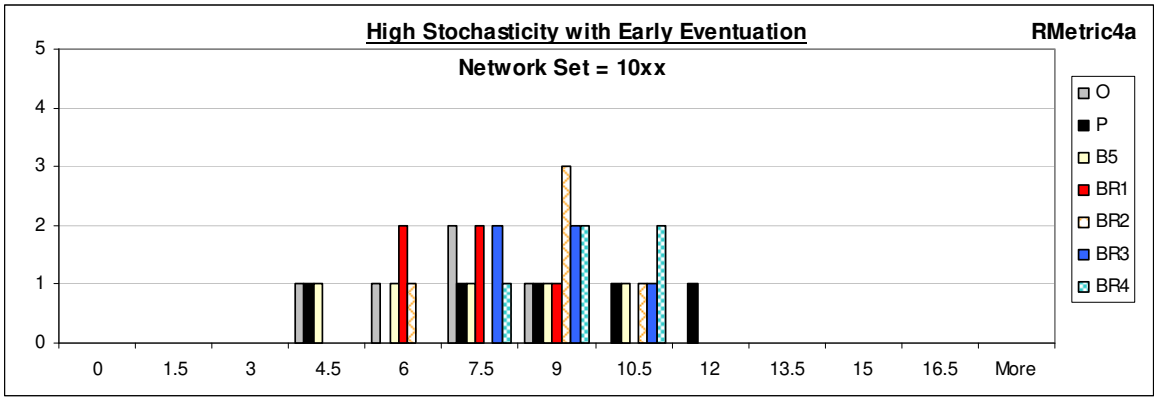


RMetric4a

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	3.80	3.00	3.00	3.10	3.70	3.20	3.50
11xx avg	6.30	7.50	7.40	6.80	6.60	7.20	5.50
12xx avg	6.20	3.00	3.70	2.50	3.70	3.20	3.70
13xx avg	5.90	7.30	6.40	7.00	7.30	7.40	7.00
All NW Avg	**5.55**	**5.20**	**5.13**	**4.85**	**5.33**	**5.25**	**4.93**




High Stochasticity with Early Eventuation
RMetric4a
Network Set = 10xx
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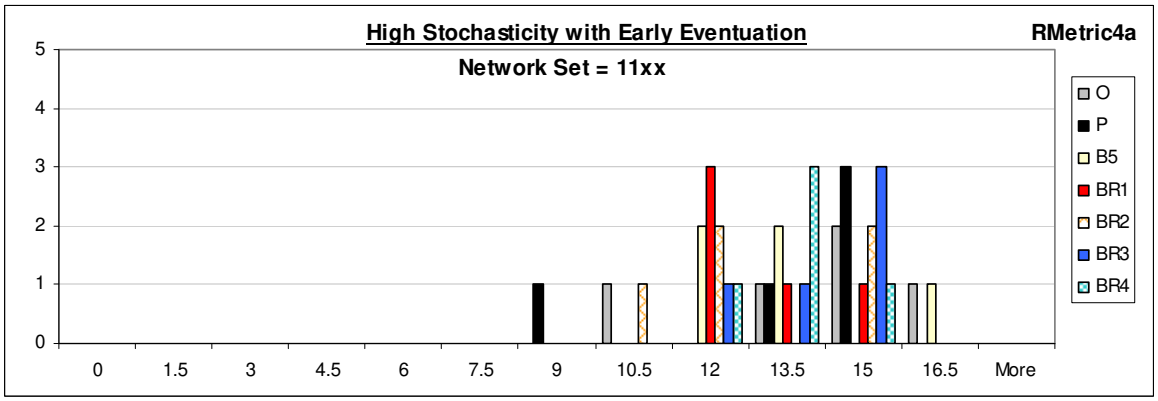
High Stochasticity with Early Eventuation
RMetric4a
Network Set = 11xx
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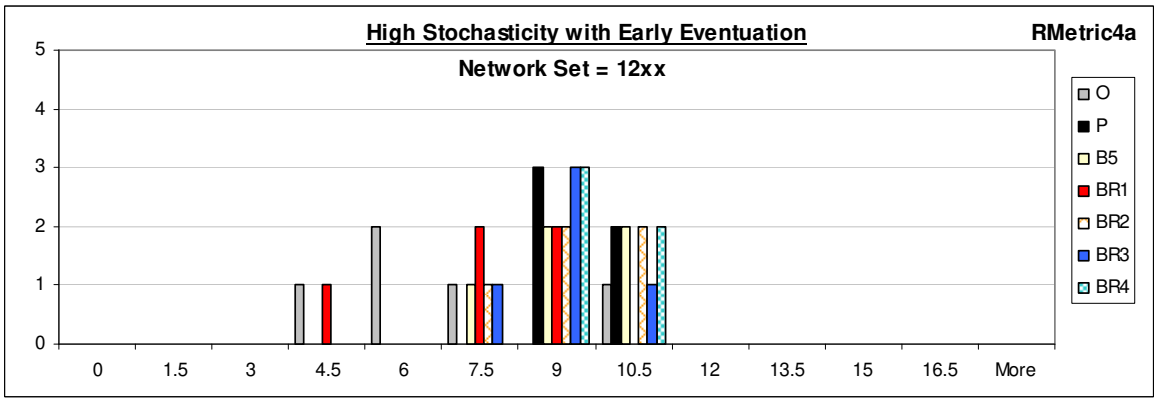
High Stochasticity with Early Eventuation
RMetric4a
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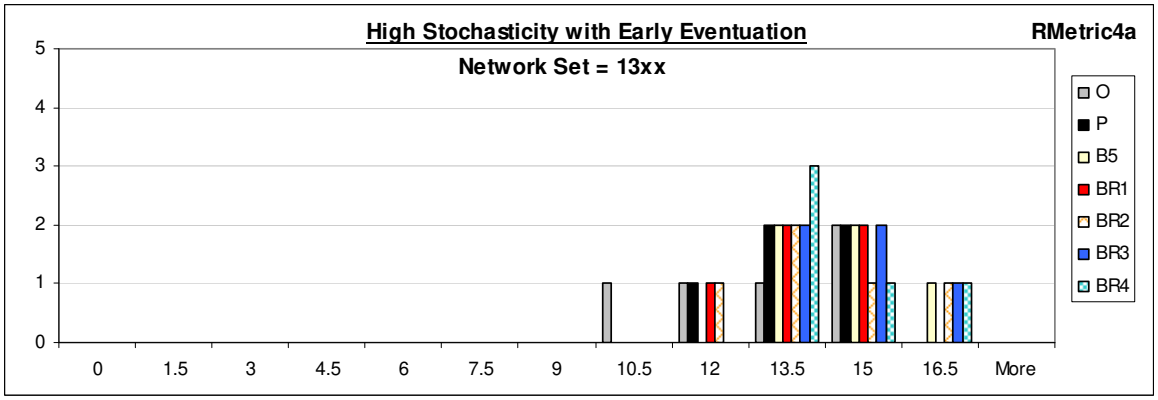
High Stochasticity with Early Eventuation
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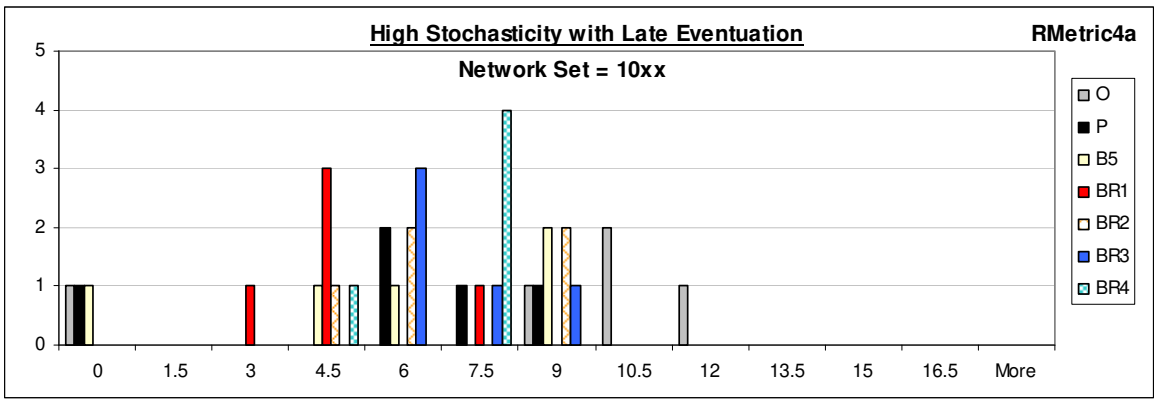
High Stochasticity with Late Eventuation
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Network Set = 10xx
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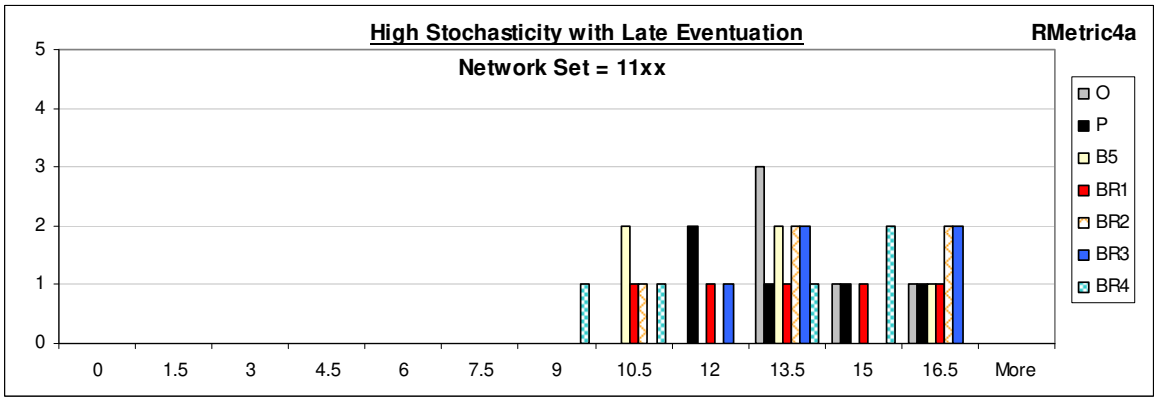
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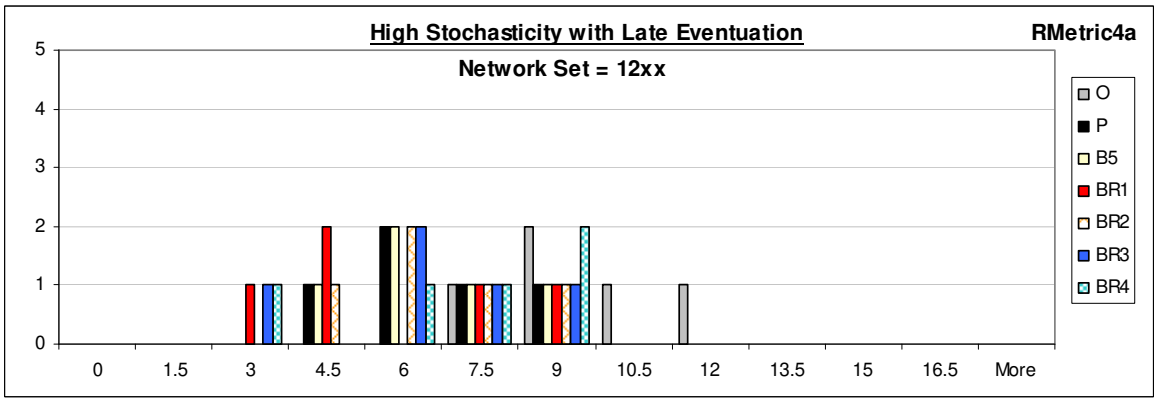
High Stochasticity with Late Eventuation
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Network Set = 12xx
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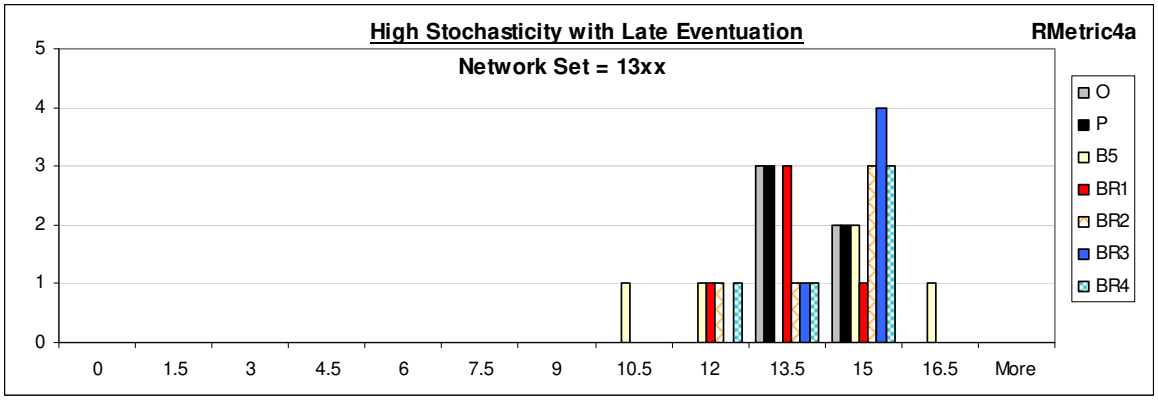
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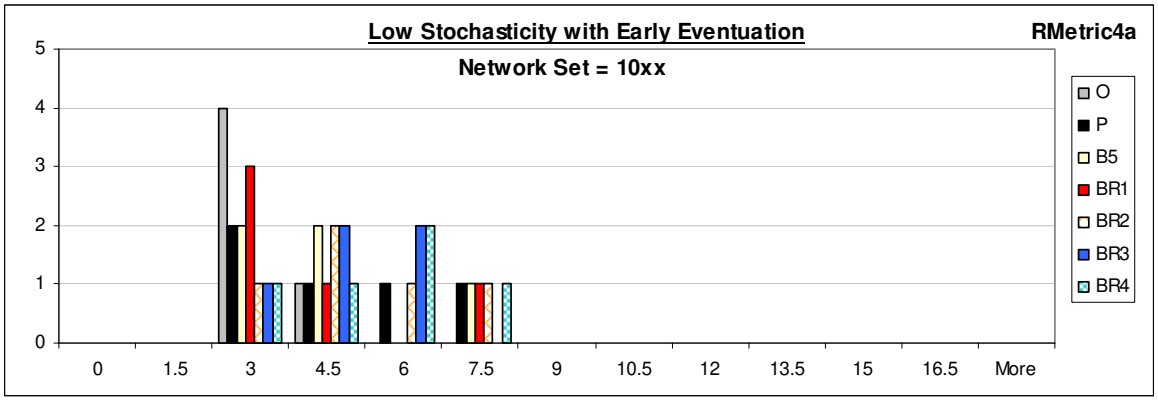
Low Stochasticity with Early Eventuation
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Network Set = 10xx
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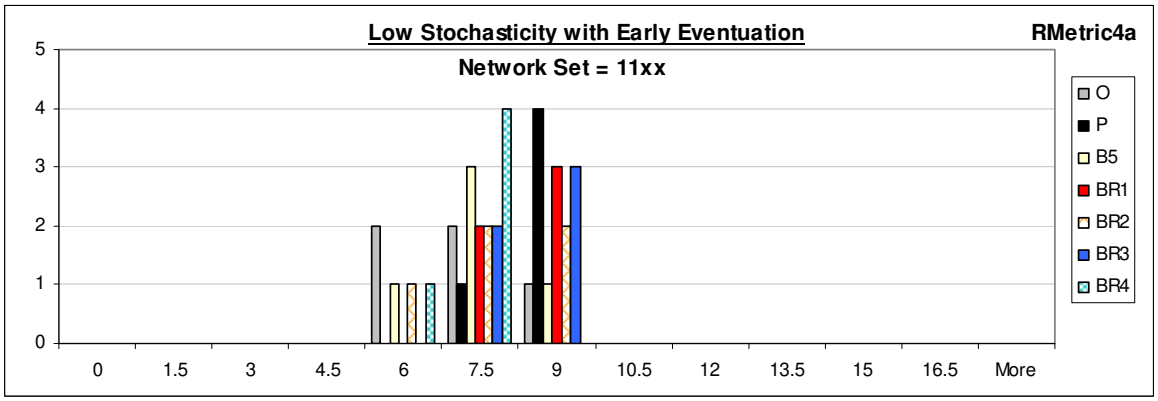
Low Stochasticity with Early Eventuation
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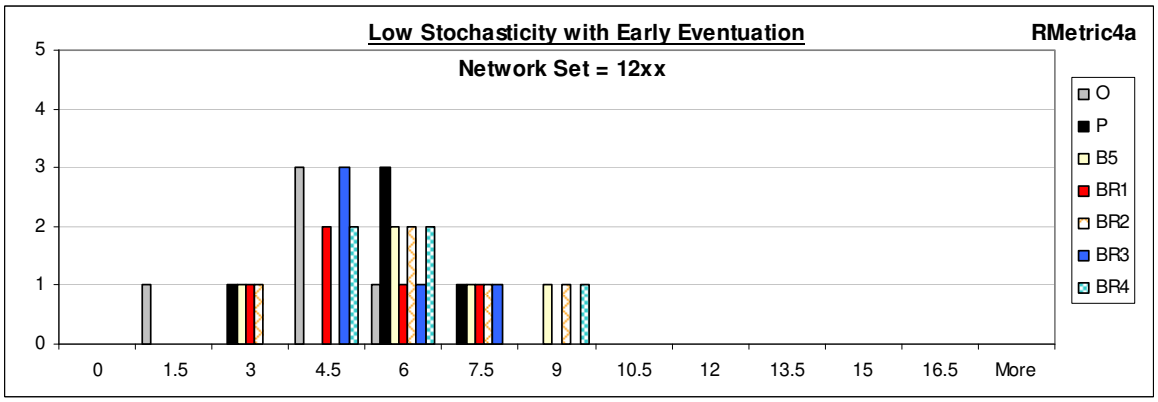
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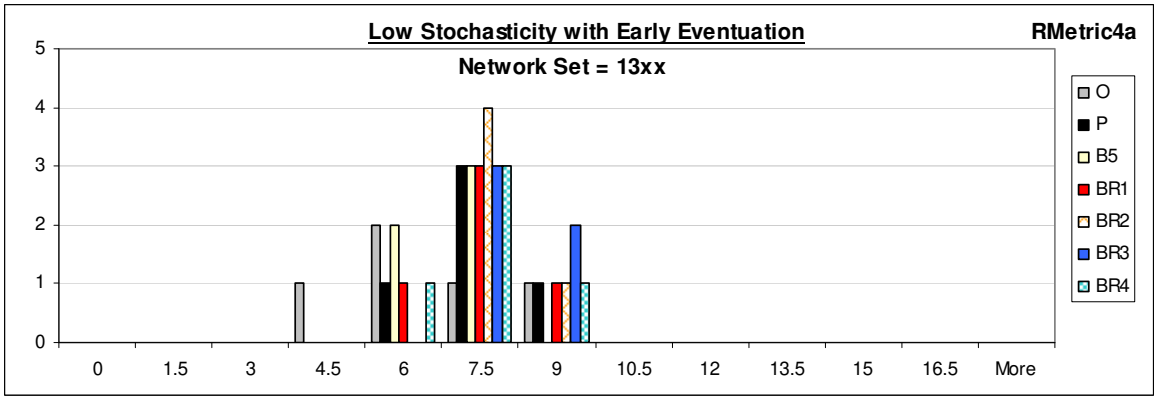
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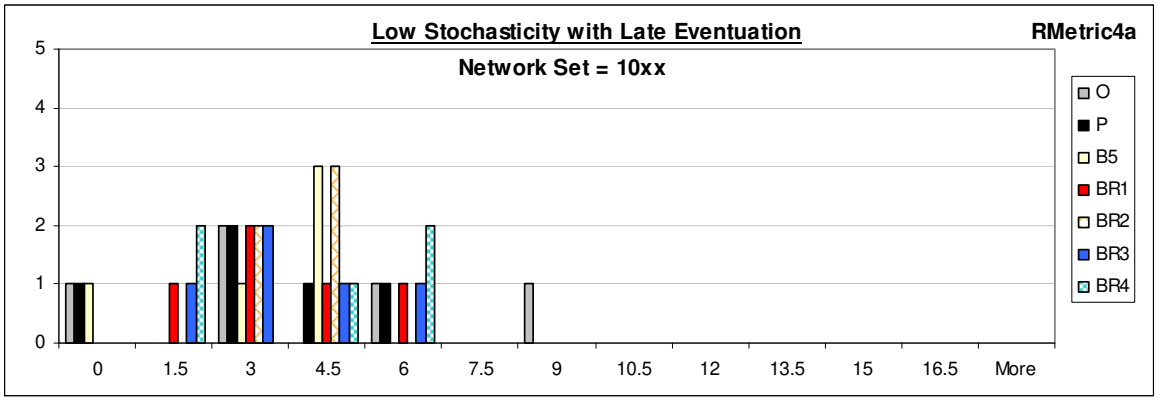
Low Stochasticity with Late Eventuation
RMetric4a
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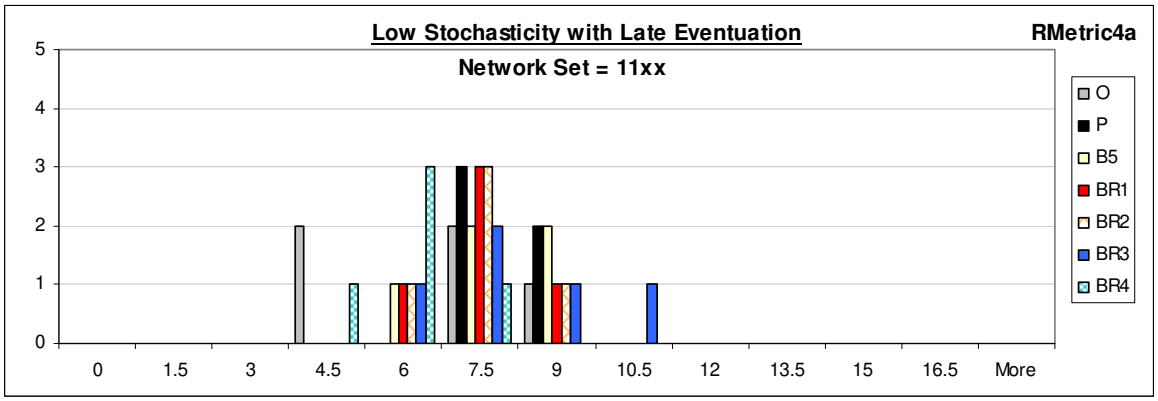
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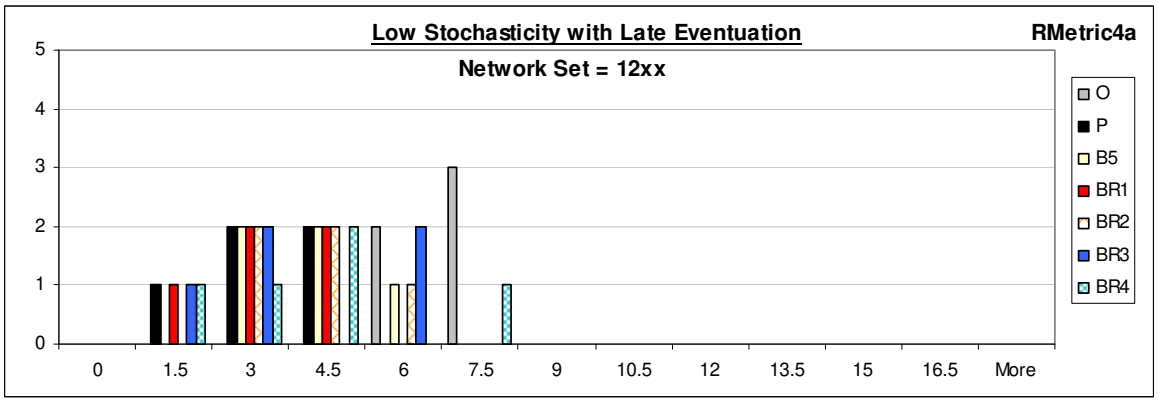
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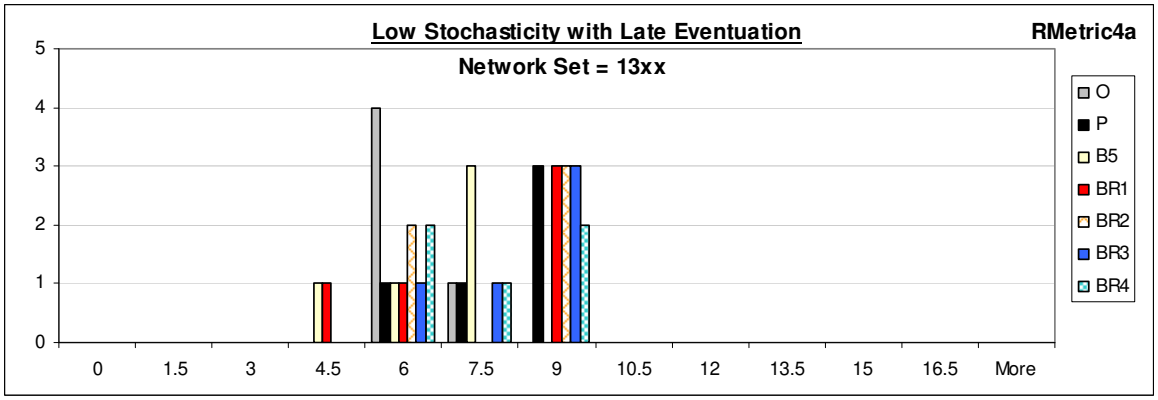
Low Stochasticity with Late Eventuation
RMetric4a
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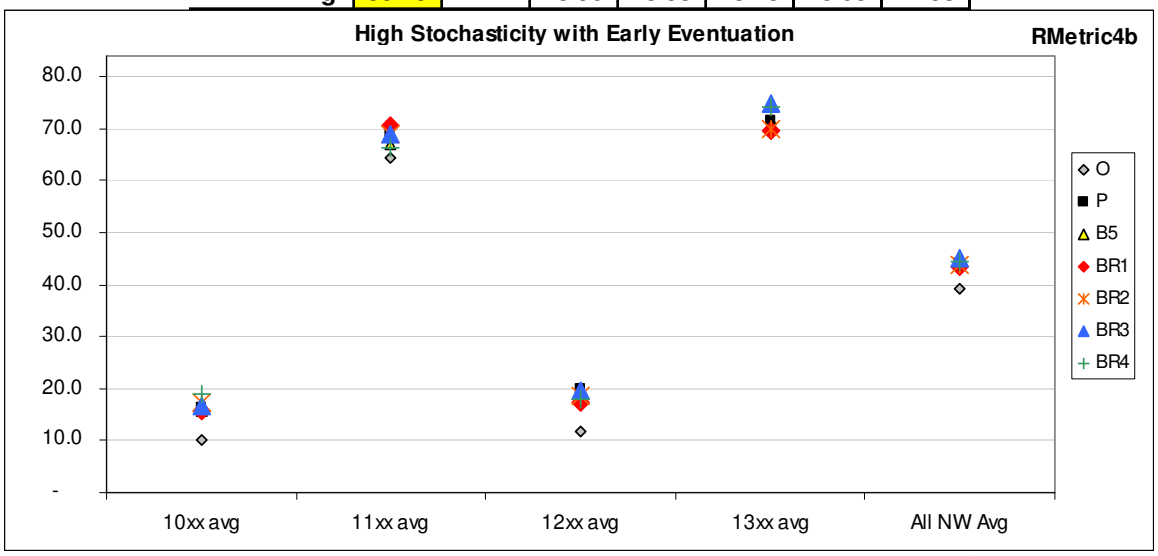
RMetric4b

High Stochasticity with Early Eventuation

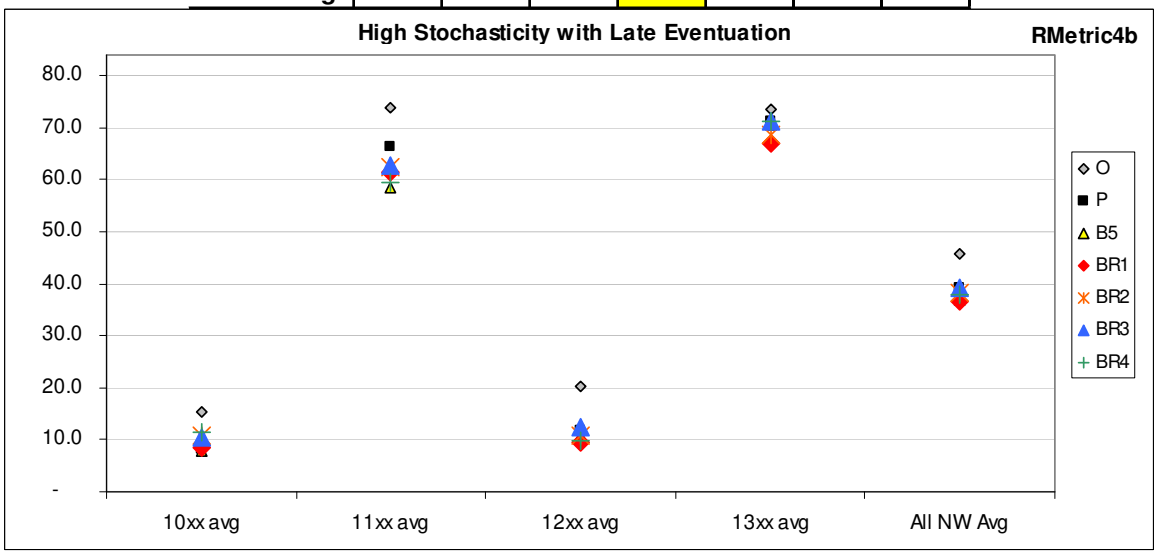
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	10.15	16.35	15.70	15.70	17.40	16.70	18.90
11xx avg	64.50	68.90	67.10	70.70	69.10	69.10	66.30
12xx avg	11.70	19.80	18.70	17.30	18.70	19.70	17.90
13xx avg	70.80	71.50	74.10	69.60	69.90	74.70	74.20
All NW Avg	**39.29**	**44.14**	**43.90**	**43.33**	**43.78**	**45.05**	**44.33**



RMetric4b

High Stochasticity with Late Eventuation

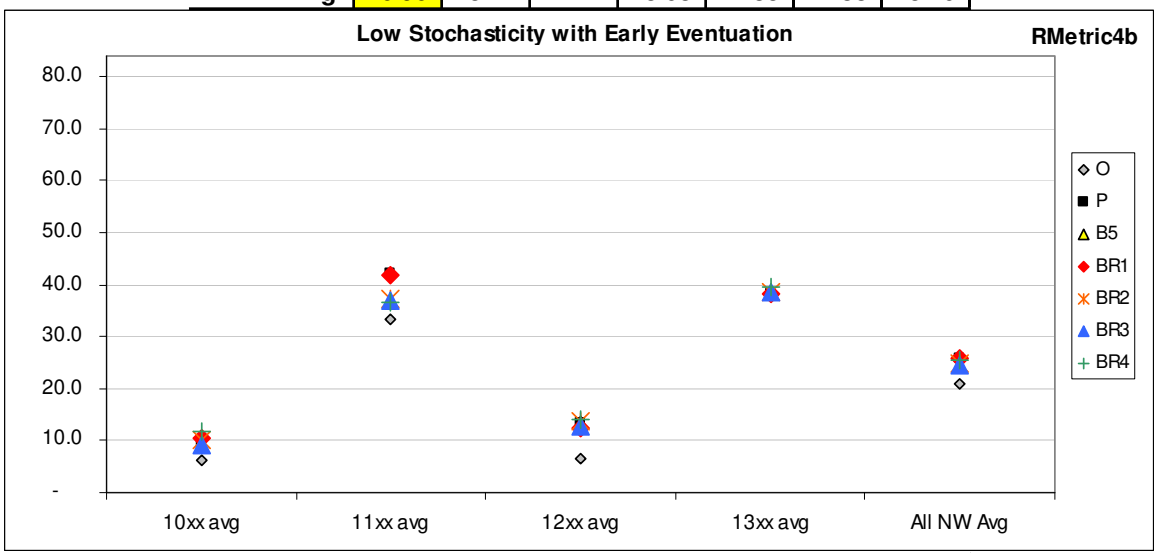
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	15.20	8.30	8.00	8.60	10.90	10.40	11.60
11xx avg	74.00	66.20	58.50	61.40	62.40	62.80	59.60
12xx avg	20.40	11.80	10.90	9.40	10.90	12.40	9.80
13xx avg	73.40	71.10	70.60	67.00	68.80	71.40	71.10
All NW Avg	**45.75**	**39.35**	**37.00**	**36.60**	**38.25**	**39.25**	**38.03**



RMetric4b

Low Stochasticity with Early Eventuation

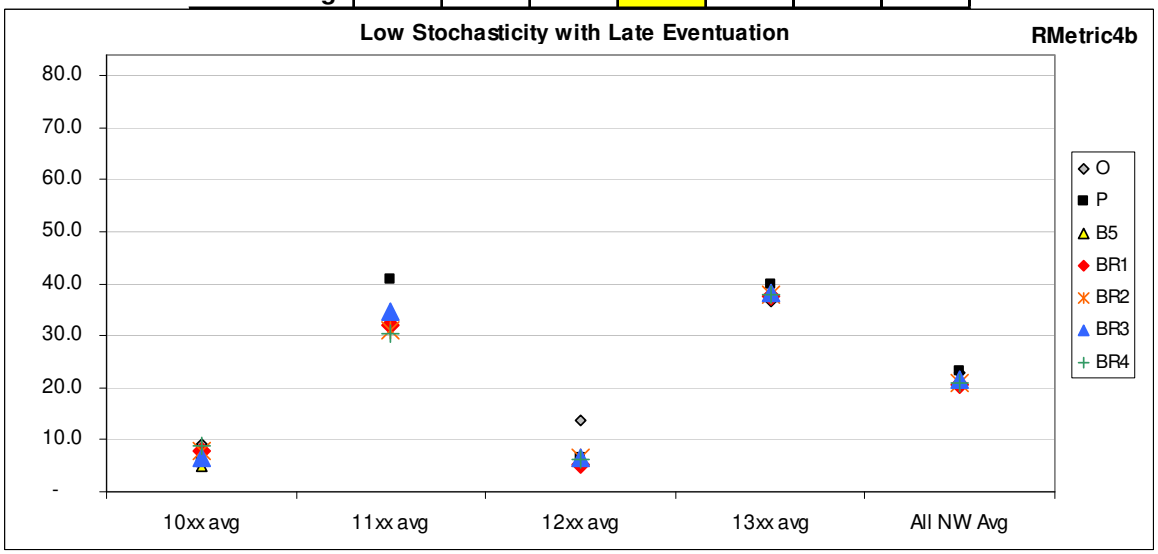
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	6.15	9.15	8.75	10.40	10.00	9.30	11.70
11xx avg	33.40	42.10	36.40	41.90	37.30	36.90	36.60
12xx avg	6.50	13.40	13.60	12.30	13.60	12.60	13.90
13xx avg	37.80	38.30	38.90	38.10	38.50	38.70	39.40
All NW Avg	**20.96**	**25.74**	**24.41**	**25.68**	**24.85**	**24.38**	**25.40**

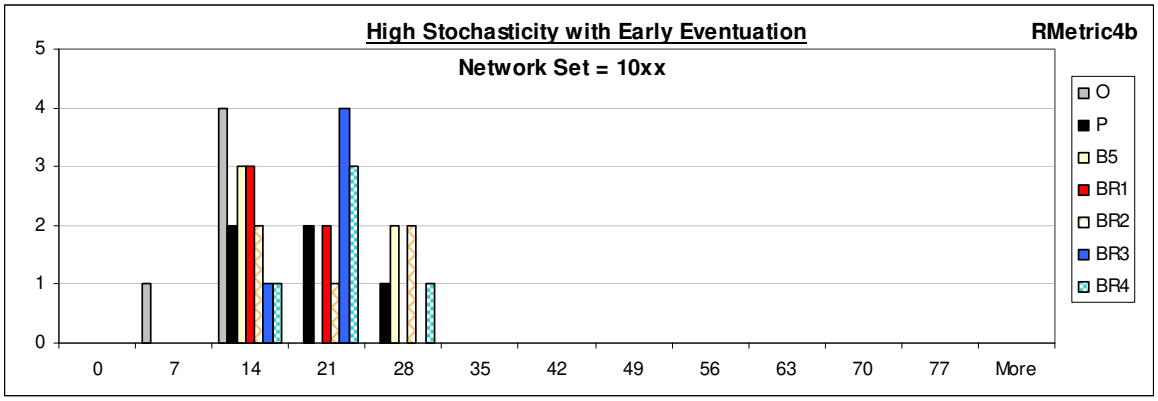


RMetric4b

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	9.20	5.40	4.90	7.90	7.80	6.40	8.80
11xx avg	32.60	40.90	34.40	32.00	31.00	34.80	30.50
12xx avg	13.80	6.60	6.40	5.20	6.40	6.70	6.20
13xx avg	36.50	39.90	37.50	37.50	37.90	38.10	38.00
All NW Avg	**23.03**	**23.20**	**20.80**	**20.65**	**20.78**	**21.50**	**20.88**

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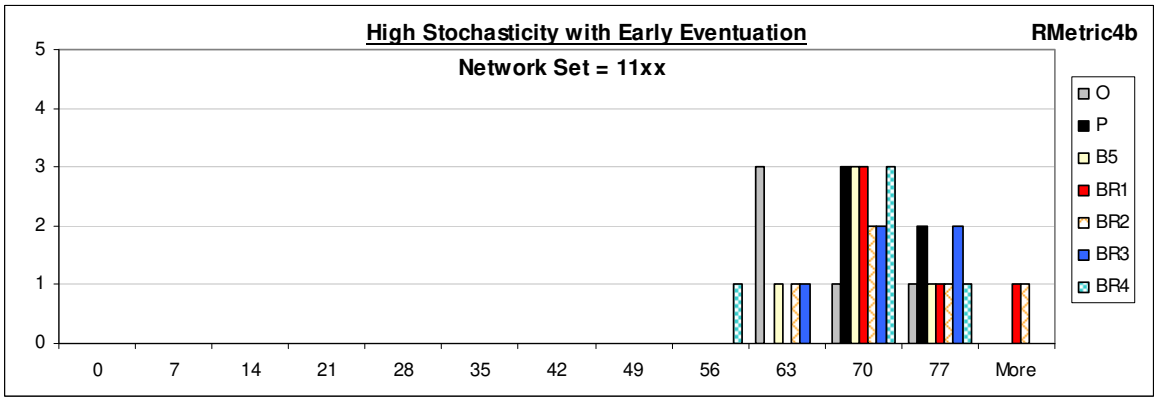
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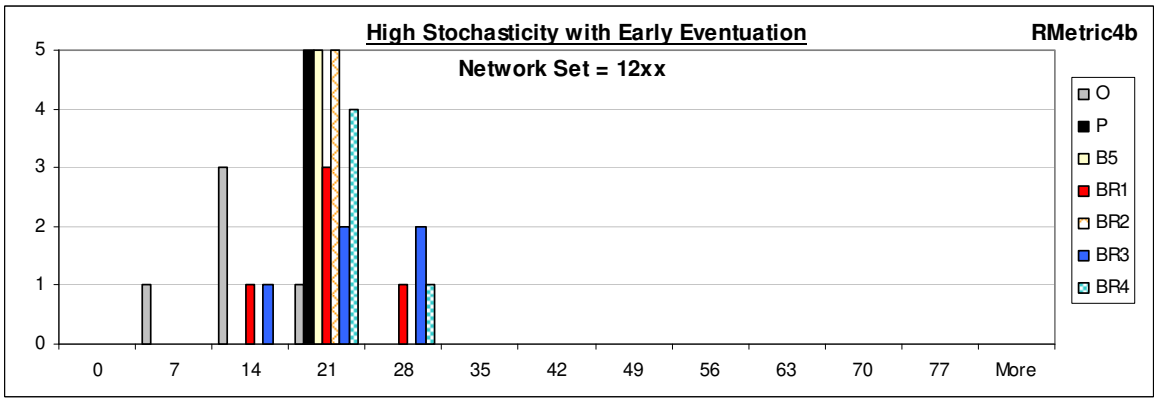
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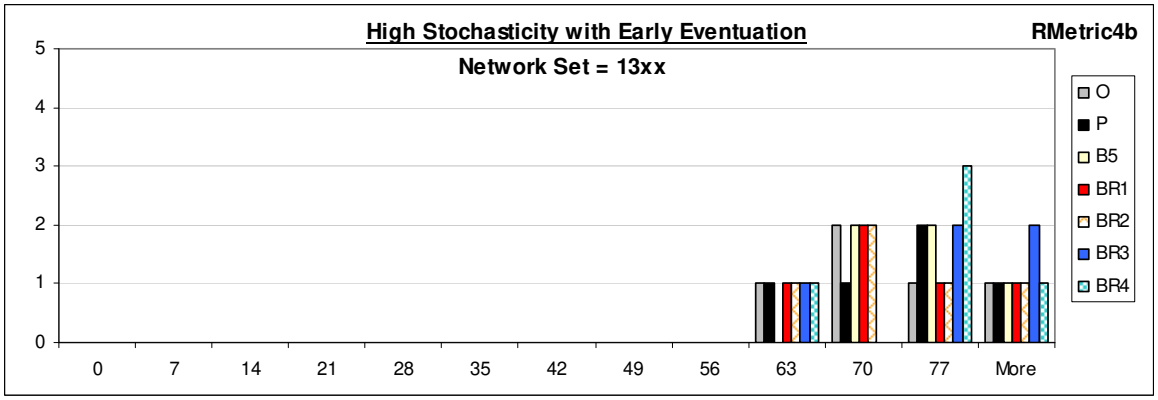
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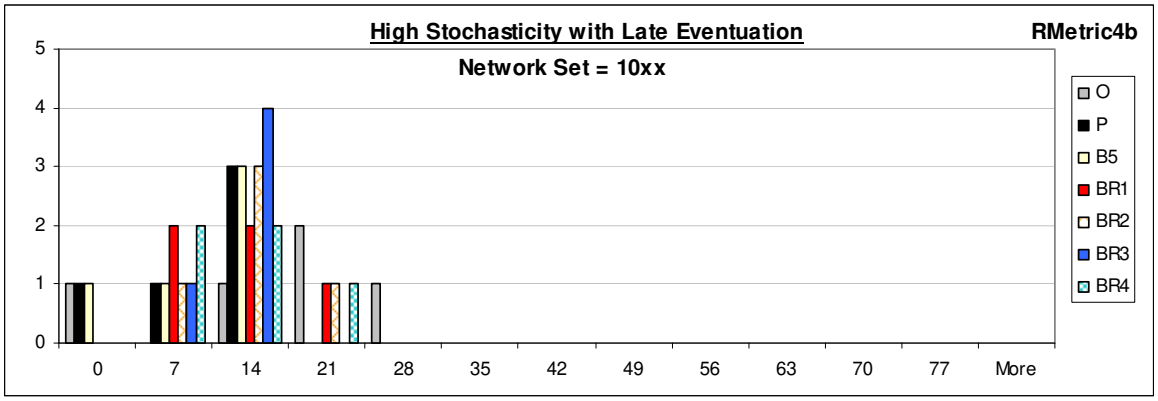
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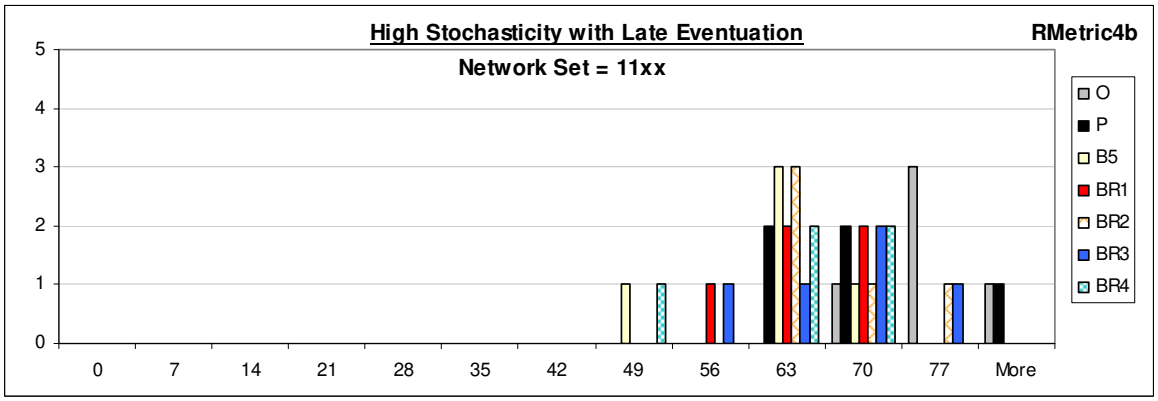
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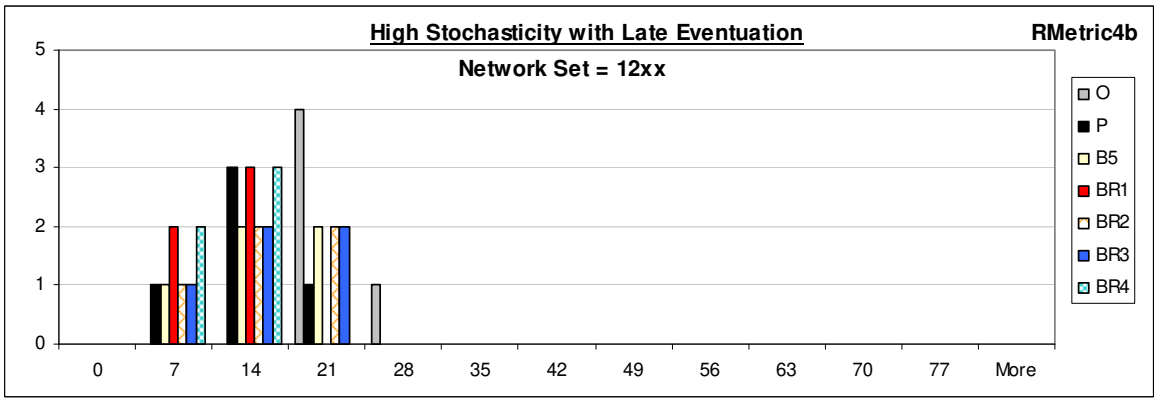
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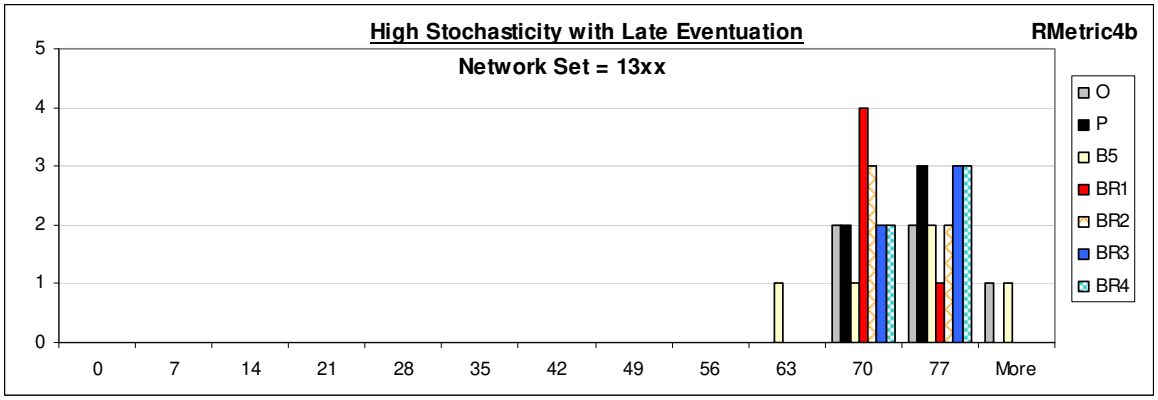
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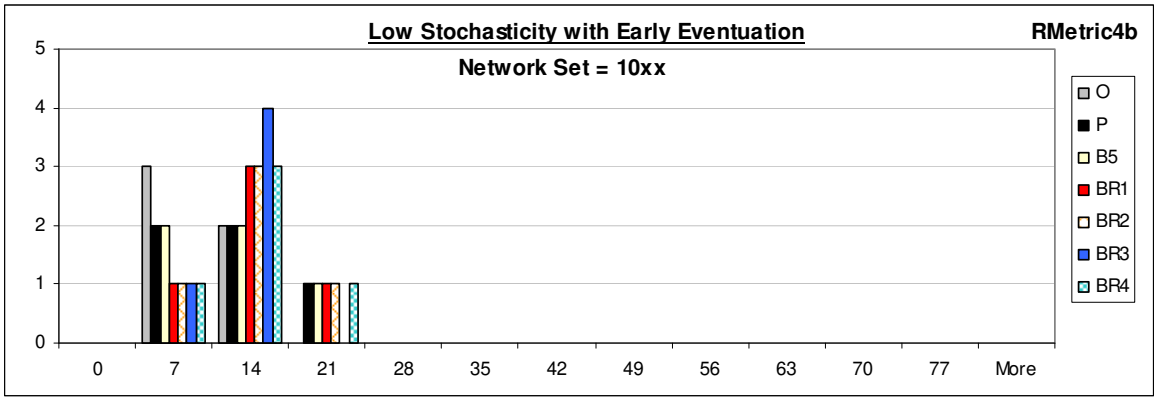
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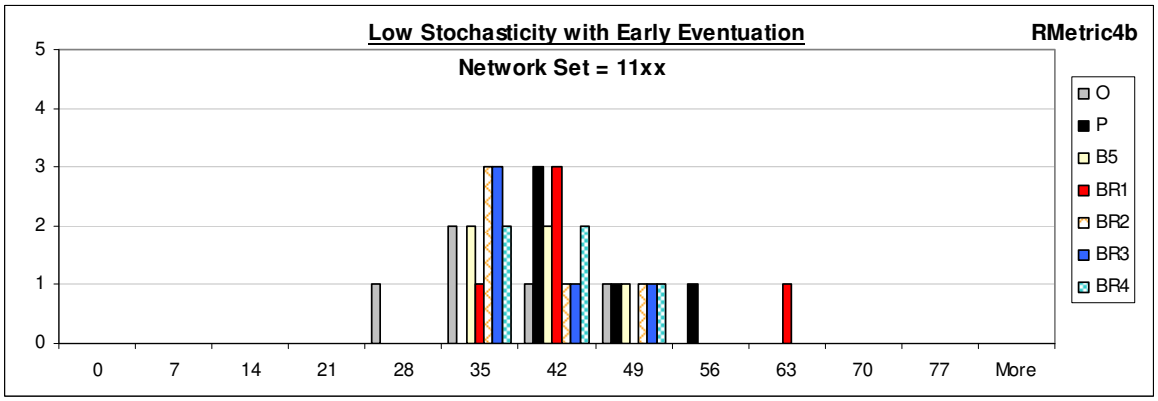
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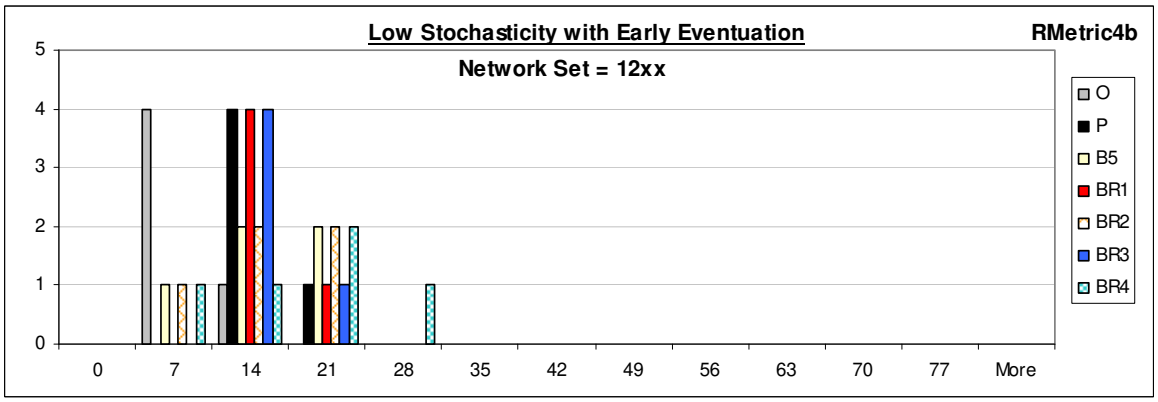
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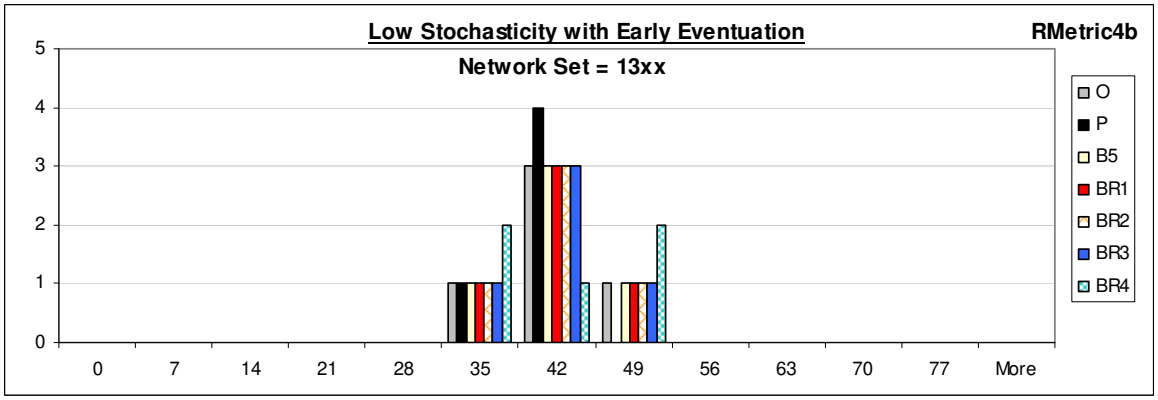
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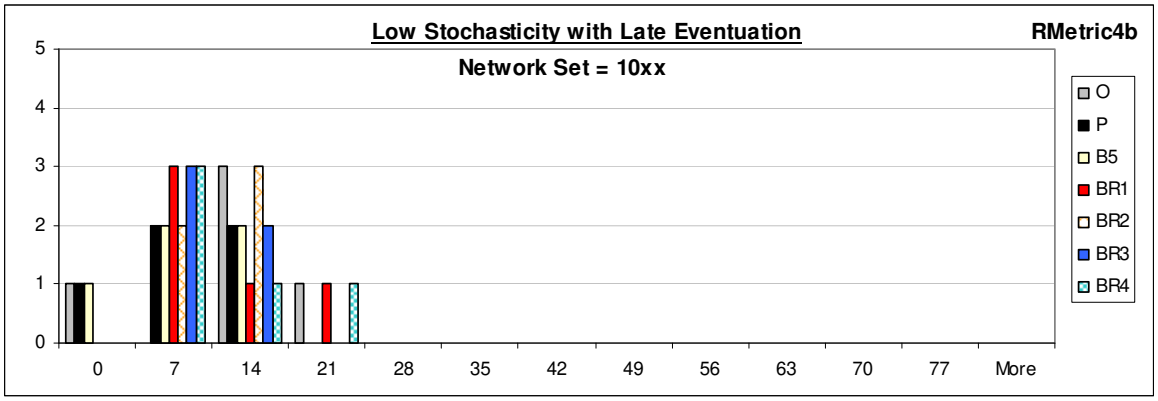
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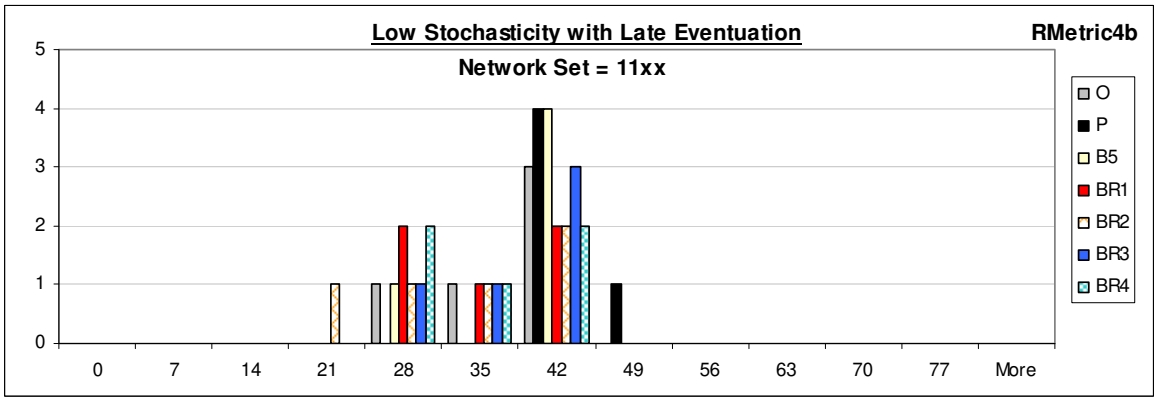
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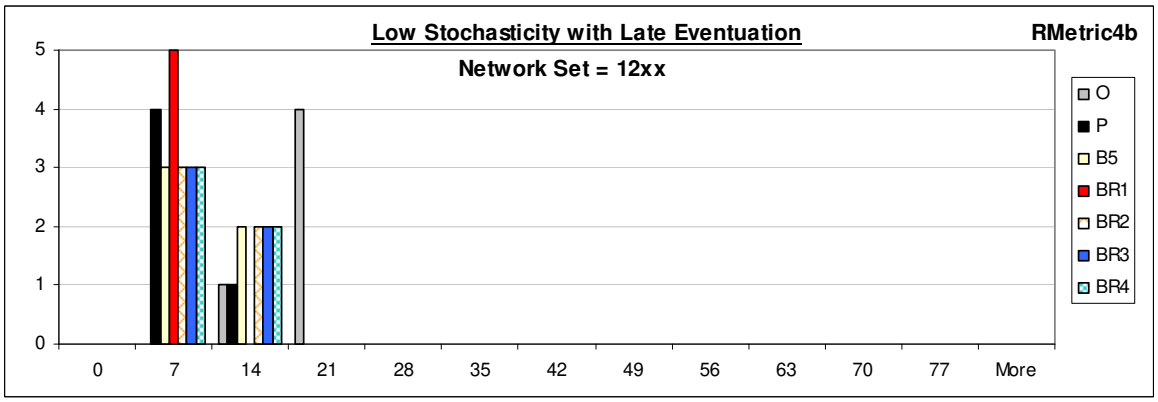
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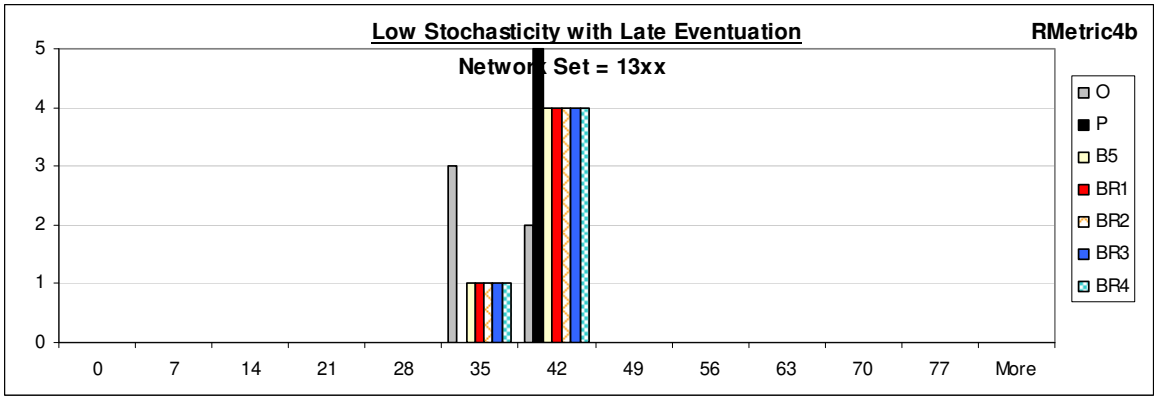
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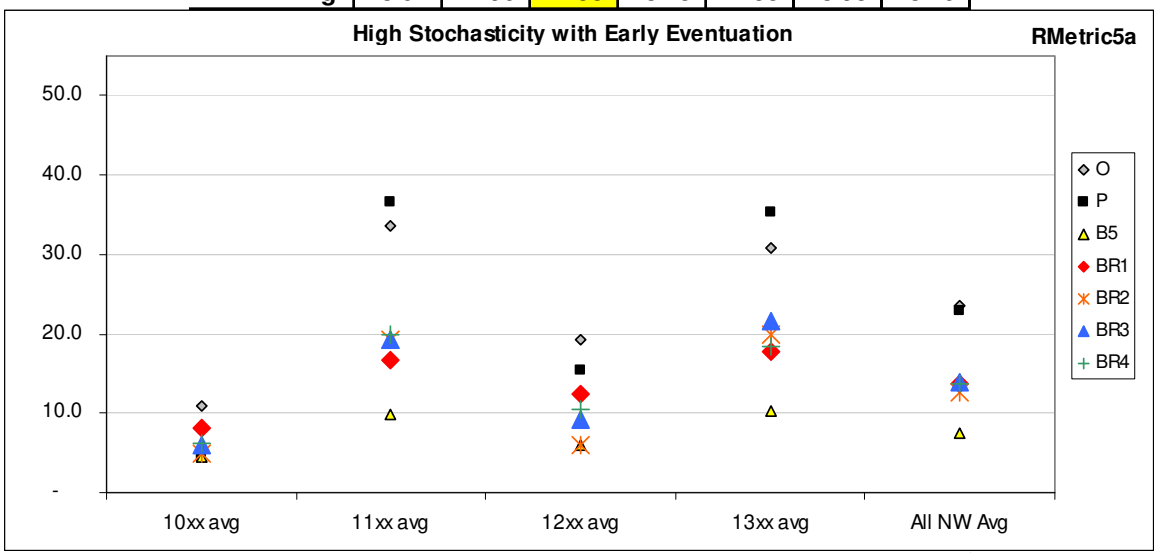
RMetric5a

High Stochasticity with Early Eventuation

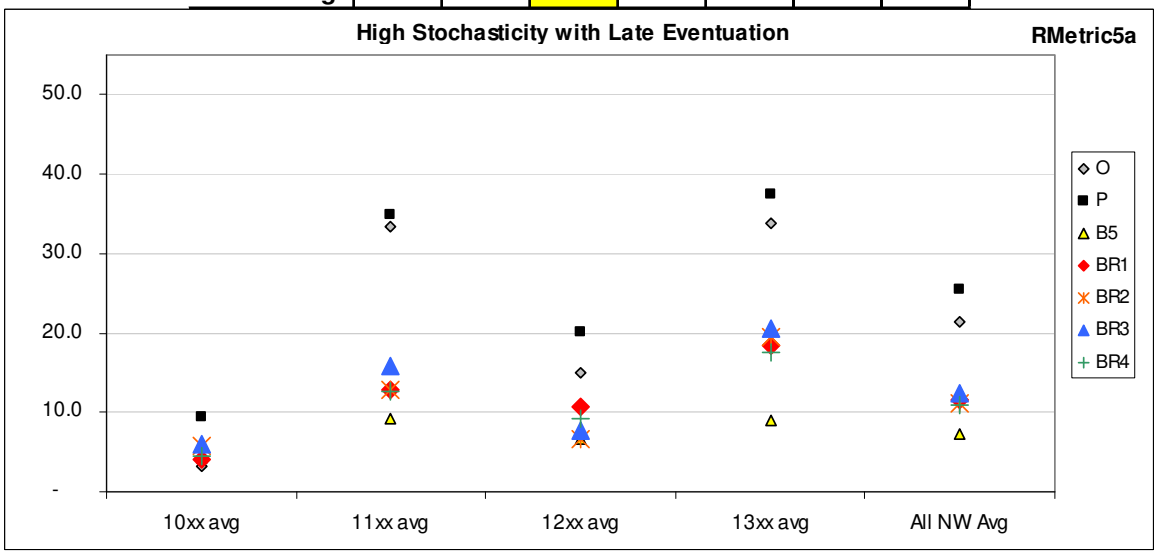
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	10.95	4.55	4.40	8.10	5.00	5.90	6.30
11xx avg	33.50	36.60	9.80	16.70	19.30	19.30	19.80
12xx avg	19.30	15.40	5.90	12.40	5.90	9.10	10.40
13xx avg	30.80	35.30	10.20	17.80	20.00	21.60	18.30
All NW Avg	**23.64**	**22.96**	**7.58**	**13.75**	**12.55**	**13.98**	**13.70**



RMetric5a

High Stochasticity with Late Eventuation

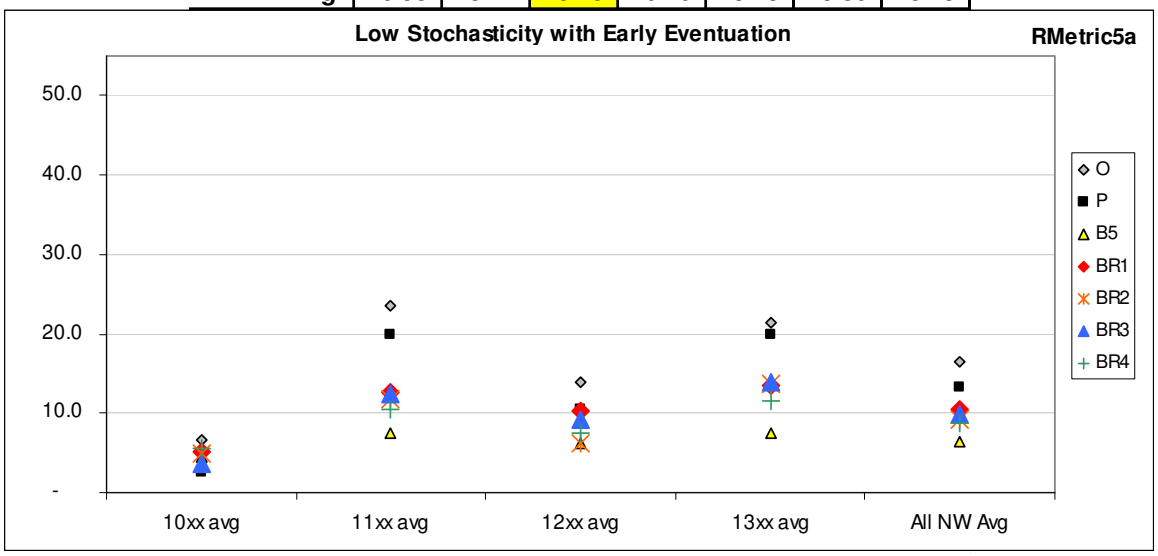
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	3.30	9.50	4.30	4.10	5.70	6.00	4.60
11xx avg	33.40	34.80	9.20	12.80	12.90	15.90	12.70
12xx avg	14.90	20.20	6.70	10.80	6.70	7.60	9.10
13xx avg	33.80	37.40	8.90	18.30	19.40	20.50	17.50
All NW Avg	**21.35**	**25.48**	**7.28**	**11.50**	**11.18**	**12.50**	**10.98**



RMetric5a

Low Stochasticity with Early Eventuation

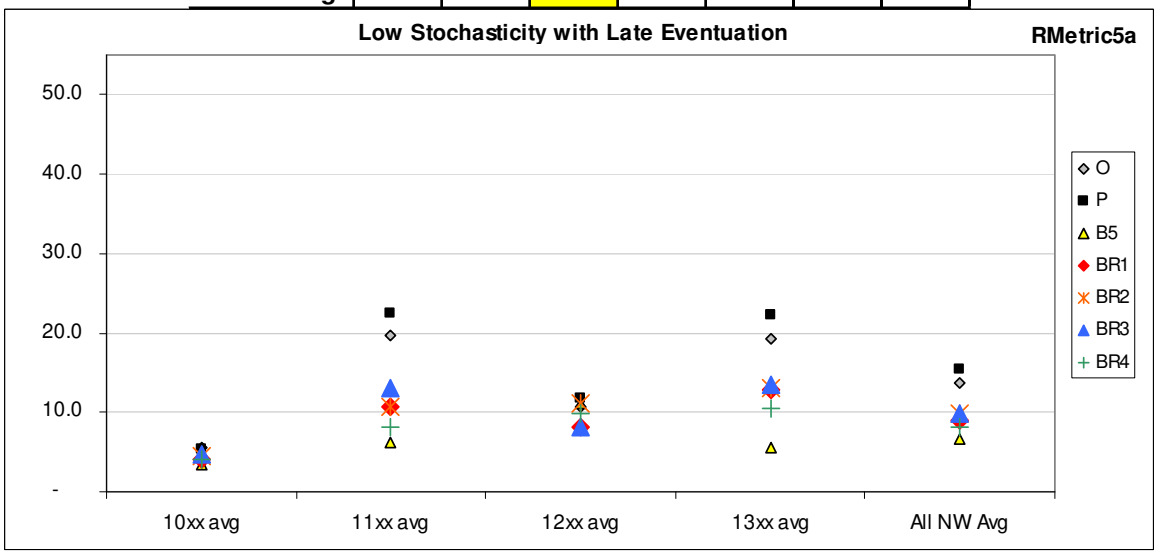
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	6.70	2.65	4.55	5.20	4.90	3.70	5.60
11xx avg	23.60	20.00	7.50	12.70	11.70	12.40	10.40
12xx avg	13.90	10.40	6.30	10.20	6.30	9.10	7.50
13xx avg	21.30	19.80	7.50	13.50	13.70	14.00	11.50
All NW Avg	**16.38**	**13.21**	**6.46**	**10.40**	**9.15**	**9.80**	**8.75**

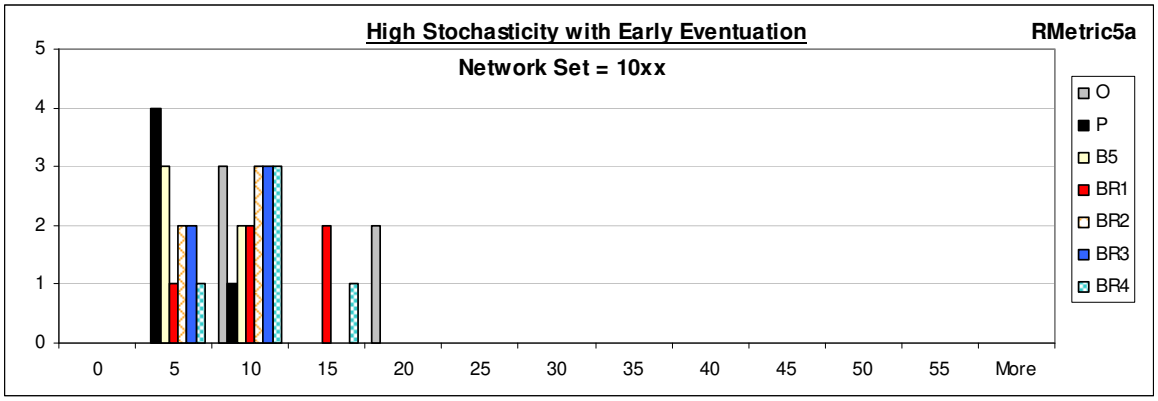


RMetric5a

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	5.50	5.30	3.40	4.00	4.60	4.70	4.10
11xx avg	19.60	22.50	6.10	10.70	10.70	13.00	8.10
12xx avg	10.70	11.70	11.20	8.20	11.20	8.20	9.90
13xx avg	19.30	22.30	5.50	12.90	13.10	13.40	10.40
All NW Avg	**13.78**	**15.45**	**6.55**	**8.95**	**9.90**	**9.83**	**8.13**




High Stochasticity with Early Eventuation
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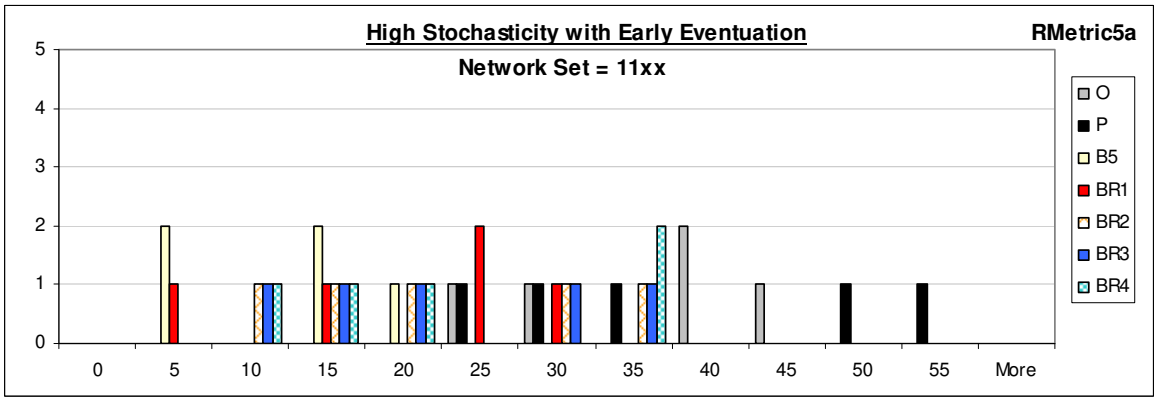
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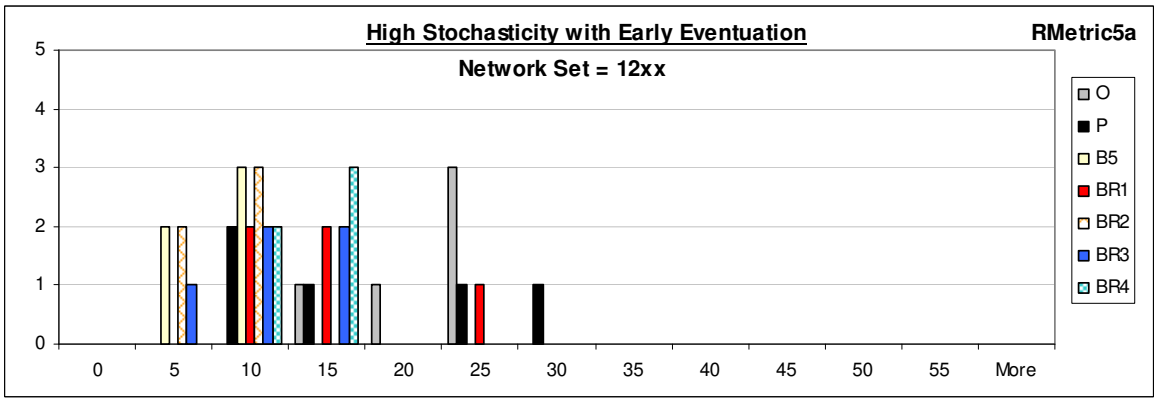
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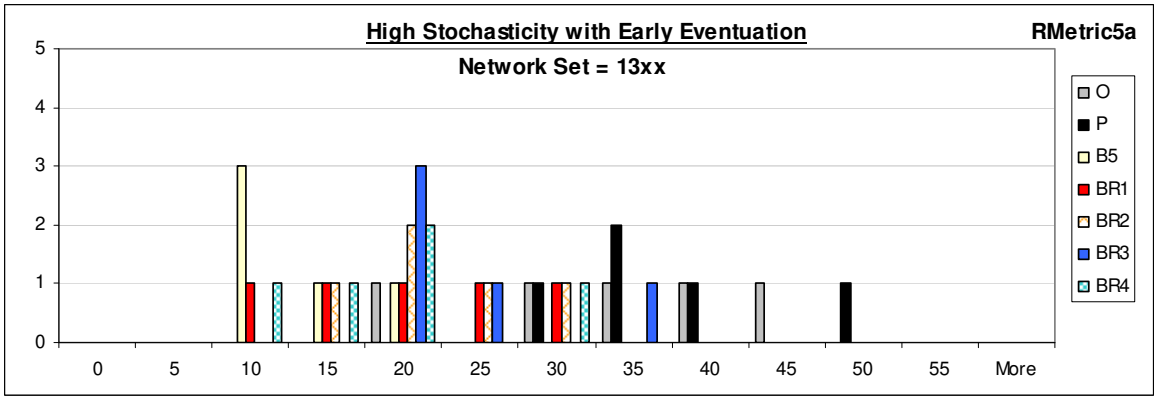
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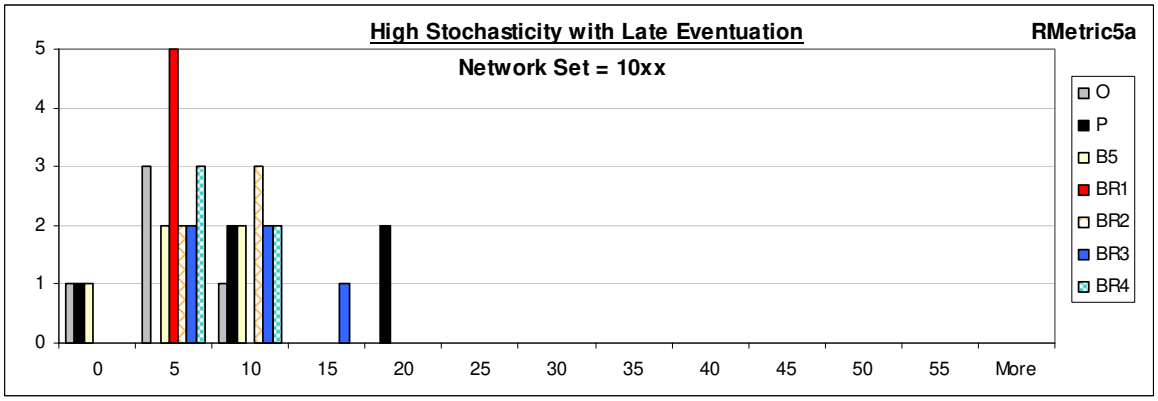
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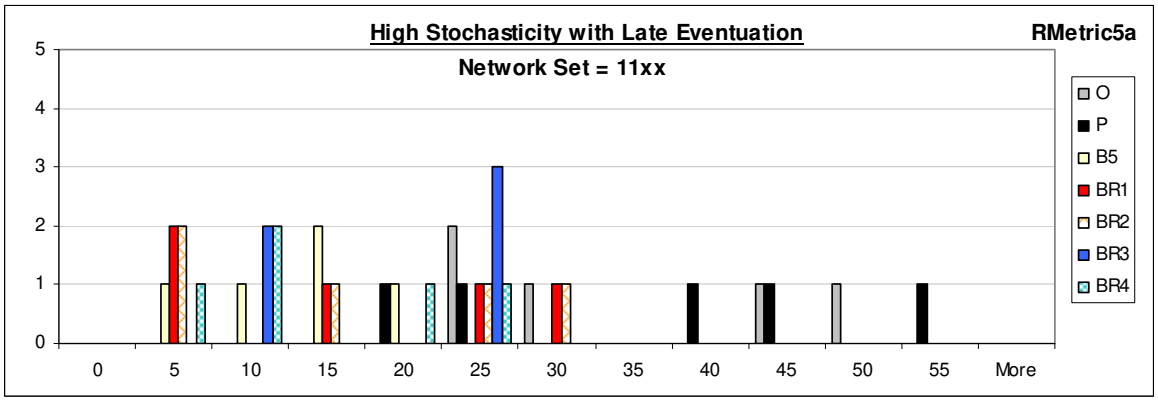
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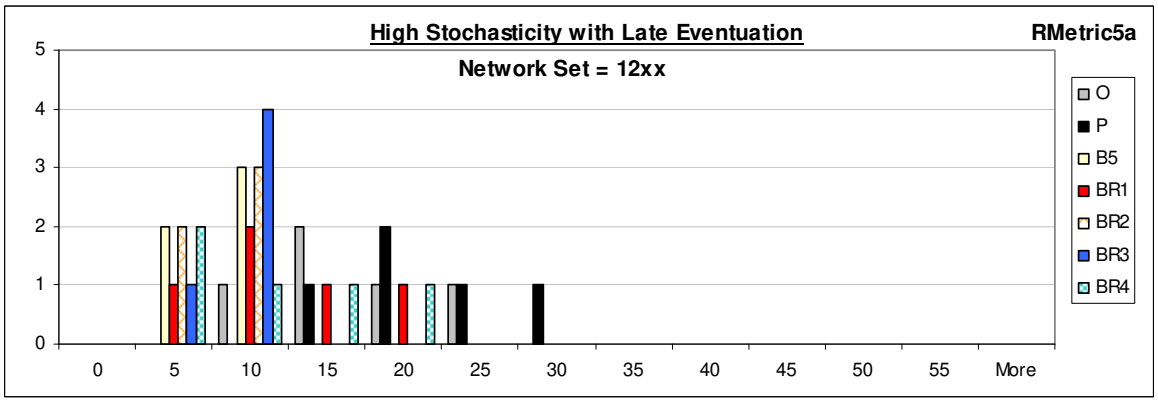
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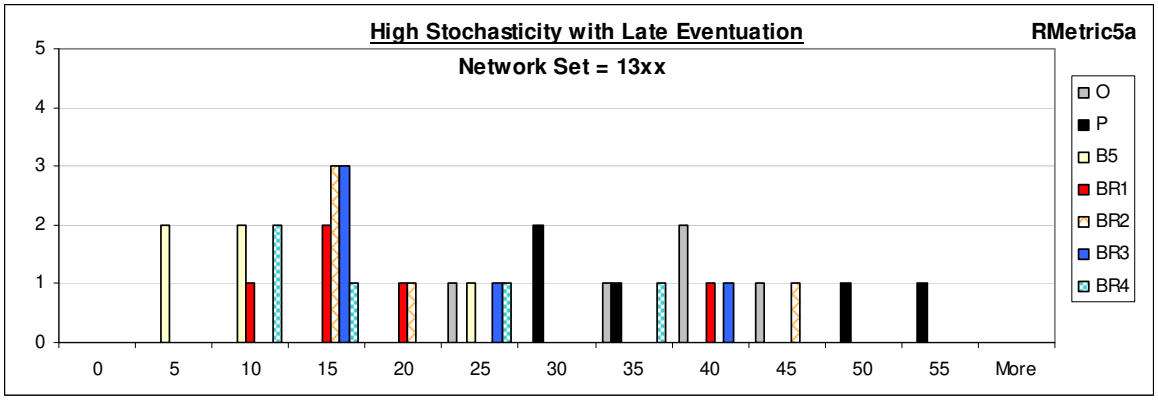
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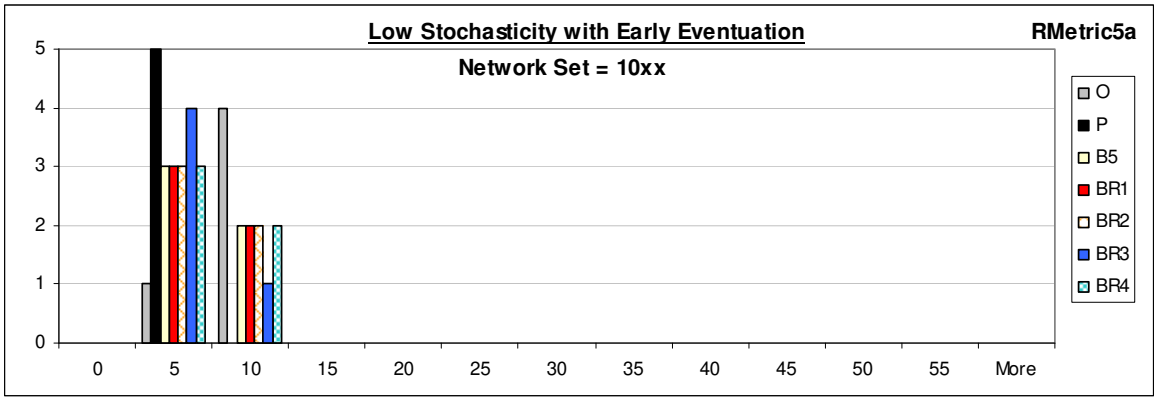
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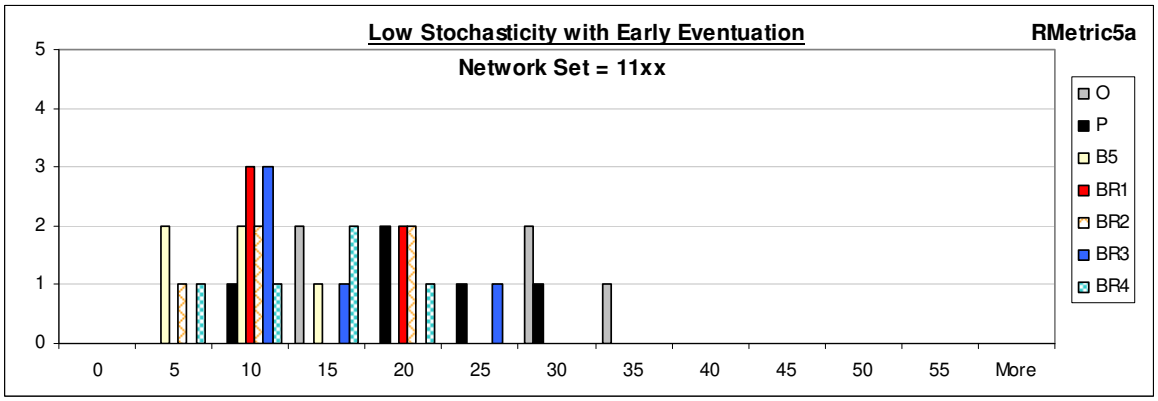
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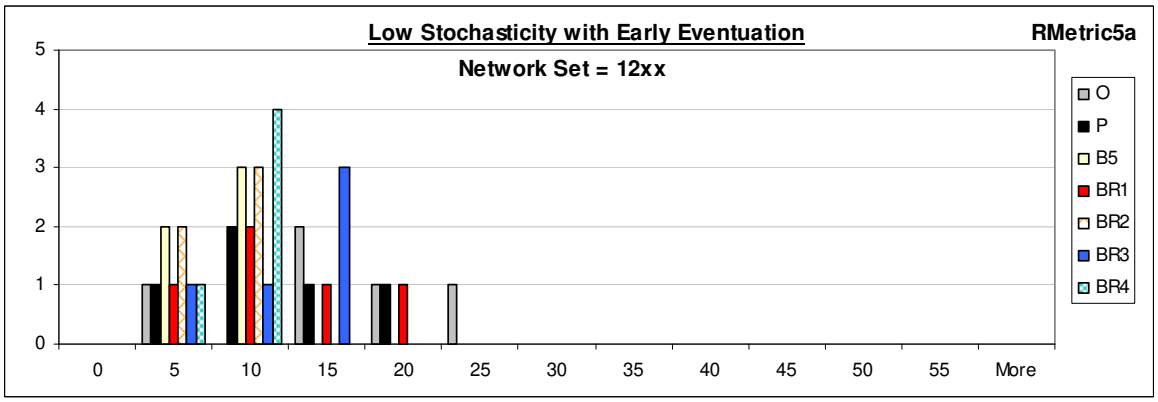
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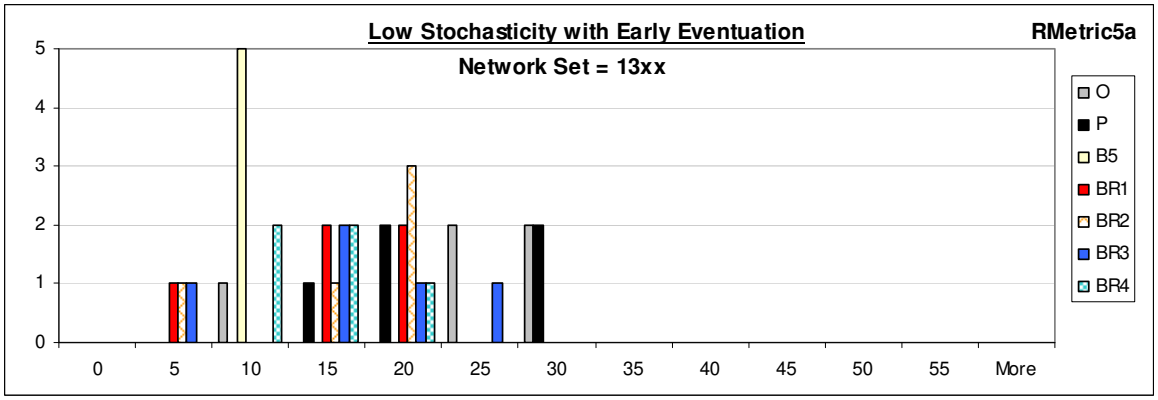
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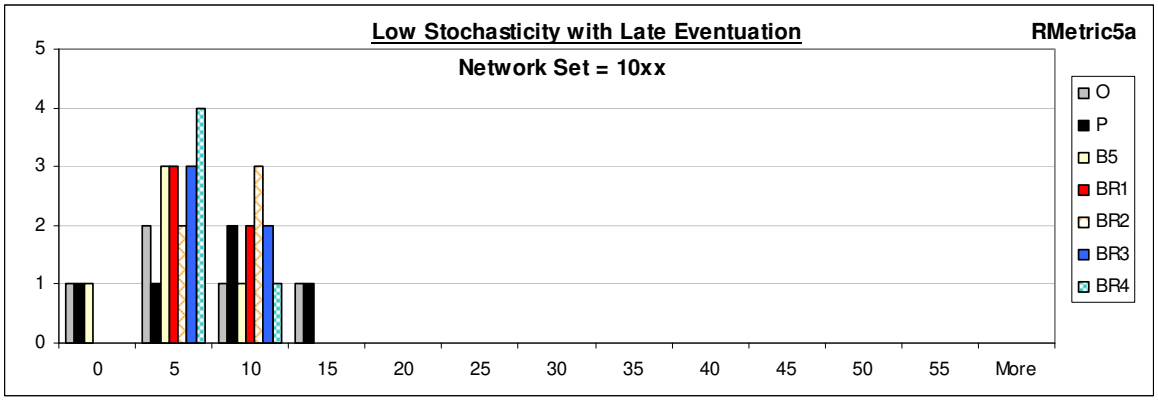
Low Stochasticity with Late Eventuation
RMetric5a
Network Set = 10xx
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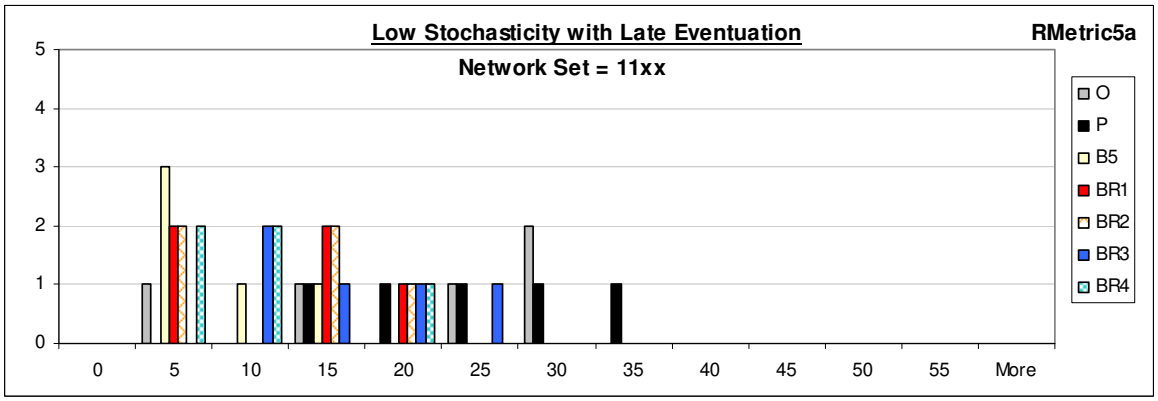
Low Stochasticity with Late Eventuation
RMetric5a
Network Set = 11xx
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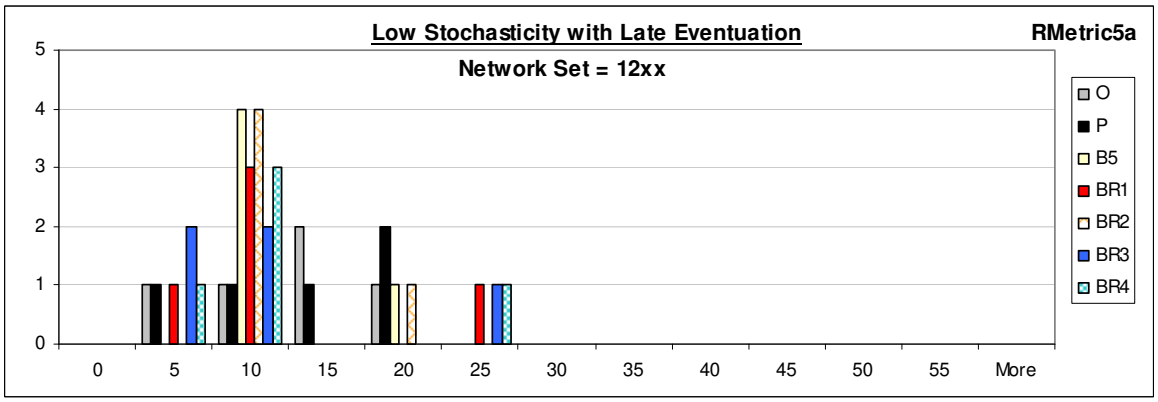
Low Stochasticity with Late Eventuation
RMetric5a
Network Set = 12xx
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BR1
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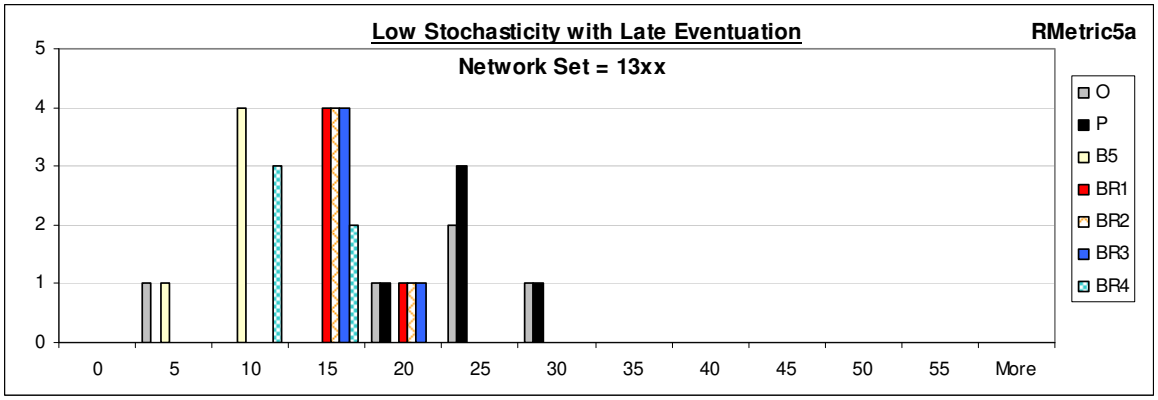
Low Stochasticity with Late Eventuation
RMetric5a
Network Set = 13xx
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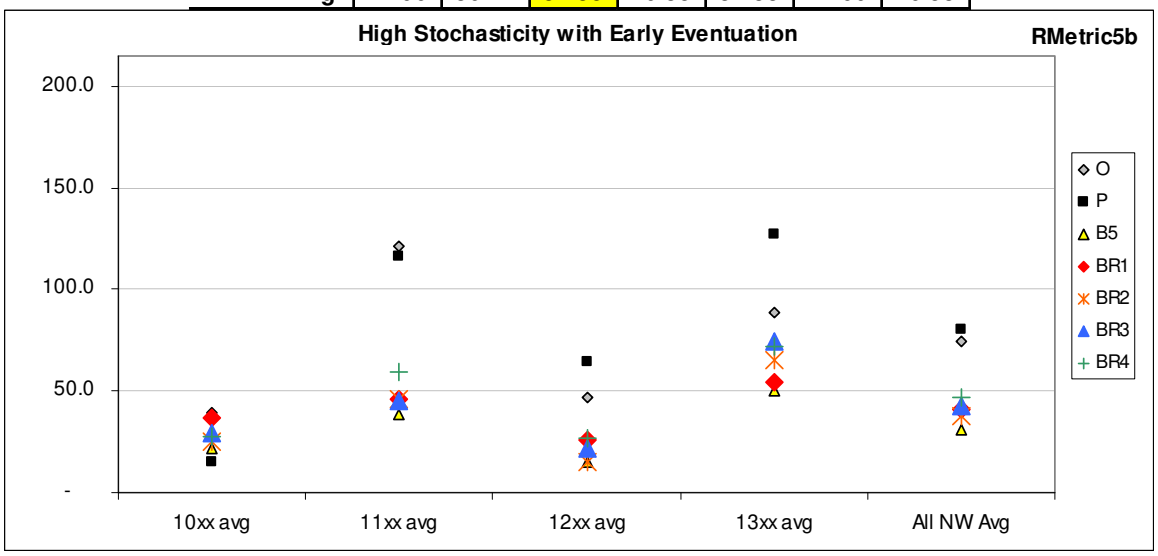
RMetric5b

High Stochasticity with Early Eventuation

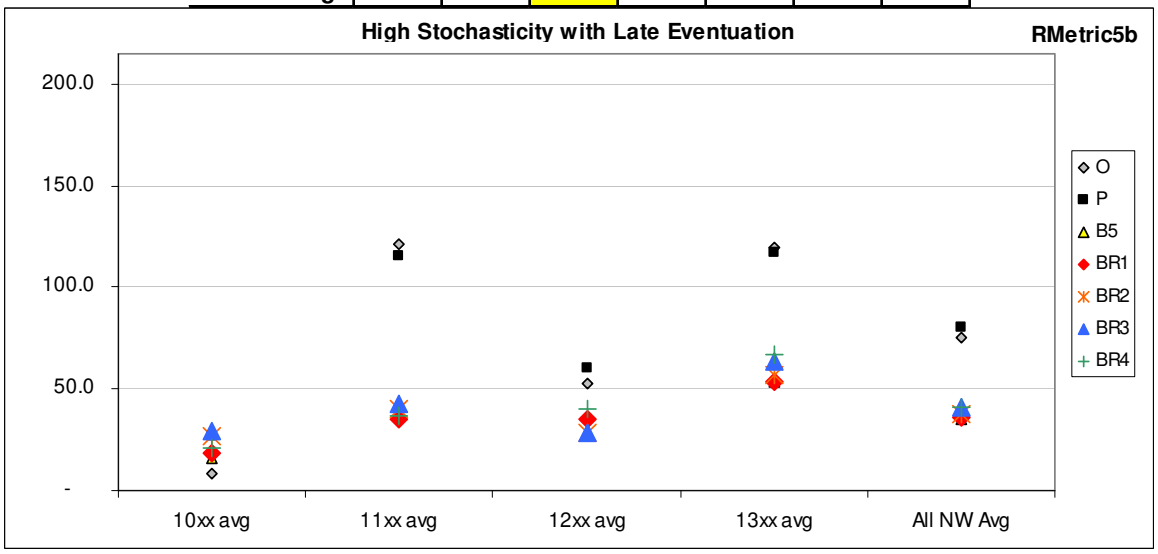
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	39.15	14.65	21.70	37.00	24.90	29.50	27.90
11xx avg	121.5	116.1	38.80	46.00	46.40	45.40	59.30
12xx avg	46.90	64.80	14.90	25.80	14.90	21.40	26.80
13xx avg	88.70	127.3	50.00	54.60	65.10	74.10	72.30
All NW Avg	**74.06**	**80.71**	**31.35**	**40.85**	**37.83**	**42.60**	**46.58**



RMetric5b

High Stochasticity with Late Eventuation

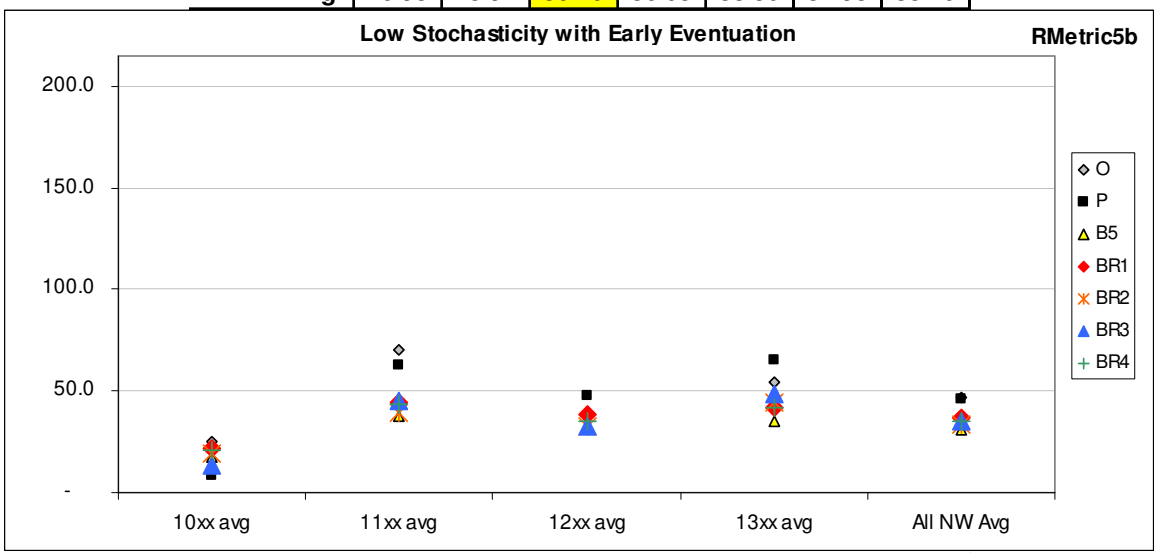
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	8.20	26.50	15.60	18.70	26.40	29.10	20.70
11xx avg	121.3	115.6	42.20	34.90	40.00	42.50	37.00
12xx avg	52.90	60.60	28.30	35.50	28.30	28.40	40.40
13xx avg	119.9	117.5	53.80	53.70	56.70	63.50	66.80
All NW Avg	**75.58**	**80.05**	**34.98**	**35.70**	**37.85**	**40.88**	**41.23**



RMetric5b

Low Stochasticity with Early Eventuation

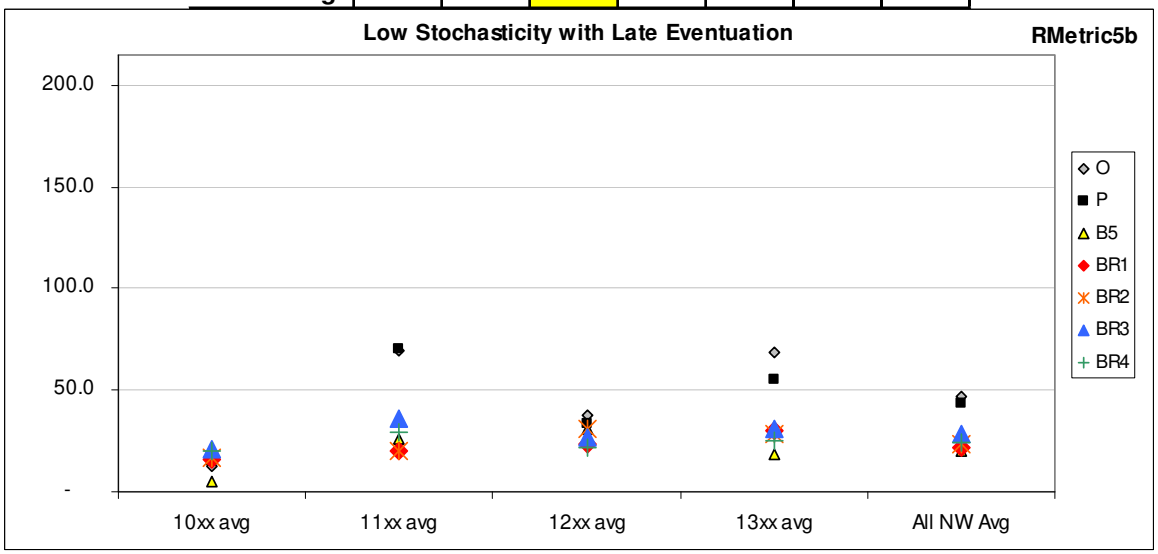
NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	25.10	8.25	17.20	21.70	19.30	13.30	20.80
11xx avg	69.90	62.40	37.80	44.70	39.30	45.10	43.70
12xx avg	38.50	48.00	32.50	38.20	32.50	32.80	34.80
13xx avg	54.40	65.00	35.30	42.00	44.10	48.70	41.50
All NW Avg	**46.98**	**45.91**	**30.70**	**36.65**	**33.80**	**34.98**	**35.20**

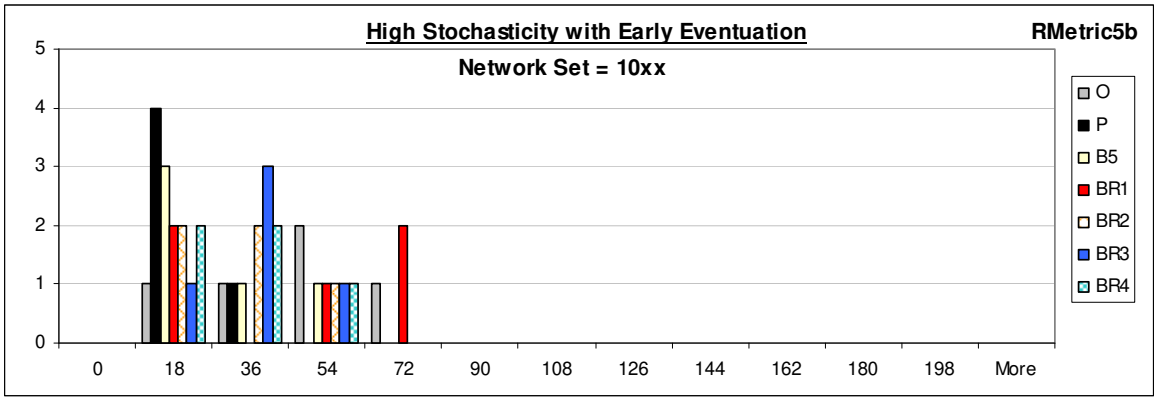


RMetric5b

Low Stochasticity with Late Eventuation

NW Set	O	P	B5	BR1	BR2	BR3	BR4
10xx avg	12.70	14.90	4.90	15.50	16.40	20.50	20.10
11xx avg	69.30	70.40	25.70	19.70	19.70	36.30	29.60
12xx avg	37.90	33.60	31.00	23.20	31.00	27.00	21.70
13xx avg	69.00	55.10	18.20	30.20	28.10	30.70	24.80
All NW Avg	**47.23**	**43.50**	**19.95**	**22.15**	**23.80**	**28.63**	**24.05**




High Stochasticity with Early Eventuation
RMetric5b
Network Set = 10xx
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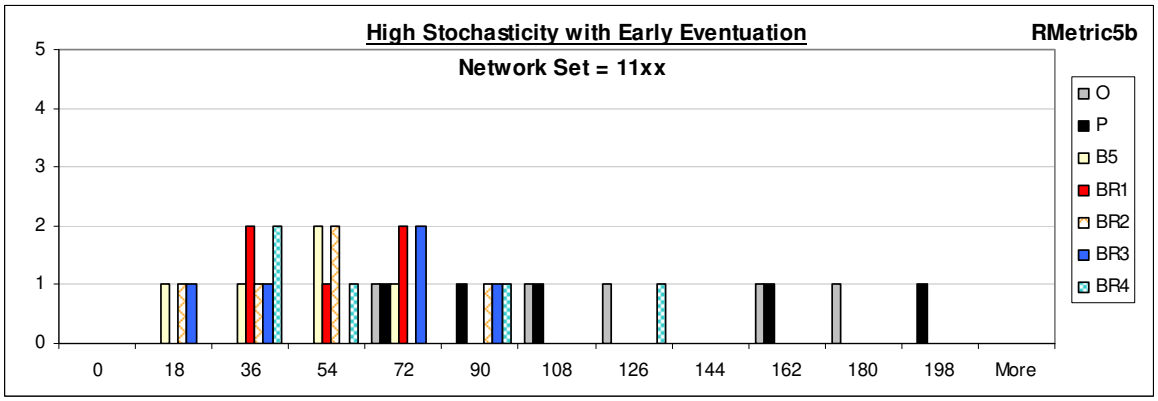
High Stochasticity with Early Eventuation
RMetric5b
Network Set = 11xx
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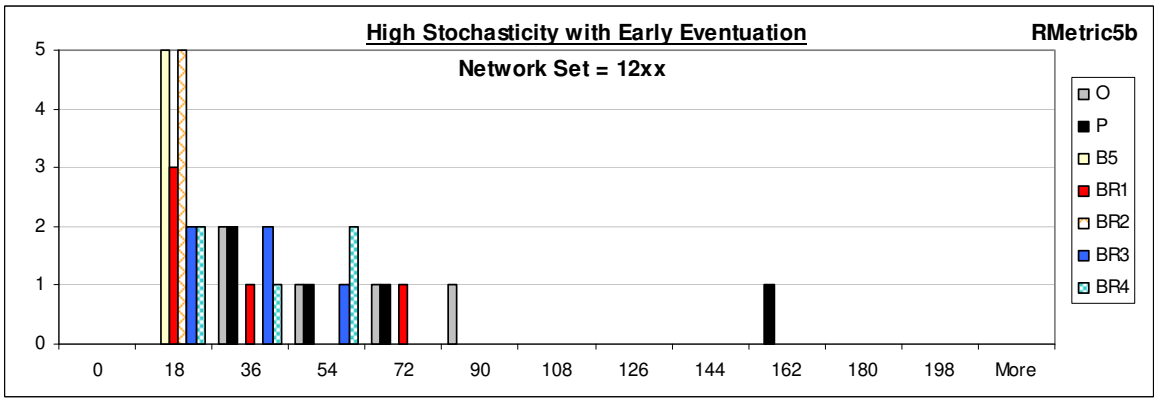
High Stochasticity with Early Eventuation
RMetric5b
Network Set = 12xx
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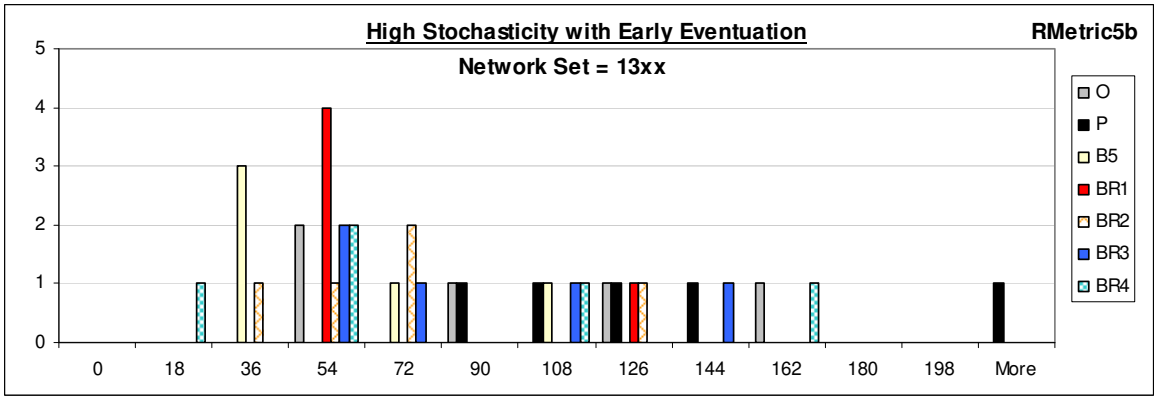
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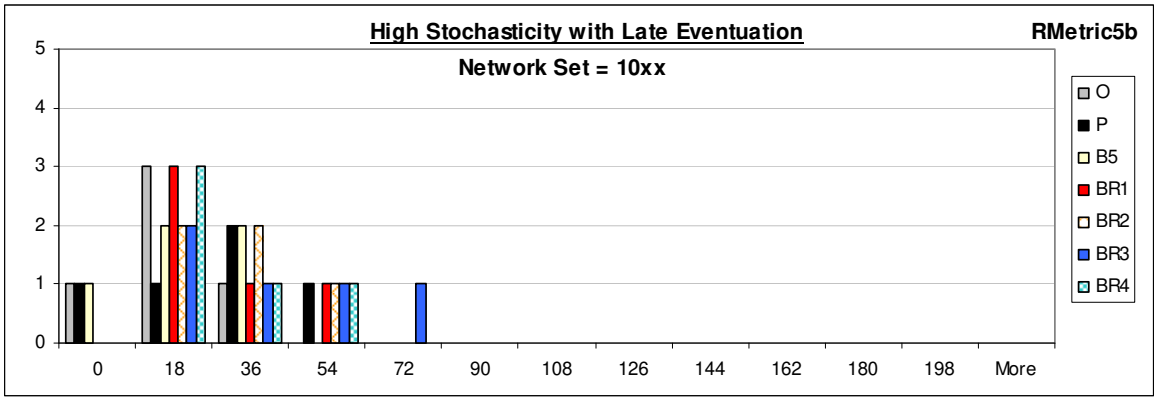
High Stochasticity with Late Eventuation
RMetric5b
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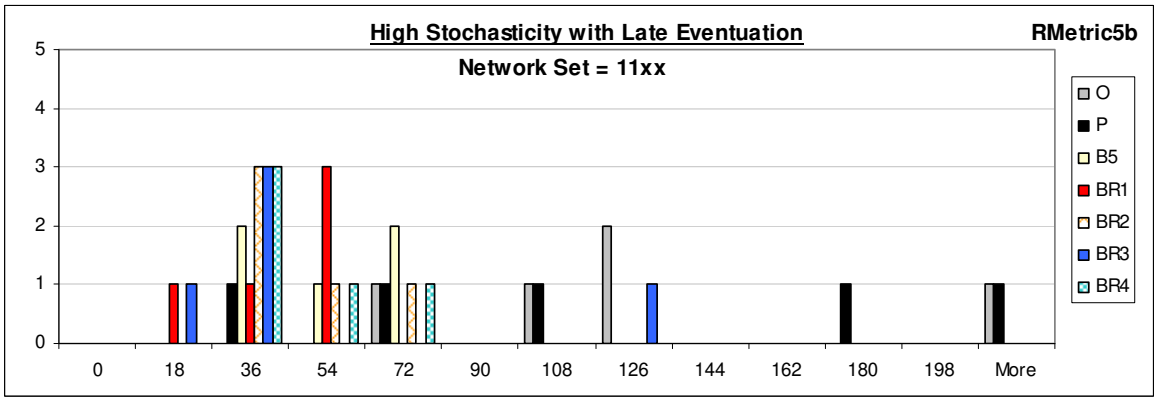
High Stochasticity with Late Eventuation
RMetric5b
Network Set = 11xx
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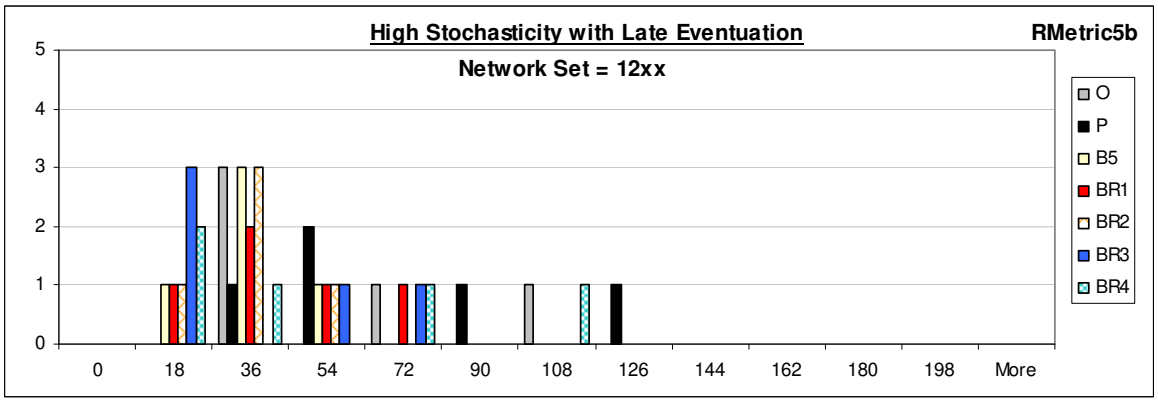
High Stochasticity with Late Eventuation
RMetric5b
Network Set = 12xx
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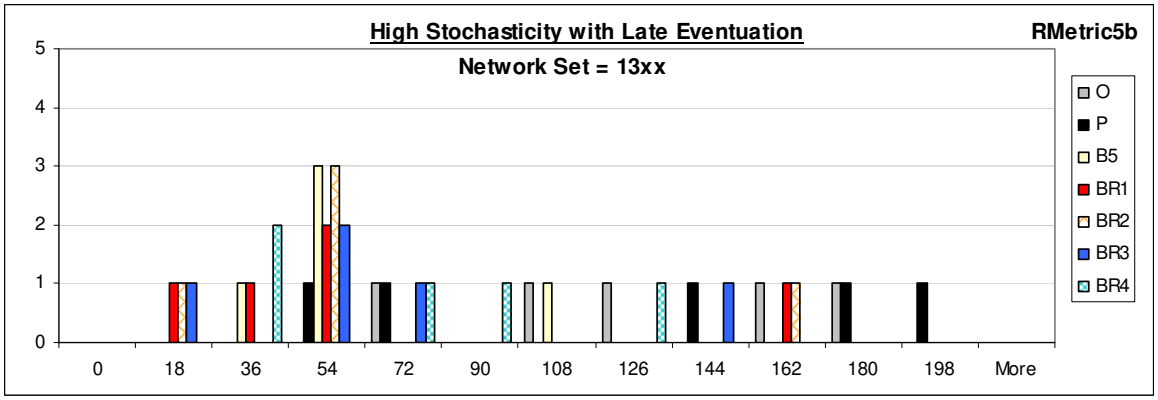
High Stochasticity with Late Eventuation
RMetric5b
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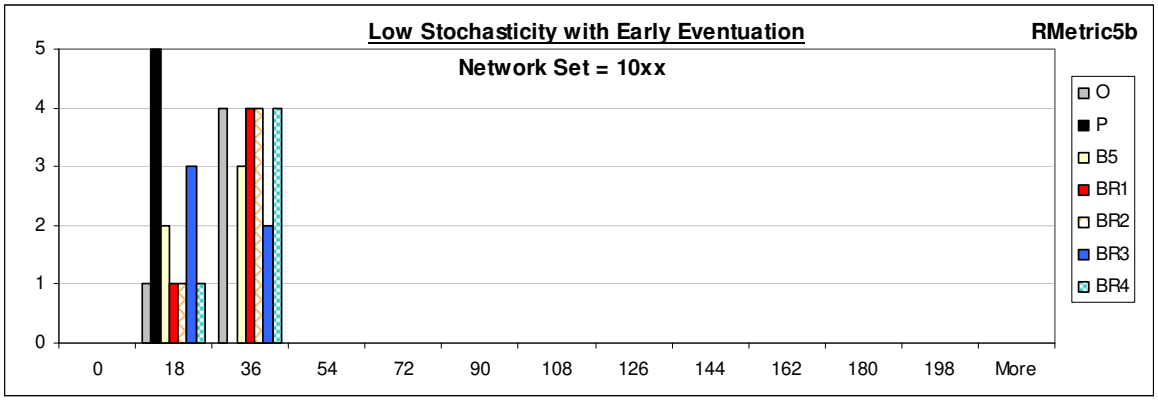
Low Stochasticity with Early Eventuation
RMetric5b
Network Set = 10xx
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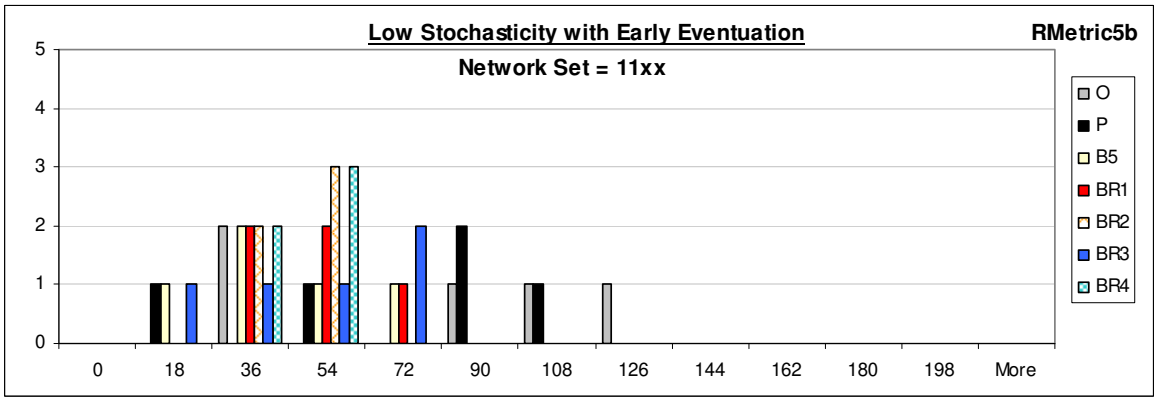
Low Stochasticity with Early Eventuation
RMetric5b
Network Set = 11xx
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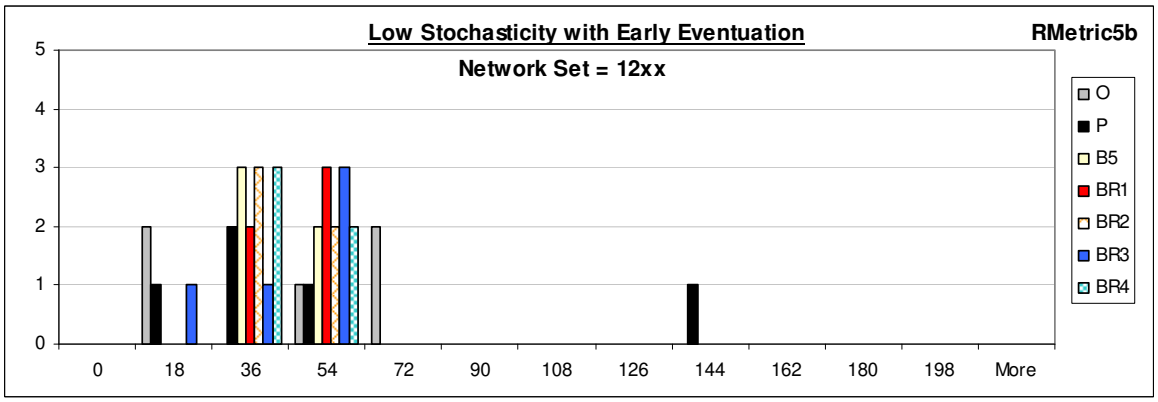
Low Stochasticity with Early Eventuation
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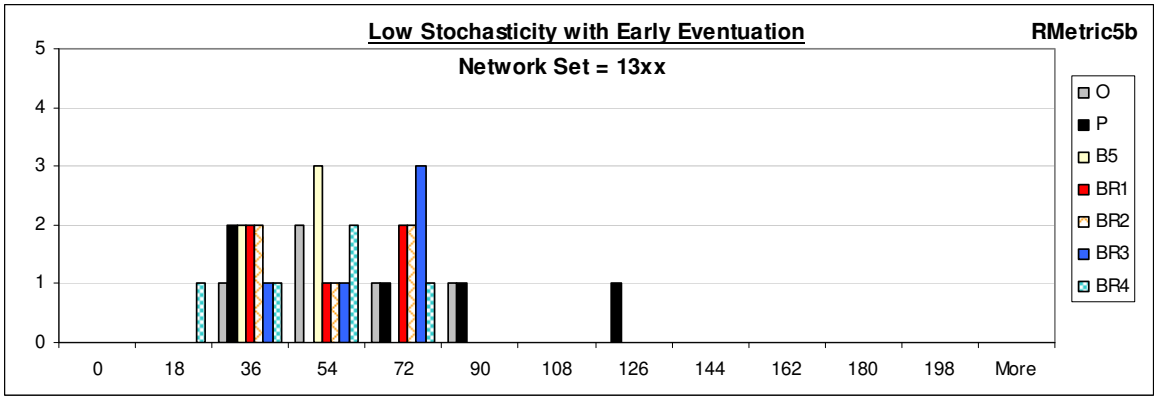
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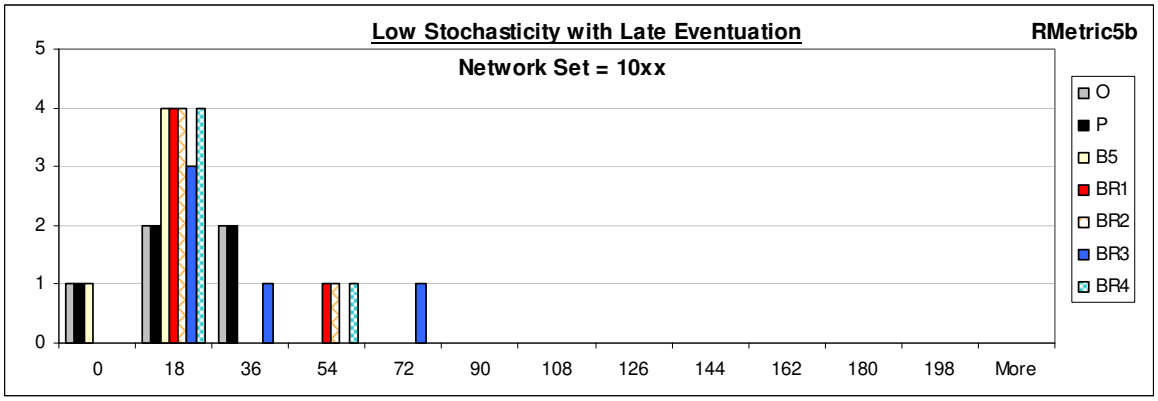
Low Stochasticity with Late Eventuation
RMetric5b
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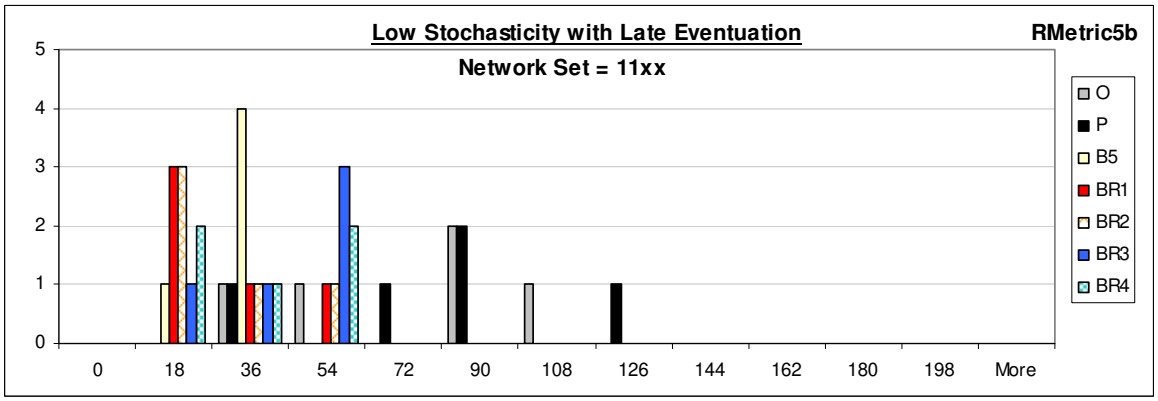
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RMetric5b
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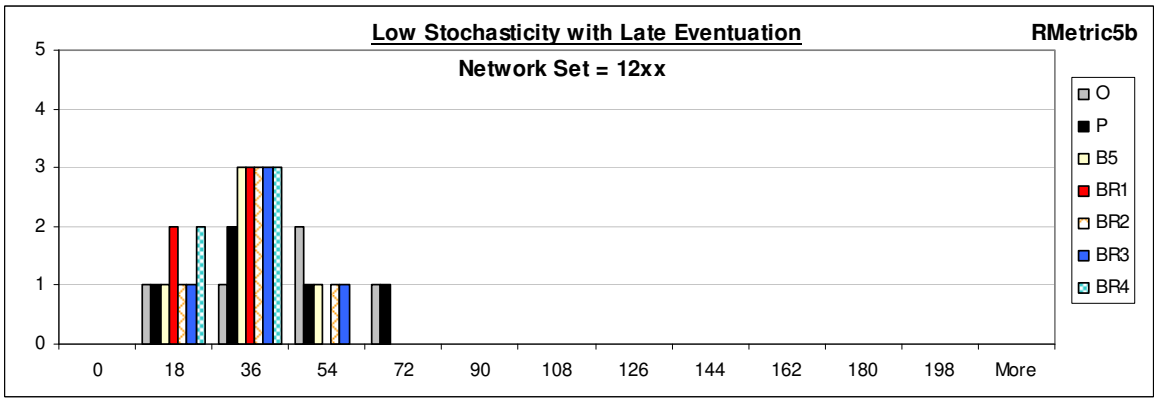
Low Stochasticity with Late Eventuation
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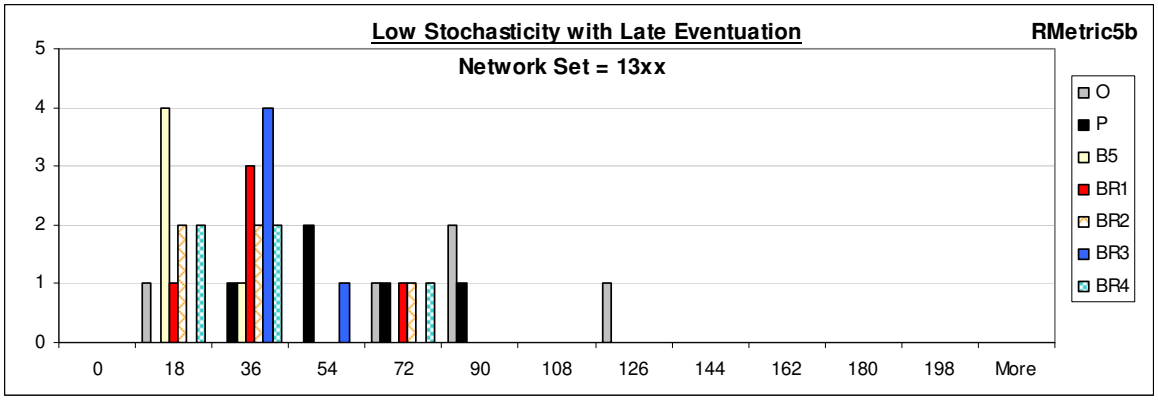
Low Stochasticity with Late Eventuation
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APPENDIX I: RESULTS FOR USING RESOURCE BUFFERS

GLM Results

The results of a series of fixed effects models are contained here, one for each metric including duration. The rows of the tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating a significant factor or interaction effect.

Duration

Metric	Source	DF	SS Error	F-Val	P-Val
Duration	loc	1	57.857	0.857	0.355
Duration	met*res*net*stoc*loc	6	4.886	0.012	1.000
Duration	meth	6	79.386	0.196	0.978
Duration	meth*loc	6	3.543	0.009	1.000
Duration	meth*net	6	36.643	0.090	0.997
Duration	meth*net*loc	6	46.386	0.114	0.995
Duration	meth*net*stoch	6	19.043	0.047	1.000
Duration	meth*net*stoch*loc	6	3.043	0.008	1.000
Duration	meth*res	6	9.743	0.024	1.000
Duration	meth*res*loc	6	8.900	0.022	1.000
Duration	meth*res*net	6	28.286	0.070	0.999
Duration	meth*res*net*loc	6	62.086	0.153	0.988
Duration	meth*res*net*stoch	6	48.943	0.121	0.994
Duration	meth*res*stoch	6	20.400	0.050	0.999
Duration	meth*res*stoch*loc	6	6.871	0.017	1.000
Duration	meth*stoch	6	14.271	0.035	1.000
Duration	meth*stoch*loc	6	10.486	0.026	1.000
Duration	net	1	36,482.857	540.237	0.000
Duration	net*loc	1	634.314	9.393	0.002
Duration	net*stoch	1	57.857	0.857	0.355
Duration	net*stoch*loc	1	9.257	0.137	0.711
Duration	res	1	387,977.857	5,745.160	0.000
Duration	res*loc	1	12.600	0.187	0.666
Duration	res*net	1	15,645.714	231.681	0.000
Duration	res*net*loc	1	0.714	0.011	0.918
Duration	res*net*stoch	1	333.257	4.935	0.027
Duration	res*net*stoch*loc	1	2.314	0.034	0.853
Duration	res*stoch	1	2,710.400	40.135	0.000
Duration	res*stoch*loc	1	71.429	1.058	0.304
Duration	stoch	1	28,286.429	418.864	0.000
Duration	stoch*loc	1	31.114	0.461	0.498
Duration	ERROR	448	30,254.000	0.000	-

Robustness Metrics

Metric	Source	DF	SS Error	F-Val	P-Val
Metric1	loc	1	0.028	17.683	0.000
Metric1	met*res*net*stoc*loc	6	0.002	0.202	0.976
Metric1	meth	6	0.009	0.955	0.455
Metric1	meth*loc	6	0.004	0.425	0.862
Metric1	meth*net	6	0.011	1.108	0.357
Metric1	meth*net*loc	6	0.016	1.669	0.127
Metric1	meth*net*stoch	6	0.003	0.352	0.909
Metric1	meth*net*stoch*loc	6	0.002	0.254	0.957
Metric1	meth*res	6	0.019	2.028	0.061
Metric1	meth*res*loc	6	0.003	0.345	0.913
Metric1	meth*res*net	6	0.002	0.197	0.978
Metric1	meth*res*net*loc	6	0.006	0.621	0.713
Metric1	meth*res*net*stoch	6	0.006	0.593	0.736
Metric1	meth*res*stoch	6	0.007	0.721	0.633
Metric1	meth*res*stoch*loc	6	0.003	0.281	0.946
Metric1	meth*stoch	6	0.000	0.026	1.000
Metric1	meth*stoch*loc	6	0.002	0.162	0.987
Metric1	net	1	0.088	55.946	0.000
Metric1	net*loc	1	0.046	28.993	0.000
Metric1	net*stoch	1	0.031	19.821	0.000
Metric1	net*stoch*loc	1	0.000	0.208	0.648
Metric1	res	1	0.000	0.032	0.858
Metric1	res*loc	1	0.020	12.713	0.000
Metric1	res*net	1	0.002	1.441	0.231
Metric1	res*net*loc	1	0.028	17.827	0.000
Metric1	res*net*stoch	1	0.001	0.516	0.473
Metric1	res*net*stoch*loc	1	0.020	12.565	0.000
Metric1	res*stoch	1	0.001	0.719	0.397
Metric1	res*stoch*loc	1	0.006	3.798	0.052
Metric1	stoch	1	0.015	9.653	0.002
Metric1	stoch*loc	1	0.000	0.099	0.753
Metric1	ERROR	448	0.709	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric2	loc	1	0.021	1.179	0.278
Metric2	met*res*net*stoc*loc	6	0.006	0.059	0.999
Metric2	meth	6	28.247	268.179	0.000
Metric2	meth*loc	6	0.007	0.069	0.999
Metric2	meth*net	6	0.966	9.170	0.000
Metric2	meth*net*loc	6	0.051	0.480	0.823
Metric2	meth*net*stoch	6	0.727	6.898	0.000
Metric2	meth*net*stoch*loc	6	0.004	0.035	1.000
Metric2	meth*res	6	5.000	47.475	0.000
Metric2	meth*res*loc	6	0.013	0.120	0.994
Metric2	meth*res*net	6	0.526	4.992	0.000
Metric2	meth*res*net*loc	6	0.039	0.368	0.899
Metric2	meth*res*net*stoch	6	0.218	2.069	0.056
Metric2	meth*res*stoch	6	1.455	13.810	0.000
Metric2	meth*res*stoch*loc	6	0.006	0.053	0.999
Metric2	meth*stoch	6	10.674	101.337	0.000
Metric2	meth*stoch*loc	6	0.011	0.101	0.996
Metric2	net	1	0.001	0.037	0.847
Metric2	net*loc	1	0.001	0.061	0.805
Metric2	net*stoch	1	0.151	8.603	0.004
Metric2	net*stoch*loc	1	0.004	0.232	0.630
Metric2	res	1	0.209	11.885	0.001
Metric2	res*loc	1	0.019	1.111	0.293
Metric2	res*net	1	0.279	15.897	0.000
Metric2	res*net*loc	1	0.054	3.052	0.081
Metric2	res*net*stoch	1	0.034	1.951	0.163
Metric2	res*net*stoch*loc	1	0.000	0.026	0.872
Metric2	res*stoch	1	0.452	25.763	0.000
Metric2	res*stoch*loc	1	0.002	0.091	0.763
Metric2	stoch	1	9.209	524.617	0.000
Metric2	stoch*loc	1	0.017	0.995	0.319
Metric2	ERROR	448	7.864	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric3	loc	1	0.725	19.713	0.000
Metric3	met*res*net*stoc*loc	6	0.009	0.042	1.000
Metric3	meth	6	0.402	1.821	0.093
Metric3	meth*loc	6	0.364	1.648	0.132
Metric3	meth*net	6	0.108	0.489	0.817
Metric3	meth*net*loc	6	0.231	1.047	0.394
Metric3	meth*net*stoch	6	0.093	0.421	0.865
Metric3	meth*net*stoch*loc	6	0.011	0.051	0.999
Metric3	meth*res	6	1.362	6.174	0.000
Metric3	meth*res*loc	6	0.263	1.190	0.310
Metric3	meth*res*net	6	0.060	0.272	0.950
Metric3	meth*res*net*loc	6	0.095	0.430	0.859
Metric3	meth*res*net*stoch	6	0.031	0.140	0.991
Metric3	meth*res*stoch	6	0.080	0.363	0.902
Metric3	meth*res*stoch*loc	6	0.067	0.302	0.936
Metric3	meth*stoch	6	0.070	0.319	0.927
Metric3	meth*stoch*loc	6	0.055	0.250	0.959
Metric3	net	1	6.237	169.570	0.000
Metric3	net*loc	1	0.967	26.304	0.000
Metric3	net*stoch	1	0.470	12.769	0.000
Metric3	net*stoch*loc	1	0.079	2.152	0.143
Metric3	res	1	17.493	475.630	0.000
Metric3	res*loc	1	0.406	11.049	0.001
Metric3	res*net	1	2.121	57.676	0.000
Metric3	res*net*loc	1	0.077	2.105	0.148
Metric3	res*net*stoch	1	0.182	4.948	0.027
Metric3	res*net*stoch*loc	1	0.025	0.672	0.413
Metric3	res*stoch	1	0.005	0.124	0.725
Metric3	res*stoch*loc	1	0.005	0.145	0.704
Metric3	stoch	1	0.046	1.257	0.263
Metric3	stoch*loc	1	0.177	4.821	0.029
Metric3	ERROR	448	16.477	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric4	loc	1	0.036	3.600	0.058
Metric4	met*res*net*stoc*loc	6	0.010	0.158	0.987
Metric4	meth	6	1.261	20.943	0.000
Metric4	meth*loc	6	0.025	0.413	0.870
Metric4	meth*net	6	0.242	4.012	0.001
Metric4	meth*net*loc	6	0.048	0.797	0.572
Metric4	meth*net*stoch	6	0.037	0.613	0.720
Metric4	meth*net*stoch*loc	6	0.041	0.674	0.671
Metric4	meth*res	6	0.289	4.796	0.000
Metric4	meth*res*loc	6	0.118	1.958	0.070
Metric4	meth*res*net	6	0.026	0.432	0.858
Metric4	meth*res*net*loc	6	0.100	1.659	0.129
Metric4	meth*res*net*stoch	6	0.022	0.361	0.904
Metric4	meth*res*stoch	6	0.044	0.724	0.631
Metric4	meth*res*stoch*loc	6	0.016	0.266	0.953
Metric4	meth*stoch	6	0.022	0.365	0.901
Metric4	meth*stoch*loc	6	0.009	0.154	0.988
Metric4	net	1	2.867	285.724	0.000
Metric4	net*loc	1	0.002	0.248	0.619
Metric4	net*stoch	1	0.028	2.760	0.097
Metric4	net*stoch*loc	1	0.017	1.678	0.196
Metric4	res	1	4.455	444.005	0.000
Metric4	res*loc	1	0.031	3.134	0.077
Metric4	res*net	1	0.192	19.153	0.000
Metric4	res*net*loc	1	0.032	3.214	0.074
Metric4	res*net*stoch	1	0.000	0.044	0.834
Metric4	res*net*stoch*loc	1	0.022	2.205	0.138
Metric4	res*stoch	1	0.018	1.807	0.180
Metric4	res*stoch*loc	1	0.002	0.248	0.618
Metric4	stoch	1	0.022	2.180	0.141
Metric4	stoch*loc	1	0.012	1.214	0.271
Metric4	ERROR	448	4.495	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric5	loc	1	0.174	22.813	0.000
Metric5	met*res*net*stoc*loc	6	0.018	0.387	0.887
Metric5	meth	6	0.043	0.938	0.468
Metric5	meth*loc	6	0.018	0.403	0.877
Metric5	meth*net	6	0.221	4.842	0.000
Metric5	meth*net*loc	6	0.019	0.425	0.862
Metric5	meth*net*stoch	6	0.010	0.224	0.969
Metric5	meth*net*stoch*loc	6	0.002	0.052	0.999
Metric5	meth*res	6	0.470	10.292	0.000
Metric5	meth*res*loc	6	0.033	0.711	0.641
Metric5	meth*res*net	6	0.312	6.826	0.000
Metric5	meth*res*net*loc	6	0.019	0.412	0.871
Metric5	meth*res*net*stoch	6	0.023	0.500	0.809
Metric5	meth*res*stoch	6	0.006	0.125	0.993
Metric5	meth*res*stoch*loc	6	0.018	0.399	0.880
Metric5	meth*stoch	6	0.004	0.095	0.997
Metric5	meth*stoch*loc	6	0.003	0.059	0.999
Metric5	net	1	0.745	97.833	0.000
Metric5	net*loc	1	0.145	19.009	0.000
Metric5	net*stoch	1	0.003	0.333	0.564
Metric5	net*stoch*loc	1	0.015	1.934	0.165
Metric5	res	1	1.635	214.659	0.000
Metric5	res*loc	1	0.004	0.568	0.452
Metric5	res*net	1	0.012	1.634	0.202
Metric5	res*net*loc	1	0.012	1.526	0.217
Metric5	res*net*stoch	1	0.000	0.034	0.855
Metric5	res*net*stoch*loc	1	0.010	1.255	0.263
Metric5	res*stoch	1	0.000	0.055	0.814
Metric5	res*stoch*loc	1	0.035	4.599	0.033
Metric5	stoch	1	0.017	2.211	0.138
Metric5	stoch*loc	1	0.029	3.773	0.053
Metric5	ERROR	448	3.413	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric6	loc	1	0.036	20.736	0.000
Metric6	met*res*net*stoc*loc	6	0.011	1.051	0.392
Metric6	meth	6	0.014	1.317	0.248
Metric6	meth*loc	6	0.020	1.915	0.077
Metric6	meth*net	6	0.010	1.002	0.423
Metric6	meth*net*loc	6	0.024	2.356	0.030
Metric6	meth*net*stoch	6	0.003	0.329	0.921
Metric6	meth*net*stoch*loc	6	0.015	1.449	0.194
Metric6	meth*res	6	0.039	3.783	0.001
Metric6	meth*res*loc	6	0.005	0.528	0.787
Metric6	meth*res*net	6	0.034	3.260	0.004
Metric6	meth*res*net*loc	6	0.007	0.695	0.654
Metric6	meth*res*net*stoch	6	0.004	0.412	0.871
Metric6	meth*res*stoch	6	0.009	0.916	0.483
Metric6	meth*res*stoch*loc	6	0.006	0.540	0.778
Metric6	meth*stoch	6	0.006	0.554	0.767
Metric6	meth*stoch*loc	6	0.009	0.890	0.502
Metric6	net	1	1.104	642.487	0.000
Metric6	net*loc	1	0.030	17.426	0.000
Metric6	net*stoch	1	0.051	29.644	0.000
Metric6	net*stoch*loc	1	0.054	31.195	0.000
Metric6	res	1	0.778	452.488	0.000
Metric6	res*loc	1	0.106	61.949	0.000
Metric6	res*net	1	0.586	341.158	0.000
Metric6	res*net*loc	1	0.096	56.123	0.000
Metric6	res*net*stoch	1	0.075	43.514	0.000
Metric6	res*net*stoch*loc	1	0.014	8.435	0.004
Metric6	res*stoch	1	0.069	40.243	0.000
Metric6	res*stoch*loc	1	0.009	5.108	0.024
Metric6	stoch	1	0.046	26.955	0.000
Metric6	stoch*loc	1	0.042	24.414	0.000
Metric6	ERROR	448	0.770	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric7	loc	1	0.003	0.136	0.712
Metric7	met*res*net*stoc*loc	6	0.008	0.064	0.999
Metric7	meth	6	26.453	216.618	0.000
Metric7	meth*loc	6	0.046	0.377	0.894
Metric7	meth*net	6	0.585	4.790	0.000
Metric7	meth*net*loc	6	0.021	0.176	0.983
Metric7	meth*net*stoch	6	0.513	4.199	0.000
Metric7	meth*net*stoch*loc	6	0.010	0.086	0.998
Metric7	meth*res	6	5.082	41.618	0.000
Metric7	meth*res*loc	6	0.015	0.119	0.994
Metric7	meth*res*net	6	0.566	4.634	0.000
Metric7	meth*res*net*loc	6	0.022	0.183	0.981
Metric7	meth*res*net*stoch	6	0.159	1.304	0.254
Metric7	meth*res*stoch	6	1.409	11.539	0.000
Metric7	meth*res*stoch*loc	6	0.015	0.122	0.994
Metric7	meth*stoch	6	9.977	81.697	0.000
Metric7	meth*stoch*loc	6	0.010	0.084	0.998
Metric7	net	1	0.031	1.526	0.217
Metric7	net*loc	1	0.017	0.821	0.365
Metric7	net*stoch	1	0.116	5.696	0.017
Metric7	net*stoch*loc	1	0.014	0.707	0.401
Metric7	res	1	0.209	10.257	0.001
Metric7	res*loc	1	0.019	0.932	0.335
Metric7	res*net	1	0.219	10.743	0.001
Metric7	res*net*loc	1	0.035	1.729	0.189
Metric7	res*net*stoch	1	0.043	2.089	0.149
Metric7	res*net*stoch*loc	1	0.008	0.409	0.523
Metric7	res*stoch	1	0.473	23.263	0.000
Metric7	res*stoch*loc	1	0.009	0.430	0.512
Metric7	stoch	1	8.920	438.248	0.000
Metric7	stoch*loc	1	0.037	1.803	0.180
Metric7	ERROR	448	9.118	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric8	loc	1	41.483	25.444	0.000
Metric8	met*res*net*stoc*loc	6	4.187	0.428	0.860
Metric8	meth	6	60.304	6.165	0.000
Metric8	meth*loc	6	34.823	3.560	0.002
Metric8	meth*net	6	8.555	0.875	0.513
Metric8	meth*net*loc	6	1.806	0.185	0.981
Metric8	meth*net*stoch	6	5.689	0.582	0.745
Metric8	meth*net*stoch*loc	6	4.098	0.419	0.866
Metric8	meth*res	6	39.802	4.069	0.001
Metric8	meth*res*loc	6	11.920	1.219	0.295
Metric8	meth*res*net	6	8.162	0.834	0.544
Metric8	meth*res*net*loc	6	4.453	0.455	0.841
Metric8	meth*res*net*stoch	6	7.121	0.728	0.627
Metric8	meth*res*stoch	6	3.105	0.317	0.928
Metric8	meth*res*stoch*loc	6	8.749	0.894	0.499
Metric8	meth*stoch	6	4.508	0.461	0.837
Metric8	meth*stoch*loc	6	14.105	1.442	0.197
Metric8	net	1	0.001	0.001	0.980
Metric8	net*loc	1	5.459	3.348	0.068
Metric8	net*stoch	1	5.057	3.102	0.079
Metric8	net*stoch*loc	1	3.987	2.446	0.119
Metric8	res	1	1.883	1.155	0.283
Metric8	res*loc	1	17.116	10.498	0.001
Metric8	res*net	1	18.741	11.495	0.001
Metric8	res*net*loc	1	5.874	3.603	0.058
Metric8	res*net*stoch	1	9.282	5.693	0.017
Metric8	res*net*stoch*loc	1	1.203	0.738	0.391
Metric8	res*stoch	1	3.045	1.868	0.172
Metric8	res*stoch*loc	1	4.304	2.640	0.105
Metric8	stoch	1	1.151	0.706	0.401
Metric8	stoch*loc	1	0.455	0.279	0.598
Metric8	ERROR	448	730.410	0.000	-

Resource Metrics

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric1	loc	1	14.731	67.031	0.000
RMetric1	met*res*net*stoc*loc	6	0.720	0.546	0.773
RMetric1	meth	6	29.808	22.607	0.000
RMetric1	meth*loc	6	23.051	17.482	0.000
RMetric1	meth*net	6	8.712	6.608	0.000
RMetric1	meth*net*loc	6	1.917	1.454	0.193
RMetric1	meth*net*stoch	6	0.257	0.195	0.978
RMetric1	meth*net*stoch*loc	6	1.211	0.919	0.481
RMetric1	meth*res	6	22.534	17.090	0.000
RMetric1	meth*res*loc	6	7.774	5.896	0.000
RMetric1	meth*res*net	6	1.759	1.334	0.240
RMetric1	meth*res*net*loc	6	0.817	0.620	0.715
RMetric1	meth*res*net*stoch	6	0.414	0.314	0.930
RMetric1	meth*res*stoch	6	2.898	2.198	0.042
RMetric1	meth*res*stoch*loc	6	1.627	1.234	0.288
RMetric1	meth*stoch	6	1.076	0.816	0.558
RMetric1	meth*stoch*loc	6	1.939	1.471	0.186
RMetric1	net	1	16.756	76.248	0.000
RMetric1	net*loc	1	0.879	3.999	0.046
RMetric1	net*stoch	1	1.874	8.527	0.004
RMetric1	net*stoch*loc	1	0.044	0.200	0.655
RMetric1	res	1	235.235	1,070.413	0.000
RMetric1	res*loc	1	6.663	30.319	0.000
RMetric1	res*net	1	21.167	96.319	0.000
RMetric1	res*net*loc	1	0.028	0.128	0.720
RMetric1	res*net*stoch	1	2.867	13.044	0.000
RMetric1	res*net*stoch*loc	1	0.272	1.238	0.266
RMetric1	res*stoch	1	0.493	2.241	0.135
RMetric1	res*stoch*loc	1	2.142	9.747	0.002
RMetric1	stoch	1	66.687	303.451	0.000
RMetric1	stoch*loc	1	0.872	3.970	0.047
RMetric1	ERROR	448	98.453	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric2	loc	1	2.019	19.153	0.000
RMetric2	met*res*net*stoc*loc	6	0.044	0.070	0.999
RMetric2	meth	6	19.292	30.510	0.000
RMetric2	meth*loc	6	5.960	9.425	0.000
RMetric2	meth*net	6	0.487	0.770	0.593
RMetric2	meth*net*loc	6	1.793	2.836	0.010
RMetric2	meth*net*stoch	6	0.648	1.024	0.409
RMetric2	meth*net*stoch*loc	6	1.014	1.603	0.144
RMetric2	meth*res	6	1.239	1.959	0.070
RMetric2	meth*res*loc	6	13.794	21.814	0.000
RMetric2	meth*res*net	6	5.327	8.425	0.000
RMetric2	meth*res*net*loc	6	0.229	0.362	0.903
RMetric2	meth*res*net*stoch	6	2.071	3.276	0.004
RMetric2	meth*res*stoch	6	1.428	2.259	0.037
RMetric2	meth*res*stoch*loc	6	1.899	3.003	0.007
RMetric2	meth*stoch	6	4.774	7.550	0.000
RMetric2	meth*stoch*loc	6	0.841	1.329	0.242
RMetric2	net	1	0.511	4.851	0.028
RMetric2	net*loc	1	1.409	13.368	0.000
RMetric2	net*stoch	1	0.127	1.208	0.272
RMetric2	net*stoch*loc	1	0.277	2.627	0.106
RMetric2	res	1	2.350	22.297	0.000
RMetric2	res*loc	1	3.841	36.446	0.000
RMetric2	res*net	1	12.630	119.839	0.000
RMetric2	res*net*loc	1	0.623	5.908	0.015
RMetric2	res*net*stoch	1	2.273	21.572	0.000
RMetric2	res*net*stoch*loc	1	0.016	0.148	0.701
RMetric2	res*stoch	1	0.062	0.586	0.444
RMetric2	res*stoch*loc	1	1.009	9.579	0.002
RMetric2	stoch	1	16.192	153.645	0.000
RMetric2	stoch*loc	1	0.007	0.068	0.794
RMetric2	ERROR	448	47.214	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric3	loc	1	17.768	46.755	0.000
RMetric3	met*res*net*stoc*loc	6	0.090	0.040	1.000
RMetric3	meth	6	6.923	3.036	0.006
RMetric3	meth*loc	6	7.952	3.487	0.002
RMetric3	meth*net	6	2.767	1.213	0.298
RMetric3	meth*net*loc	6	1.492	0.654	0.687
RMetric3	meth*net*stoch	6	0.903	0.396	0.882
RMetric3	meth*net*stoch*loc	6	0.090	0.040	1.000
RMetric3	meth*res	6	3.444	1.511	0.173
RMetric3	meth*res*loc	6	7.952	3.487	0.002
RMetric3	meth*res*net	6	1.570	0.689	0.659
RMetric3	meth*res*net*loc	6	1.492	0.654	0.687
RMetric3	meth*res*net*stoch	6	0.414	0.181	0.982
RMetric3	meth*res*stoch	6	2.897	1.270	0.270
RMetric3	meth*res*stoch*loc	6	3.570	1.566	0.155
RMetric3	meth*stoch	6	5.304	2.326	0.032
RMetric3	meth*stoch*loc	6	3.570	1.566	0.155
RMetric3	net	1	4.509	11.865	0.001
RMetric3	net*loc	1	0.415	1.093	0.296
RMetric3	net*stoch	1	0.032	0.085	0.771
RMetric3	net*stoch*loc	1	1.139	2.996	0.084
RMetric3	res	1	110.494	290.756	0.000
RMetric3	res*loc	1	17.768	46.755	0.000
RMetric3	res*net	1	5.255	13.829	0.000
RMetric3	res*net*loc	1	0.415	1.093	0.296
RMetric3	res*net*stoch	1	0.122	0.320	0.572
RMetric3	res*net*stoch*loc	1	1.139	2.996	0.084
RMetric3	res*stoch	1	6.164	16.219	0.000
RMetric3	res*stoch*loc	1	1.184	3.116	0.078
RMetric3	stoch	1	7.956	20.937	0.000
RMetric3	stoch*loc	1	1.184	3.116	0.078
RMetric3	ERROR	448	170.250	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric4a	loc	1	85.645	28.985	0.000
RMetric4a	met*res*net*stoc*loc	6	5.080	0.287	0.943
RMetric4a	meth	6	30.955	1.746	0.109
RMetric4a	meth*loc	6	65.893	3.717	0.001
RMetric4a	meth*net	6	4.396	0.248	0.960
RMetric4a	meth*net*loc	6	5.948	0.336	0.918
RMetric4a	meth*net*stoch	6	9.536	0.538	0.779
RMetric4a	meth*net*stoch*loc	6	0.873	0.049	1.000
RMetric4a	meth*res	6	40.398	2.279	0.035
RMetric4a	meth*res*loc	6	61.761	3.484	0.002
RMetric4a	meth*res*net	6	18.568	1.047	0.394
RMetric4a	meth*res*net*loc	6	3.173	0.179	0.983
RMetric4a	meth*res*net*stoch	6	1.518	0.086	0.998
RMetric4a	meth*res*stoch	6	9.593	0.541	0.777
RMetric4a	meth*res*stoch*loc	6	3.659	0.206	0.975
RMetric4a	meth*stoch	6	15.736	0.888	0.504
RMetric4a	meth*stoch*loc	6	3.748	0.211	0.973
RMetric4a	net	1	20.829	7.049	0.008
RMetric4a	net*loc	1	0.714	0.242	0.623
RMetric4a	net*stoch	1	1.886	0.638	0.425
RMetric4a	net*stoch*loc	1	0.611	0.207	0.649
RMetric4a	res	1	2,925.714	990.157	0.000
RMetric4a	res*loc	1	55.314	18.720	0.000
RMetric4a	res*net	1	4.645	1.572	0.211
RMetric4a	res*net*loc	1	1.302	0.441	0.507
RMetric4a	res*net*stoch	1	4.554	1.541	0.215
RMetric4a	res*net*stoch*loc	1	2.929	0.991	0.320
RMetric4a	res*stoch	1	378.679	128.157	0.000
RMetric4a	res*stoch*loc	1	8.625	2.919	0.088
RMetric4a	stoch	1	3,038.786	1,028.424	0.000
RMetric4a	stoch*loc	1	1.661	0.562	0.454
RMetric4a	ERROR	448	1,323.750	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric4b	loc	1	1,797.340	66.648	0.000
RMetric4b	met*res*net*stoc*loc	6	14.962	0.092	0.997
RMetric4b	meth	6	149.523	0.924	0.477
RMetric4b	meth*loc	6	1,500.173	9.271	0.000
RMetric4b	meth*net	6	171.412	1.059	0.386
RMetric4b	meth*net*loc	6	23.350	0.144	0.990
RMetric4b	meth*net*stoch	6	73.162	0.452	0.843
RMetric4b	meth*net*stoch*loc	6	37.700	0.233	0.966
RMetric4b	meth*res	6	194.698	1.203	0.303
RMetric4b	meth*res*loc	6	245.710	1.519	0.170
RMetric4b	meth*res*net	6	314.744	1.945	0.072
RMetric4b	meth*res*net*loc	6	263.527	1.629	0.137
RMetric4b	meth*res*net*stoch	6	94.794	0.586	0.742
RMetric4b	meth*res*stoch	6	112.344	0.694	0.654
RMetric4b	meth*res*stoch*loc	6	43.850	0.271	0.950
RMetric4b	meth*stoch	6	187.298	1.158	0.328
RMetric4b	meth*stoch*loc	6	201.948	1.248	0.280
RMetric4b	net	1	1,125.070	41.719	0.000
RMetric4b	net*loc	1	24.970	0.926	0.336
RMetric4b	net*stoch	1	100.514	3.727	0.054
RMetric4b	net*stoch*loc	1	9.451	0.350	0.554
RMetric4b	res	1	237,878.559	8,820.818	0.000
RMetric4b	res*loc	1	115.434	4.280	0.039
RMetric4b	res*net	1	188.906	7.005	0.008
RMetric4b	res*net*loc	1	179.162	6.644	0.010
RMetric4b	res*net*stoch	1	68.425	2.537	0.112
RMetric4b	res*net*stoch*loc	1	25.607	0.950	0.330
RMetric4b	res*stoch	1	24,621.831	913.007	0.000
RMetric4b	res*stoch*loc	1	12.826	0.476	0.491
RMetric4b	stoch	1	46,733.747	1,732.943	0.000
RMetric4b	stoch*loc	1	57.697	2.139	0.144
RMetric4b	ERROR	448	12,081.600	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric5a	loc	1	64.125	1.540	0.215
RMetric5a	met*res*net*stoc*loc	6	46.922	0.188	0.980
RMetric5a	meth	6	10,102.969	40.437	0.000
RMetric5a	meth*loc	6	305.379	1.222	0.293
RMetric5a	meth*net	6	103.326	0.414	0.870
RMetric5a	meth*net*loc	6	46.733	0.187	0.980
RMetric5a	meth*net*stoch	6	54.704	0.219	0.971
RMetric5a	meth*net*stoch*loc	6	32.070	0.128	0.993
RMetric5a	meth*res	6	3,997.119	15.998	0.000
RMetric5a	meth*res*loc	6	169.276	0.678	0.668
RMetric5a	meth*res*net	6	411.567	1.647	0.132
RMetric5a	meth*res*net*loc	6	41.967	0.168	0.985
RMetric5a	meth*res*net*stoch	6	84.034	0.336	0.918
RMetric5a	meth*res*stoch	6	228.779	0.916	0.483
RMetric5a	meth*res*stoch*loc	6	130.123	0.521	0.793
RMetric5a	meth*stoch	6	1,178.029	4.715	0.000
RMetric5a	meth*stoch*loc	6	32.120	0.129	0.993
RMetric5a	net	1	1,350.054	32.421	0.000
RMetric5a	net*loc	1	81.397	1.955	0.163
RMetric5a	net*stoch	1	11.004	0.264	0.607
RMetric5a	net*stoch*loc	1	14.625	0.351	0.554
RMetric5a	res	1	13,352.661	320.661	0.000
RMetric5a	res*loc	1	37.804	0.908	0.341
RMetric5a	res*net	1	533.325	12.808	0.000
RMetric5a	res*net*loc	1	8.625	0.207	0.649
RMetric5a	res*net*stoch	1	6.536	0.157	0.692
RMetric5a	res*net*stoch*loc	1	29.486	0.708	0.401
RMetric5a	res*stoch	1	1,319.179	31.680	0.000
RMetric5a	res*stoch*loc	1	1.772	0.043	0.837
RMetric5a	stoch	1	2,717.004	65.248	0.000
RMetric5a	stoch*loc	1	28.575	0.686	0.408
RMetric5a	ERROR	448	18,655.200	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric5b	loc	1	2,802.469	3.859	0.050
RMetric5b	met*res*net*stoc*loc	6	357.429	0.082	0.998
RMetric5b	meth	6	91,277.413	20.950	0.000
RMetric5b	meth*loc	6	1,629.563	0.374	0.895
RMetric5b	meth*net	6	1,956.757	0.449	0.846
RMetric5b	meth*net*loc	6	4,710.123	1.081	0.373
RMetric5b	meth*net*stoch	6	1,401.653	0.322	0.926
RMetric5b	meth*net*stoch*loc	6	550.439	0.126	0.993
RMetric5b	meth*res	6	43,275.682	9.932	0.000
RMetric5b	meth*res*loc	6	4,404.112	1.011	0.417
RMetric5b	meth*res*net	6	10,656.056	2.446	0.024
RMetric5b	meth*res*net*loc	6	439.442	0.101	0.996
RMetric5b	meth*res*net*stoch	6	3,165.898	0.727	0.628
RMetric5b	meth*res*stoch	6	4,603.489	1.057	0.388
RMetric5b	meth*res*stoch*loc	6	644.228	0.148	0.989
RMetric5b	meth*stoch	6	14,595.398	3.350	0.003
RMetric5b	meth*stoch*loc	6	680.782	0.156	0.988
RMetric5b	net	1	11,723.438	16.144	0.000
RMetric5b	net*loc	1	583.747	0.804	0.370
RMetric5b	net*stoch	1	458.564	0.631	0.427
RMetric5b	net*stoch*loc	1	1,482.815	2.042	0.154
RMetric5b	res	1	121,311.938	167.059	0.000
RMetric5b	res*loc	1	686.982	0.946	0.331
RMetric5b	res*net	1	2,822.639	3.887	0.049
RMetric5b	res*net*loc	1	71.965	0.099	0.753
RMetric5b	res*net*stoch	1	3,150.443	4.338	0.038
RMetric5b	res*net*stoch*loc	1	422.213	0.581	0.446
RMetric5b	res*stoch	1	17,930.315	24.692	0.000
RMetric5b	res*stoch*loc	1	28.014	0.039	0.844
RMetric5b	stoch	1	36,713.255	50.558	0.000
RMetric5b	stoch*loc	1	1,590.472	2.190	0.140
RMetric5b	ERROR	448	325,321.550	0.000	-

ANOVA Results

For all preceding ANOVA table results, the degrees of freedom for the model is 6, error is 28, and the corrected total is 34. The rows of the ANOVA tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating a significant factor or interaction effect.

Stochasticity = High, Location = Early

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE10	Duration	7.886	222.000	0.166	0.984
HE10	Metric1	0.009	0.030	1.442	0.234
HE10	Metric2	4.275	2.769	7.206	0.000
HE10	Metric3	0.116	0.108	5.011	0.001
HE10	Metric4	0.249	0.192	6.048	0.000
HE10	Metric5	0.091	0.122	3.481	0.011
HE10	Metric6	0.003	0.023	0.585	0.739
HE10	Metric7	4.265	2.751	7.234	0.000
HE10	Metric8	58.817	91.926	2.986	0.022
HE10	RMetric1	2.091	5.395	1.809	0.133
HE10	RMetric2	2.762	9.592	1.344	0.271
HE10	RMetric3	2.546	22.050	0.539	0.774
HE10	RMetric4a	26.600	94.300	1.316	0.283
HE10	RMetric4b	226.061	707.950	1.490	0.218
HE10	RMetric5a	166.061	349.250	2.219	0.071
HE10	RMetric5b	2,174.496	5,363.350	1.892	0.117

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE11	Duration	68.000	2,004.400	0.158	0.986
HE11	Metric1	0.004	0.060	0.280	0.942
HE11	Metric2	10.959	1.055	48.479	0.000
HE11	Metric3	0.478	0.285	7.841	0.000
HE11	Metric4	0.170	0.371	2.131	0.081
HE11	Metric5	0.259	0.129	9.354	0.000
HE11	Metric6	0.109	0.134	3.784	0.007
HE11	Metric7	9.427	1.344	32.725	0.000
HE11	Metric8	2.021	3.409	2.766	0.031
HE11	RMetric1	18.464	4.580	18.812	0.000
HE11	RMetric2	0.678	2.109	1.499	0.215
HE11	RMetric3	0.386	0.800	2.250	0.068
HE11	RMetric4a	10.086	91.800	0.513	0.794
HE11	RMetric4b	132.286	1,003.400	0.615	0.716
HE11	RMetric5a	2,708.086	2,666.700	4.739	0.002
HE11	RMetric5b	37,823.086	29,751.700	5.933	0.000
HE12	Duration	13.486	1,780.400	0.035	1.000
HE12	Metric1	0.005	0.006	3.892	0.006
HE12	Metric2	3.265	0.306	49.857	0.000
HE12	Metric3	0.164	0.386	1.982	0.102
HE12	Metric4	0.021	0.058	1.739	0.149
HE12	Metric5	0.026	0.067	1.827	0.130
HE12	Metric6	-	-	-	-
HE12	Metric7	3.318	0.313	49.521	0.000
HE12	Metric8	44.493	61.865	3.356	0.013
HE12	RMetric1	1.723	2.798	2.874	0.026
HE12	RMetric2	1.169	1.325	4.118	0.004
HE12	RMetric3	5.071	46.000	0.514	0.792
HE12	RMetric4a	28.386	69.300	1.911	0.114
HE12	RMetric4b	233.043	259.000	4.199	0.004
HE12	RMetric5a	729.600	578.000	5.891	0.000
HE12	RMetric5b	10,250.943	15,955.200	2.998	0.022
HE13	Duration	20.286	3,788.400	0.025	1.000
HE13	Metric1	0.002	0.011	0.689	0.660
HE13	Metric2	3.960	0.258	71.558	0.000
HE13	Metric3	0.360	1.826	0.919	0.496
HE13	Metric4	0.055	0.209	1.219	0.326
HE13	Metric5	0.029	0.100	1.381	0.257
HE13	Metric6	0.001	0.011	0.440	0.846
HE13	Metric7	4.358	0.394	51.638	0.000
HE13	Metric8	3.013	29.386	0.479	0.818
HE13	RMetric1	15.930	7.070	10.515	0.000
HE13	RMetric2	17.897	3.183	26.241	0.000
HE13	RMetric3	0.043	0.200	1.000	0.445
HE13	RMetric4a	5.971	52.700	0.529	0.782
HE13	RMetric4b	141.543	1,790.000	0.369	0.892
HE13	RMetric5a	2,145.300	1,437.200	6.966	0.000
HE13	RMetric5b	20,315.243	46,939.000	2.020	0.096

Stochasticity = High, Location = Late

HL10	Duration	26.286	659.600	0.186	0.978
HL10	Metric1	0.032	0.231	0.639	0.698
HL10	Metric2	4.930	0.919	25.026	0.000
HL10	Metric3	0.279	1.972	0.659	0.683
HL10	Metric4	0.122	0.352	1.615	0.180
HL10	Metric5	0.040	0.678	0.276	0.943
HL10	Metric6	0.012	0.043	1.345	0.271
HL10	Metric7	4.246	1.444	13.722	0.000
HL10	Metric8	6.794	49.816	0.636	0.700
HL10	RMetric1	5.856	10.136	2.696	0.034
HL10	RMetric2	18.782	2.088	41.978	0.000
HL10	RMetric3	21.843	16.200	6.292	0.000
HL10	RMetric4a	33.871	216.100	0.731	0.628
HL10	RMetric4b	190.671	838.900	1.061	0.409
HL10	RMetric5a	125.986	362.800	1.621	0.178
HL10	RMetric5b	1,614.686	8,669.000	0.869	0.530

HL11	Duration	33.771	3,831.200	0.041	1.000
HL11	Metric1	0.004	0.027	0.736	0.625
HL11	Metric2	10.638	0.362	137.287	0.000
HL11	Metric3	0.060	0.802	0.347	0.905
HL11	Metric4	0.333	0.159	9.756	0.000
HL11	Metric5	0.072	0.198	1.693	0.160
HL11	Metric6	0.021	0.095	1.054	0.413
HL11	Metric7	9.612	0.262	171.038	0.000
HL11	Metric8	1.398	3.104	2.102	0.085
HL11	RMetric1	16.189	5.154	14.657	0.000
HL11	RMetric2	1.048	3.979	1.229	0.321
HL11	RMetric3	0.386	0.800	2.250	0.068
HL11	RMetric4a	7.843	148.200	0.247	0.956
HL11	RMetric4b	819.186	1,550.200	2.466	0.048
HL11	RMetric5a	3,388.743	3,184.300	4.966	0.001
HL11	RMetric5b	45,025.571	43,694.000	4.809	0.002

Group	Metric	SS Model	SS Error	F-Val	P-Val
HL12	Duration	0.343	401.200	0.004	1.000
HL12	Metric1	0.000	0.001	0.667	0.677
HL12	Metric2	2.911	0.739	18.385	0.000
HL12	Metric3	0.307	0.542	2.638	0.037
HL12	Metric4	0.139	0.149	4.351	0.003
HL12	Metric5	0.044	0.035	5.844	0.000
HL12	Metric6	-	-	-	-
HL12	Metric7	2.935	0.739	18.535	0.000
HL12	Metric8	5.193	43.672	0.555	0.762
HL12	RMetric1	0.950	3.898	1.138	0.367
HL12	RMetric2	3.441	2.315	6.934	0.000
HL12	RMetric3	15.186	11.500	6.162	0.000
HL12	RMetric4a	46.643	120.400	1.808	0.134
HL12	RMetric4b	422.071	532.100	3.702	0.008
HL12	RMetric5a	759.486	557.300	6.360	0.000
HL12	RMetric5b	5,075.200	21,863.400	1.083	0.396
HL13	Duration	41.543	1,991.600	0.097	0.996
HL13	Metric1	0.009	0.016	2.652	0.036
HL13	Metric2	3.986	0.100	186.694	0.000
HL13	Metric3	0.268	0.529	2.361	0.057
HL13	Metric4	0.104	0.559	0.872	0.528
HL13	Metric5	0.050	0.306	0.767	0.602
HL13	Metric6	0.002	0.017	0.515	0.792
HL13	Metric7	3.749	0.241	72.582	0.000
HL13	Metric8	1.760	24.454	0.336	0.912
HL13	RMetric1	3.298	8.756	1.758	0.145
HL13	RMetric2	5.802	6.256	4.328	0.003
HL13	RMetric3	0.043	0.200	1.000	0.445
HL13	RMetric4a	1.871	44.700	0.195	0.975
HL13	RMetric4b	125.443	507.300	1.154	0.358
HL13	RMetric5a	2,952.486	3,454.700	3.988	0.005
HL13	RMetric5b	26,264.843	63,811.400	1.921	0.112

Stochasticity = Late, Location = Early

Group	Metric	SS Model	SS Error	F-Val	P-Val
LE10	Duration	0.686	519.600	0.006	1.000
LE10	Metric1	0.001	0.003	1.000	0.445
LE10	Metric2	0.105	0.195	2.524	0.044
LE10	Metric3	0.029	0.112	1.224	0.324
LE10	Metric4	0.134	0.250	2.492	0.047
LE10	Metric5	0.033	0.095	1.605	0.183
LE10	Metric6	0.001	0.007	0.637	0.699
LE10	Metric7	0.108	0.202	2.493	0.046
LE10	Metric8	18.778	115.299	0.760	0.607
LE10	RMetric1	4.490	9.337	2.244	0.068
LE10	RMetric2	0.766	5.814	0.615	0.717
LE10	RMetric3	1.168	20.500	0.266	0.948
LE10	RMetric4a	15.693	70.850	1.034	0.425
LE10	RMetric4b	88.450	348.950	1.183	0.344
LE10	RMetric5a	51.511	122.050	1.970	0.104
LE10	RMetric5b	957.025	2,598.700	1.719	0.154
LE11	Duration	23.143	1,693.600	0.064	0.999
LE11	Metric1	0.003	0.011	1.387	0.255
LE11	Metric2	0.691	0.065	49.932	0.000
LE11	Metric3	0.379	1.112	1.591	0.187
LE11	Metric4	0.332	0.586	2.645	0.037
LE11	Metric5	0.178	0.160	5.213	0.001
LE11	Metric6	0.016	0.128	0.569	0.751
LE11	Metric7	0.777	0.161	22.530	0.000
LE11	Metric8	2.724	8.790	1.446	0.233
LE11	RMetric1	11.223	3.252	16.107	0.000
LE11	RMetric2	0.293	1.500	0.912	0.501
LE11	RMetric3	-	-	-	-
LE11	RMetric4a	10.343	23.800	2.028	0.095
LE11	RMetric4b	295.600	1,340.500	1.029	0.427
LE11	RMetric5a	964.486	1,113.700	4.041	0.005
LE11	RMetric5b	4,488.443	16,792.800	1.247	0.313

Group	Metric	SS Model	SS Error	F-Val	P-Val
LE12	Duration	8.743	1,946.800	0.021	1.000
LE12	Metric1	0.003	0.018	0.661	0.681
LE12	Metric2	0.210	0.343	2.858	0.027
LE12	Metric3	0.070	0.315	1.038	0.422
LE12	Metric4	0.005	0.031	0.776	0.596
LE12	Metric5	0.015	0.033	2.073	0.089
LE12	Metric6	-	-	-	-
LE12	Metric7	0.240	0.350	3.208	0.016
LE12	Metric8	44.442	119.290	1.739	0.149
LE12	RMetric1	1.554	2.227	3.257	0.015
LE12	RMetric2	0.579	1.206	2.239	0.069
LE12	RMetric3	1.871	32.200	0.271	0.946
LE12	RMetric4a	18.243	93.000	0.915	0.499
LE12	RMetric4b	204.371	448.800	2.125	0.082
LE12	RMetric5a	220.900	502.500	2.051	0.092
LE12	RMetric5b	936.286	14,567.900	0.300	0.932
LE13	Duration	12.571	3,312.400	0.018	1.000
LE13	Metric1	0.001	0.025	0.153	0.987
LE13	Metric2	0.558	0.063	41.591	0.000
LE13	Metric3	0.066	1.528	0.201	0.974
LE13	Metric4	0.089	0.308	1.349	0.269
LE13	Metric5	0.033	0.171	0.914	0.500
LE13	Metric6	0.002	0.014	0.739	0.623
LE13	Metric7	0.572	0.105	25.488	0.000
LE13	Metric8	3.750	20.842	0.840	0.550
LE13	RMetric1	8.079	6.688	5.637	0.001
LE13	RMetric2	1.053	2.181	2.253	0.067
LE13	RMetric3	-	-	-	-
LE13	RMetric4a	5.686	38.500	0.689	0.660
LE13	RMetric4b	8.471	444.500	0.089	0.997
LE13	RMetric5a	671.071	1,010.900	3.098	0.019
LE13	RMetric5b	2,908.143	15,143.000	0.896	0.511

Stochasticity = Low, Location = Late

Group	Metric	SS Model	SS Error	F-Val	P-Val
LL10	Duration	27.543	233.200	0.551	0.765
LL10	Metric1	0.007	0.200	0.169	0.983
LL10	Metric2	0.139	0.460	1.412	0.245
LL10	Metric3	0.193	2.410	0.374	0.889
LL10	Metric4	0.101	0.487	0.968	0.465
LL10	Metric5	0.078	0.947	0.382	0.884
LL10	Metric6	0.013	0.203	0.292	0.936
LL10	Metric7	0.145	0.528	1.277	0.299
LL10	Metric8	7.058	55.592	0.592	0.734
LL10	RMetric1	1.701	8.450	0.940	0.483
LL10	RMetric2	4.274	2.345	8.506	0.000
LL10	RMetric3	0.643	6.500	0.462	0.831
LL10	RMetric4a	3.371	104.600	0.150	0.987
LL10	RMetric4b	82.900	593.700	0.652	0.689
LL10	RMetric5a	16.543	347.200	0.222	0.966
LL10	RMetric5b	828.900	6,653.100	0.581	0.742
LL11	Duration	82.171	3,570.000	0.107	0.995
LL11	Metric1	0.010	0.040	1.108	0.383
LL11	Metric2	0.636	0.048	62.151	0.000
LL11	Metric3	0.055	0.614	0.419	0.860
LL11	Metric4	0.366	0.506	3.369	0.013
LL11	Metric5	0.196	0.207	4.416	0.003
LL11	Metric6	0.035	0.087	1.872	0.121
LL11	Metric7	0.549	0.066	39.122	0.000
LL11	Metric8	0.381	6.050	0.293	0.935
LL11	RMetric1	8.983	7.536	5.562	0.001
LL11	RMetric2	0.174	0.739	1.098	0.388
LL11	RMetric3	-	-	-	-
LL11	RMetric4a	14.886	52.300	1.328	0.278
LL11	RMetric4b	375.786	1,302.900	1.346	0.270
LL11	RMetric5a	1,079.986	1,377.200	3.660	0.008
LL11	RMetric5b	14,604.071	13,551.900	5.029	0.001

Group	Metric	SS Model	SS Error	F-Val	P-Val
LL12	Duration	9.886	1,554.000	0.030	1.000
LL12	Metric1	0.003	0.019	0.701	0.651
LL12	Metric2	0.196	0.154	5.962	0.000
LL12	Metric3	0.373	1.787	0.974	0.461
LL12	Metric4	0.009	0.034	1.252	0.311
LL12	Metric5	0.015	0.048	1.495	0.216
LL12	Metric6	-	-	-	-
LL12	Metric7	0.218	0.160	6.358	0.000
LL12	Metric8	19.315	72.336	1.246	0.313
LL12	RMetric1	2.889	3.188	4.229	0.004
LL12	RMetric2	1.500	0.913	7.663	0.000
LL12	RMetric3	1.243	13.300	0.436	0.848
LL12	RMetric4a	42.143	58.500	3.362	0.013
LL12	RMetric4b	251.671	119.800	9.804	0.000
LL12	RMetric5a	62.886	1,099.000	0.267	0.948
LL12	RMetric5b	992.386	5,879.500	0.788	0.587
LL13	Duration	26.571	2,745.600	0.045	1.000
LL13	Metric1	0.003	0.011	1.137	0.367
LL13	Metric2	0.486	0.031	73.548	0.000
LL13	Metric3	0.105	2.150	0.228	0.964
LL13	Metric4	0.080	0.245	1.520	0.208
LL13	Metric5	0.060	0.118	2.375	0.056
LL13	Metric6	0.002	0.006	1.291	0.294
LL13	Metric7	0.372	0.058	29.718	0.000
LL13	Metric8	1.451	24.580	0.276	0.944
LL13	RMetric1	3.094	9.988	1.446	0.233
LL13	RMetric2	0.623	1.667	1.744	0.148
LL13	RMetric3	-	-	-	-
LL13	RMetric4a	9.200	44.700	0.960	0.469
LL13	RMetric4b	31.643	293.600	0.503	0.801
LL13	RMetric5a	921.986	492.400	8.738	0.000
LL13	RMetric5b	10,089.143	14,087.600	3.342	0.013

Tukey Results

In the following tables, means with the same letter in the columns labeled "Tukey Grouping" are not significantly different. Additionally, a 1 indicates no pairwise difference in the metric mean. Zeros, indicating significant pairwise differences are highlighted, and a note is made if at least one of the resource buffering methods shows improvement over the 50% buffering method in the "B5 vs R Buffers" column. Finally, a note is made in the "B5 sig better" column if the 50% buffer is significantly better than the method indicated by that row.

Stochasticity = High, Location = Early

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE10	Metric2	B		C	0.326	P	1	0	1	1	1	1	1		
HE10	Metric2		A		1.121	O	0	1	0	1	0	0	1	**At least one RBuffer differs from B5**	B5 better
HE10	Metric2			C	0.164	B5	1	0	1	0	1	1	1		
HE10	Metric2	B	A		0.825	BR1	1	1	0	1	0	0	1	Worse	B5 better
HE10	Metric2			C	0.164	BR2	1	0	1	0	1	1	1		
HE10	Metric2			C	0.170	BR3	1	0	1	0	1	1	1		
HE10	Metric2	B	A	C	0.556	BR4	1	1	1	1	1	1	1		
HE10	Metric3	B	A		0.144	P	1	0	1	1	1	1	1		
HE10	Metric3			C	0.000	O	0	1	1	1	1	0	1	**No diff btwn RBuffers and B5**	
HE10	Metric3	B	A	C	0.119	B5	1	1	1	1	1	1	1		
HE10	Metric3	B		C	0.063	BR1	1	1	1	1	1	0	1		
HE10	Metric3	B	A	C	0.119	BR2	1	1	1	1	1	1	1		
HE10	Metric3		A		0.194	BR3	1	0	1	0	1	1	1		
HE10	Metric3	B	A	C	0.081	BR4	1	1	1	1	1	1	1		
HE10	Metric4		A		0.238	P	1	0	1	1	1	1	1		
HE10	Metric4	B			0.000	O	0	1	0	1	0	0	1	**No diff btwn RBuffers and B5**	
HE10	Metric4		A		0.250	B5	1	0	1	1	1	1	1		
HE10	Metric4	B	A		0.094	BR1	1	1	1	1	1	1	1		
HE10	Metric4		A		0.219	BR2	1	0	1	1	1	1	1		
HE10	Metric4		A		0.169	BR3	1	0	1	1	1	1	1		
HE10	Metric4	B	A		0.113	BR4	1	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE10	Metric5	B	A		0.094	P	1	1	1	1	1	1	1		
HE10	Metric5	B			0.000	O	1	1	1	1	1	0	1	**No diff btwn**	
HE10	Metric5	B	A		0.094	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE10	Metric5	B	A		0.075	BR1	1	1	1	1	1	1	1		
HE10	Metric5	B	A		0.131	BR2	1	1	1	1	1	1	1		
HE10	Metric5		A		0.181	BR3	1	0	1	1	1	1	1		
HE10	Metric5	B	A		0.094	BR4	1	1	1	1	1	1	1		
HE10	Metric7	B		C	0.340	P	1	0	1	1	1	1	1		
HE10	Metric7		A		1.121	O	0	1	0	1	0	0	1	**At least one RBuffer**	B5 better
HE10	Metric7			C	0.156	B5	1	0	1	0	1	1	1	**differs from B5**	
HE10	Metric7	B	A		0.848	BR1	1	1	0	1	0	0	1	Worse	B5 better
HE10	Metric7			C	0.171	BR2	1	0	1	0	1	1	1		
HE10	Metric7			C	0.201	BR3	1	0	1	0	1	1	1		
HE10	Metric7	B	A	C	0.577	BR4	1	1	1	1	1	1	1		
HE10	Metric8		A		3.907	P	1	0	1	1	1	1	1		
HE10	Metric8	B			0.000	O	0	1	0	1	1	1	1	**No diff btwn**	
HE10	Metric8		A		4.039	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE10	Metric8	B	A		1.876	BR1	1	1	1	1	1	1	1		
HE10	Metric8	B	A		3.101	BR2	1	1	1	1	1	1	1		
HE10	Metric8	B	A		2.660	BR3	1	1	1	1	1	1	1		
HE10	Metric8	B	A		1.876	BR4	1	1	1	1	1	1	1		
HE11	Metric2	B			0.370	P	1	0	1	1	1	1	1		
HE11	Metric2	A			1.795	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE11	Metric2	B			0.042	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric2	B			0.209	BR1	1	0	1	1	1	1	1		
HE11	Metric2	B			0.225	BR2	1	0	1	1	1	1	1		
HE11	Metric2	B			0.258	BR3	1	0	1	1	1	1	1		
HE11	Metric2	B			0.197	BR4	1	0	1	1	1	1	1		
HE11	Metric3		C		0.500	P	1	0	0	0	0	1	1		
HE11	Metric3		A		0.906	O	0	1	1	1	1	0	0	**No diff btwn**	
HE11	Metric3	B	A		0.769	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric3	B	A		0.763	BR1	0	1	1	1	1	1	1		
HE11	Metric3	B	A		0.763	BR2	0	1	1	1	1	1	1		
HE11	Metric3	B	C		0.663	BR3	1	0	1	1	1	1	1		
HE11	Metric3	B	C		0.662	BR4	1	0	1	1	1	1	1		
HE11	Metric5	B			0.144	P	1	0	1	1	1	1	1		
HE11	Metric5	A			0.382	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE11	Metric5	B			0.125	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric5	B			0.138	BR1	1	0	1	1	1	1	1		
HE11	Metric5	B			0.144	BR2	1	0	1	1	1	1	1		
HE11	Metric5	B			0.119	BR3	1	0	1	1	1	1	1		
HE11	Metric5	B			0.162	BR4	1	0	1	1	1	1	1		
HE11	Metric6	B			0.213	P	1	1	1	0	1	1	1		
HE11	Metric6	B			0.207	O	1	1	1	0	1	1	1	**No diff btwn**	
HE11	Metric6	B	A		0.300	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric6		A		0.363	BR1	0	0	1	1	1	1	1		
HE11	Metric6	B	A		0.319	BR2	1	1	1	1	1	1	1		
HE11	Metric6	B	A		0.294	BR3	1	1	1	1	1	1	1		
HE11	Metric6	B	A		0.225	BR4	1	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE11	Metric7	B			0.392	P	1	0	1	1	1	1	1		
HE11	Metric7	A			1.691	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE11	Metric7	B			0.087	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric7	B			0.217	BR1	1	0	1	1	1	1	1		
HE11	Metric7	B			0.223	BR2	1	0	1	1	1	1	1		
HE11	Metric7	B			0.255	BR3	1	0	1	1	1	1	1		
HE11	Metric7	B			0.191	BR4	1	0	1	1	1	1	1		
HE11	Metric8		A		1.644	P	1	0	1	1	1	1	1		
HE11	Metric8	B			0.873	O	0	1	1	1	1	1	1	**No diff btwn**	
HE11	Metric8	B	A		1.022	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE11	Metric8	B	A		1.099	BR1	1	1	1	1	1	1	1		
HE11	Metric8	B	A		1.065	BR2	1	1	1	1	1	1	1		
HE11	Metric8	B	A		1.387	BR3	1	1	1	1	1	1	1		
HE11	Metric8	B	A		1.271	BR4	1	1	1	1	1	1	1		
HE11	RMetric1	B			3.189	P	1	0	1	1	1	1	1		
HE11	RMetric1	A			5.245	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE11	RMetric1	B			2.759	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE11	RMetric1	B			3.459	BR1	1	0	1	1	1	1	1		
HE11	RMetric1	B			3.521	BR2	1	0	1	1	1	1	1		
HE11	RMetric1	B			3.359	BR3	1	0	1	1	1	1	1		
HE11	RMetric1	B			3.408	BR4	1	0	1	1	1	1	1		
HE11	RMetric5a		A		36.600	P	1	1	0	0	1	1	1		B5 better
HE11	RMetric5a	B	A		33.500	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
HE11	RMetric5a			C	9.800	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE11	RMetric5a	B		C	16.700	BR1	0	1	1	1	1	1	1		
HE11	RMetric5a	B	A	C	19.300	BR2	1	1	1	1	1	1	1		
HE11	RMetric5a	B	A	C	19.300	BR3	1	1	1	1	1	1	1		
HE11	RMetric5a	B	A	C	19.800	BR4	1	1	1	1	1	1	1		
HE11	RMetric5b		A		116.10	P	1	1	0	0	0	0	1		B5 better
HE11	RMetric5b		A		121.50	O	1	1	0	0	0	0	1	**No diff btwn**	B5 better
HE11	RMetric5b	B			38.800	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE11	RMetric5b	B			46.000	BR1	0	0	1	1	1	1	1		
HE11	RMetric5b	B			46.400	BR2	0	0	1	1	1	1	1		
HE11	RMetric5b	B			45.400	BR3	0	0	1	1	1	1	1		
HE11	RMetric5b	B	A		59.300	BR4	1	1	1	1	1	1	1		
HE12	Metric1		A		0.039	P	1	0	1	0	1	1	0		
HE12	Metric1	B			0.000	O	0	1	1	1	1	1	1	**No diff btwn**	
HE12	Metric1	B	A		0.016	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE12	Metric1	B			0.003	BR1	0	1	1	1	1	1	1		
HE12	Metric1	B	A		0.016	BR2	1	1	1	1	1	1	1		
HE12	Metric1	B	A		0.012	BR3	1	1	1	1	1	1	1		
HE12	Metric1	B			0.003	BR4	0	1	1	1	1	1	1		
HE12	Metric2	D	E		0.289	P	1	0	1	0	1	1	0		
HE12	Metric2		A		1.065	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
HE12	Metric2		E		0.188	B5	1	0	1	0	1	0	0	**differs from B5**	
HE12	Metric2		B		0.799	BR1	0	0	0	1	0	0	0	Worse	B5 better
HE12	Metric2		E		0.188	BR2	1	0	1	0	1	0	0		
HE12	Metric2	D	C		0.495	BR3	1	0	0	0	0	1	1	Worse	B5 better
HE12	Metric2		C		0.583	BR4	0	0	0	0	0	1	1	Worse	B5 better

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE12	Metric6	A			0.000	P	1	1	1	1	1	1	1		
HE12	Metric6	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
HE12	Metric6	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE12	Metric6	A			0.000	BR1	1	1	1	1	1	1	1		
HE12	Metric6	A			0.000	BR2	1	1	1	1	1	1	1		
HE12	Metric6	A			0.000	BR3	1	1	1	1	1	1	1		
HE12	Metric6	A			0.000	BR4	1	1	1	1	1	1	1		
HE12	Metric7	D	E		0.314	P	1	0	1	0	1	1	0		
HE12	Metric7		A		1.065	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
HE12	Metric7		E		0.170	B5	1	0	1	0	1	0	0	**differs from B5**	
HE12	Metric7		B		0.794	BR1	0	0	0	1	0	0	0	Worse	B5 better
HE12	Metric7		E		0.170	BR2	1	0	1	0	1	0	0		
HE12	Metric7	D	C		0.479	BR3	1	0	0	0	0	1	1	Worse	B5 better
HE12	Metric7		C		0.578	BR4	0	0	0	0	0	1	1	Worse	B5 better
HE12	Metric8		A		3.555	P	1	0	1	1	1	1	1		
HE12	Metric8	B			0.000	O	0	1	1	1	1	1	1	**No diff btwn**	
HE12	Metric8	B	A		2.663	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HE12	Metric8	B	A		1.063	BR1	1	1	1	1	1	1	1		
HE12	Metric8	B	A		2.663	BR2	1	1	1	1	1	1	1		
HE12	Metric8	B	A		1.725	BR3	1	1	1	1	1	1	1		
HE12	Metric8	B	A		1.063	BR4	1	1	1	1	1	1	1		
HE12	RMetric1	B			1.355	P	1	1	0	1	0	1	1		
HE12	RMetric1	B	A		1.515	O	1	1	1	1	1	1	1	**No diff btwn**	
HE12	RMetric1		A		1.991	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
HE12	RMetric1	B	A		1.717	BR1	1	1	1	1	1	1	1		
HE12	RMetric1		A		1.991	BR2	0	1	1	1	1	1	1		
HE12	RMetric1	B	A		1.876	BR3	1	1	1	1	1	1	1		
HE12	RMetric1	B	A		1.757	BR4	1	1	1	1	1	1	1		
HE12	RMetric2	B	A		0.829	P	1	1	1	1	1	1	1		
HE12	RMetric2	B			0.422	O	1	1	0	1	0	0	1	**No diff btwn**	
HE12	RMetric2		A		0.877	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE12	RMetric2	B	A		0.601	BR1	1	1	1	1	1	1	1		
HE12	RMetric2		A		0.877	BR2	1	0	1	1	1	1	1		
HE12	RMetric2		A		1.000	BR3	1	0	1	1	1	1	1		
HE12	RMetric2	B	A		0.689	BR4	1	1	1	1	1	1	1		
HE12	RMetric4b		A		19.800	P	1	0	1	1	1	1	1		
HE12	RMetric4b	B			11.700	O	0	1	0	1	0	0	0	**No diff btwn**	
HE12	RMetric4b		A		18.700	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE12	RMetric4b	B	A		17.300	BR1	1	1	1	1	1	1	1		
HE12	RMetric4b		A		18.700	BR2	1	0	1	1	1	1	1		
HE12	RMetric4b		A		19.700	BR3	1	0	1	1	1	1	1		
HE12	RMetric4b		A		17.900	BR4	1	0	1	1	1	1	1		
HE12	RMetric5a	B	A		15.400	P	1	1	0	1	0	1	1		B5 better
HE12	RMetric5a		A		19.300	O	1	1	0	1	0	0	1	**No diff btwn**	B5 better
HE12	RMetric5a			C	5.900	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE12	RMetric5a	B	A	C	12.400	BR1	1	1	1	1	1	1	1		
HE12	RMetric5a			C	5.900	BR2	0	0	1	1	1	1	1		
HE12	RMetric5a	B		C	9.100	BR3	1	0	1	1	1	1	1		
HE12	RMetric5a	B	A	C	10.400	BR4	1	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HE12	RMetric5b		A		64.800	P	1	1	0	1	0	1	1		B5 better
HE12	RMetric5b	B	A		46.900	O	1	1	1	1	1	1	1	**No diff btwn**	
HE12	RMetric5b	B			14.900	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
HE12	RMetric5b	B	A		25.800	BR1	1	1	1	1	1	1	1		
HE12	RMetric5b	B			14.900	BR2	0	1	1	1	1	1	1		
HE12	RMetric5b	B	A		21.400	BR3	1	1	1	1	1	1	1		
HE12	RMetric5b	B	A		26.800	BR4	1	1	1	1	1	1	1		
HE13	Metric2		B		0.333	P	1	0	0	1	1	1	1		B5 better
HE13	Metric2		A		1.130	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE13	Metric2	C			0.066	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE13	Metric2	C	B		0.187	BR1	1	0	1	1	1	1	1		
HE13	Metric2	C	B		0.201	BR2	1	0	1	1	1	1	1		
HE13	Metric2	C	B		0.222	BR3	1	0	1	1	1	1	1		
HE13	Metric2	C	B		0.146	BR4	1	0	1	1	1	1	1		
HE13	Metric7		B		0.333	P	1	0	0	1	1	1	1		B5 better
HE13	Metric7		A		1.174	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE13	Metric7	C			0.071	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE13	Metric7	C	B		0.174	BR1	1	0	1	1	1	1	1		
HE13	Metric7	C	B		0.188	BR2	1	0	1	1	1	1	1		
HE13	Metric7	C	B		0.214	BR3	1	0	1	1	1	1	1		
HE13	Metric7	C	B		0.146	BR4	1	0	1	1	1	1	1		
HE13	RMetric1	B			2.769	P	1	0	1	1	1	1	1		
HE13	RMetric1	A			5.097	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE13	RMetric1	B			3.123	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE13	RMetric1	B			3.491	BR1	1	0	1	1	1	1	1		
HE13	RMetric1	B			3.550	BR2	1	0	1	1	1	1	1		
HE13	RMetric1	B			3.632	BR3	1	0	1	1	1	1	1		
HE13	RMetric1	B			3.499	BR4	1	0	1	1	1	1	1		
HE13	RMetric2	B			0.683	P	1	0	1	1	1	1	1		
HE13	RMetric2	A			2.634	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HE13	RMetric2	B			0.404	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HE13	RMetric2	B			0.710	BR1	1	0	1	1	1	1	1		
HE13	RMetric2	B			0.669	BR2	1	0	1	1	1	1	1		
HE13	RMetric2	B			0.703	BR3	1	0	1	1	1	1	1		
HE13	RMetric2	B			0.512	BR4	1	0	1	1	1	1	1		
HE13	RMetric5a		A		35.300	P	1	1	0	0	0	1	0		B5 better
HE13	RMetric5a	B	A		30.800	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
HE13	RMetric5a			C	10.200	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HE13	RMetric5a	B		C	17.800	BR1	0	1	1	1	1	1	1		
HE13	RMetric5a	B		C	20.000	BR2	0	1	1	1	1	1	1		
HE13	RMetric5a	B	A	C	21.600	BR3	1	1	1	1	1	1	1		
HE13	RMetric5a	B		C	18.300	BR4	0	1	1	1	1	1	1		

Stochasticity = High, Location = Late

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HL10	Metric2	C	D		0.274	P	1	0	1	0	1	1	1		
HL10	Metric2		A		1.176	O	0	1	0	0	0	0	0	**At least one RBuffer differs from B5**	B5 better
HL10	Metric2		D		0.154	B5	1	0	1	0	1	1	0		
HL10	Metric2		B		0.757	BR1	0	0	0	1	0	0	1	Worse	B5 better
HL10	Metric2		D		0.154	BR2	1	0	1	0	1	1	0		
HL10	Metric2		D		0.072	BR3	1	0	1	0	1	1	0		
HL10	Metric2	C	B		0.573	BR4	1	0	0	1	0	0	1	Worse	B5 better
HL10	Metric7	D	C		0.348	P	1	0	1	0	1	1	1		
HL10	Metric7		A		1.060	O	0	1	0	1	0	0	0	**At least one RBuffer differs from B5**	B5 better
HL10	Metric7	D	C		0.139	B5	1	0	1	0	1	1	1		
HL10	Metric7	B	A		0.829	BR1	0	1	0	1	0	0	1	Worse	B5 better
HL10	Metric7	D	C		0.183	BR2	1	0	1	0	1	1	1		
HL10	Metric7	D			0.073	BR3	1	0	1	0	1	1	0		
HL10	Metric7	B	C		0.562	BR4	1	0	1	1	1	0	1		
HL10	RMetric1	A			3.564	P	1	1	1	1	1	1	1		
HL10	RMetric1	A			3.598	O	1	1	1	1	1	1	1	**No diff btwn RBuffers and B5**	
HL10	RMetric1	A			2.559	B5	1	1	1	1	1	1	1		
HL10	RMetric1	A			3.186	BR1	1	1	1	1	1	1	1		
HL10	RMetric1	A			2.559	BR2	1	1	1	1	1	1	1		
HL10	RMetric1	A			2.732	BR3	1	1	1	1	1	1	1		
HL10	RMetric1	A			3.121	BR4	1	1	1	1	1	1	1		
HL10	RMetric2	B			0.439	P	1	0	1	1	1	1	1		
HL10	RMetric2	A			2.591	O	0	1	0	0	0	0	0	**No diff btwn RBuffers and B5**	B5 better
HL10	RMetric2	B			0.395	B5	1	0	1	1	1	1	1		
HL10	RMetric2	B			0.852	BR1	1	0	1	1	1	1	1		
HL10	RMetric2	B			0.395	BR2	1	0	1	1	1	1	1		
HL10	RMetric2	B			0.516	BR3	1	0	1	1	1	1	1		
HL10	RMetric2	B			0.670	BR4	1	0	1	1	1	1	1		
HL10	RMetric3	B			0.300	P	1	0	1	1	1	1	1		
HL10	RMetric3	A			2.500	O	0	1	0	0	0	0	0	**No diff btwn RBuffers and B5**	B5 better
HL10	RMetric3	B			0.200	B5	1	0	1	1	1	1	1		
HL10	RMetric3	B			0.700	BR1	1	0	1	1	1	1	1		
HL10	RMetric3	B			0.200	BR2	1	0	1	1	1	1	1		
HL10	RMetric3	B			0.100	BR3	1	0	1	1	1	1	1		
HL10	RMetric3	B			0.300	BR4	1	0	1	1	1	1	1		
HL11	Metric2		B		0.353	P	1	0	0	1	1	1	1		B5 better
HL11	Metric2		A		1.750	O	0	1	0	0	0	0	0	**No diff btwn RBuffers and B5**	B5 better
HL11	Metric2	C			0.066	B5	0	0	1	1	1	1	1		
HL11	Metric2	C	B		0.168	BR1	1	0	1	1	1	1	1		
HL11	Metric2	C	B		0.190	BR2	1	0	1	1	1	1	1		
HL11	Metric2	C	B		0.210	BR3	1	0	1	1	1	1	1		
HL11	Metric2	C	B		0.159	BR4	1	0	1	1	1	1	1		
HL11	Metric4	B	C		0.244	P	1	1	1	0	0	1	1		
HL11	Metric4		C		0.150	O	1	1	0	0	0	0	0	**No diff btwn RBuffers and B5**	
HL11	Metric4	B	A		0.375	B5	1	0	1	1	1	1	1		
HL11	Metric4		A		0.450	BR1	0	0	1	1	1	1	1		
HL11	Metric4		A		0.419	BR2	0	0	1	1	1	1	1		
HL11	Metric4	B	A		0.375	BR3	1	0	1	1	1	1	1		
HL11	Metric4	B	A		0.356	BR4	1	0	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HL11	Metric7		B		0.384	P	1	0	0	1	1	1	0		B5 better
HL11	Metric7		A		1.694	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HL11	Metric7	C			0.067	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HL11	Metric7	C	B		0.208	BR1	1	0	1	1	1	1	1		
HL11	Metric7	C	B		0.215	BR2	1	0	1	1	1	1	1		
HL11	Metric7	C	B		0.246	BR3	1	0	1	1	1	1	1		
HL11	Metric7	C			0.183	BR4	0	0	1	1	1	1	1		
HL11	RMetric1	B	A		4.627	P	1	1	0	0	0	0	1		B5 better
HL11	RMetric1		A		5.342	O	1	1	0	0	0	0	0	**No diff btwn**	B5 better
HL11	RMetric1		C		3.099	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HL11	RMetric1		C		3.705	BR1	0	0	1	1	1	1	1		
HL11	RMetric1		C		3.736	BR2	0	0	1	1	1	1	1		
HL11	RMetric1		C		3.733	BR3	0	0	1	1	1	1	1		
HL11	RMetric1	B	C		3.911	BR4	1	0	1	1	1	1	1		
HL11	RMetric4b	B	A		66.200	P	1	1	1	1	1	1	1		
HL11	RMetric4b		A		74.000	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
HL11	RMetric4b	B			58.500	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HL11	RMetric4b	B	A		61.400	BR1	1	1	1	1	1	1	1		
HL11	RMetric4b	B	A		62.400	BR2	1	1	1	1	1	1	1		
HL11	RMetric4b	B	A		62.800	BR3	1	1	1	1	1	1	1		
HL11	RMetric4b	B	A		59.600	BR4	1	1	1	1	1	1	1		
HL11	RMetric5a		A		34.800	P	1	1	0	0	0	1	0		B5 better
HL11	RMetric5a	B	A		33.400	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
HL11	RMetric5a			C	9.200	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HL11	RMetric5a	B		C	12.800	BR1	0	1	1	1	1	1	1		
HL11	RMetric5a	B		C	12.900	BR2	0	1	1	1	1	1	1		
HL11	RMetric5a	B	A	C	15.900	BR3	1	1	1	1	1	1	1		
HL11	RMetric5a	B		C	12.700	BR4	0	1	1	1	1	1	1		
HL11	RMetric5b	B	A		115.60	P	1	1	1	0	1	1	1		
HL11	RMetric5b		A		121.30	O	1	1	1	0	0	1	0	**No diff btwn**	
HL11	RMetric5b	B	A	C	42.200	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL11	RMetric5b			C	34.900	BR1	0	0	1	1	1	1	1		
HL11	RMetric5b	B		C	40.000	BR2	1	0	1	1	1	1	1		
HL11	RMetric5b	B	A	C	42.500	BR3	1	1	1	1	1	1	1		
HL11	RMetric5b	B		C	37.000	BR4	1	0	1	1	1	1	1		
HL12	Metric2		C	D	0.344	P	1	0	1	0	1	1	1		
HL12	Metric2		A		0.982	O	0	1	0	1	0	0	0	**At least one RBuffer**	B5 better
HL12	Metric2			D	0.126	B5	1	0	1	0	1	1	0	**differs from B5**	
HL12	Metric2	B	A		0.725	BR1	0	1	0	1	0	1	1	Worse	B5 better
HL12	Metric2			D	0.126	BR2	1	0	1	0	1	1	0		
HL12	Metric2	B	C	D	0.420	BR3	1	0	1	1	1	1	1		
HL12	Metric2	B	C		0.508	BR4	1	0	0	1	0	1	1	Worse	B5 better
HL12	Metric3	A			0.225	P	1	1	1	1	1	1	1		
HL12	Metric3	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
HL12	Metric3	A			0.181	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL12	Metric3	A			0.000	BR1	1	1	1	1	1	1	1		
HL12	Metric3	A			0.181	BR2	1	1	1	1	1	1	1		
HL12	Metric3	A			0.013	BR3	1	1	1	1	1	1	1		
HL12	Metric3	A			0.025	BR4	1	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HL12	Metric4		A		0.169	P	1	0	1	0	1	1	1		
HL12	Metric4	B			0.000	O	0	1	1	1	1	1	1	**No diff btwn**	
HL12	Metric4	B	A		0.131	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL12	Metric4	B			0.000	BR1	0	1	1	1	1	1	1		
HL12	Metric4	B	A		0.131	BR2	1	1	1	1	1	1	1		
HL12	Metric4	B	A		0.038	BR3	1	1	1	1	1	1	1		
HL12	Metric4	B	A		0.069	BR4	1	1	1	1	1	1	1		
HL12	Metric5		A		0.094	P	1	0	1	0	1	0	1		
HL12	Metric5	B			0.000	O	0	1	1	1	1	1	1	**No diff btwn**	
HL12	Metric5	B	A		0.069	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL12	Metric5	B			0.000	BR1	0	1	1	1	1	1	1		
HL12	Metric5	B	A		0.069	BR2	1	1	1	1	1	1	1		
HL12	Metric5	B			0.013	BR3	0	1	1	1	1	1	1		
HL12	Metric5	B	A		0.025	BR4	1	1	1	1	1	1	1		
HL12	Metric6	A			0.000	P	1	1	1	1	1	1	1		
HL12	Metric6	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
HL12	Metric6	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL12	Metric6	A			0.000	BR1	1	1	1	1	1	1	1		
HL12	Metric6	A			0.000	BR2	1	1	1	1	1	1	1		
HL12	Metric6	A			0.000	BR3	1	1	1	1	1	1	1		
HL12	Metric6	A			0.000	BR4	1	1	1	1	1	1	1		
HL12	Metric7		C	D	0.346	P	1	0	1	0	1	1	1		
HL12	Metric7		A		0.982	O	0	1	0	1	0	0	0	**At least one RBuffer**	B5 better
HL12	Metric7			D	0.122	B5	1	0	1	0	1	1	0	**differs from B5**	
HL12	Metric7	B	A		0.725	BR1	0	1	0	1	0	1	1	Worse	B5 better
HL12	Metric7			D	0.122	BR2	1	0	1	0	1	1	0		
HL12	Metric7	B	C	D	0.420	BR3	1	0	1	1	1	1	1		
HL12	Metric7	B	C		0.508	BR4	1	0	0	1	0	1	1	Worse	B5 better
HL12	RMetric2	B			0.371	P	1	0	1	1	1	1	1		
HL12	RMetric2	A			1.352	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
HL12	RMetric2	B			0.436	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HL12	RMetric2	B			0.574	BR1	1	0	1	1	1	1	1		
HL12	RMetric2	B			0.436	BR2	1	0	1	1	1	1	1		
HL12	RMetric2	B			0.488	BR3	1	0	1	1	1	1	1		
HL12	RMetric2	B			0.547	BR4	1	0	1	1	1	1	1		
HL12	RMetric3	B			0.300	P	1	0	1	1	1	1	1		
HL12	RMetric3		A		2.200	O	0	1	0	1	0	0	0	**No diff btwn**	B5 better
HL12	RMetric3	B			0.300	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HL12	RMetric3	B	A		1.100	BR1	1	1	1	1	1	1	1		
HL12	RMetric3	B			0.300	BR2	1	0	1	1	1	1	1		
HL12	RMetric3	B			0.300	BR3	1	0	1	1	1	1	1		
HL12	RMetric3	B			0.700	BR4	1	0	1	1	1	1	1		
HL12	RMetric4b	B	A		11.800	P	1	1	1	1	1	1	1		
HL12	RMetric4b		A		20.400	O	1	1	0	0	0	1	0	**No diff btwn**	B5 better
HL12	RMetric4b	B			10.900	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HL12	RMetric4b	B			9.400	BR1	1	0	1	1	1	1	1		
HL12	RMetric4b	B			10.900	BR2	1	0	1	1	1	1	1		
HL12	RMetric4b	B	A		12.400	BR3	1	1	1	1	1	1	1		
HL12	RMetric4b	B			9.800	BR4	1	0	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
HL12	RMetric5a		A		20.200	P	1	1	0	0	0	0	0		B5 better
HL12	RMetric5a	B	A		14.900	O	1	1	1	1	1	1	1	**No diff btwn**	
HL12	RMetric5a	B			6.700	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
HL12	RMetric5a	B			10.800	BR1	0	1	1	1	1	1	1		
HL12	RMetric5a	B			6.700	BR2	0	1	1	1	1	1	1		
HL12	RMetric5a	B			7.600	BR3	0	1	1	1	1	1	1		
HL12	RMetric5a	B			9.100	BR4	0	1	1	1	1	1	1		
HL13	Metric1	A			0.000	P	1	1	1	1	1	1	1		
HL13	Metric1	A			0.047	O	1	1	1	1	1	1	1	**No diff btwn**	
HL13	Metric1	A			0.024	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
HL13	Metric1	A			0.014	BR1	1	1	1	1	1	1	1		
HL13	Metric1	A			0.000	BR2	1	1	1	1	1	1	1		
HL13	Metric1	A			0.000	BR3	1	1	1	1	1	1	1		
HL13	Metric1	A			0.008	BR4	1	1	1	1	1	1	1		
HL13	Metric2		B		0.355	P	1	0	0	0	0	1	0		B5 better
HL13	Metric2		A		1.138	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
HL13	Metric2		D		0.043	B5	0	0	1	0	0	0	0	**differs from B5**	
HL13	Metric2	C			0.214	BR1	0	0	0	1	1	1	1	Worse	B5 better
HL13	Metric2	C			0.216	BR2	0	0	0	1	1	1	1	Worse	B5 better
HL13	Metric2	C	B		0.240	BR3	1	0	0	1	1	1	1	Worse	B5 better
HL13	Metric2	C			0.166	BR4	0	0	0	1	1	1	1	Worse	B5 better
HL13	Metric7		B		0.355	P	1	0	0	1	1	1	1		B5 better
HL13	Metric7		A		1.110	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
HL13	Metric7	C			0.048	B5	0	0	1	1	1	0	1	**differs from B5**	
HL13	Metric7	C	B		0.202	BR1	1	0	1	1	1	1	1		
HL13	Metric7	C	B		0.216	BR2	1	0	1	1	1	1	1		
HL13	Metric7		B		0.240	BR3	1	0	0	1	1	1	1	Worse	B5 better
HL13	Metric7	C	B		0.173	BR4	1	0	1	1	1	1	1		
HL13	RMetric2	B			0.950	P	1	0	1	1	1	1	1		
HL13	RMetric2		A		2.020	O	0	1	0	1	1	0	0	**No diff btwn**	B5 better
HL13	RMetric2	B			0.668	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
HL13	RMetric2	B	A		1.086	BR1	1	1	1	1	1	1	1		
HL13	RMetric2	B	A		1.103	BR2	1	1	1	1	1	1	1		
HL13	RMetric2	B			1.042	BR3	1	0	1	1	1	1	1		
HL13	RMetric2	B			0.782	BR4	1	0	1	1	1	1	1		
HL13	RMetric5a		A		37.400	P	1	1	0	1	1	1	1		B5 better
HL13	RMetric5a		A		33.800	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
HL13	RMetric5a	B			8.900	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
HL13	RMetric5a	B	A		18.300	BR1	1	1	1	1	1	1	1		
HL13	RMetric5a	B	A		19.400	BR2	1	1	1	1	1	1	1		
HL13	RMetric5a	B	A		20.500	BR3	1	1	1	1	1	1	1		
HL13	RMetric5a	B	A		17.500	BR4	1	1	1	1	1	1	1		

Stochasticity = Low, Location = Early

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LE10	Metric2	A			0.150	P	1	1	1	1	1	1	1		
LE10	Metric2	A			0.194	O	1	1	1	1	1	1	1	**No diff btwn**	
LE10	Metric2	A			0.064	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE10	Metric2	A			0.184	BR1	1	1	1	1	1	1	1		
LE10	Metric2	A			0.064	BR2	1	1	1	1	1	1	1		
LE10	Metric2	A			0.059	BR3	1	1	1	1	1	1	1		
LE10	Metric2	A			0.144	BR4	1	1	1	1	1	1	1		
LE10	Metric4	A			0.175	P	1	1	1	1	1	1	1		
LE10	Metric4	A			0.013	O	1	1	1	1	1	1	1	**No diff btwn**	
LE10	Metric4	A			0.194	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE10	Metric4	A			0.175	BR1	1	1	1	1	1	1	1		
LE10	Metric4	A			0.200	BR2	1	1	1	1	1	1	1		
LE10	Metric4	A			0.200	BR3	1	1	1	1	1	1	1		
LE10	Metric4	A			0.175	BR4	1	1	1	1	1	1	1		
LE10	Metric7	A			0.158	P	1	1	1	1	1	1	1		
LE10	Metric7	A			0.194	O	1	1	1	1	1	1	1	**No diff btwn**	
LE10	Metric7	A			0.064	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE10	Metric7	A			0.184	BR1	1	1	1	1	1	1	1		
LE10	Metric7	A			0.064	BR2	1	1	1	1	1	1	1		
LE10	Metric7	A			0.059	BR3	1	1	1	1	1	1	1		
LE10	Metric7	A			0.144	BR4	1	1	1	1	1	1	1		
LE11	Metric2		B		0.224	P	1	0	0	1	1	1	0		B5 better
LE11	Metric2		A		0.498	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LE11	Metric2		D		0.023	B5	0	0	1	0	0	0	1	**differs from B5**	
LE11	Metric2	C	B		0.138	BR1	1	0	0	1	1	1	1	Worse	B5 better
LE11	Metric2	C	B		0.138	BR2	1	0	0	1	1	1	1	Worse	B5 better
LE11	Metric2	C	B		0.157	BR3	1	0	0	1	1	1	1	Worse	B5 better
LE11	Metric2	C	D		0.101	BR4	0	0	1	1	1	1	1		
LE11	Metric4		A		0.462	P	1	0	1	1	1	1	1		
LE11	Metric4	B			0.144	O	0	1	1	1	1	1	1	**No diff btwn**	
LE11	Metric4	B	A		0.394	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE11	Metric4	B	A		0.369	BR1	1	1	1	1	1	1	1		
LE11	Metric4	B	A		0.369	BR2	1	1	1	1	1	1	1		
LE11	Metric4	B	A		0.419	BR3	1	1	1	1	1	1	1		
LE11	Metric4	B	A		0.431	BR4	1	1	1	1	1	1	1		
LE11	Metric5	B			0.175	P	1	0	1	1	1	1	1		
LE11	Metric5	A			0.381	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LE11	Metric5	B			0.188	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LE11	Metric5	B			0.175	BR1	1	0	1	1	1	1	1		
LE11	Metric5	B			0.175	BR2	1	0	1	1	1	1	1		
LE11	Metric5	B			0.188	BR3	1	0	1	1	1	1	1		
LE11	Metric5	B			0.169	BR4	1	0	1	1	1	1	1		
LE11	Metric7		B		0.228	P	1	0	0	1	1	1	1		B5 better
LE11	Metric7		A		0.521	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LE11	Metric7	C			0.024	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
LE11	Metric7	C	B		0.131	BR1	1	0	1	1	1	1	1		
LE11	Metric7	C	B		0.131	BR2	1	0	1	1	1	1	1		
LE11	Metric7	C	B		0.167	BR3	1	0	1	1	1	1	1		
LE11	Metric7	C	B		0.094	BR4	1	0	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LE11	RMetric1	B			2.728	P	1	0	1	1	1	1	1		
LE11	RMetric1	A			4.187	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LE11	RMetric1	B			2.449	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LE11	RMetric1	B			2.594	BR1	1	0	1	1	1	1	1		
LE11	RMetric1	B			2.594	BR2	1	0	1	1	1	1	1		
LE11	RMetric1	B			2.732	BR3	1	0	1	1	1	1	1		
LE11	RMetric1	B			2.472	BR4	1	0	1	1	1	1	1		
LE11	RMetric3	A			0.000	P	1	1	1	1	1	1	1		
LE11	RMetric3	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LE11	RMetric3	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE11	RMetric3	A			0.000	BR1	1	1	1	1	1	1	1		
LE11	RMetric3	A			0.000	BR2	1	1	1	1	1	1	1		
LE11	RMetric3	A			0.000	BR3	1	1	1	1	1	1	1		
LE11	RMetric3	A			0.000	BR4	1	1	1	1	1	1	1		
LE11	RMetric5a	B	A		20.000	P	1	1	1	1	1	1	1		
LE11	RMetric5a		A		23.600	O	1	1	0	1	1	1	0	**No diff btwn**	B5 better
LE11	RMetric5a	B			7.500	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LE11	RMetric5a	B	A		12.700	BR1	1	1	1	1	1	1	1		
LE11	RMetric5a	B	A		11.700	BR2	1	1	1	1	1	1	1		
LE11	RMetric5a	B	A		12.400	BR3	1	1	1	1	1	1	1		
LE11	RMetric5a	B			10.400	BR4	1	0	1	1	1	1	1		
LE12	Metric2	A			0.151	P	1	1	1	1	1	1	1		
LE12	Metric2	A			0.335	O	1	1	1	1	1	1	1	**No diff btwn**	
LE12	Metric2	A			0.122	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE12	Metric2	A			0.291	BR1	1	1	1	1	1	1	1		
LE12	Metric2	A			0.122	BR2	1	1	1	1	1	1	1		
LE12	Metric2	A			0.224	BR3	1	1	1	1	1	1	1		
LE12	Metric2	A			0.236	BR4	1	1	1	1	1	1	1		
LE12	Metric6	A			0.000	P	1	1	1	1	1	1	1		
LE12	Metric6	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LE12	Metric6	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE12	Metric6	A			0.000	BR1	1	1	1	1	1	1	1		
LE12	Metric6	A			0.000	BR2	1	1	1	1	1	1	1		
LE12	Metric6	A			0.000	BR3	1	1	1	1	1	1	1		
LE12	Metric6	A			0.000	BR4	1	1	1	1	1	1	1		
LE12	Metric7	B	A		0.168	P	1	1	1	1	1	1	1		
LE12	Metric7		A		0.335	O	1	1	0	1	0	1	1	**No diff btwn**	B5 better
LE12	Metric7	B			0.100	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LE12	Metric7	B	A		0.291	BR1	1	1	1	1	1	1	1		
LE12	Metric7	B			0.100	BR2	1	0	1	1	1	1	1		
LE12	Metric7	B	A		0.212	BR3	1	1	1	1	1	1	1		
LE12	Metric7	B	A		0.224	BR4	1	1	1	1	1	1	1		
LE12	RMetric1	B			1.138	P	1	1	0	0	0	0	0		
LE12	RMetric1	B	A		1.588	O	1	1	1	1	1	1	1	**No diff btwn**	
LE12	RMetric1		A		1.749	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
LE12	RMetric1		A		1.716	BR1	0	1	1	1	1	1	1		
LE12	RMetric1		A		1.749	BR2	0	1	1	1	1	1	1		
LE12	RMetric1		A		1.774	BR3	0	1	1	1	1	1	1		
LE12	RMetric1		A		1.734	BR4	0	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LE13	Metric2		B		0.210	P	1	0	0	1	1	1	0		B5 better
LE13	Metric2		A		0.448	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LE13	Metric2		D		0.014	B5	0	0	1	0	0	0	1	**differs from B5**	
LE13	Metric2	C	B		0.144	BR1	1	0	0	1	1	1	1	Worse	B5 better
LE13	Metric2	C	B		0.145	BR2	1	0	0	1	1	1	1	Worse	B5 better
LE13	Metric2	C	B		0.150	BR3	1	0	0	1	1	1	1	Worse	B5 better
LE13	Metric2	C	D		0.087	BR4	0	0	1	1	1	1	1		
LE13	Metric7		B		0.207	P	1	0	0	1	1	1	1		B5 better
LE13	Metric7		A		0.460	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LE13	Metric7	C			0.025	B5	0	0	1	1	1	0	1	**differs from B5**	
LE13	Metric7	C	B		0.145	BR1	1	0	1	1	1	1	1		
LE13	Metric7	C	B		0.147	BR2	1	0	1	1	1	1	1		
LE13	Metric7		B		0.152	BR3	1	0	0	1	1	1	1	Worse	B5 better
LE13	Metric7	C	B		0.086	BR4	1	0	1	1	1	1	1		
LE13	RMetric1	B			2.315	P	1	0	1	1	1	1	1		
LE13	RMetric1	A			3.848	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LE13	RMetric1	B			2.666	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LE13	RMetric1	B			2.693	BR1	1	0	1	1	1	1	1		
LE13	RMetric1	B			2.696	BR2	1	0	1	1	1	1	1		
LE13	RMetric1	B			2.713	BR3	1	0	1	1	1	1	1		
LE13	RMetric1	B			2.294	BR4	1	0	1	1	1	1	1		
LE13	RMetric3	A			0.000	P	1	1	1	1	1	1	1		
LE13	RMetric3	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LE13	RMetric3	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LE13	RMetric3	A			0.000	BR1	1	1	1	1	1	1	1		
LE13	RMetric3	A			0.000	BR2	1	1	1	1	1	1	1		
LE13	RMetric3	A			0.000	BR3	1	1	1	1	1	1	1		
LE13	RMetric3	A			0.000	BR4	1	1	1	1	1	1	1		
LE13	RMetric5a		A		19.800	P	1	1	0	1	1	1	1		B5 better
LE13	RMetric5a		A		21.300	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
LE13	RMetric5a	B			7.500	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
LE13	RMetric5a	B	A		13.500	BR1	1	1	1	1	1	1	1		
LE13	RMetric5a	B	A		13.700	BR2	1	1	1	1	1	1	1		
LE13	RMetric5a	B	A		14.000	BR3	1	1	1	1	1	1	1		
LE13	RMetric5a	B	A		11.500	BR4	1	1	1	1	1	1	1		

Stochasticity = Low, Location = Late

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LL10	RMetric2	B	A		0.734	P	1	1	1	1	1	1	1		
LL10	RMetric2		A		1.311	O	1	1	0	0	0	0	0	**No diff btwn**	B5 better
LL10	RMetric2	B			0.254	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL10	RMetric2	B			0.577	BR1	1	0	1	1	1	1	1		
LL10	RMetric2	B			0.260	BR2	1	0	1	1	1	1	1		
LL10	RMetric2	B			0.282	BR3	1	0	1	1	1	1	1		
LL10	RMetric2	B			0.552	BR4	1	0	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LL11	Metric2		B		0.217	P	1	0	0	1	1	1	0		B5 better
LL11	Metric2		A		0.478	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LL11	Metric2		D		0.021	B5	0	0	1	0	0	0	1	**differs from B5**	
LL11	Metric2	C	B		0.139	BR1	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric2	C	B		0.139	BR2	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric2	C	B		0.150	BR3	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric2	C	D		0.094	BR4	0	0	1	1	1	1	1		
LL11	Metric4	B	A		0.356	P	1	1	1	1	1	1	1		
LL11	Metric4	B			0.131	O	1	1	0	1	1	1	0	**No diff btwn**	
LL11	Metric4		A		0.463	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL11	Metric4	B	A		0.400	BR1	1	1	1	1	1	1	1		
LL11	Metric4	B	A		0.400	BR2	1	1	1	1	1	1	1		
LL11	Metric4	B	A		0.381	BR3	1	1	1	1	1	1	1		
LL11	Metric4		A		0.444	BR4	1	0	1	1	1	1	1		
LL11	Metric5	B			0.131	P	1	0	1	1	1	1	1		
LL11	Metric5	A			0.394	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LL11	Metric5	B			0.200	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL11	Metric5	B			0.213	BR1	1	0	1	1	1	1	1		
LL11	Metric5	B			0.213	BR2	1	0	1	1	1	1	1		
LL11	Metric5	B			0.194	BR3	1	0	1	1	1	1	1		
LL11	Metric5	B			0.213	BR4	1	0	1	1	1	1	1		
LL11	Metric7		B		0.253	P	1	0	0	1	1	1	0		B5 better
LL11	Metric7		A		0.466	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LL11	Metric7		D		0.035	B5	0	0	1	0	0	0	1	**differs from B5**	
LL11	Metric7	C	B		0.159	BR1	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric7	C	B		0.159	BR2	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric7	C	B		0.193	BR3	1	0	0	1	1	1	1	Worse	B5 better
LL11	Metric7	C	D		0.122	BR4	0	0	1	1	1	1	1		
LL11	RMetric1		A		3.953	P	1	1	0	1	1	1	1		B5 better
LL11	RMetric1		A		3.950	O	1	1	0	1	1	1	1	**At least one RBuffer**	B5 better
LL11	RMetric1	B			2.372	B5	0	0	1	1	1	0	1	**differs from B5**	
LL11	RMetric1	B	A		3.142	BR1	1	1	1	1	1	1	1		
LL11	RMetric1	B	A		3.142	BR2	1	1	1	1	1	1	1		
LL11	RMetric1		A		3.471	BR3	1	1	0	1	1	1	1	Worse	B5 better
LL11	RMetric1	B	A		3.197	BR4	1	1	1	1	1	1	1		
LL11	RMetric3	A			0.000	P	1	1	1	1	1	1	1		
LL11	RMetric3	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LL11	RMetric3	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LL11	RMetric3	A			0.000	BR1	1	1	1	1	1	1	1		
LL11	RMetric3	A			0.000	BR2	1	1	1	1	1	1	1		
LL11	RMetric3	A			0.000	BR3	1	1	1	1	1	1	1		
LL11	RMetric3	A			0.000	BR4	1	1	1	1	1	1	1		
LL11	RMetric5a		A		22.500	P	1	1	0	1	1	1	0		B5 better
LL11	RMetric5a	B	A		19.600	O	1	1	1	1	1	1	1	**No diff btwn**	
LL11	RMetric5a	B			6.100	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
LL11	RMetric5a	B	A		10.700	BR1	1	1	1	1	1	1	1		
LL11	RMetric5a	B	A		10.700	BR2	1	1	1	1	1	1	1		
LL11	RMetric5a	B	A		13.000	BR3	1	1	1	1	1	1	1		
LL11	RMetric5a	B			8.100	BR4	0	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LL11	RMetric5b		A		70.400	P	1	1	0	0	0	1	1		B5 better
LL11	RMetric5b	B	A		69.300	O	1	1	1	0	0	1	1	**No diff btwn**	
LL11	RMetric5b	B		C	25.700	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
LL11	RMetric5b			C	19.700	BR1	0	0	1	1	1	1	1		
LL11	RMetric5b			C	19.700	BR2	0	0	1	1	1	1	1		
LL11	RMetric5b	B	A	C	36.300	BR3	1	1	1	1	1	1	1		
LL11	RMetric5b	B	A	C	29.600	BR4	1	1	1	1	1	1	1		
LL12	Metric2	B	A		0.178	P	1	1	1	1	1	1	1		
LL12	Metric2		A		0.282	O	1	1	0	1	0	1	1	**At least one RBuffer**	B5 better
LL12	Metric2	B			0.067	B5	1	0	1	0	1	1	1	**differs from B5**	
LL12	Metric2		A		0.240	BR1	1	1	0	1	0	1	1	Worse	B5 better
LL12	Metric2	B			0.067	BR2	1	0	1	0	1	1	1		
LL12	Metric2	B	A		0.189	BR3	1	1	1	1	1	1	1		
LL12	Metric2	B	A		0.186	BR4	1	1	1	1	1	1	1		
LL12	Metric6	A			0.000	P	1	1	1	1	1	1	1		
LL12	Metric6	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LL12	Metric6	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LL12	Metric6	A			0.000	BR1	1	1	1	1	1	1	1		
LL12	Metric6	A			0.000	BR2	1	1	1	1	1	1	1		
LL12	Metric6	A			0.000	BR3	1	1	1	1	1	1	1		
LL12	Metric6	A			0.000	BR4	1	1	1	1	1	1	1		
LL12	Metric7	B	A		0.198	P	1	1	1	1	1	1	1		
LL12	Metric7		A		0.282	O	1	1	0	1	0	1	1	**At least one RBuffer**	B5 better
LL12	Metric7	B			0.058	B5	1	0	1	0	1	1	1	**differs from B5**	
LL12	Metric7		A		0.240	BR1	1	1	0	1	0	1	1	Worse	B5 better
LL12	Metric7	B			0.058	BR2	1	0	1	0	1	1	1		
LL12	Metric7	B	A		0.163	BR3	1	1	1	1	1	1	1		
LL12	Metric7	B	A		0.175	BR4	1	1	1	1	1	1	1		
LL12	RMetric1		A		2.235	P	1	0	0	0	0	0	1		B5 better
LL12	RMetric1	B			1.449	O	0	1	1	1	1	1	1	**No diff btwn**	
LL12	RMetric1	B			1.338	B5	0	1	1	1	1	1	1	**RBuffers and B5**	
LL12	RMetric1	B			1.482	BR1	0	1	1	1	1	1	1		
LL12	RMetric1	B			1.338	BR2	0	1	1	1	1	1	1		
LL12	RMetric1	B			1.526	BR3	0	1	1	1	1	1	1		
LL12	RMetric1	B	A		1.627	BR4	1	1	1	1	1	1	1		
LL12	RMetric2	B			0.367	P	1	0	1	1	1	1	1		
LL12	RMetric2	A			0.878	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LL12	RMetric2	B			0.219	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL12	RMetric2	B			0.473	BR1	1	0	1	1	1	1	1		
LL12	RMetric2	B			0.219	BR2	1	0	1	1	1	1	1		
LL12	RMetric2	B			0.373	BR3	1	0	1	1	1	1	1		
LL12	RMetric2	B			0.382	BR4	1	0	1	1	1	1	1		
LL12	RMetric4a	B			3.000	P	1	0	1	1	1	1	1		
LL12	RMetric4a		A		6.200	O	0	1	1	0	1	0	1	**No diff btwn**	
LL12	RMetric4a	B	A		3.700	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LL12	RMetric4a	B			2.500	BR1	1	0	1	1	1	1	1		
LL12	RMetric4a	B	A		3.700	BR2	1	1	1	1	1	1	1		
LL12	RMetric4a	B			3.200	BR3	1	0	1	1	1	1	1		
LL12	RMetric4a	B	A		3.700	BR4	1	1	1	1	1	1	1		

Group	Metric	Tukey Grouping			Mean	Buff Meth	P	O	B 5	Rbuffers 1	2	3	4	B5 vs RBuffers	B5 sig better
LL12	RMetric4b	B			6.600	P	1	0	1	1	1	1	1		
LL12	RMetric4b	A			13.800	O	0	1	0	0	0	0	0	**No diff btwn**	B5 better
LL12	RMetric4b	B			6.400	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL12	RMetric4b	B			5.200	BR1	1	0	1	1	1	1	1		
LL12	RMetric4b	B			6.400	BR2	1	0	1	1	1	1	1		
LL12	RMetric4b	B			6.700	BR3	1	0	1	1	1	1	1		
LL12	RMetric4b	B			6.200	BR4	1	0	1	1	1	1	1		
LL13	Metric2		B		0.238	P	1	0	0	1	1	1	0		B5 better
LL13	Metric2		A		0.436	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LL13	Metric2		D		0.020	B5	0	0	1	0	0	0	0	**differs from B5**	
LL13	Metric2	C	B		0.174	BR1	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric2	C	B		0.175	BR2	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric2	C	B		0.181	BR3	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric2	C			0.119	BR4	0	0	0	1	1	1	1	Worse	B5 better
LL13	Metric7		B		0.238	P	1	0	0	1	1	1	0		B5 better
LL13	Metric7		A		0.402	O	0	1	0	0	0	0	0	**At least one RBuffer**	B5 better
LL13	Metric7		D		0.042	B5	0	0	1	0	0	0	1	**differs from B5**	
LL13	Metric7	C	B		0.179	BR1	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric7	C	B		0.181	BR2	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric7	C	B		0.186	BR3	1	0	0	1	1	1	1	Worse	B5 better
LL13	Metric7	C	D		0.119	BR4	0	0	1	1	1	1	1		
LL13	RMetric3	A			0.000	P	1	1	1	1	1	1	1		
LL13	RMetric3	A			0.000	O	1	1	1	1	1	1	1	**No diff btwn**	
LL13	RMetric3	A			0.000	B5	1	1	1	1	1	1	1	**RBuffers and B5**	
LL13	RMetric3	A			0.000	BR1	1	1	1	1	1	1	1		
LL13	RMetric3	A			0.000	BR2	1	1	1	1	1	1	1		
LL13	RMetric3	A			0.000	BR3	1	1	1	1	1	1	1		
LL13	RMetric3	A			0.000	BR4	1	1	1	1	1	1	1		
LL13	RMetric5a		A		22.300	P	1	1	0	0	0	0	0		B5 better
LL13	RMetric5a	B	A		19.300	O	1	1	0	1	1	1	0	**No diff btwn**	B5 better
LL13	RMetric5a		C		5.500	B5	0	0	1	1	1	1	1	**RBuffers and B5**	
LL13	RMetric5a	B	C		12.900	BR1	0	1	1	1	1	1	1		
LL13	RMetric5a	B	C		13.100	BR2	0	1	1	1	1	1	1		
LL13	RMetric5a	B	C		13.400	BR3	0	1	1	1	1	1	1		
LL13	RMetric5a		C		10.400	BR4	0	0	1	1	1	1	1		
LL13	RMetric5b	B	A		55.100	P	1	1	1	1	1	1	1		
LL13	RMetric5b		A		69.000	O	1	1	0	1	1	1	1	**No diff btwn**	B5 better
LL13	RMetric5b	B			18.200	B5	1	0	1	1	1	1	1	**RBuffers and B5**	
LL13	RMetric5b	B	A		30.200	BR1	1	1	1	1	1	1	1		
LL13	RMetric5b	B	A		28.100	BR2	1	1	1	1	1	1	1		
LL13	RMetric5b	B	A		30.700	BR3	1	1	1	1	1	1	1		
LL13	RMetric5b	B	A		24.800	BR4	1	1	1	1	1	1	1		

APPENDIX J: INITIAL STUDY - USING PRIOR KNOWLEDGE TO SIZE BUFFERS

Robustness Metrics

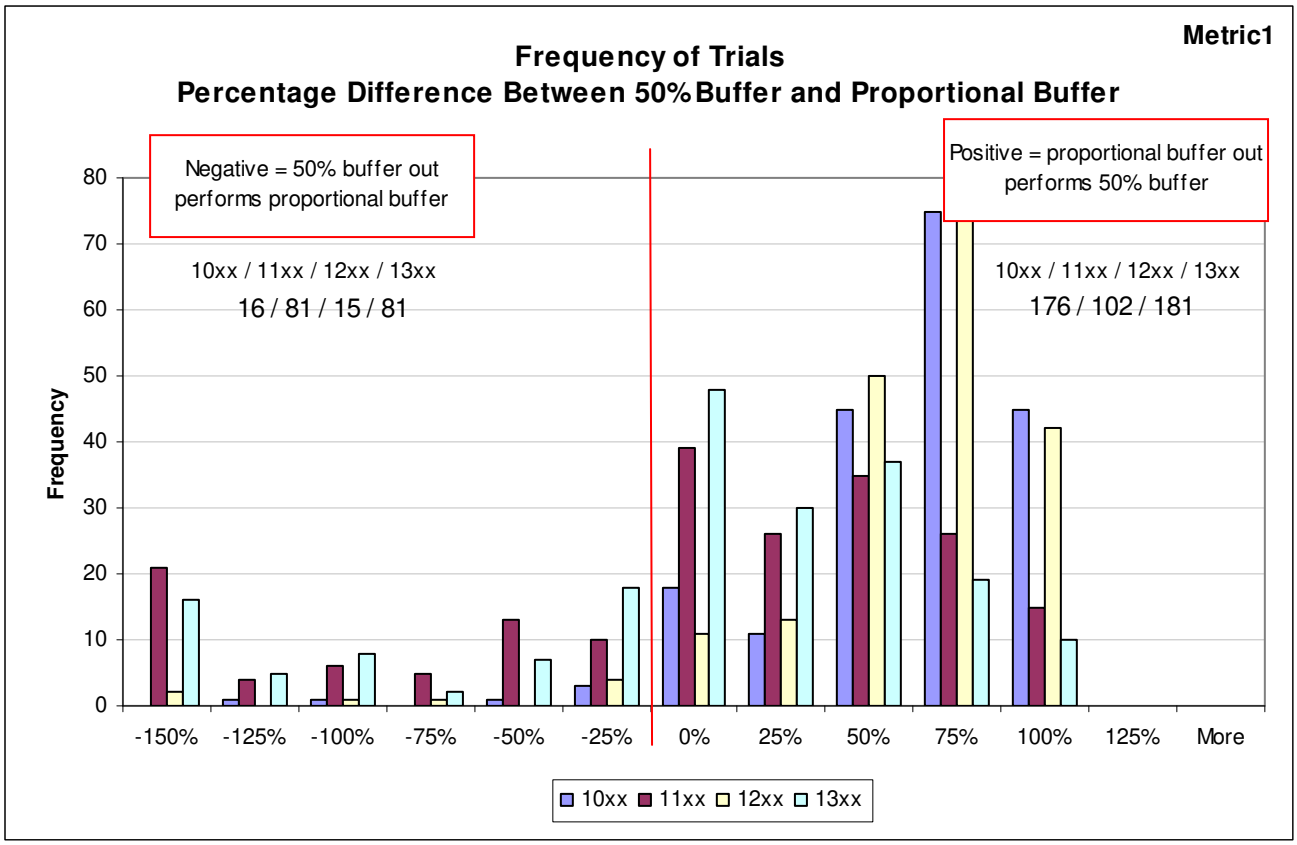
The following table highlights the averages of the Selim/Grey robustness metrics over 100 replications used in the initial feasibility study to determine if proportional buffers are potentially useful when prior knowledge about the probability of occurrence exists. The highlights indicate the lowest average between the two methods.

		Average of Metric1		Average of Metric2		Average of Metric3		Average of Metric4		Average of Metric5		Average of Metric6		Average of Metric7		Average of Metric8	
NW Set	NW	B1	B5	B1	B5	B1	B5	B1	B5	B1	B5	B1	B5	B1	B5	B1	B5
10	NW1004	0.493	1.026	0.572	1.213	0.753	0.792	0.304	0.262	0.192	0.277	0.105	0.253	0.136	0.164	1.179	0.804
	NW1010	0.333	0.686	0.378	1.483	0.635	0.698	0.292	0.239	0.151	0.224	0.119	0.147	0.138	0.499	1.129	0.928
11	NW1102	0.194	0.146	0.182	0.114	0.854	0.906	0.336	0.317	0.199	0.224	0.273	0.309	0.148	0.162	0.786	0.881
	NW1105	0.093	0.135	0.129	0.098	0.806	0.835	0.403	0.338	0.158	0.158	0.392	0.409	0.108	0.121	1.129	0.955
12	NW1200	0.294	0.692	0.414	0.939	0.931	0.906	0.148	0.172	0.211	0.296	0.024	0.028	0.136	0.183	0.590	0.619
	NW1201	0.320	0.607	0.447	0.481	0.646	0.771	0.152	0.183	0.168	0.311	0.011	0.044	0.146	0.130	1.020	0.830
13	NW1300	0.103	0.080	0.157	0.136	0.723	0.726	0.373	0.231	0.245	0.183	0.043	0.007	0.121	0.180	1.045	0.979
	NW1304	0.111	0.147	0.158	0.125	0.769	0.834	0.336	0.364	0.283	0.334	0.043	0.058	0.118	0.109	0.946	0.836
Grand Total		0.243	0.440	0.305	0.574	0.764	0.809	0.293	0.263	0.201	0.251	0.126	0.157	0.131	0.193	0.978	0.854

The following 8 tables and histograms provide the frequency of replicates for which the best value for that metric was generated when conducting pairwise comparisons between the proportional 80/20 proportional buffer and the 50% buffer for that replicated eventuation.

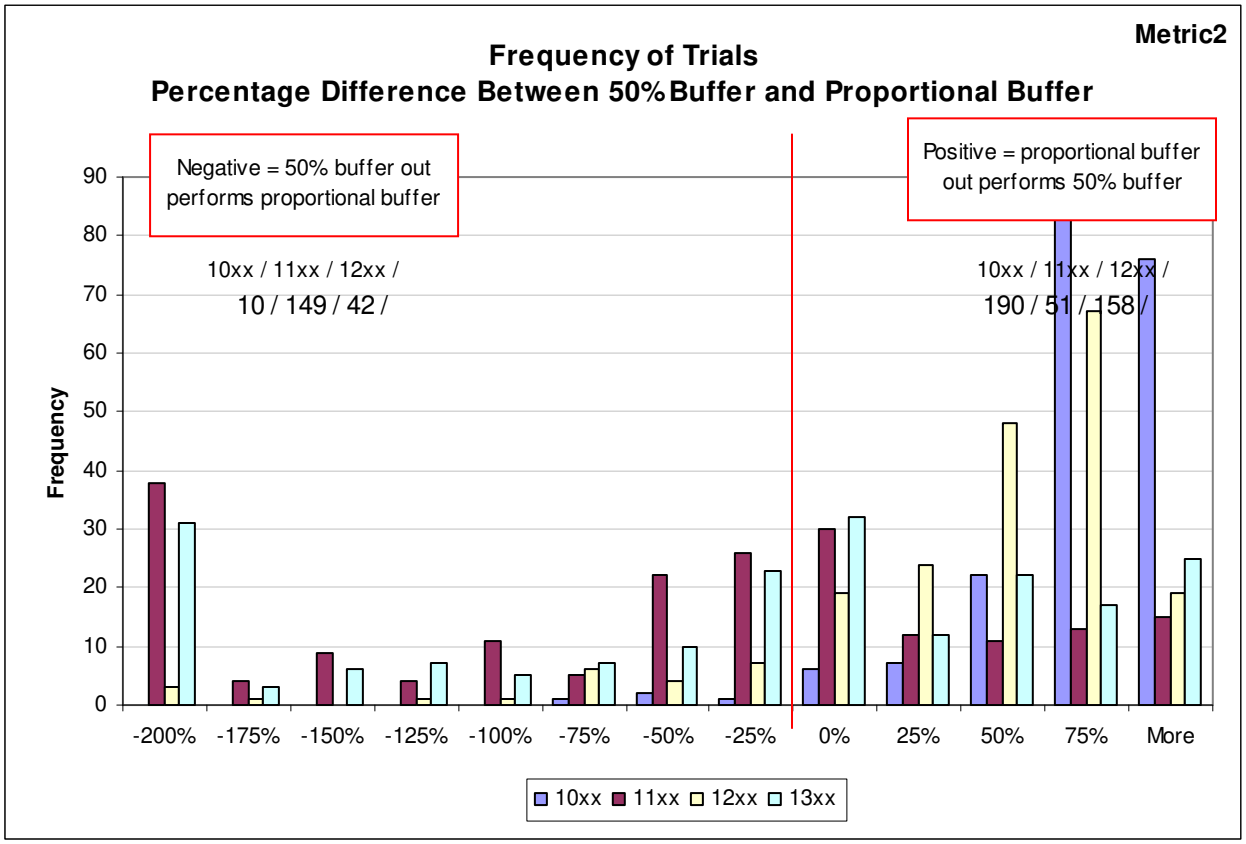
Comparison of Performance for Metric1

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	86	11	3
	NW1010	100	90	5	5
10 Total		200	176	16	8
11	NW1102	100	30	62	8
	NW1105	100	72	19	9
11 Total		200	102	81	17
12	NW1200	100	95	3	2
	NW1201	100	86	12	2
12 Total		200	181	15	4
13	NW1300	100	25	59	16
	NW1304	100	71	22	7
13 Total		200	96	81	23
Grand Total		800	555	193	52



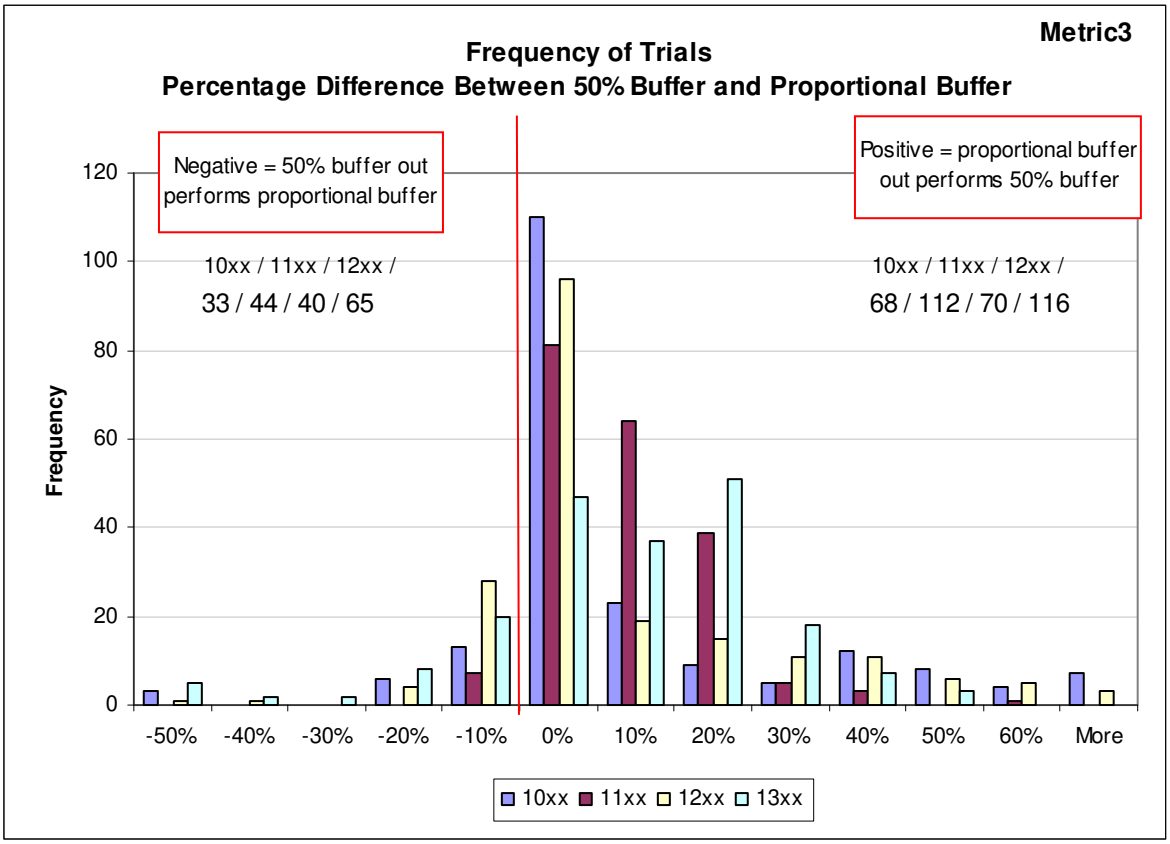
Comparison of Performance for Metric2

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	90	10	-
	NW1010	100	100	-	-
10 Total		200	190	10	-
11	NW1102	100	26	74	-
	NW1105	100	25	75	-
11 Total		200	51	149	-
12	NW1200	100	99	1	-
	NW1201	100	59	41	-
12 Total		200	158	42	-
13	NW1300	100	51	49	-
	NW1304	100	25	75	-
13 Total		200	76	124	-
Grand Total		800	475	325	-



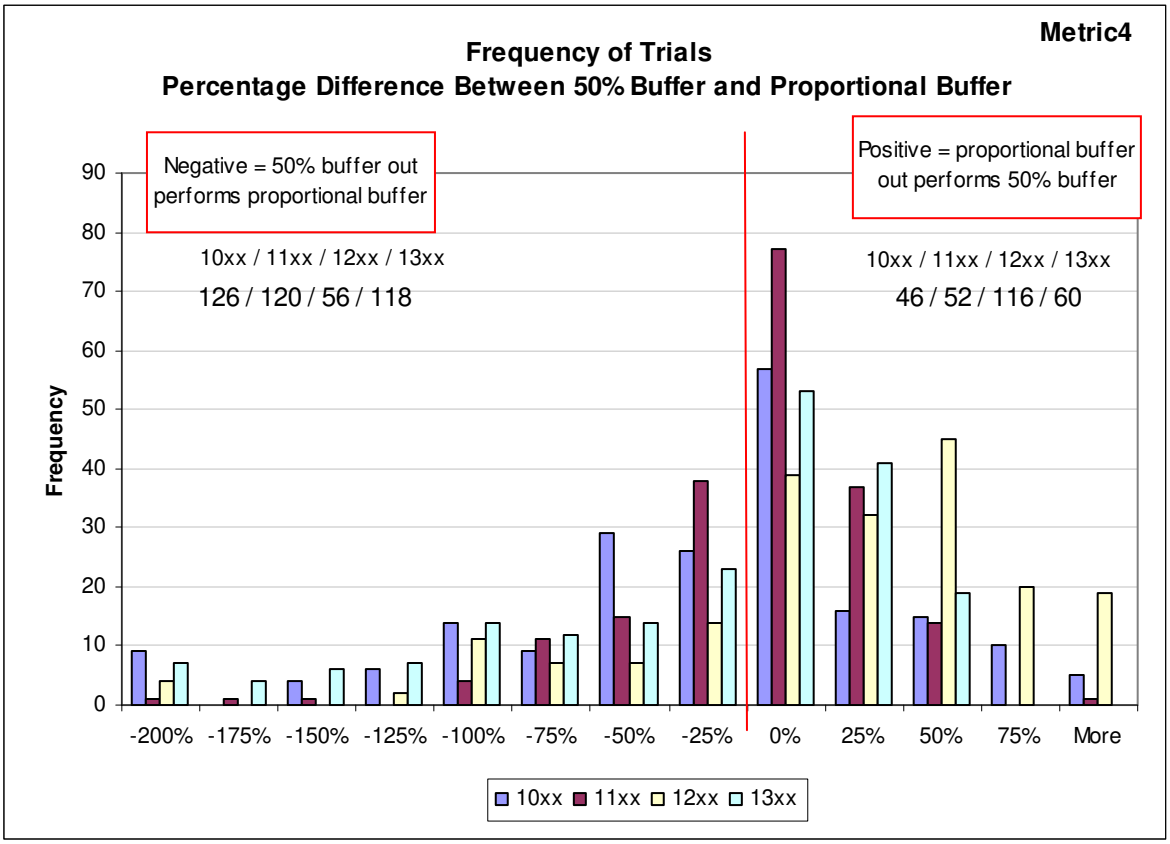
Comparison of Performance for Metric3

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	27	25	48
	NW1010	100	41	8	51
10 Total		200	68	33	99
11	NW1102	100	61	15	24
	NW1105	100	51	29	20
11 Total		200	112	44	44
12	NW1200	100	7	31	62
	NW1201	100	63	9	28
12 Total		200	70	40	90
13	NW1300	100	43	44	13
	NW1304	100	73	21	6
13 Total		200	116	65	19
Grand Total		800	366	182	252



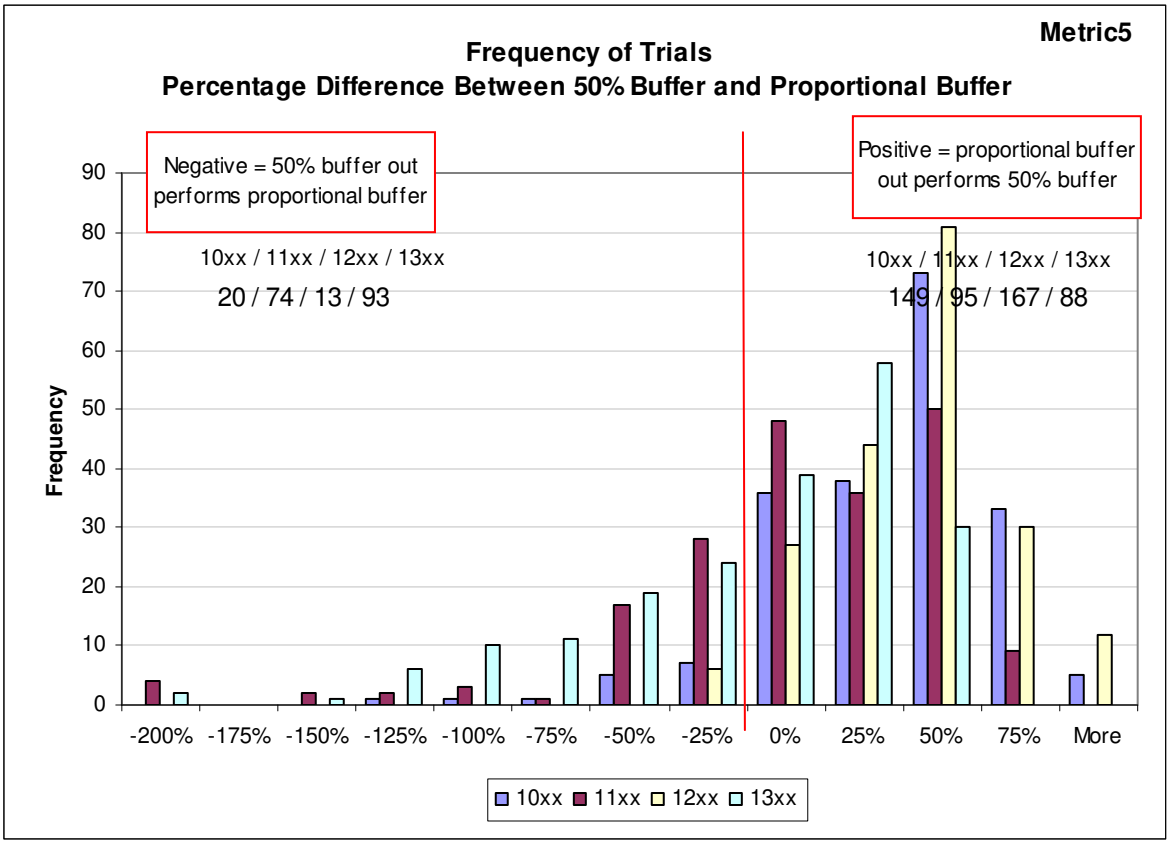
Comparison of Performance for Metric4

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	31	54	15
	NW1010	100	15	72	13
10 Total		200	46	126	28
11	NW1102	100	32	52	16
	NW1105	100	20	68	12
11 Total		200	52	120	28
12	NW1200	100	56	26	18
	NW1201	100	60	30	10
12 Total		200	116	56	28
13	NW1300	100	6	85	9
	NW1304	100	54	33	13
13 Total		200	60	118	22
Grand Total		800	274	420	106



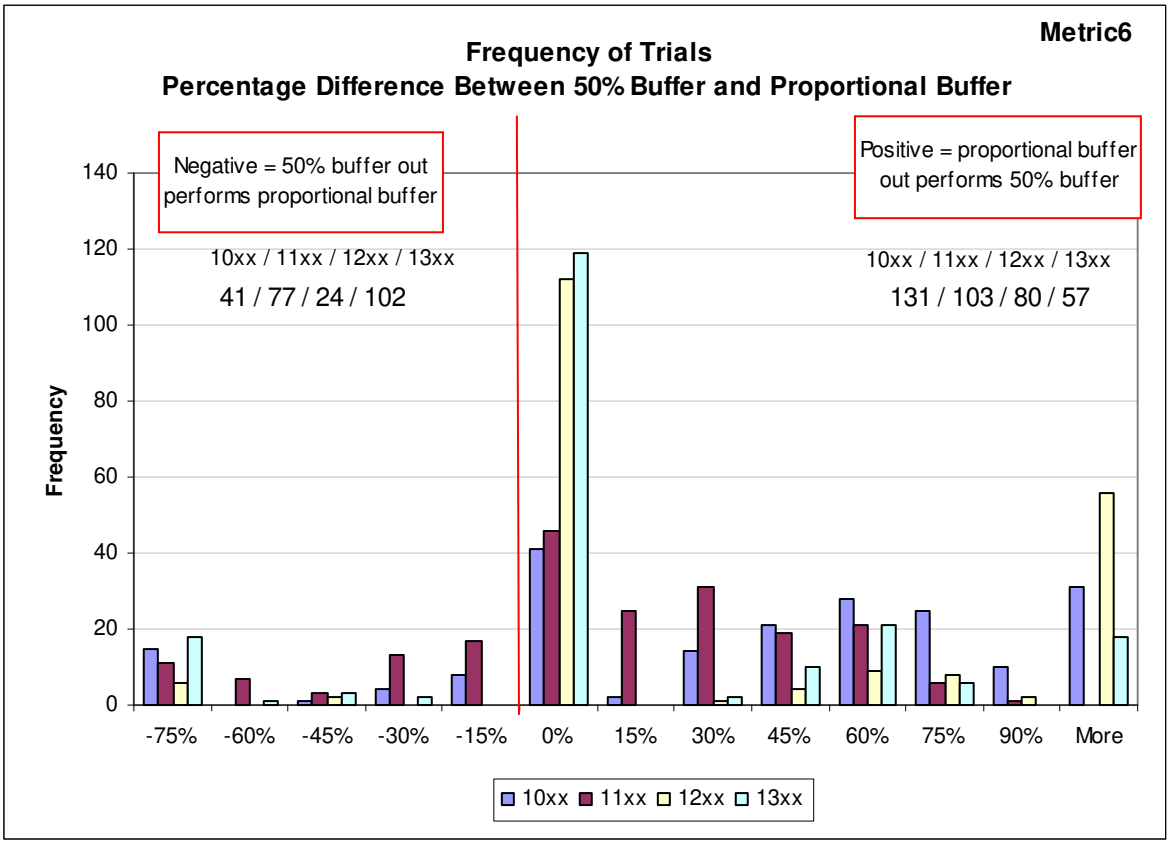
Comparison of Performance for Metric5

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	74	15	11
	NW1010	100	75	5	20
10 Total		200	149	20	31
11	NW1102	100	52	32	16
	NW1105	100	43	42	15
11 Total		200	95	74	31
12	NW1200	100	80	8	12
	NW1201	100	87	5	8
12 Total		200	167	13	20
13	NW1300	100	12	74	14
	NW1304	100	76	19	5
13 Total		200	88	93	19
Grand Total		800	499	200	101



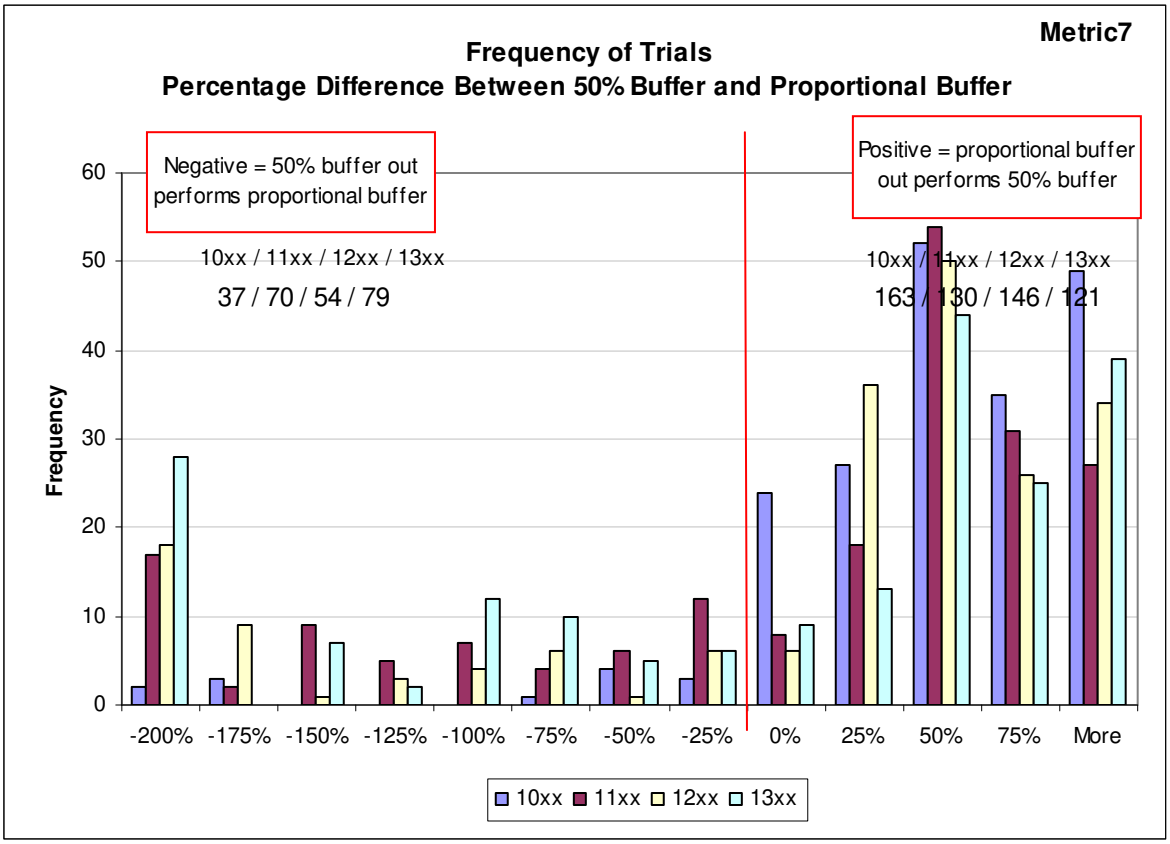
Comparison of Performance for Metric6

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	78	10	12
	NW1010	100	53	31	16
10 Total		200	131	41	28
11	NW1102	100	55	35	10
	NW1105	100	48	42	10
11 Total		200	103	77	20
12	NW1200	100	26	20	54
	NW1201	100	54	4	42
12 Total		200	80	24	96
13	NW1300	100	1	81	18
	NW1304	100	56	21	23
13 Total		200	57	102	41
Grand Total		800	371	244	185



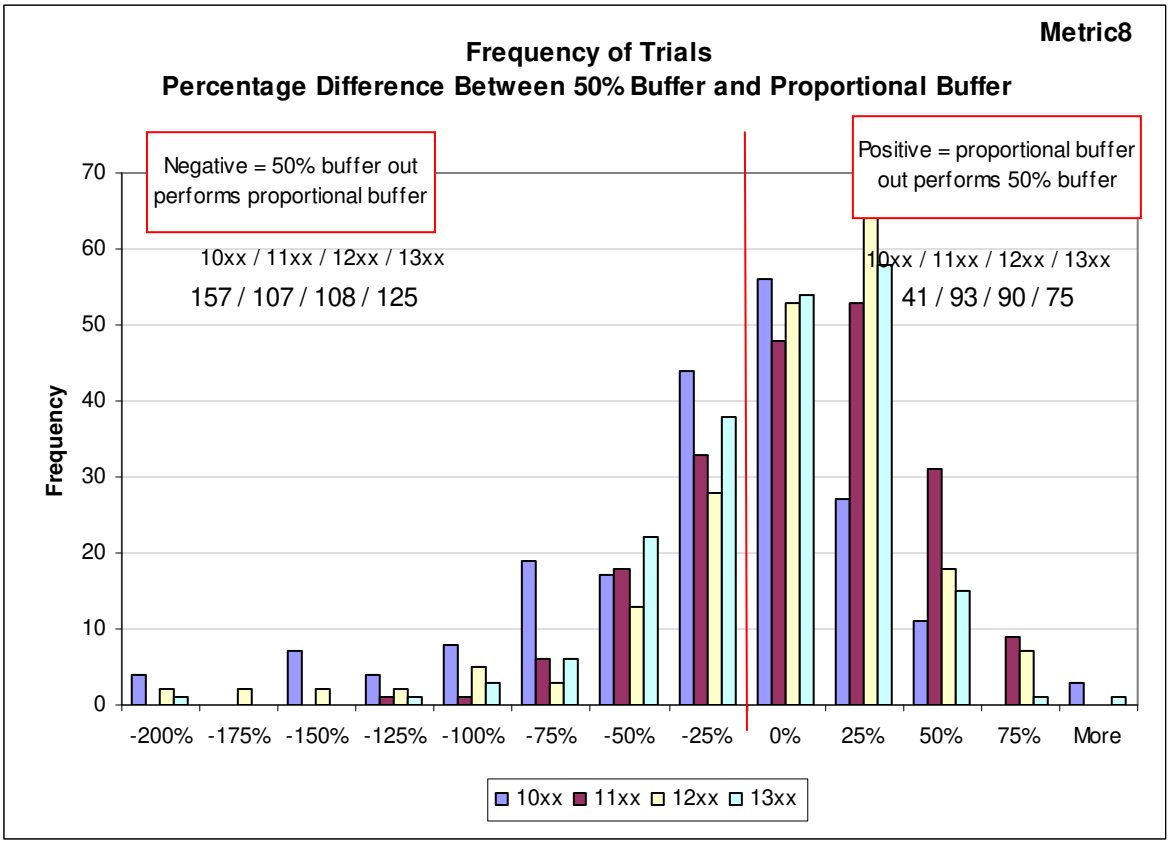
Comparison of Performance for Metric7

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	80	20	-
	NW1010	100	83	17	-
10 Total		200	163	37	-
11	NW1102	100	64	36	-
	NW1105	100	66	34	-
11 Total		200	130	70	-
12	NW1200	100	87	13	-
	NW1201	100	59	41	-
12 Total		200	146	54	-
13	NW1300	100	73	27	-
	NW1304	100	48	52	-
13 Total		200	121	79	-
Grand Total		800	560	240	-



Comparison of Performance for Metric8

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	100	22	77	1
	NW1010	100	19	80	1
10 Total		200	41	157	2
11	NW1102	100	63	37	-
	NW1105	100	30	70	-
11 Total		200	93	107	-
12	NW1200	100	51	48	1
	NW1201	100	39	60	1
12 Total		200	90	108	2
13	NW1300	100	42	58	-
	NW1304	100	33	67	-
13 Total		200	75	125	-
Grand Total		800	299	497	4



Resource Metrics

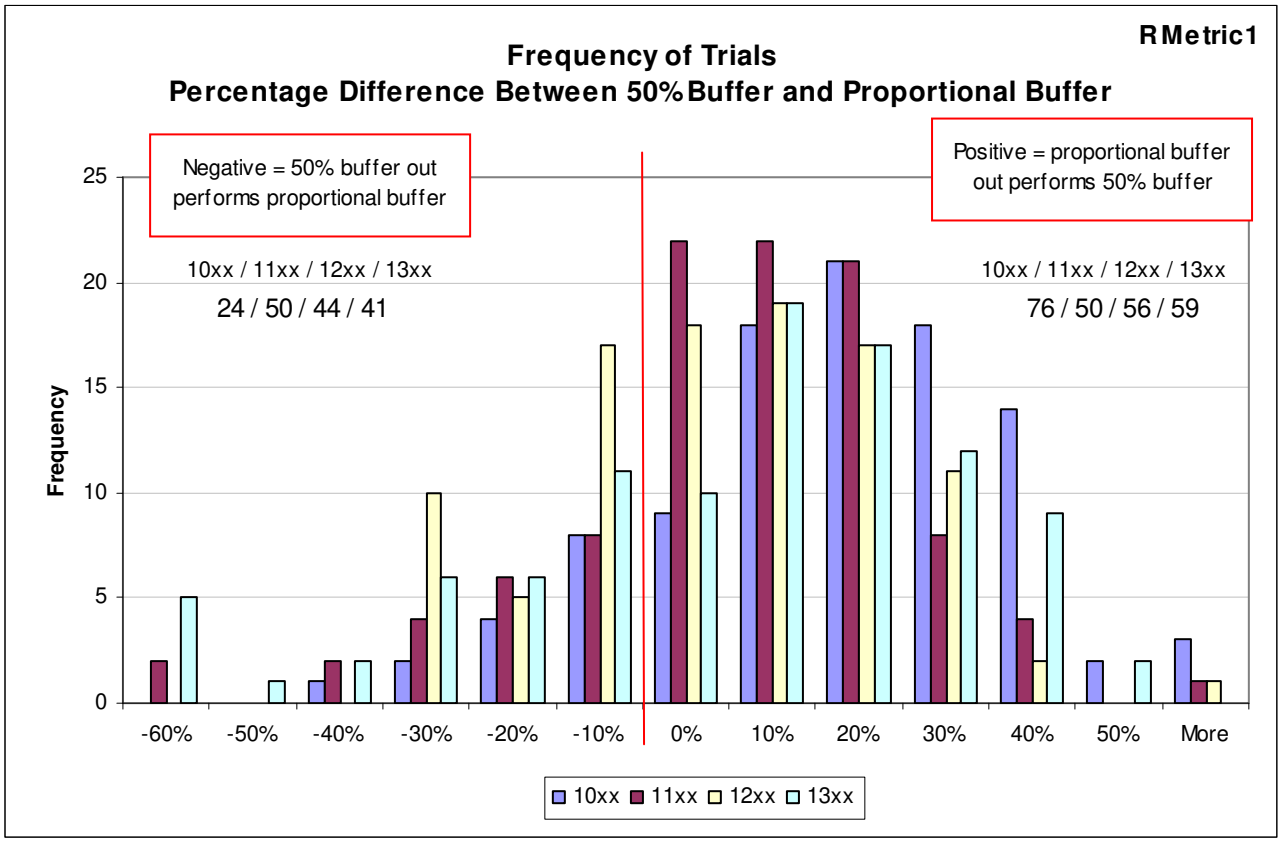
The following table highlights the averages of the resource metrics over 50 replications and the frequency of replicates for which the best value for that metric was generated when conducting pairwise comparisons between the 80/20 proportional buffer and the 50% buffer .

Average for RMetric1

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	2.036	2.296
	NW1010	50	1.821	2.213
10 Total		100	1.929	2.255
11	NW1102	50	3.598	3.603
	NW1105	50	3.312	3.501
11 Total		100	3.455	3.552
12	NW1200	50	1.660	1.685
	NW1201	50	1.414	1.433
12 Total		100	1.537	1.559
13	NW1300	50	2.970	3.021
	NW1304	50	3.304	3.502
13 Total		100	3.137	3.261
Grand Total		400	2.514	2.657

Comparison of Performance for RMetric1

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	35	15	-
	NW1010	50	41	9	-
10 Total		100	76	24	-
12	NW1200	50	23	27	-
	NW1201	50	27	23	-
12 Total		100	50	50	-
11	NW1102	50	27	23	-
	NW1105	50	29	21	-
11 Total		100	56	44	-
13	NW1300	50	26	24	-
	NW1304	50	33	17	-
13 Total		100	59	41	-
Grand Total		400	241	159	-

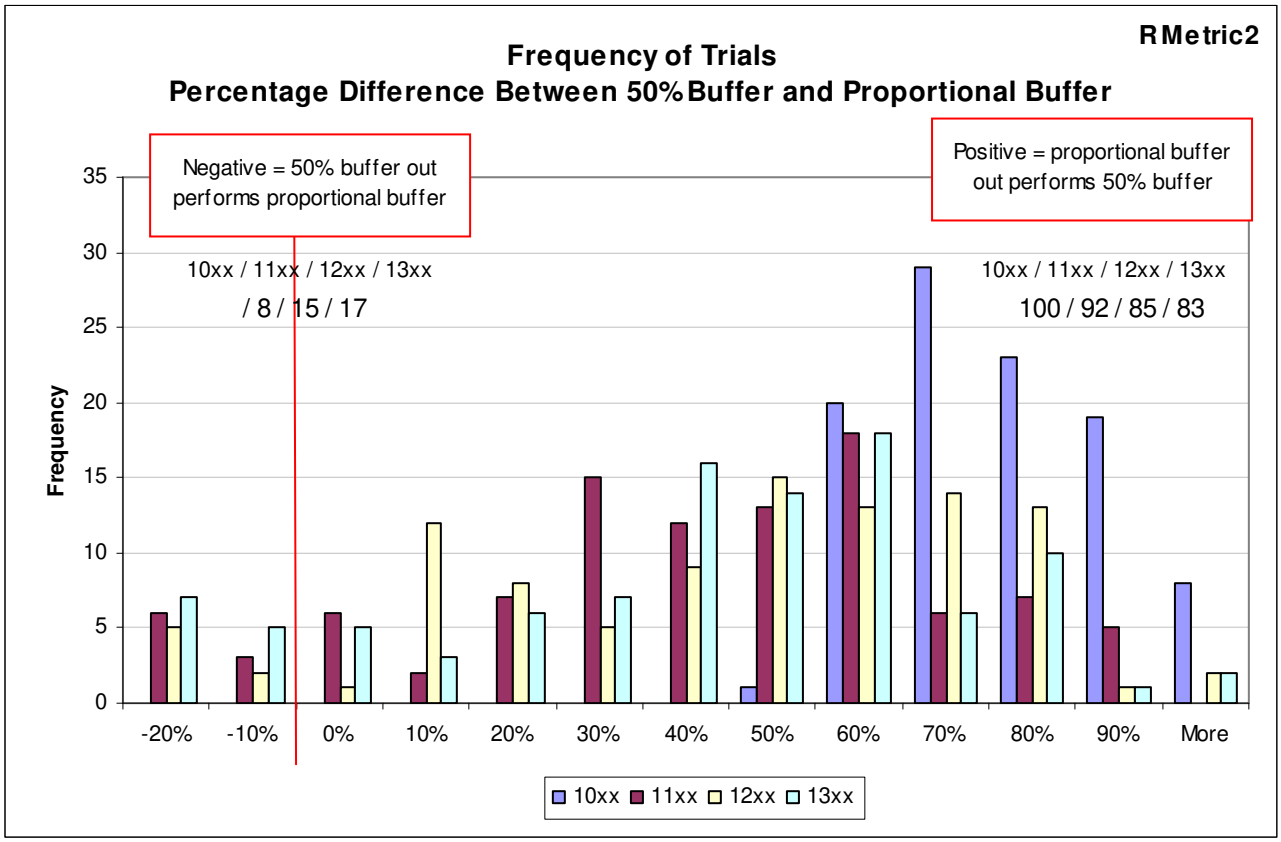


Average for RMetric2

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	0.877	2.593
	NW1010	50	0.705	2.827
10 Total		100	0.791	2.710
11	NW1102	50	0.962	1.383
	NW1105	50	0.750	1.327
11 Total		100	0.856	1.355
12	NW1200	50	0.463	1.180
	NW1201	50	0.634	0.776
12 Total		100	0.548	0.978
13	NW1300	50	0.705	0.853
	NW1304	50	0.731	1.548
13 Total		100	0.718	1.201
Grand Total		400	0.728	1.561

Comparison of Performance for RMetric2

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	50	-	-
	NW1010	50	50	-	-
10 Total		100	100	-	-
12	NW1200	50	50	-	-
	NW1201	50	42	8	-
12 Total		100	92	8	-
11	NW1102	50	37	13	-
	NW1105	50	48	2	-
11 Total		100	85	15	-
13	NW1300	50	35	15	-
	NW1304	50	48	2	-
13 Total		100	83	17	-
Grand Total		400	360	40	-

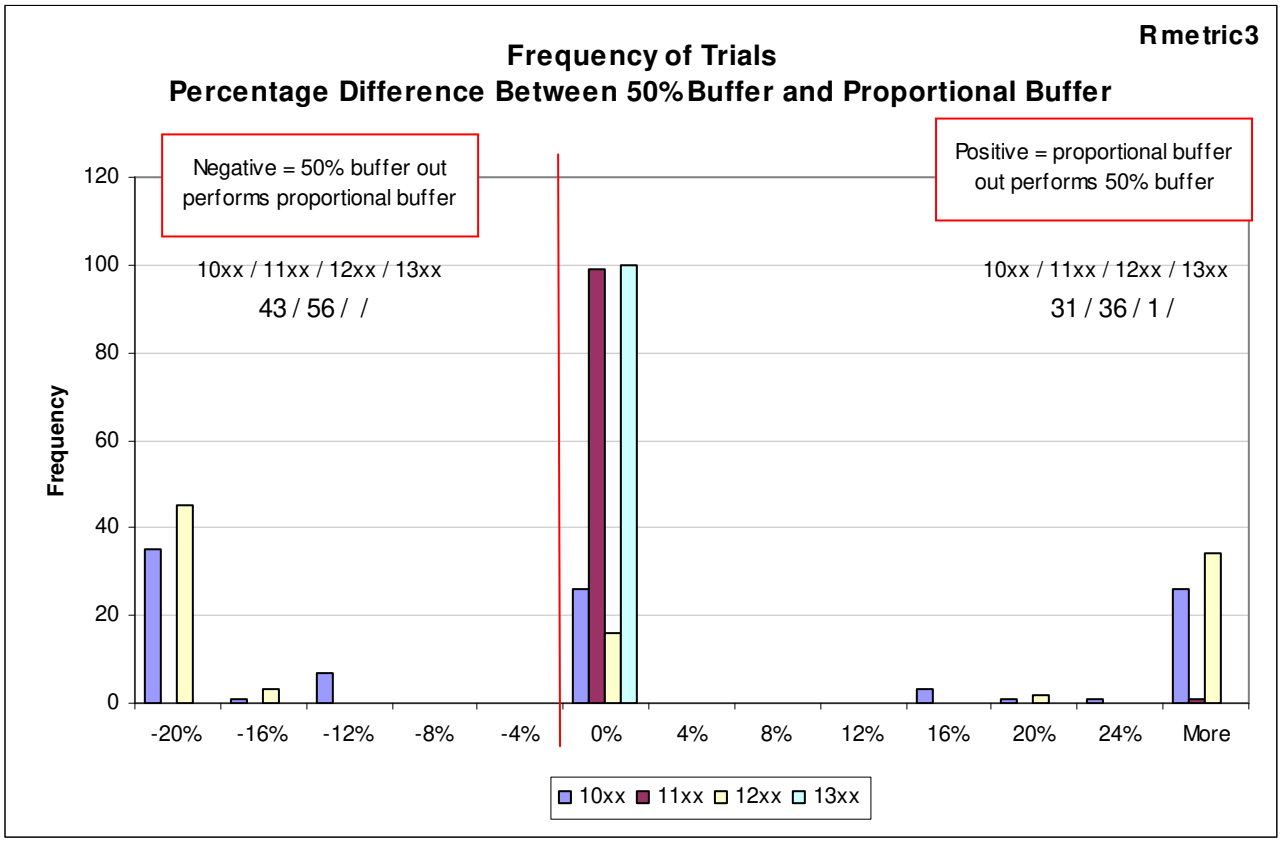


Average for Rmetric3

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	2.490	2.180
	NW1010	50	2.780	3.070
10 Total		100	2.635	2.625
11	NW1102	50	0.010	0.010
	NW1105	50	-	0.020
11 Total		100	0.005	0.015
12	NW1200	50	1.570	1.900
	NW1201	50	1.970	1.420
12 Total		100	1.770	1.660
13	NW1300	50	-	-
	NW1304	50	-	-
13 Total		100	-	-
Grand Total		400	1.103	1.075

Comparison of Performance for Rmetric3

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	11	30	9
	NW1010	50	20	13	17
10 Total		100	31	43	26
12	NW1200	50	24	23	3
	NW1201	50	12	33	5
12 Total		100	36	56	8
11	NW1102	50	-	-	50
	NW1105	50	1	-	49
11 Total		100	1	-	99
13	NW1300	50	-	-	50
	NW1304	50	-	-	50
13 Total		100	-	-	100
Grand Total		400	68	99	233

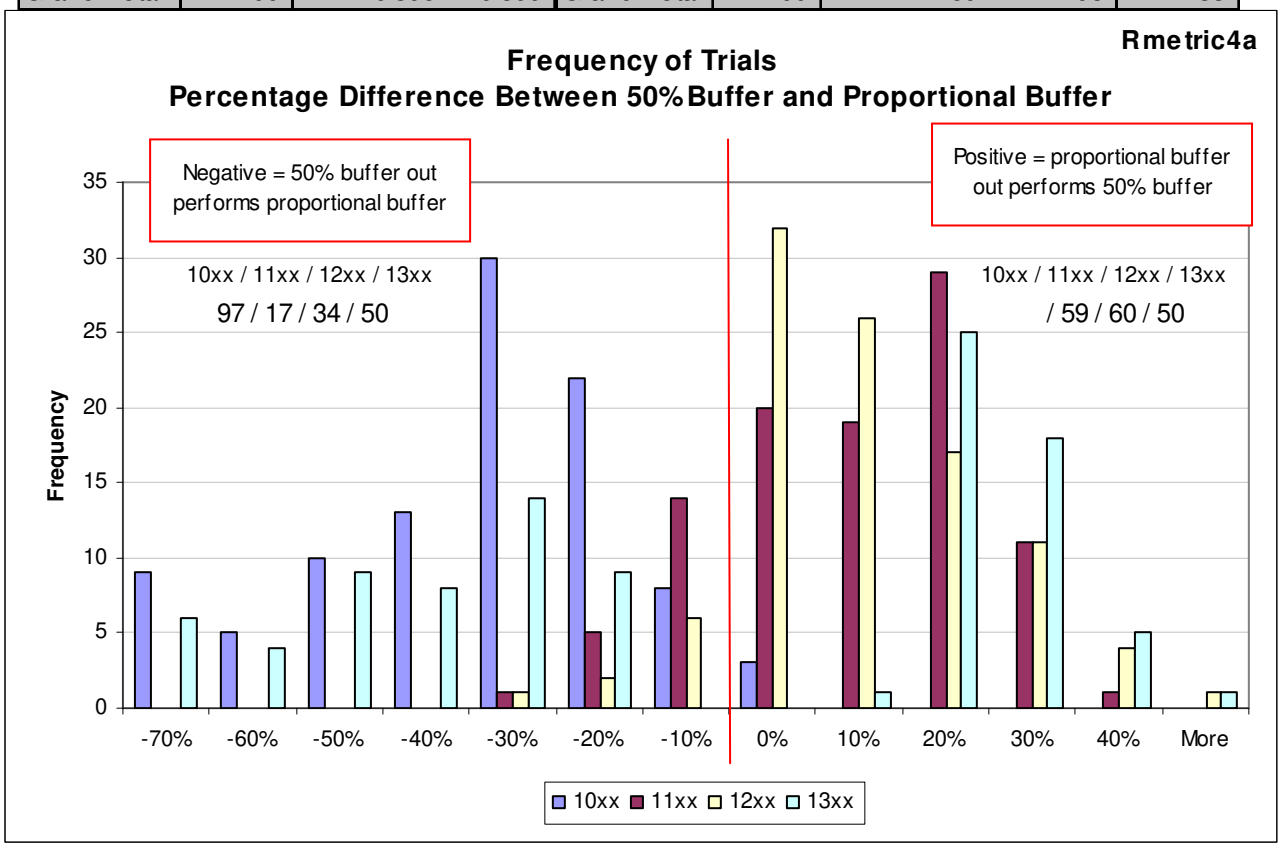

Rmetric3
Frequency of Trials
Percentage Difference Between 50% Buffer and Proportional Buffer
Negative = 50% buffer out performs proportional buffer
Positive = proportional buffer out performs 50% buffer
10xx / 11xx / 12xx / 13xx
43 / 56 / /
10xx / 11xx / 12xx / 13xx
31 / 36 / 1 /
Frequency
120
100
80
60
40
20
0
-20%
-16%
-12%
-8%
-4%
0%
4%
8%
12%
16%
20%
24%
More
10xx
11xx
12xx
13xx

Average for Rmetric4a

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	9.470	7.170
	NW1010	50	9.760	6.910
10 Total		100	9.615	7.040
11	NW1102	50	13.300	12.650
	NW1105	50	12.310	14.170
11 Total		100	12.805	13.410
12	NW1200	50	7.590	7.670
	NW1201	50	5.890	6.740
12 Total		100	6.740	7.205
13	NW1300	50	11.500	14.450
	NW1304	50	13.350	9.360
13 Total		100	12.425	11.905
Grand Total		400	10.396	9.890

Comparison of Performance for Rmetric4a

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	-	48	2
	NW1010	50	-	49	1
10 Total		100	-	97	3
12	NW1200	50	18	13	19
	NW1201	50	41	4	5
12 Total		100	59	17	24
11	NW1102	50	14	32	4
	NW1105	50	46	2	2
11 Total		100	60	34	6
13	NW1300	50	50	-	-
	NW1304	50	-	50	-
13 Total		100	50	50	-
Grand Total		400	169	198	33

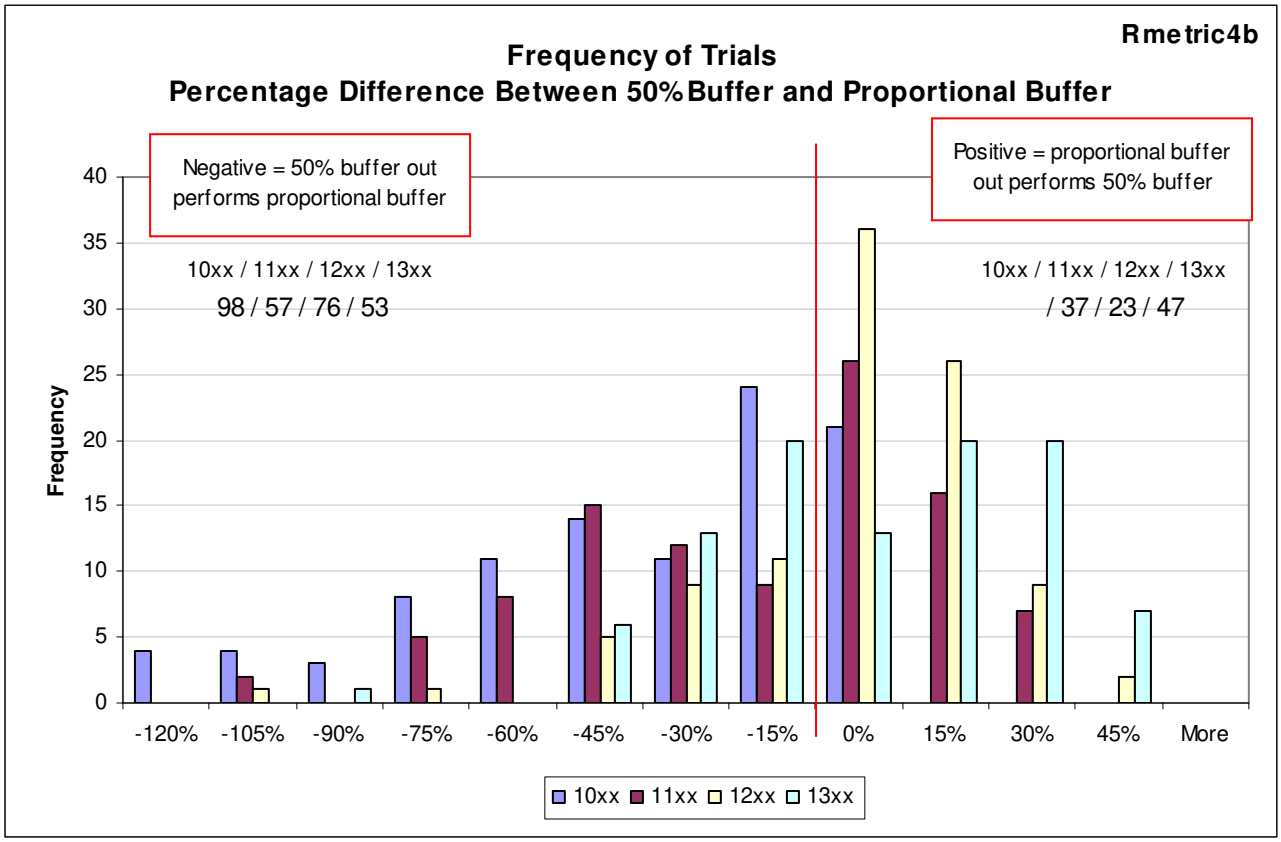


Average for Rmetric4b

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	20.870	17.740
	NW1010	50	20.620	12.410
10 Total		100	20.745	15.075
11	NW1102	50	64.110	44.630
	NW1105	50	66.290	66.220
11 Total		100	65.200	55.425
12	NW1200	50	15.650	13.670
	NW1201	50	11.990	12.590
12 Total		100	13.820	13.130
13	NW1300	50	52.140	61.610
	NW1304	50	60.300	48.300
13 Total		100	56.220	54.955
Grand Total		400	38.996	34.646

Comparison of Performance for Rmetric4b

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	-	48	2
	NW1010	50	-	50	-
10 Total		100	-	98	2
12	NW1200	50	4	43	3
	NW1201	50	33	14	3
12 Total		100	37	57	6
11	NW1102	50	-	50	-
	NW1105	50	23	26	1
11 Total		100	23	76	1
13	NW1300	50	45	5	-
	NW1304	50	2	48	-
13 Total		100	47	53	-
Grand Total		400	107	284	9

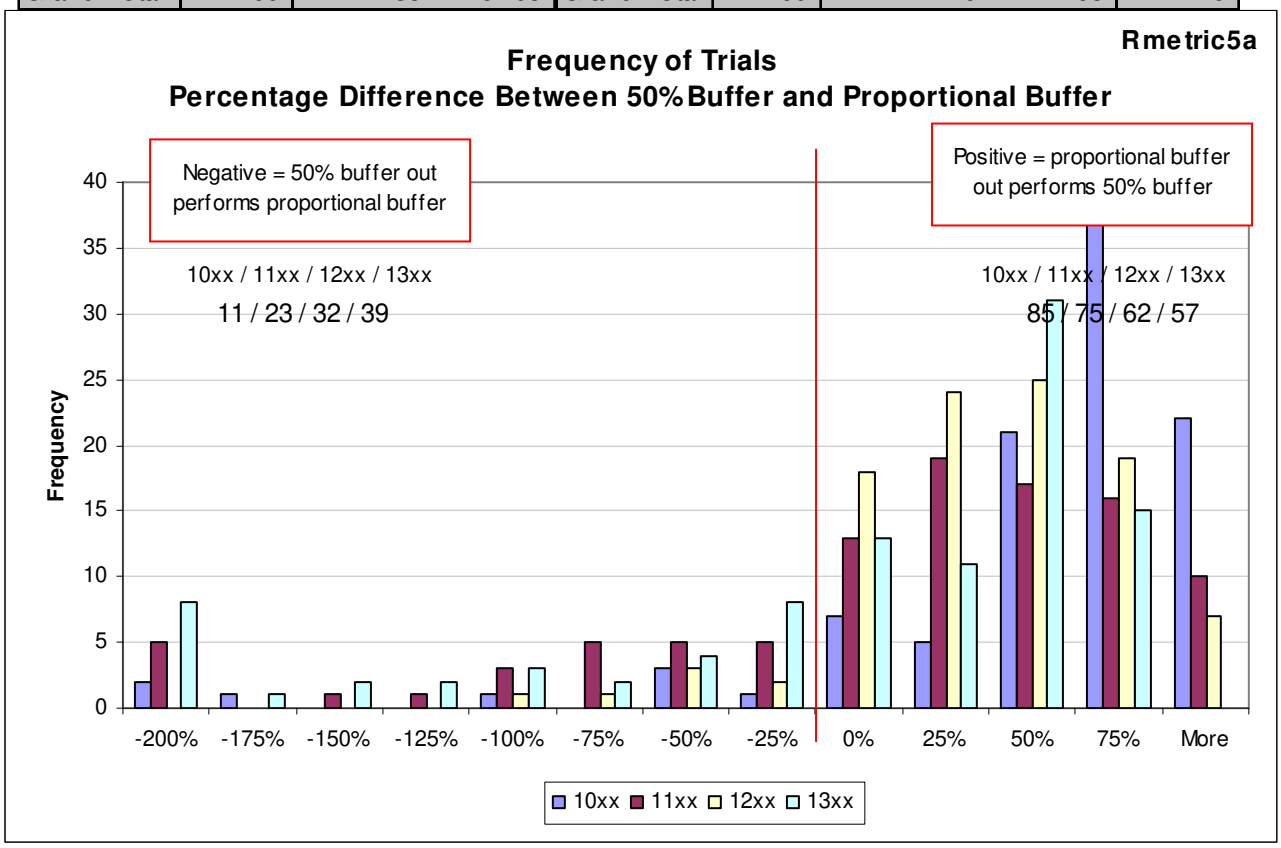


Average for Rmetric5a

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	8.440	15.900
	NW1010	50	6.990	18.450
10 Total		100	7.715	17.175
11	NW1102	50	11.220	11.980
	NW1105	50	7.690	11.020
11 Total		100	9.455	11.500
12	NW1200	50	18.990	31.270
	NW1201	50	13.620	18.640
12 Total		100	16.305	24.955
13	NW1300	50	12.660	10.400
	NW1304	50	11.200	13.580
13 Total		100	11.930	11.990
Grand Total		400	11.351	16.405

Comparison of Performance for Rmetric5a

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	41	8	1
	NW1010	50	44	3	3
10 Total		100	85	11	4
12	NW1200	50	42	8	-
	NW1201	50	33	15	2
12 Total		100	75	23	2
11	NW1102	50	26	21	3
	NW1105	50	36	11	3
11 Total		100	62	32	6
13	NW1300	50	21	26	3
	NW1304	50	36	13	1
13 Total		100	57	39	4
Grand Total		400	279	105	16

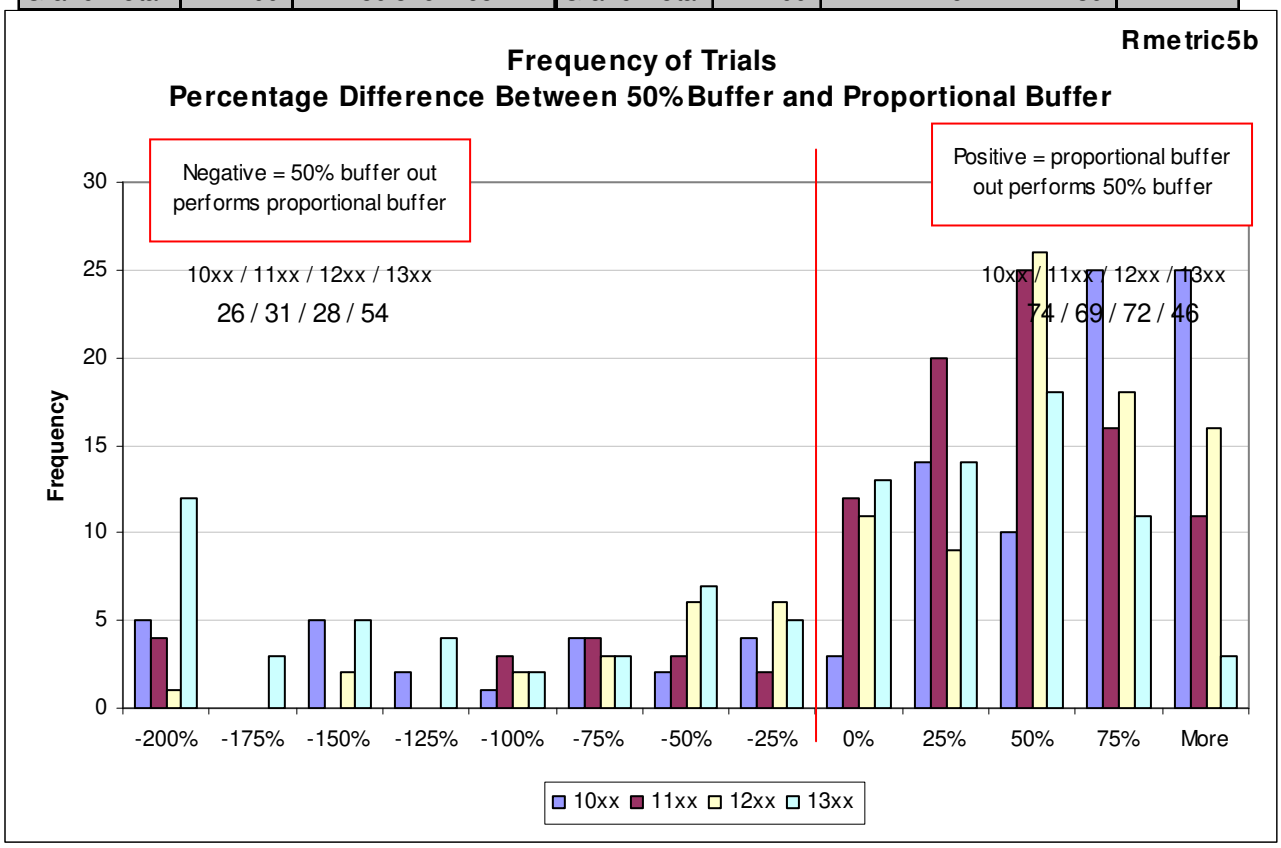


Average for Rmetric5b

		Number of Trials	Proportional Buffer	50% Buffer
10	NW1004	50	35.790	39.890
	NW1010	50	23.320	76.180
10 Total		100	29.555	58.035
11	NW1102	50	72.470	99.260
	NW1105	50	59.500	82.260
11 Total		100	65.985	90.760
12	NW1200	50	28.210	64.700
	NW1201	50	33.070	37.890
12 Total		100	30.640	51.295
13	NW1300	50	84.760	43.280
	NW1304	50	69.890	82.230
13 Total		100	77.325	62.755
Grand Total		400	50.876	65.711

Comparison of Performance for Rmetric5b

		Number of Trials	Proportional Buffer	50% Buffer	Equal
10	NW1004	50	28	22	-
	NW1010	50	46	4	-
10 Total		100	74	26	-
12	NW1200	50	44	6	-
	NW1201	50	25	25	-
12 Total		100	69	31	-
11	NW1102	50	38	12	-
	NW1105	50	34	16	-
11 Total		100	72	28	-
13	NW1300	50	11	39	-
	NW1304	50	35	15	-
13 Total		100	46	54	-
Grand Total		400	261	139	-



APPENDIX K: RESULTS FOR USING BUFFERS PROPORTIONAL TO A PRIORI KNOWLEDGE OF OCCURENCE PROBABILITY

GLM Model

The following table contains the result of a GLM model for each of the robustness and resource metrics. Here, the dependent variable is the improvement value of the metric over the 50% buffer. Factors and interactions significant at α = 0.5 are highlighted.

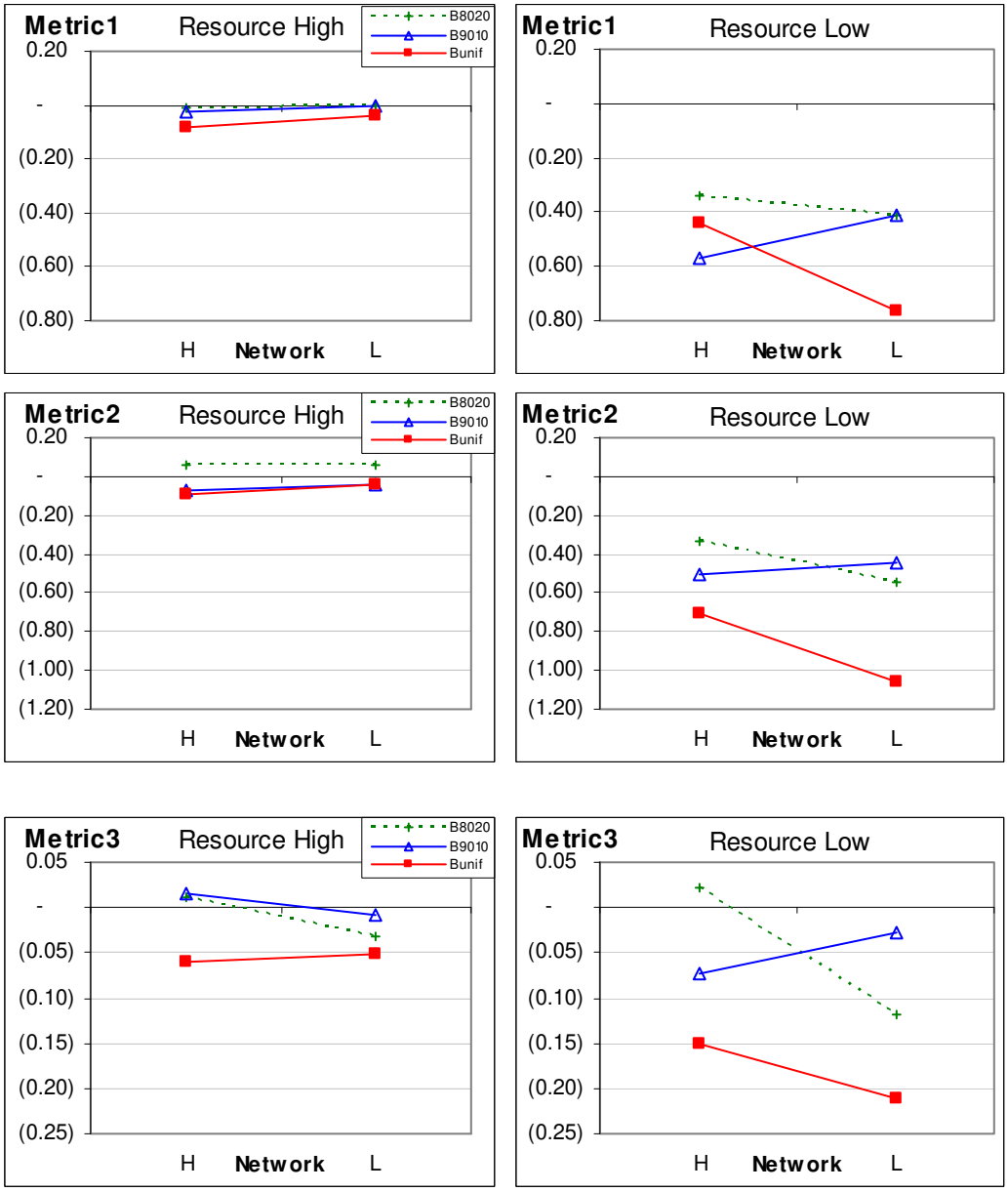
Metric	Source	DF	SS Error	F-Val	P-Val
Dur	Method	2	28,921.374	98.155	0.000
Dur	Res	1	173,234.403	1,175.862	0.000
Dur	Method*Res	2	2,894.742	9.824	0.000
Dur	Net	1	11,473.896	77.881	0.000
Dur	Method*Net	2	1,033.013	3.506	0.030
Dur	Res*Net	1	806.008	5.471	0.019
Dur	Method*Res*Net	2	2,287.341	7.763	0.000
Dur	ERROR	2988	440,208.556	0.000	-
Metric1	Method	2	9.676	35.810	0.000
Metric1	Res	1	160.496	1,188.024	0.000
Metric1	Method*Res	2	3.839	14.210	0.000
Metric1	Net	1	0.539	3.986	0.046
Metric1	Method*Net	2	6.828	25.273	0.000
Metric1	Res*Net	1	2.128	15.755	0.000
Metric1	Method*Res*Net	2	7.990	29.571	0.000
Metric1	ERROR	2988	403.662	0.000	-
Metric2	Method	2	43.779	152.424	0.000
Metric2	Res	1	249.171	1,735.072	0.000
Metric2	Method*Res	2	21.920	76.318	0.000
Metric2	Net	1	3.505	24.407	0.000
Metric2	Method*Net	2	5.558	19.351	0.000
Metric2	Res*Net	1	7.655	53.304	0.000
Metric2	Method*Res*Net	2	5.824	20.277	0.000
Metric2	ERROR	2988	429.101	0.000	-
Metric3	Method	2	5.695	107.443	0.000
Metric3	Res	1	3.999	150.887	0.000
Metric3	Method*Res	2	1.089	20.543	0.000
Metric3	Net	1	0.957	36.125	0.000
Metric3	Method*Net	2	1.380	26.044	0.000
Metric3	Res*Net	1	0.205	7.724	0.005
Metric3	Method*Res*Net	2	0.988	18.646	0.000
Metric3	ERROR	2988	79.192	0.000	-

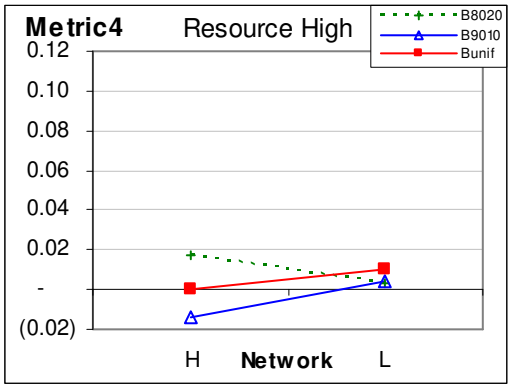
Metric	Source	DF	SS Error	F-Val	P-Val
Metric4	Method	2	0.386	21.272	0.000
Metric4	Res	1	0.594	65.516	0.000
Metric4	Method*Res	2	0.701	38.636	0.000
Metric4	Net	1	0.006	0.674	0.412
Metric4	Method*Net	2	0.484	26.690	0.000
Metric4	Res*Net	1	0.044	4.835	0.028
Metric4	Method*Res*Net	2	1.054	58.135	0.000
Metric4	ERROR	2988	27.097	0.000	-
Metric5	Method	2	0.340	17.312	0.000
Metric5	Res	1	0.683	69.593	0.000
Metric5	Method*Res	2	0.546	27.794	0.000
Metric5	Net	1	0.213	21.693	0.000
Metric5	Method*Net	2	0.235	11.962	0.000
Metric5	Res*Net	1	0.075	7.605	0.006
Metric5	Method*Res*Net	2	0.014	0.692	0.501
Metric5	ERROR	2988	29.345	0.000	-
Metric6	Method	2	0.403	17.012	0.000
Metric6	Res	1	1.617	136.597	0.000
Metric6	Method*Res	2	0.823	34.743	0.000
Metric6	Net	1	0.476	40.186	0.000
Metric6	Method*Net	2	1.563	65.995	0.000
Metric6	Res*Net	1	0.042	3.543	0.060
Metric6	Method*Res*Net	2	0.426	17.984	0.000
Metric6	ERROR	2988	35.378	0.000	-
Metric7	Method	2	1.643	70.283	0.000
Metric7	Res	1	0.786	67.233	0.000
Metric7	Method*Res	2	1.987	85.020	0.000
Metric7	Net	1	0.024	2.027	0.155
Metric7	Method*Net	2	0.140	5.985	0.003
Metric7	Res*Net	1	0.073	6.272	0.012
Metric7	Method*Res*Net	2	0.275	11.785	0.000
Metric7	ERROR	2988	34.922	0.000	-
Metric8	Method	2	22.544	54.740	0.000
Metric8	Res	1	3.136	15.231	0.000
Metric8	Method*Res	2	0.848	2.059	0.128
Metric8	Net	1	8.406	40.820	0.000
Metric8	Method*Net	2	0.582	1.412	0.244
Metric8	Res*Net	1	2.935	14.253	0.000
Metric8	Method*Res*Net	2	0.853	2.072	0.126
Metric8	ERROR	2988	615.289	0.000	-
RMetric1	Method	2	51.604	64.576	0.000
RMetric1	Res	1	150.869	377.588	0.000
RMetric1	Method*Res	2	82.594	103.356	0.000
RMetric1	Net	1	1.661	4.157	0.042
RMetric1	Method*Net	2	7.323	9.163	0.000
RMetric1	Res*Net	1	3.526	8.825	0.003
RMetric1	Method*Res*Net	2	5.222	6.535	0.001
RMetric1	ERROR	2988	1,193.885	0.000	-

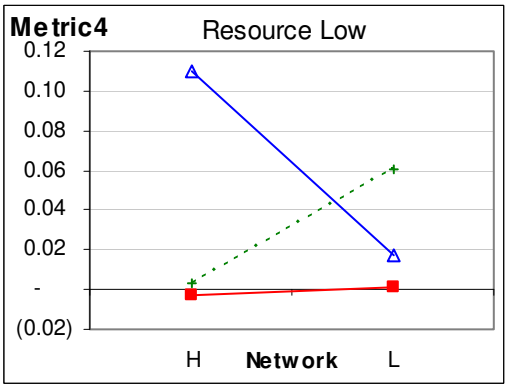
Metric	Source	DF	SS Error	F-Val	P-Val
RMetric2	Method	2	333.262	800.879	0.000
RMetric2	Res	1	134.140	644.719	0.000
RMetric2	Method*Res	2	36.787	88.404	0.000
RMetric2	Net	1	32.429	155.866	0.000
RMetric2	Method*Net	2	21.992	52.849	0.000
RMetric2	Res*Net	1	40.047	192.476	0.000
RMetric2	Method*Res*Net	2	41.524	99.788	0.000
RMetric2	ERROR	2988	621.684	0.000	-
Rmetric3	Method	2	506.806	382.591	0.000
Rmetric3	Res	1	0.705	1.065	0.302
Rmetric3	Method*Res	2	501.420	378.526	0.000
Rmetric3	Net	1	57.132	86.259	0.000
Rmetric3	Method*Net	2	87.937	66.384	0.000
Rmetric3	Res*Net	1	53.868	81.331	0.000
Rmetric3	Method*Res*Net	2	89.694	67.711	0.000
Rmetric3	ERROR	2988	1,979.052	0.000	-
Rmetric4a	Method	2	93,166.129	7,792.481	-
Rmetric4a	Res	1	39,179.374	6,553.981	-
Rmetric4a	Method*Res	2	47,051.461	3,935.418	-
Rmetric4a	Net	1	67.051	11.216	0.001
Rmetric4a	Method*Net	2	353.378	29.557	0.000
Rmetric4a	Res*Net	1	37.297	6.239	0.013
Rmetric4a	Method*Res*Net	2	309.656	25.900	0.000
Rmetric4a	ERROR	2988	17,862.115	0.000	-
Rmetric4b	Method	2	3,331,190.020	13,514.612	-
Rmetric4b	Res	1	2,767,678.880	22,456.903	-
Rmetric4b	Method*Res	2	4,388,773.206	17,805.219	-
Rmetric4b	Net	1	4,752.725	38.564	0.000
Rmetric4b	Method*Net	2	3,715.431	15.073	0.000
Rmetric4b	Res*Net	1	1,815.852	14.734	0.000
Rmetric4b	Method*Res*Net	2	8,894.190	36.084	0.000
Rmetric4b	ERROR	2988	368,253.108	0.000	-
Rmetric5a	Method	2	68,508.721	237.281	0.000
Rmetric5a	Res	1	97,190.900	673.243	0.000
Rmetric5a	Method*Res	2	28,343.942	98.169	0.000
Rmetric5a	Net	1	7,171.894	49.680	0.000
Rmetric5a	Method*Net	2	10,945.853	37.911	0.000
Rmetric5a	Res*Net	1	3,163.160	21.911	0.000
Rmetric5a	Method*Res*Net	2	1,258.390	4.358	0.013
Rmetric5a	ERROR	2988	431,354.565	0.000	-
Rmetric5b	Method	2	1,948,581.631	292.313	0.000
Rmetric5b	Res	1	1,395,514.304	418.691	0.000
Rmetric5b	Method*Res	2	480,578.967	72.093	0.000
Rmetric5b	Net	1	175.450	0.053	0.819
Rmetric5b	Method*Net	2	5,631.002	0.845	0.430
Rmetric5b	Res*Net	1	253.171	0.076	0.783
Rmetric5b	Method*Res*Net	2	211,836.489	31.778	0.000
Rmetric5b	ERROR	2988	9,959,136.651	0.000	-

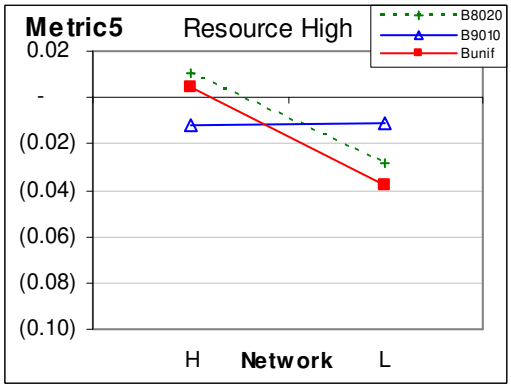
Interaction Plots

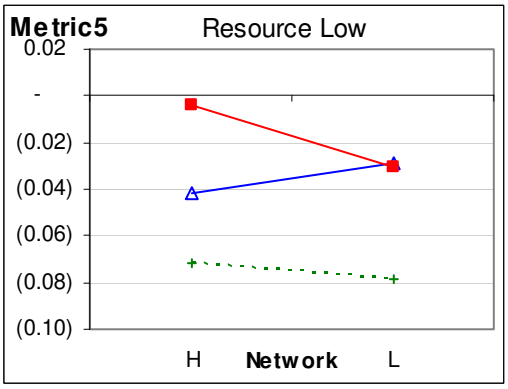
The 2-way interaction plots display the means for the interaction effects for the high and low settings for resource and network factor settings for each buffering method used. The dependent variable plotted is the value of improvement over the 50% buffer. Therefore, a negative value is improvement.

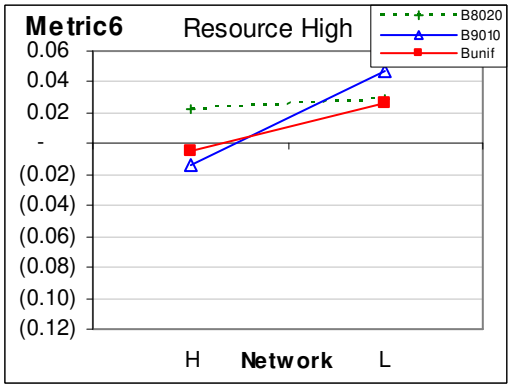


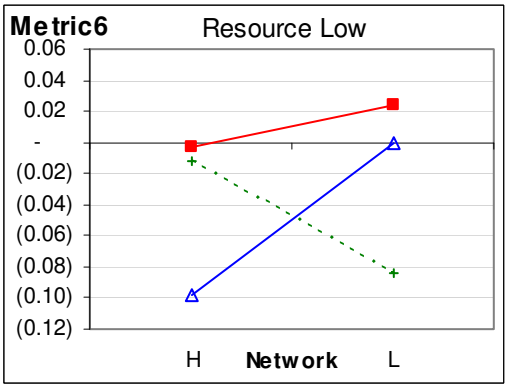

Metric4
Resource High
B8020
B9010
Bunif
0.12
0.10
0.08
0.06
0.04
0.02
-
(0.02)
H
Network
L

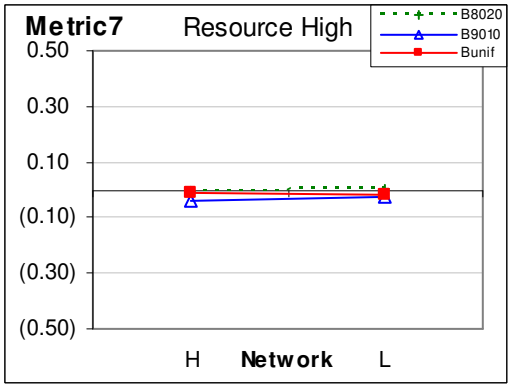

Metric4
Resource Low
0.12
0.10
0.08
0.06
0.04
0.02
-
(0.02)
H
Network
L

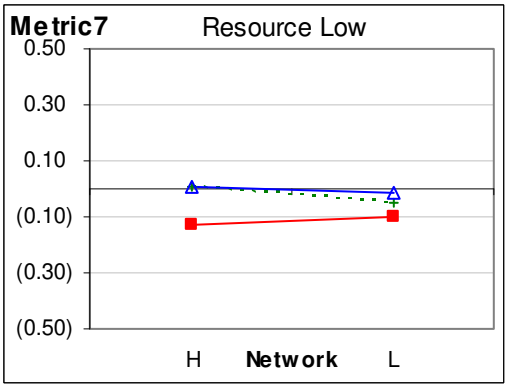

Metric5
Resource High
B8020
B9010
Bunif
0.02
-
(0.02)
(0.04)
(0.06)
(0.08)
(0.10)
H
Network
L

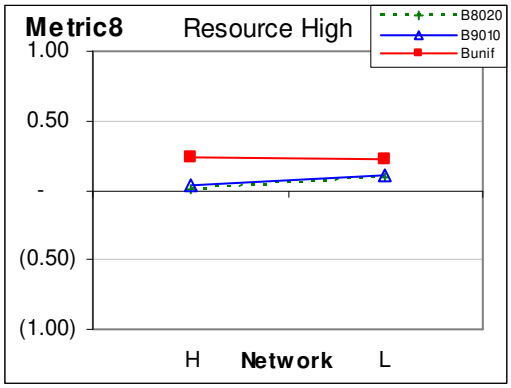

Metric5
Resource Low
0.02
-
(0.02)
(0.04)
(0.06)
(0.08)
(0.10)
H
Network
L

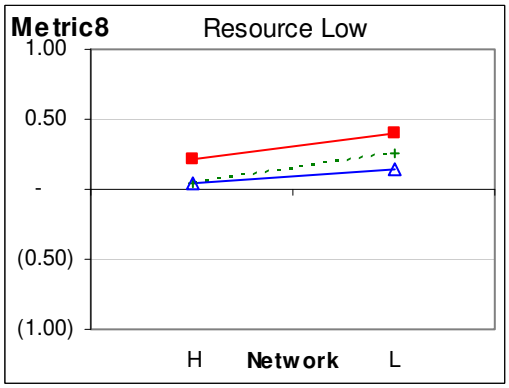

Metric6
Resource High
B8020
B9010
Bunif
0.06
0.04
0.02
-
(0.02)
(0.04)
(0.06)
(0.08)
(0.10)
(0.12)
H
Network
L

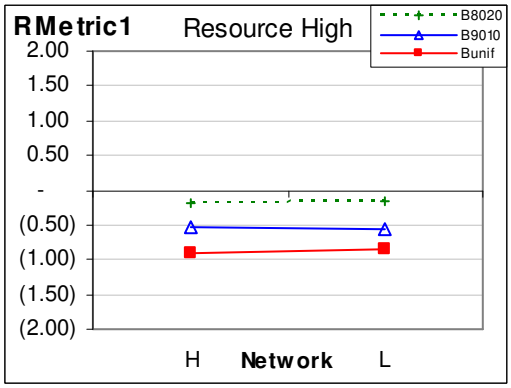

Metric6
Resource Low
0.06
0.04
0.02
-
(0.02)
(0.04)
(0.06)
(0.08)
(0.10)
(0.12)
H
Network
L

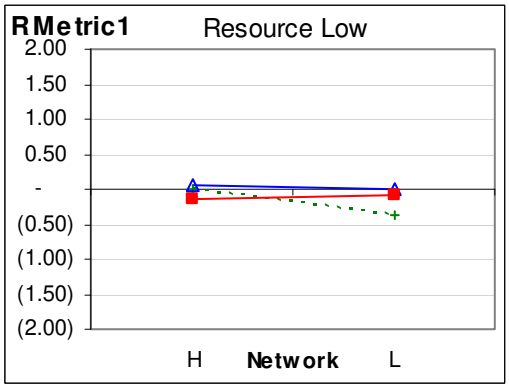

Metric7
Resource High
B8020
B9010
Bunif
0.50
0.30
0.10
(0.10)
(0.30)
(0.50)
H
Network
L

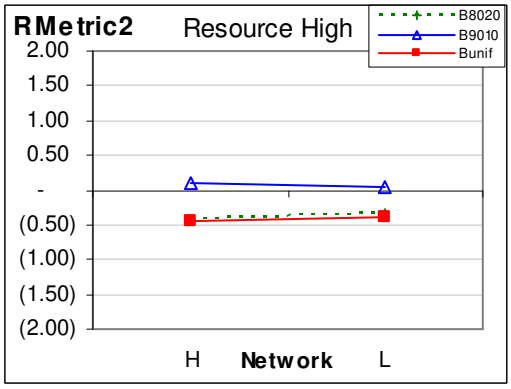

Metric7
Resource Low
0.50
0.30
0.10
(0.10)
(0.30)
(0.50)
H
Network
L

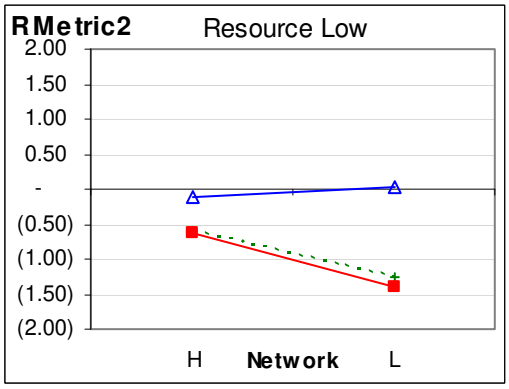

Metric8
Resource High
B8020
B9010
Bunif
1.00
0.50
-
(0.50)
(1.00)
H
Network
L

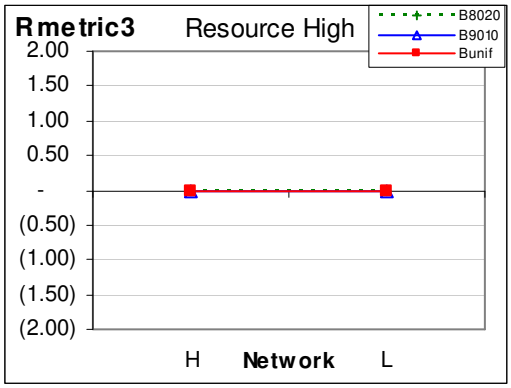

Metric8
Resource Low
1.00
0.50
-
(0.50)
(1.00)
H
Network
L

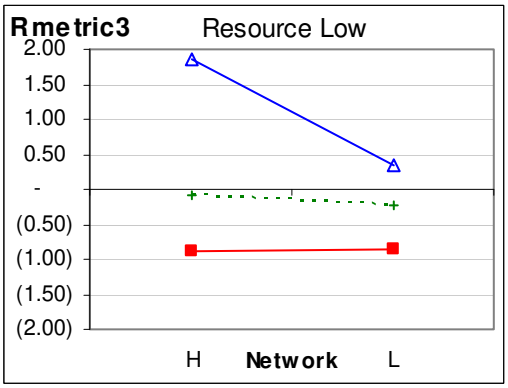

RMetric1
Resource High
B8020
B9010
Bunif
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
(1.50)
(2.00)
H
Network
L


RMetric1
Resource Low
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
(1.50)
(2.00)
H
Network
L


RMetric2
Resource High
B8020
B9010
Bunif
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
(1.50)
(2.00)
H
Network
L


RMetric2
Resource Low
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
(1.50)
(2.00)
H
Network
L


Rmetric3
Resource High
B8020
B9010
Bunif
2.00
1.50
1.00
0.50
-
(0.50)
(1.00)
(1.50)
(2.00)
H
Network
L


Rmetric3
Resource Low
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0.50
-
(0.50)
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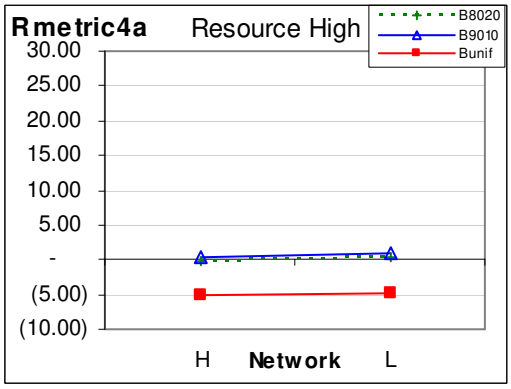
(1.50)
(2.00)
H
Network
L


Rmetric4a
Resource High
B8020
B9010
Bunif
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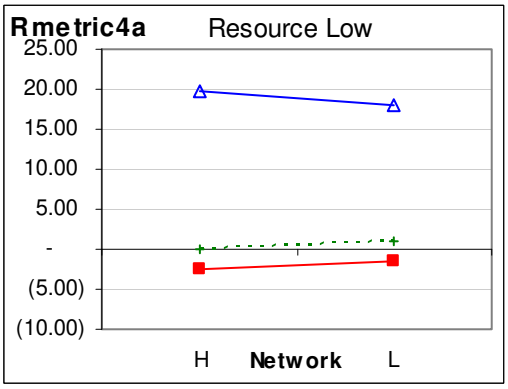
20.00
15.00
10.00
5.00
-
(5.00)
(10.00)
H
Network
L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Resource Low
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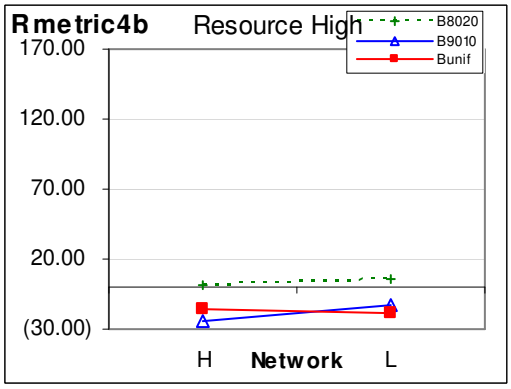
5.00
-
(5.00)
(10.00)
H
Network
L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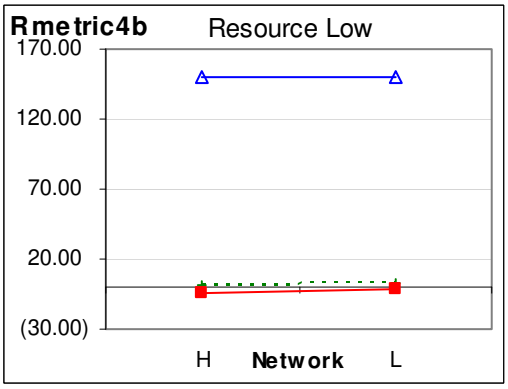
Resource High
B8020
B9010
Bunif
170.00
120.00
70.00
20.00
(30.00)
H
Network
L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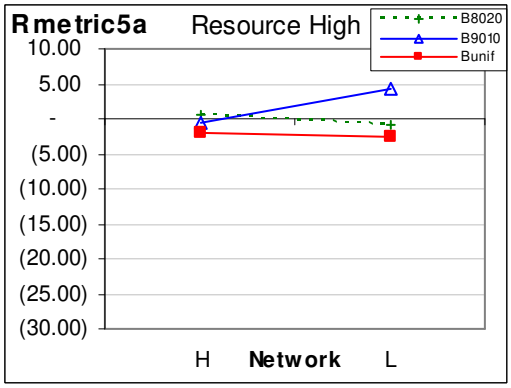
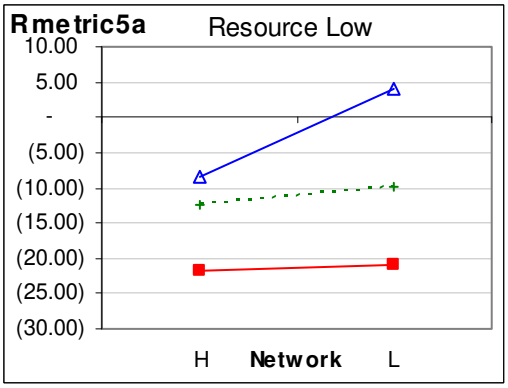
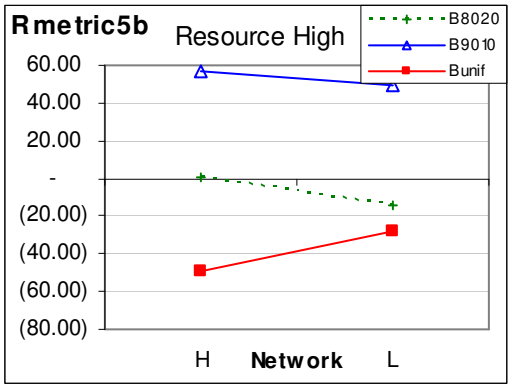
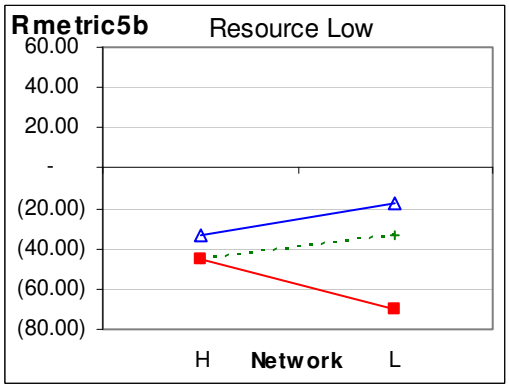
120.00
70.00
20.00
(30.00)
H
Network
L


Rmetric5a
Resource High
B8020
B9010
Bunif
10.00
5.00
-
(5.00)
(10.00)
(15.00)
(20.00)
(25.00)
(30.00)
H
Network
L


Rmetric5a
Resource Low
10.00
5.00
-
(5.00)
(10.00)
(15.00)
(20.00)
(25.00)
(30.00)
H
Network
L





t-Test Results

Each row of the following table demonstrates the mean value of the difference between the metric value using the proportional buffer over the 50% buffer, simulated over 250 replications within the factor settings for resource (high/low) and network (high/low). The t-test determines if the differences in mean is significantly different than zero with $\alpha = 0.05$. Significant p-values are highlighted in yellow, while significantly improved mean values (negative) are highlighted in green and significantly worsened values (positive) are highlighted in red.

						95% CI			
Meth	Res	Net	Metric	Mean	Std Err	Lower	Upper	t	p-val
B8020	H	H	Dur	(1.284)	0.389	(2.051)	(0.517)	(3.297)	0.0011
B9010	H	H	Dur	(2.844)	0.320	(3.474)	(2.214)	(8.887)	0.0000
Bunif	H	H	Dur	(7.888)	0.377	(8.630)	(7.146)	(20.938)	0.0000
B8020	H	L	Dur	(0.360)	0.395	(1.138)	0.418	(0.911)	0.3632
B9010	H	L	Dur	0.204	0.377	(0.538)	0.946	0.542	0.5885
Bunif	H	L	Dur	(3.236)	0.409	(4.041)	(2.431)	(7.915)	0.0000
B8020	L	H	Dur	(17.144)	1.077	(19.265)	(15.023)	(15.917)	0.0000
B9010	L	H	Dur	(19.128)	1.240	(21.570)	(16.686)	(15.430)	0.0000
Bunif	L	H	Dur	(24.448)	0.899	(26.218)	(22.678)	(27.207)	0.0000
B8020	L	L	Dur	(12.196)	0.789	(13.750)	(10.642)	(15.453)	0.0000
B9010	L	L	Dur	(11.052)	1.248	(13.509)	(8.595)	(8.858)	0.0000
Bunif	L	L	Dur	(22.628)	0.726	(24.057)	(21.199)	(31.183)	0.0000

Test Set	Res	Net	Metric	Mean	Std Err	95% CI Lower	95% CI Upper	t	p-val
B8020	H	H	Metric1	(0.010)	0.005	(0.019)	(0.001)	(2.237)	0.0262
B9010	H	H	Metric1	(0.028)	0.003	(0.035)	(0.021)	(8.180)	0.0000
Bunif	H	H	Metric1	(0.082)	0.004	(0.090)	(0.074)	(19.846)	0.0000
B8020	H	L	Metric1	(0.004)	0.005	(0.014)	0.006	(0.760)	0.4480
B9010	H	L	Metric1	(0.001)	0.004	(0.009)	0.008	(0.206)	0.8373
Bunif	H	L	Metric1	(0.036)	0.005	(0.045)	(0.027)	(7.609)	0.0000
B8020	L	H	Metric1	(0.337)	0.022	(0.382)	(0.293)	(15.033)	0.0000
B9010	L	H	Metric1	(0.571)	0.041	(0.651)	(0.490)	(13.957)	0.0000
Bunif	L	H	Metric1	(0.440)	0.017	(0.473)	(0.407)	(26.346)	0.0000
B8020	L	L	Metric1	(0.415)	0.028	(0.471)	(0.359)	(14.658)	0.0000
B9010	L	L	Metric1	(0.410)	0.049	(0.505)	(0.314)	(8.406)	0.0000
Bunif	L	L	Metric1	(0.764)	0.027	(0.817)	(0.710)	(28.152)	0.0000
B8020	H	H	Metric2	0.059	0.007	0.044	0.073	8.159	0.0000
B9010	H	H	Metric2	(0.077)	0.005	(0.087)	(0.067)	(15.188)	0.0000
Bunif	H	H	Metric2	(0.095)	0.005	(0.105)	(0.085)	(19.077)	0.0000
B8020	H	L	Metric2	0.064	0.007	0.051	0.077	9.779	0.0000
B9010	H	L	Metric2	(0.038)	0.005	(0.048)	(0.027)	(6.936)	0.0000
Bunif	H	L	Metric2	(0.041)	0.007	(0.054)	(0.028)	(6.319)	0.0000
B8020	L	H	Metric2	(0.330)	0.028	(0.385)	(0.275)	(11.871)	0.0000
B9010	L	H	Metric2	(0.504)	0.028	(0.559)	(0.449)	(17.953)	0.0000
Bunif	L	H	Metric2	(0.705)	0.020	(0.744)	(0.666)	(35.524)	0.0000
B8020	L	L	Metric2	(0.549)	0.037	(0.621)	(0.476)	(14.896)	0.0000
B9010	L	L	Metric2	(0.441)	0.049	(0.537)	(0.345)	(9.065)	0.0000
Bunif	L	L	Metric2	(1.057)	0.032	(1.119)	(0.995)	(33.531)	0.0000
B8020	H	H	Metric3	0.012	0.008	(0.004)	0.028	1.420	0.1568
B9010	H	H	Metric3	0.016	0.008	0.001	0.031	2.136	0.0336
Bunif	H	H	Metric3	(0.061)	0.010	(0.081)	(0.041)	(6.134)	0.0000
B8020	H	L	Metric3	(0.033)	0.006	(0.045)	(0.021)	(5.462)	0.0000
B9010	H	L	Metric3	(0.008)	0.005	(0.018)	0.003	(1.410)	0.1598
Bunif	H	L	Metric3	(0.051)	0.008	(0.066)	(0.035)	(6.278)	0.0000
B8020	L	H	Metric3	0.022	0.016	(0.010)	0.055	1.362	0.1743
B9010	L	H	Metric3	(0.074)	0.007	(0.088)	(0.059)	(9.989)	0.0000
Bunif	L	H	Metric3	(0.152)	0.013	(0.177)	(0.127)	(11.947)	0.0000
B8020	L	L	Metric3	(0.119)	0.013	(0.145)	(0.093)	(9.118)	0.0000
B9010	L	L	Metric3	(0.029)	0.009	(0.046)	(0.012)	(3.310)	0.0011
Bunif	L	L	Metric3	(0.212)	0.014	(0.239)	(0.185)	(15.414)	0.0000
B8020	H	H	Metric4	0.017	0.006	0.006	0.028	2.933	0.0037
B9010	H	H	Metric4	(0.014)	0.006	(0.025)	(0.002)	(2.351)	0.0195
Bunif	H	H	Metric4	-	-				
B8020	H	L	Metric4	0.003	0.008	(0.013)	0.020	0.404	0.6863
B9010	H	L	Metric4	0.004	0.007	(0.010)	0.018	0.572	0.5680
Bunif	H	L	Metric4	0.010	0.002	0.007	0.013	5.817	0.0000
B8020	L	H	Metric4	0.003	0.006	(0.009)	0.015	0.442	0.6585
B9010	L	H	Metric4	0.110	0.009	0.092	0.128	12.100	0.0000
Bunif	L	H	Metric4	(0.003)	0.001	(0.004)	(0.001)	(3.221)	0.0014
B8020	L	L	Metric4	0.061	0.009	0.044	0.078	7.121	0.0000
B9010	L	L	Metric4	0.017	0.007	0.003	0.030	2.464	0.0144
Bunif	L	L	Metric4	0.001	0.001	0.000	0.002	2.701	0.0074

Test Set	Res	Net	Metric	Mean	Std Err	95% CI Lower	95% CI Upper	t	p-val
B8020	H	H	Metric5	0.011	0.005	0.001	0.020	2.115	0.0355
B9010	H	H	Metric5	(0.012)	0.004	(0.020)	(0.004)	(3.057)	0.0025
Bunif	H	H	Metric5	0.005	0.005	(0.004)	0.014	1.061	0.2896
B8020	H	L	Metric5	(0.029)	0.004	(0.037)	(0.020)	(6.860)	0.0000
B9010	H	L	Metric5	(0.011)	0.005	(0.020)	(0.002)	(2.488)	0.0135
Bunif	H	L	Metric5	(0.038)	0.006	(0.050)	(0.025)	(6.058)	0.0000
B8020	L	H	Metric5	(0.072)	0.008	(0.087)	(0.056)	(9.281)	0.0000
B9010	L	H	Metric5	(0.042)	0.006	(0.053)	(0.031)	(7.434)	0.0000
Bunif	L	H	Metric5	(0.004)	0.005	(0.014)	0.006	(0.765)	0.4449
B8020	L	L	Metric5	(0.079)	0.008	(0.094)	(0.063)	(9.972)	0.0000
B9010	L	L	Metric5	(0.029)	0.006	(0.041)	(0.016)	(4.466)	0.0000
Bunif	L	L	Metric5	(0.031)	0.011	(0.052)	(0.010)	(2.898)	0.0041
B8020	H	H	Metric6	0.023	0.003	0.016	0.029	7.155	0.0000
B9010	H	H	Metric6	(0.014)	0.003	(0.019)	(0.008)	(4.641)	0.0000
Bunif	H	H	Metric6	(0.005)	0.005	(0.014)	0.004	(1.032)	0.3030
B8020	H	L	Metric6	0.029	0.009	0.011	0.047	3.142	0.0019
B9010	H	L	Metric6	0.047	0.008	0.032	0.063	6.028	0.0000
Bunif	H	L	Metric6	0.026	0.006	0.013	0.038	4.103	0.0001
B8020	L	H	Metric6	(0.012)	0.002	(0.017)	(0.007)	(4.960)	0.0000
B9010	L	H	Metric6	(0.098)	0.008	(0.114)	(0.081)	(11.510)	0.0000
Bunif	L	H	Metric6	(0.003)	0.005	(0.012)	0.007	(0.603)	0.5470
B8020	L	L	Metric6	(0.084)	0.009	(0.101)	(0.066)	(9.303)	0.0000
B9010	L	L	Metric6	(0.000)	0.007	(0.014)	0.013	(0.037)	0.9707
Bunif	L	L	Metric6	0.024	0.011	0.003	0.045	2.285	0.0232
B8020	H	H	Metric7	(0.005)	0.007	(0.019)	0.009	(0.712)	0.4772
B9010	H	H	Metric7	(0.036)	0.004	(0.044)	(0.028)	(8.864)	0.0000
Bunif	H	H	Metric7	(0.011)	0.002	(0.015)	(0.007)	(4.918)	0.0000
B8020	H	L	Metric7	0.001	0.006	(0.011)	0.013	0.179	0.8578
B9010	H	L	Metric7	(0.023)	0.005	(0.032)	(0.014)	(5.018)	0.0000
Bunif	H	L	Metric7	(0.018)	0.004	(0.025)	(0.011)	(4.921)	0.0000
B8020	L	H	Metric7	0.004	0.007	(0.009)	0.017	0.558	0.5770
B9010	L	H	Metric7	0.004	0.004	(0.004)	0.012	1.037	0.3005
Bunif	L	H	Metric7	(0.127)	0.007	(0.141)	(0.114)	(18.839)	0.0000
B8020	L	L	Metric7	(0.050)	0.013	(0.076)	(0.024)	(3.783)	0.0002
B9010	L	L	Metric7	(0.015)	0.006	(0.027)	(0.002)	(2.312)	0.0216
Bunif	L	L	Metric7	(0.102)	0.010	(0.122)	(0.082)	(10.037)	0.0000
B8020	H	H	Metric8	0.008	0.020	(0.032)	0.049	0.409	0.6831
B9010	H	H	Metric8	0.039	0.021	(0.003)	0.081	1.835	0.0677
Bunif	H	H	Metric8	0.242	0.032	0.179	0.306	7.505	0.0000
B8020	H	L	Metric8	0.089	0.021	0.048	0.129	4.294	0.0000
B9010	H	L	Metric8	0.103	0.018	0.068	0.138	5.839	0.0000
Bunif	H	L	Metric8	0.228	0.028	0.173	0.283	8.157	0.0000
B8020	L	H	Metric8	0.043	0.046	(0.047)	0.133	0.938	0.3492
B9010	L	H	Metric8	0.038	0.014	0.010	0.067	2.654	0.0085
Bunif	L	H	Metric8	0.215	0.027	0.162	0.267	8.043	0.0000
B8020	L	L	Metric8	0.253	0.034	0.186	0.320	7.431	0.0000
B9010	L	L	Metric8	0.142	0.025	0.093	0.191	5.731	0.0000
Bunif	L	L	Metric8	0.406	0.041	0.326	0.486	9.970	0.0000

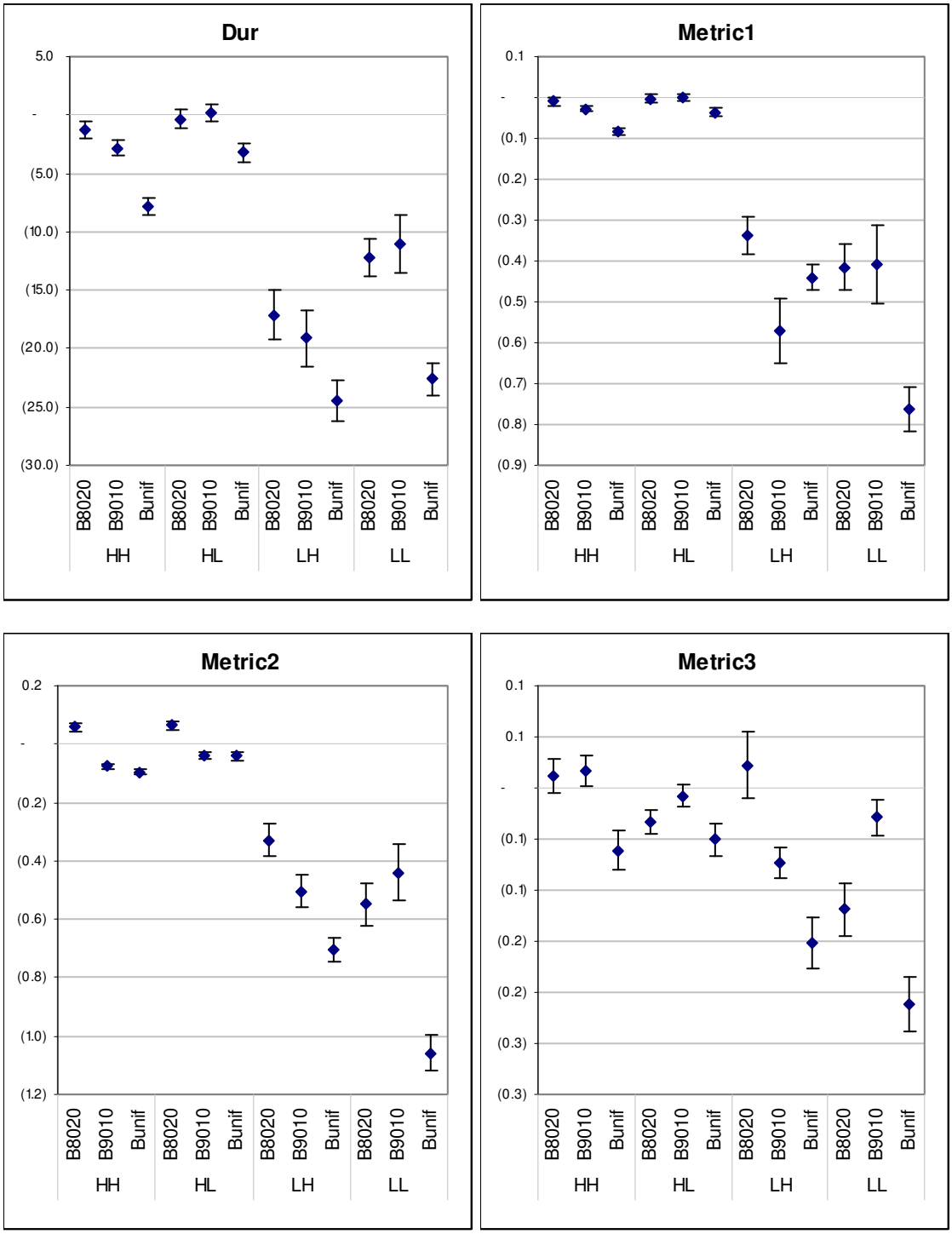
Test Set	Res	Net	Metric	Mean	Std Err	95% CI Lower	95% CI Upper	t	p-val
B8020	H	H	RMetric1	(0.187)	0.046	(0.277)	(0.098)	(4.108)	0.0001
B9010	H	H	RMetric1	(0.538)	0.044	(0.625)	(0.451)	(12.172)	0.0000
Bunif	H	H	RMetric1	(0.915)	0.052	(1.018)	(0.812)	(17.519)	0.0000
B8020	H	L	RMetric1	(0.170)	0.050	(0.268)	(0.072)	(3.411)	0.0008
B9010	H	L	RMetric1	(0.569)	0.040	(0.648)	(0.491)	(14.322)	0.0000
Bunif	H	L	RMetric1	(0.836)	0.048	(0.930)	(0.743)	(17.538)	0.0000
B8020	L	H	RMetric1	(0.010)	0.022	(0.053)	0.034	(0.447)	0.6552
B9010	L	H	RMetric1	0.062	0.021	0.021	0.104	2.977	0.0032
Bunif	L	H	RMetric1	(0.142)	0.023	(0.187)	(0.096)	(6.168)	0.0000
B8020	L	L	RMetric1	(0.365)	0.039	(0.442)	(0.288)	(9.377)	0.0000
B9010	L	L	RMetric1	0.003	0.039	(0.073)	0.079	0.083	0.9339
Bunif	L	L	RMetric1	(0.074)	0.040	(0.153)	0.006	(1.831)	0.0682
B8020	H	H	RMetric2	(0.414)	0.027	(0.466)	(0.361)	(15.561)	0.0000
B9010	H	H	RMetric2	0.108	0.017	0.074	0.141	6.394	0.0000
Bunif	H	H	RMetric2	(0.450)	0.022	(0.494)	(0.406)	(20.240)	0.0000
B8020	H	L	RMetric2	(0.342)	0.029	(0.400)	(0.284)	(11.671)	0.0000
B9010	H	L	RMetric2	0.039	0.018	0.003	0.076	2.138	0.0335
Bunif	H	L	RMetric2	(0.384)	0.031	(0.446)	(0.322)	(12.209)	0.0000
B8020	L	H	RMetric2	(0.590)	0.029	(0.648)	(0.533)	(20.342)	0.0000
B9010	L	H	RMetric2	(0.104)	0.017	(0.139)	(0.070)	(5.976)	0.0000
Bunif	L	H	RMetric2	(0.637)	0.017	(0.670)	(0.604)	(38.490)	0.0000
B8020	L	L	RMetric2	(1.268)	0.048	(1.362)	(1.174)	(26.461)	0.0000
B9010	L	L	RMetric2	0.029	0.034	(0.039)	0.096	0.840	0.4015
Bunif	L	L	RMetric2	(1.410)	0.038	(1.484)	(1.335)	(37.263)	0.0000
B8020	H	H	Rmetric3	-	-				
B9010	H	H	Rmetric3	-	-				
Bunif	H	H	Rmetric3	-	-				
B8020	H	L	Rmetric3	(0.004)	0.004	(0.012)	0.004	(1.000)	0.3183
B9010	H	L	Rmetric3	(0.004)	0.004	(0.012)	0.004	(1.000)	0.3183
Bunif	H	L	Rmetric3	(0.016)	0.008	(0.032)	(0.000)	(2.012)	0.0453
B8020	L	H	Rmetric3	(0.078)	0.058	(0.192)	0.036	(1.352)	0.1776
B9010	L	H	Rmetric3	1.866	0.088	1.693	2.039	21.255	0.0000
Bunif	L	H	Rmetric3	(0.892)	0.074	(1.037)	(0.747)	(12.104)	0.0000
B8020	L	L	Rmetric3	(0.242)	0.070	(0.380)	(0.104)	(3.451)	0.0007
B9010	L	L	Rmetric3	0.356	0.072	0.214	0.498	4.955	0.0000
Bunif	L	L	Rmetric3	(0.850)	0.072	(0.991)	(0.709)	(11.844)	0.0000
B8020	H	H	Rmetric4a	(0.262)	0.164	(0.586)	0.062	(1.593)	0.1125
B9010	H	H	Rmetric4a	0.384	0.190	0.010	0.758	2.023	0.0442
Bunif	H	H	Rmetric4a	(5.092)	0.157	(5.401)	(4.783)	(32.492)	0.0000
B8020	H	L	Rmetric4a	0.454	0.108	0.241	0.667	4.199	0.0000
B9010	H	L	Rmetric4a	0.844	0.174	0.500	1.188	4.837	0.0000
Bunif	H	L	Rmetric4a	(4.702)	0.151	(5.000)	(4.404)	(31.121)	0.0000
B8020	L	H	Rmetric4a	0.072	0.076	(0.078)	0.222	0.948	0.3438
B9010	L	H	Rmetric4a	19.856	0.253	19.358	20.354	78.450	0.0000
Bunif	L	H	Rmetric4a	(2.546)	0.107	(2.758)	(2.334)	(23.686)	0.0000
B8020	L	L	Rmetric4a	1.086	0.117	0.856	1.316	9.308	0.0000
B9010	L	L	Rmetric4a	18.062	0.143	17.781	18.343	126.490	0.0000
Bunif	L	L	Rmetric4a	(1.538)	0.138	(1.809)	(1.267)	(11.176)	0.0000

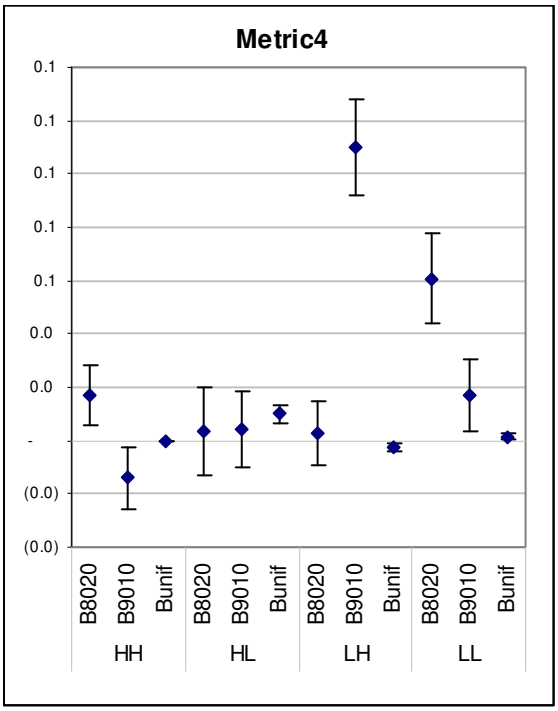
Test Set	Res	Net	Metric	Mean	Std Err	95% CI Lower	95% CI Upper	t	p-val
B8020	H	H	Rmetric4b	0.934	0.706	(0.457)	2.325	1.323	0.1872
B9010	H	H	Rmetric4b	(23.598)	0.816	(25.206)	(21.990)	(28.903)	0.0000
Bunif	H	H	Rmetric4b	(15.998)	1.413	(18.780)	(13.216)	(11.326)	0.0000
B8020	H	L	Rmetric4b	5.238	0.722	3.816	6.660	7.256	0.0000
B9010	H	L	Rmetric4b	(12.700)	1.020	(14.710)	(10.690)	(12.447)	0.0000
Bunif	H	L	Rmetric4b	(18.980)	0.798	(20.552)	(17.408)	(23.784)	0.0000
B8020	L	H	Rmetric4b	1.206	0.201	0.810	1.602	5.996	0.0000
B9010	L	H	Rmetric4b	150.644	0.374	149.907	151.381	402.779	-
Bunif	L	H	Rmetric4b	(3.602)	0.244	(4.083)	(3.121)	(14.746)	0.0000
B8020	L	L	Rmetric4b	2.230	0.311	1.618	2.842	7.181	0.0000
B9010	L	L	Rmetric4b	150.080	0.298	149.494	150.666	504.384	-
Bunif	L	L	Rmetric4b	(1.178)	0.362	(1.891)	(0.465)	(3.253)	0.0013
B8020	H	H	Rmetric5a	0.486	0.447	(0.394)	1.366	1.088	0.2776
B9010	H	H	Rmetric5a	(0.472)	0.592	(1.637)	0.693	(0.798)	0.4258
Bunif	H	H	Rmetric5a	(2.080)	0.407	(2.881)	(1.279)	(5.115)	0.0000
B8020	H	L	Rmetric5a	(0.784)	0.448	(1.667)	0.099	(1.750)	0.0814
B9010	H	L	Rmetric5a	4.292	0.519	3.270	5.314	8.268	0.0000
Bunif	H	L	Rmetric5a	(2.458)	0.382	(3.211)	(1.705)	(6.427)	0.0000
B8020	L	H	Rmetric5a	(12.290)	0.926	(14.114)	(10.466)	(13.273)	0.0000
B9010	L	H	Rmetric5a	(8.300)	1.132	(10.529)	(6.071)	(7.334)	0.0000
Bunif	L	H	Rmetric5a	(21.788)	0.934	(23.627)	(19.949)	(23.338)	0.0000
B8020	L	L	Rmetric5a	(9.830)	0.795	(11.396)	(8.264)	(12.364)	0.0000
B9010	L	L	Rmetric5a	3.916	1.203	1.546	6.286	3.255	0.0013
Bunif	L	L	Rmetric5a	(21.026)	0.713	(22.430)	(19.622)	(29.489)	0.0000
B8020	H	H	Rmetric5b	0.430	3.586	(6.633)	7.493	0.120	0.9047
B9010	H	H	Rmetric5b	56.538	3.534	49.578	63.498	15.999	0.0000
Bunif	H	H	Rmetric5b	(49.742)	3.030	(55.709)	(43.775)	(16.419)	0.0000
B8020	H	L	Rmetric5b	(14.132)	3.637	(21.296)	(6.968)	(3.885)	0.0001
B9010	H	L	Rmetric5b	49.020	3.834	41.468	56.572	12.785	0.0000
Bunif	H	L	Rmetric5b	(27.954)	3.666	(35.174)	(20.734)	(7.626)	0.0000
B8020	L	H	Rmetric5b	(44.904)	3.604	(52.002)	(37.806)	(12.461)	0.0000
B9010	L	H	Rmetric5b	(33.442)	4.386	(42.080)	(24.804)	(7.625)	0.0000
Bunif	L	H	Rmetric5b	(45.578)	2.790	(51.074)	(40.082)	(16.334)	0.0000
B8020	L	L	Rmetric5b	(33.378)	3.448	(40.169)	(26.587)	(9.680)	0.0000
B9010	L	L	Rmetric5b	(17.208)	4.060	(25.205)	(9.211)	(4.238)	0.0000
Bunif	L	L	Rmetric5b	(70.144)	3.963	(77.949)	(62.339)	(17.699)	0.0000

Confidence Interval Plots

The following confidence interval plots are a visualization of the confidence interval plots in the table above. Each plot represents the expected value of the improvement over the 50% buffer under that set of network characteristics. Here, the first letter represents the level for

resource characteristics and the second letter represents level for network characteristics (H = High, L = Low).




Metric4
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0.1
0.1
0.1
0.1
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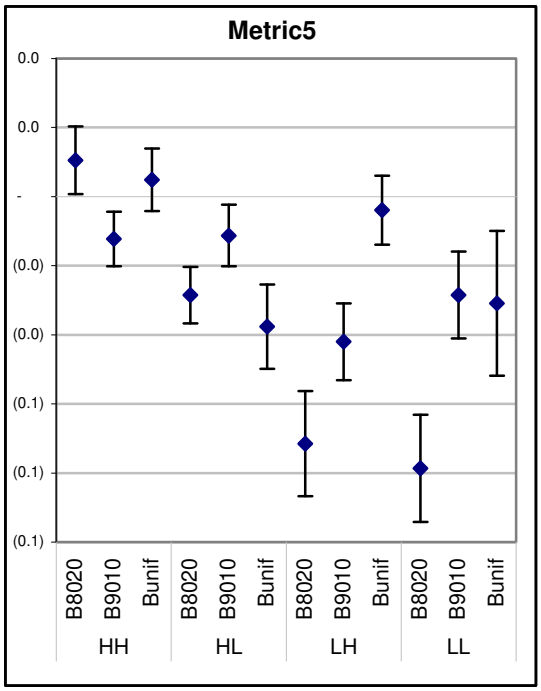
0.0
-
(0.0)
(0.0)
B8020
B9010
Bunif
HH
HL
LH
LL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0.0
-
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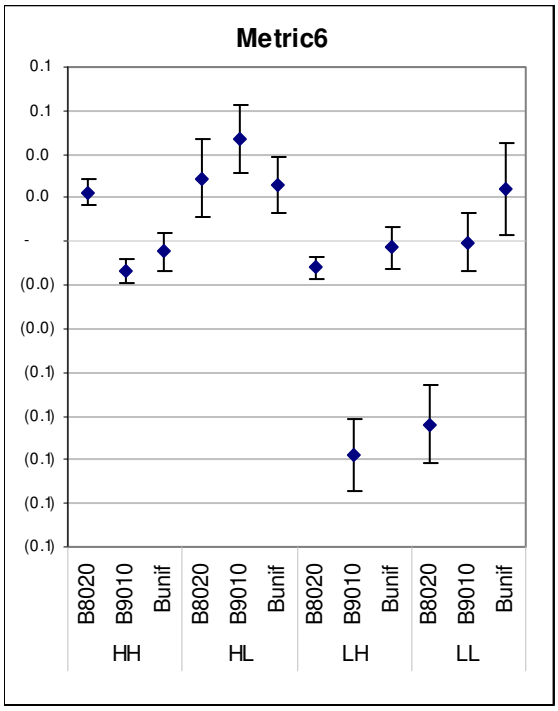
(0.0)
(0.1)
(0.1)
(0.1)
B8020
B9010
Bunif
HH
HL
LH
LL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0.0
0.0
-
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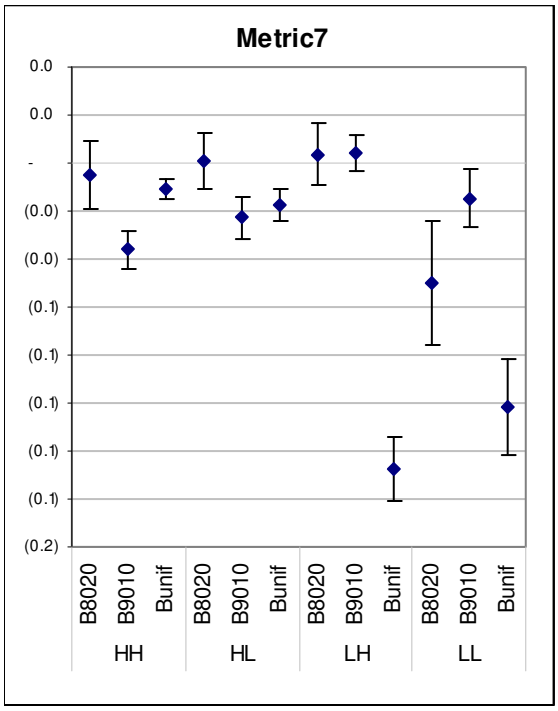
(0.0)
(0.1)
(0.1)
(0.1)
(0.1)
(0.1)
B8020
B9010
Bunif
HH
HL
LH
LL


Metric7
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0.0
-
(0.0)
(0.0)
(0.1)
(0.1)
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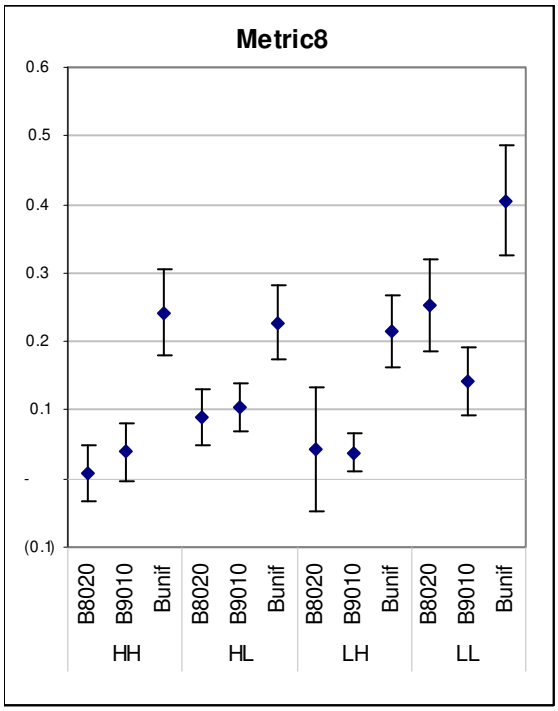
(0.1)
(0.1)
(0.2)
B8020
B9010
Bunif
HH
HL
LH
LL


Metric8
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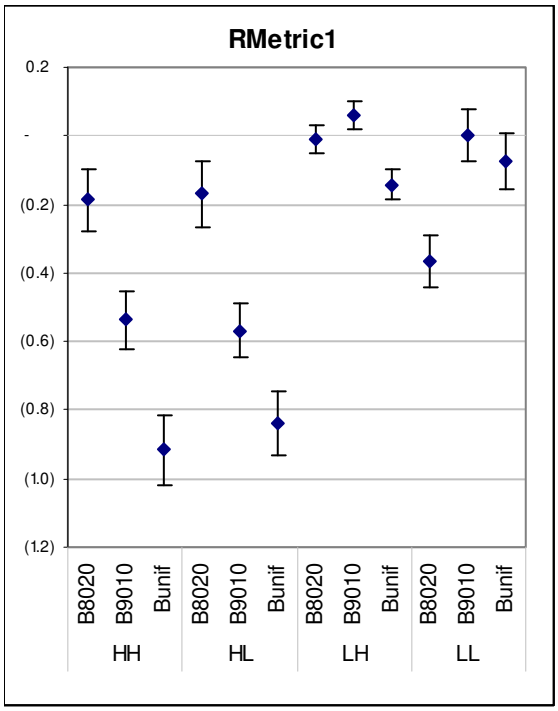
0.5
0.4
0.3
0.2
0.1
-
(0.1)
B8020
B9010
Bunif
HH
HL
LH
LL


RMetric1
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-
(0.2)
(0.4)
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(0.8)
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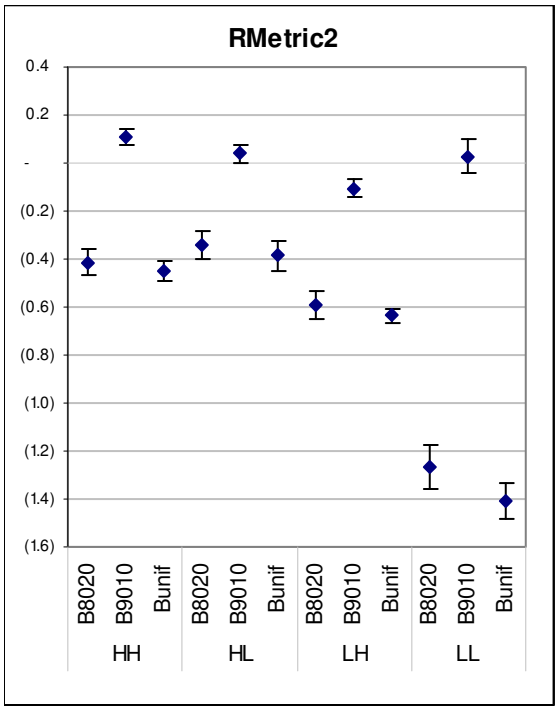
(1.2)
B8020
B9010
Bunif
HH
HL
LH
LL


RMetric2
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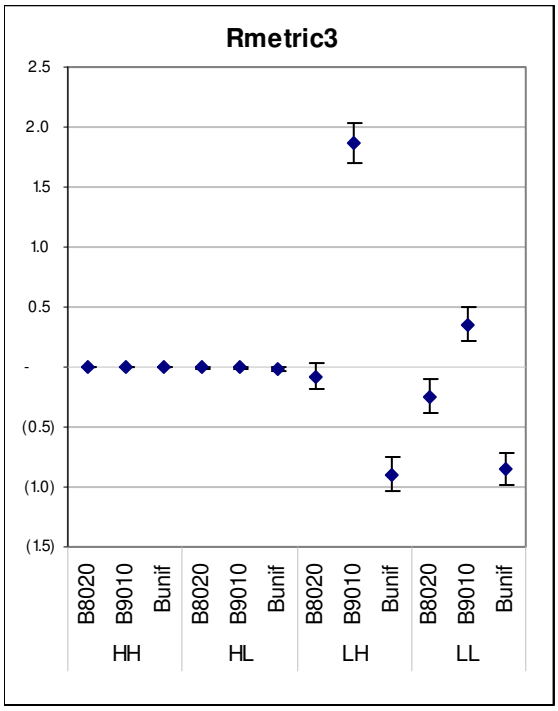
0.2
-
(0.2)
(0.4)
(0.6)
(0.8)
(1.0)
(1.2)
(1.4)
(1.6)
B8020
B9010
Bunif
HH
HL
LH
LL


Rmetric3
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1.5
1.0
0.5
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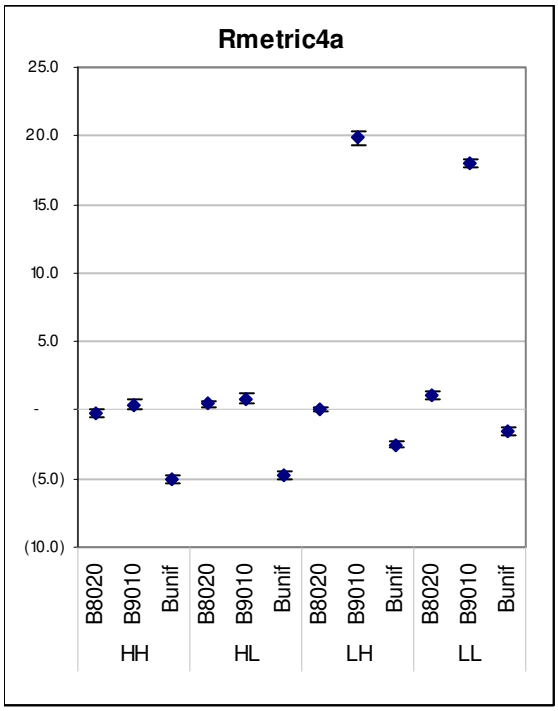
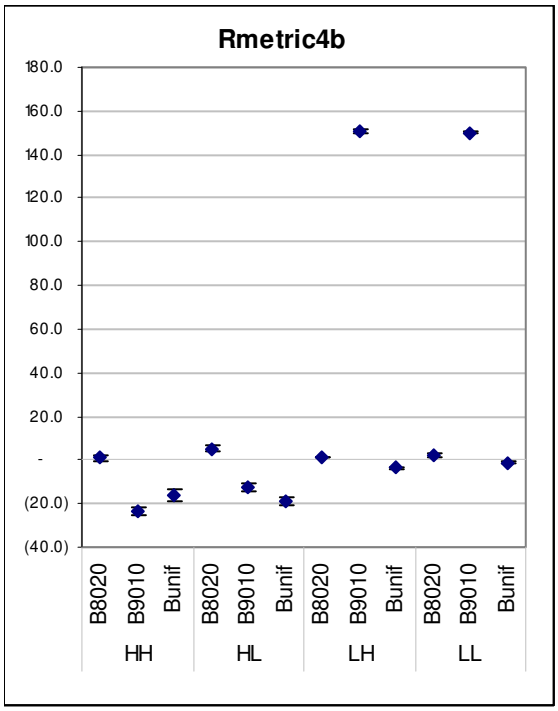
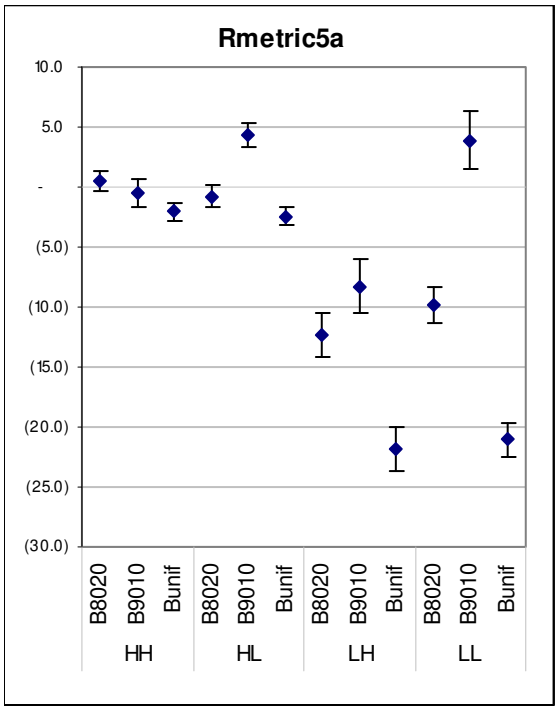
(0.5)
(1.0)
(1.5)
B8020
B9010
Bunif
HH
HL
LH
LL


Rmetric4a
25.0
20.0
15.0
10.0
5.0
-
(5.0)
(10.0)
B8020
B9010
Bunif
HH
HL
LH
LL


Rmetric4b
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
-
(20.0)
(40.0)
B8020
B9010
Bunif
HH
HL
LH
LL


Rmetric5a
10.0
5.0
-
(5.0)
(10.0)
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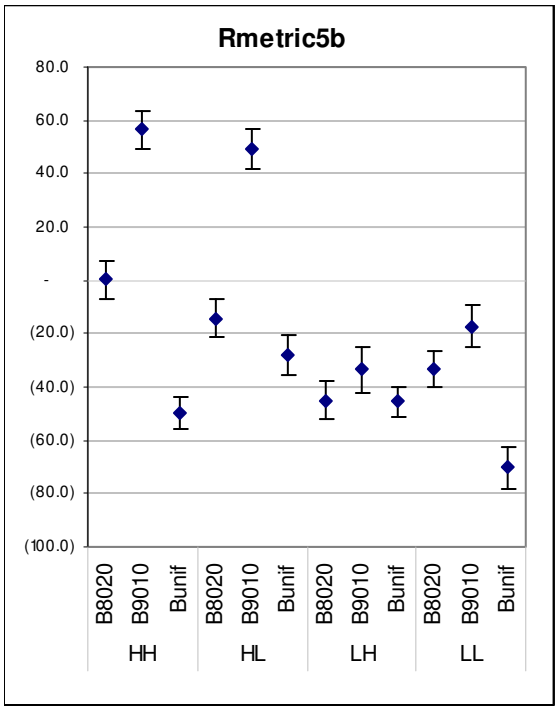
B8020
B9010
Bunif
HH
HL
LH
LL


Rmetric5b
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60.0
40.0
20.0
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(20.0)
(40.0)
(60.0)
(80.0)
(100.0)
B8020
B9010
Bunif
HH
HL
LH
LL

ANOVA Results

For all preceding ANOVA table results, the degrees of freedom for the model are 2, error is 747, and the corrected total is 749. The highlighted rows indicate where the metric value was statistically different for the three proportional buffering methods at $\alpha = 0.5$.

Res	Net	Metric	SS Model	SS Error	F-Val	P-Val
H	H	Dur	5,957.363	24,652.616	90.257	0.000
H	H	Metric1	0.697	3.097	84.046	0.000
H	H	Metric2	3.527	6.353	207.330	0.000
H	H	Metric3	0.937	13.873	25.224	0.000
H	H	Metric4	0.120	4.260	10.484	0.000
H	H	Metric5	0.070	3.848	6.815	0.001
H	H	Metric6	0.176	2.461	26.752	0.000
H	H	Metric7	0.136	4.507	11.263	0.000
H	H	Metric8	8.072	119.115	25.310	0.000
H	H	RMetric1	66.229	420.891	58.772	0.000
H	H	RMetric2	48.671	92.404	196.731	0.000
H	H	Rmetric3	-	-	-	-
H	H	Rmetric4a	4,477.733	5,456.609	306.497	0.000
H	H	Rmetric4b	78,855.971	196,746.259	149.699	0.000
H	H	Rmetric5a	840.649	44,509.905	7.054	0.001
H	H	Rmetric5b	1,413,397.971	2,149,233.523	245.624	0.000
L	H	Dur	7,132.256	218,150.544	12.211	0.000
L	H	Metric1	6.847	152.863	16.731	0.000
L	H	Metric2	17.630	121.723	54.096	0.000
L	H	Metric3	3.798	30.185	46.991	0.000
L	H	Metric4	2.025	7.610	99.371	0.000
L	H	Metric5	0.575	7.278	29.495	0.000
L	H	Metric6	1.370	6.269	81.605	0.000
L	H	Metric7	2.867	6.549	163.506	0.000
L	H	Metric8	5.060	187.942	10.056	0.000
L	H	RMetric1	5.348	90.413	22.093	0.000
L	H	RMetric2	43.492	88.512	183.525	0.000
L	H	Rmetric3	1,004.025	1,025.074	365.830	0.000
L	H	Rmetric4a	75,009.182	5,065.741	5,530.470	-
L	H	Rmetric4b	3,845,555.102	14,940.606	96,134.978	-
L	H	Rmetric5a	24,004.854	187,345.989	47.857	0.000
L	H	Rmetric5b	23,259.518	2,490,470.334	3.488	0.031

Res	Net	Metric	SS Model	SS Error	F-Val	P-Val
H	L	Dur	1,701.923	28,953.272	21.955	0.000
H	L	Metric1	0.189	4.205	16.768	0.000
H	L	Metric2	1.777	7.137	93.014	0.000
H	L	Metric3	0.232	8.087	10.718	0.000
H	L	Metric4	0.007	7.761	0.317	0.729
H	L	Metric5	0.090	4.748	7.056	0.001
H	L	Metric6	0.066	11.650	2.127	0.120
H	L	Metric7	0.079	4.256	6.923	0.001
H	L	Metric8	2.939	94.499	11.618	0.000
H	L	RMetric1	56.291	394.195	53.335	0.000
H	L	RMetric2	27.217	136.188	74.644	0.000
H	L	Rmetric3	0.024	5.928	1.512	0.221
H	L	Rmetric4a	4,791.213	4,044.186	442.492	0.000
H	L	Rmetric4b	78,976.814	136,886.989	215.490	0.000
H	L	Rmetric5a	6,177.546	38,378.829	60.119	0.000
H	L	Rmetric5b	842,018.289	2,575,268.265	122.121	0.000
L	L	Dur	20,344.928	168,452.124	45.110	0.000
L	L	Metric1	20.600	243.497	31.598	0.000
L	L	Metric2	54.147	293.889	68.815	0.000
L	L	Metric3	4.186	27.048	57.810	0.000
L	L	Metric4	0.474	7.467	23.722	0.000
L	L	Metric5	0.400	13.470	11.087	0.000
L	L	Metric6	1.602	14.998	39.891	0.000
L	L	Metric7	0.964	19.610	18.361	0.000
L	L	Metric8	8.755	213.733	15.300	0.000
L	L	RMetric1	18.874	288.387	24.445	0.000
L	L	RMetric2	314.184	304.579	385.277	0.000
L	L	Rmetric3	181.809	948.050	71.627	0.000
L	L	Rmetric4a	56,602.496	3,295.579	6,414.968	-
L	L	Rmetric4b	3,729,184.961	19,679.254	70,777.611	-
L	L	Rmetric5a	78,033.858	161,119.842	180.894	0.000
L	L	Rmetric5b	367,952.313	2,744,164.529	50.081	0.000

Tukey Test Results

In the following tables, means with the same letter in the columns labeled "Tukey Grouping" are not significantly different. Additionally, a 1 indicates no pair-wise difference significant at $\alpha = 0.05$. Zeros, indicating significant pair-wise differences are highlighted, and a note is made indicating the technique that produced the lowest average improvement metric value. The lowest value indicates the most improvement over the 50% buffering method.

Res	Net	Metric	Tukey Grouping		Mean	Test Set	Method B8020	B9010	Bunif	Min Mean
H	H	Dur	A		(1.284)	B8020	1	0	0	
H	H	Dur	B		(2.844)	B9010	0	1	0	
H	H	Dur	C		(7.888)	Bunif	0	0	1	Bunif
H	H	Metric1	A		(0.010)	B8020	1	0	0	
H	H	Metric1	B		(0.028)	B9010	0	1	0	
H	H	Metric1	C		(0.082)	Bunif	0	0	1	Bunif
H	H	Metric2	A		0.059	B8020	1	0	0	
H	H	Metric2	B		(0.077)	B9010	0	1	1	
H	H	Metric2	B		(0.095)	Bunif	0	1	1	Bunif
H	H	Metric3	A		0.012	B8020	1	1	0	
H	H	Metric3	A		0.016	B9010	1	1	0	
H	H	Metric3	B		(0.061)	Bunif	0	0	1	Bunif
H	H	Metric4	A		0.017	B8020	1	0	0	
H	H	Metric4	B		(0.014)	B9010	0	1	1	B9010
H	H	Metric4	B		-	Bunif	0	1	1	
H	H	Metric5	A		0.011	B8020	1	0	1	
H	H	Metric5	B		(0.012)	B9010	0	1	0	B9010
H	H	Metric5	A		0.005	Bunif	1	0	1	
H	H	Metric6	A		0.023	B8020	1	0	0	
H	H	Metric6	B		(0.014)	B9010	0	1	1	B9010
H	H	Metric6	B		(0.005)	Bunif	0	1	1	
H	H	Metric7	A		(0.005)	B8020	1	0	1	
H	H	Metric7	B		(0.036)	B9010	0	1	0	B9010
H	H	Metric7	A		(0.011)	Bunif	1	0	1	
H	H	Metric8	B		0.008	B8020	1	1	0	B8020
H	H	Metric8	B		0.039	B9010	1	1	0	
H	H	Metric8	A		0.242	Bunif	0	0	1	
H	H	RMetric1	A		(0.187)	B8020	1	0	0	
H	H	RMetric1	B		(0.538)	B9010	0	1	0	
H	H	RMetric1	C		(0.915)	Bunif	0	0	1	Bunif
H	H	RMetric2	B		(0.414)	B8020	1	0	1	
H	H	RMetric2	A		0.108	B9010	0	1	0	
H	H	RMetric2	B		(0.450)	Bunif	1	0	1	Bunif
H	H	Rmetric3	A		-	B8020	1	1	1	
H	H	Rmetric3	A		-	B9010	1	1	1	
H	H	Rmetric3	A		-	Bunif	1	1	1	
H	H	Rmetric4a	B		(0.262)	B8020	1	0	0	
H	H	Rmetric4a	A		0.384	B9010	0	1	0	
H	H	Rmetric4a	C		(5.092)	Bunif	0	0	1	Bunif
H	H	Rmetric4b	A		0.934	B8020	1	0	0	
H	H	Rmetric4b	C		(23.598)	B9010	0	1	0	B9010
H	H	Rmetric4b	B		(15.998)	Bunif	0	0	1	
H	H	Rmetric5a		A	0.486	B8020	1	1	0	
H	H	Rmetric5a	B	A	(0.472)	B9010	1	1	1	
H	H	Rmetric5a	B		(2.080)	Bunif	0	1	1	Bunif
H	H	Rmetric5b	B		0.430	B8020	1	0	0	
H	H	Rmetric5b	A		56.538	B9010	0	1	0	
H	H	Rmetric5b	C		(49.742)	Bunif	0	0	1	Bunif

Res	Net	Metric	Tukey Grouping		Mean	Test Set	Method B8020	B9010	Bunif	Min Mean
H	L	Dur	A		(0.360)	B8020	1	1	0	
H	L	Dur	A		0.204	B9010	1	1	0	
H	L	Dur	B		(3.236)	Bunif	0	0	1	Bunif
H	L	Metric1	A		(0.004)	B8020	1	1	0	
H	L	Metric1	A		(0.001)	B9010	1	1	0	
H	L	Metric1	B		(0.036)	Bunif	0	0	1	Bunif
H	L	Metric2	A		0.064	B8020	1	0	0	
H	L	Metric2	B		(0.038)	B9010	0	1	1	
H	L	Metric2	B		(0.041)	Bunif	0	1	1	Bunif
H	L	Metric3	B		(0.033)	B8020	1	0	1	
H	L	Metric3	A		(0.008)	B9010	0	1	0	
H	L	Metric3	B		(0.051)	Bunif	1	0	1	Bunif
H	L	Metric4	A		0.003	B8020	1	1	1	
H	L	Metric4	A		0.004	B9010	1	1	1	
H	L	Metric4	A		0.010	Bunif	1	1	1	
H	L	Metric5	B		(0.029)	B8020	1	0	1	
H	L	Metric5	A		(0.011)	B9010	0	1	0	
H	L	Metric5	B		(0.038)	Bunif	1	0	1	Bunif
H	L	Metric6	A		0.029	B8020	1	1	1	
H	L	Metric6	A		0.047	B9010	1	1	1	
H	L	Metric6	A		0.026	Bunif	1	1	1	
H	L	Metric7	A		0.001	B8020	1	0	0	
H	L	Metric7	B		(0.023)	B9010	0	1	1	B9010
H	L	Metric7	B		(0.018)	Bunif	0	1	1	
H	L	Metric8	B		0.089	B8020	1	1	0	B8020
H	L	Metric8	B		0.103	B9010	1	1	0	
H	L	Metric8	A		0.228	Bunif	0	0	1	
H	L	RMetric1	A		(0.170)	B8020	1	0	0	
H	L	RMetric1	B		(0.569)	B9010	0	1	0	
H	L	RMetric1	C		(0.836)	Bunif	0	0	1	Bunif
H	L	RMetric2	B		(0.342)	B8020	1	0	1	
H	L	RMetric2	A		0.039	B9010	0	1	0	
H	L	RMetric2	B		(0.384)	Bunif	1	0	1	Bunif
H	L	Rmetric3	A		(0.004)	B8020	1	1	1	
H	L	Rmetric3	A		(0.004)	B9010	1	1	1	
H	L	Rmetric3	A		(0.016)	Bunif	1	1	1	
H	L	Rmetric4a	A		0.454	B8020	1	1	0	
H	L	Rmetric4a	A		0.844	B9010	1	1	0	
H	L	Rmetric4a	B		(4.702)	Bunif	0	0	1	Bunif
H	L	Rmetric4b	A		5.238	B8020	1	0	0	
H	L	Rmetric4b	B		(12.700)	B9010	0	1	0	
H	L	Rmetric4b	C		(18.980)	Bunif	0	0	1	Bunif
H	L	Rmetric5a	B		(0.784)	B8020	1	0	0	
H	L	Rmetric5a	A		4.292	B9010	0	1	0	
H	L	Rmetric5a	C		(2.458)	Bunif	0	0	1	Bunif
H	L	Rmetric5b	B		(14.132)	B8020	1	0	0	
H	L	Rmetric5b	A		49.020	B9010	0	1	0	
H	L	Rmetric5b	C		(27.954)	Bunif	0	0	1	Bunif

Res	Net	Metric	Tukey Grouping		Mean	Test Set	Method B8020	Method B9010	Method Bunif	Min Mean
L	H	Dur	A		(17.144)	B8020	1	1	0	
L	H	Dur	A		(19.128)	B9010	1	1	0	
L	H	Dur	B		(24.448)	Bunif	0	0	1	Bunif
L	H	Metric1	A		(0.337)	B8020	1	0	0	
L	H	Metric1	C		(0.571)	B9010	0	1	0	B9010
L	H	Metric1	B		(0.440)	Bunif	0	0	1	
L	H	Metric2	A		(0.330)	B8020	1	0	0	
L	H	Metric2	B		(0.504)	B9010	0	1	0	
L	H	Metric2	C		(0.705)	Bunif	0	0	1	Bunif
L	H	Metric3	A		0.022	B8020	1	0	0	
L	H	Metric3	B		(0.074)	B9010	0	1	0	
L	H	Metric3	C		(0.152)	Bunif	0	0	1	Bunif
L	H	Metric4	B		0.003	B8020	1	0	1	
L	H	Metric4	A		0.110	B9010	0	1	0	
L	H	Metric4	B		(0.003)	Bunif	1	0	1	
L	H	Metric5	C		(0.072)	B8020	1	0	0	B8020
L	H	Metric5	B		(0.042)	B9010	0	1	0	
L	H	Metric5	A		(0.004)	Bunif	0	0	1	
L	H	Metric6	A		(0.012)	B8020	1	0	1	
L	H	Metric6	B		(0.098)	B9010	0	1	0	
L	H	Metric6	A		(0.003)	Bunif	1	0	1	
L	H	Metric7	A		0.004	B8020	1	1	0	
L	H	Metric7	A		0.004	B9010	1	1	0	
L	H	Metric7	B		(0.127)	Bunif	0	0	1	Bunif
L	H	Metric8	B		0.043	B8020	1	1	0	
L	H	Metric8	B		0.038	B9010	1	1	0	B9010
L	H	Metric8	A		0.215	Bunif	0	0	1	
L	H	RMetric1	A		(0.010)	B8020	1	1	0	
L	H	RMetric1	A		0.062	B9010	1	1	0	
L	H	RMetric1	B		(0.142)	Bunif	0	0	1	Bunif
L	H	RMetric2	B		(0.590)	B8020	1	0	1	
L	H	RMetric2	A		(0.104)	B9010	0	1	0	
L	H	RMetric2	B		(0.637)	Bunif	1	0	1	Bunif
L	H	Rmetric3	B		(0.078)	B8020	1	0	0	
L	H	Rmetric3	A		1.866	B9010	0	1	0	
L	H	Rmetric3	C		(0.892)	Bunif	0	0	1	
L	H	Rmetric4a	B		0.072	B8020	1	0	0	
L	H	Rmetric4a	A		19.856	B9010	0	1	0	
L	H	Rmetric4a	C		(2.546)	Bunif	0	0	1	Bunif
L	H	Rmetric4b	B		1.206	B8020	1	0	0	
L	H	Rmetric4b	A		150.644	B9010	0	1	0	
L	H	Rmetric4b	C		(3.602)	Bunif	0	0	1	Bunif
L	H	Rmetric5a	B		(12.290)	B8020	1	0	0	
L	H	Rmetric5a	A		(8.300)	B9010	0	1	0	
L	H	Rmetric5a	C		(21.788)	Bunif	0	0	1	Bunif
L	H	Rmetric5b	B	A	(44.904)	B8020	1	1	1	
L	H	Rmetric5b		A	(33.442)	B9010	1	1	0	
L	H	Rmetric5b	B		(45.578)	Bunif	1	0	1	Bunif

Res	Net	Metric	Tukey Grouping		Mean	Test Set	Method B8020	B9010	Bunif	Min Mean
L	L	Dur	A		(12.196)	B8020	1	1	0	
L	L	Dur	A		(11.052)	B9010	1	1	0	
L	L	Dur	B		(22.628)	Bunif	0	0	1	Bunif
L	L	Metric1	A		(0.415)	B8020	1	1	0	
L	L	Metric1	A		(0.410)	B9010	1	1	0	
L	L	Metric1	B		(0.764)	Bunif	0	0	1	Bunif
L	L	Metric2	A		(0.549)	B8020	1	1	0	
L	L	Metric2	A		(0.441)	B9010	1	1	0	
L	L	Metric2	B		(1.057)	Bunif	0	0	1	Bunif
L	L	Metric3	B		(0.119)	B8020	1	0	0	
L	L	Metric3	A		(0.029)	B9010	0	1	0	
L	L	Metric3	C		(0.212)	Bunif	0	0	1	Bunif
L	L	Metric4	A		0.061	B8020	1	0	0	
L	L	Metric4	B		0.017	B9010	0	1	1	
L	L	Metric4	B		0.001	Bunif	0	1	1	Bunif
L	L	Metric5	B		(0.079)	B8020	1	0	0	B8020
L	L	Metric5	A		(0.029)	B9010	0	1	1	
L	L	Metric5	A		(0.031)	Bunif	0	1	1	
L	L	Metric6	B		(0.084)	B8020	1	0	0	B8020
L	L	Metric6	A		(0.000)	B9010	0	1	1	
L	L	Metric6	A		0.024	Bunif	0	1	1	
L	L	Metric7	B		(0.050)	B8020	1	0	0	
L	L	Metric7	A		(0.015)	B9010	0	1	0	
L	L	Metric7	C		(0.102)	Bunif	0	0	1	Bunif
L	L	Metric8	B		0.253	B8020	1	1	0	
L	L	Metric8	B		0.142	B9010	1	1	0	B9010
L	L	Metric8	A		0.406	Bunif	0	0	1	
L	L	RMetric1	B		(0.365)	B8020	1	0	0	B8020
L	L	RMetric1	A		0.003	B9010	0	1	1	
L	L	RMetric1	A		(0.074)	Bunif	0	1	1	
L	L	RMetric2	B		(1.268)	B8020	1	0	0	
L	L	RMetric2	A		0.029	B9010	0	1	0	
L	L	RMetric2	C		(1.410)	Bunif	0	0	1	Bunif
L	L	Rmetric3	B		(0.242)	B8020	1	0	0	
L	L	Rmetric3	A		0.356	B9010	0	1	0	
L	L	Rmetric3	C		(0.850)	Bunif	0	0	1	Bunif
L	L	Rmetric4a	B		1.086	B8020	1	0	0	
L	L	Rmetric4a	A		18.062	B9010	0	1	0	
L	L	Rmetric4a	C		(1.538)	Bunif	0	0	1	Bunif
L	L	Rmetric4b	B		2.230	B8020	1	0	0	
L	L	Rmetric4b	A		150.080	B9010	0	1	0	
L	L	Rmetric4b	C		(1.178)	Bunif	0	0	1	Bunif
L	L	Rmetric5a	B		(9.830)	B8020	1	0	0	
L	L	Rmetric5a	A		3.916	B9010	0	1	0	
L	L	Rmetric5a	C		(21.026)	Bunif	0	0	1	Bunif
L	L	Rmetric5b	B		(33.378)	B8020	1	0	0	
L	L	Rmetric5b	A		(17.208)	B9010	0	1	0	
L	L	Rmetric5b	C		(70.144)	Bunif	0	0	1	Bunif

APPENDIX L: INITIAL STUDY – RESCHEDULING

SAS Code to Implement Mid-Point Rescheduling During Schedule Repair

```
*****************************************************************************************************;
* Repairing a buffered schedule - with reoptimization                                               ;
* -- use the left and right shift code - but re-optimize with PROC CPM at some point;
* -- goal = improve overall project duration of the final MB;
* -- therefore, compare these project durations with the proj durations discovered with the other repaired MB;

* The first half of every schedule is already repaired ;
      * -- just use these and start with a re-opt at some point;
      * -- repair only the second half of the schedule ;
*****************************************************************************************************;

*****************************************************************************************************;
*problem set-up;
*****************************************************************************************************;
dm "log;clear;"; *clear the log;

*Select the buffer lable and formula for this run here;
%let B = B5;                                                    *50% buffer;

* Select the stochasticity level for this run here - here these are the tasks that DO occur;
%let stoch = "Low"; %let S = L;                          *Low;
/*%let stoch = "Low","High"; %let S = H;          *High;*/

* Select the timing setting this run here - here these are the stoch tasks that DO occur;
%let timing = "Late"; %let T = L;                                    *Late;
/*%let timing = "Early"; %let T = E;                                       *Early;*/

* Select the type of reoptimization trigger - UPDATE CODE LINE 161 to select appropriate method;
/*%let reopt = max;                                      *option#1: max project buffer;*/
%let reopt = eff;                                        *option#2: effective project buffer;
/*%let reopt = time;                              *option#3: reopt at time period = half way point;*/

%let path = C:\Sandra_laptop\IEMS\data\selim; *run for each prob type: pat, RCP files;
libname NW_soln "&path.\Non-optimal SAS Solutions";
/*libname NW "&path.\SAS Solutions";*/
```

```
%let outpath = C:\Sandra_laptop\IEMS\data\Selim\Repaired;
libname prob "&outpath.";
libname reopt "&outpath.\reopt";

*****************************************************************************************************;
*end problem set-up;
*****************************************************************************************************;

/*%macro merge_soln(NW);*/
dm "log;clear;"; *clear the log;

*****************************************************************************************************;
*initilize datasets;
*****************************************************************************************************;
*get number of successors;
      data work.succ;   set NW_soln.&NW._optimal_stats;     keep succ:;run;
      data work._null_;
          %let dsid=%sysfunc(open(work.succ));
          %let num_succ=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activites types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The max number of successors are: &num_succ.; *re-create this global macro var for use here (from Input
RCP.sas);

*get number of resource types;
      data work.R; set NW_soln.&NW._resources_avail;  keep R:;run; *changed source 17may;
      data work._null_;
          %let dsid=%sysfunc(open(work.R));
          %let num_R=%sysfunc(attrn(&dsid,nvar)); *num_act contains the number of activites types;
            %let rc=%sysfunc(close(&dsid));
      run;
      %put The number of resource types are: &num_R.; *re-create this global macro var for use here (from Input RCP.sas);

*get number of preds - from running _build pred data.sas_;
      data work._null_;
          %let dsid=%sysfunc(open(NW_Soln.&NW._preds)); *changed libname from NW 16May2008;
          %let num_vars=%sysfunc(attrn(&dsid,nvars)); *num_vars contains the number of vars in the data set pred;
            %let num_preds = %eval(%sysfunc(sum(&num_vars.,-3))/2);
            %let rc=%sysfunc(close(&dsid));
      run;
```

```
      %put &num_vars.;
      %put the highest number of predecessors for any activity is: &num_preds.;

*create a copy of the optimal data set into work ;
      data work.&NW.&S.&B._optimal_stats;
          set NW_soln.&NW.&S.&B._optimal_stats; *from running create and solve buffered schedules.sas;
            PDuration = Bduration;
                  *this is the _planning duration_ that will be a mix of actual (zero or full) for stoch tasks in the
past ;
                  *and buffered durations in the future;
            *identify stochastic tasks;
            format remove $20.;

            if stoch not in (&stoch.) then remove = "occur"; *set all non-stoch tasks to occur;

            if stoch in (&stoch.) and timing in (&timing.) then remove = "occur";

            if remove = '' then remove = "remove";

            keep activity_num succ1-succ&num_succ. duration Bduration Pduration R1 R2 s_start s_finish SN timing stoch
remove;
      run;

*create a copy of the pred data set into work ;
      data work.pred_data; *pred data from running _build pred data.sas_;
          set NW_soln.&NW.&S.&B._preds;
            Pduration = Bduration; *initalize; *****CHANGED TO Bdur******;
      run;

*****************************************************************************************************;
*end initilize datasets;
*****************************************************************************************************;

* re-optimizing point - Max Project buffer;
data work.&NW.&S.&B._optimal_stats;
    set work.&NW.&S.&B._optimal_stats; *from running create and solve buffered schedules.sas;
      if stoch in (&stoch.)then MaxPBuffer = Bduration; *this is the amount this activity's buffer contributed to the
total project buffer;
run;
proc summary data=work.&NW.&S.&B._optimal_stats;
      var MaxPBuffer;
```

```
      output out=work.sum sum=;
run;
data _null_;
      set work.sum;
      call symput("MaxPBuffer",MaxPBuffer/2); *get Max Buffer length and divide by 2;
run;
%put The max buffer is: &MaxPBuffer.;

* re-optimizing point - Effective Project buffer;
proc summary data=work.&NW.&S.&B._optimal_stats;
      var s_start;
      output out=work.Buff_TMax max=Buff_TMax; *get finish time of the 50% IB;
run;
data _null_;
      set work.Buff_TMax;
      call symput("Buff_TMax",Buff_TMax);
run;
%put The duration of the buffered schedule is: &Buff_TMax.;

proc summary data=NW_soln.&NW.&S.O_optimal_stats;
      var s_start;
      output out=work.Opt_TMax max=Opt_TMax;
run;
data _null_;
      set work.Opt_TMax;
      call symput("Opt_TMax",Opt_TMax); *get finish time of the optimistic IB - none stoch scheduled;
run;
%put The duration of the optimistic schedule is: &Opt_TMax.;

data _null_;
      call symput("EffectivePBuff",%eval(%eval(&Buff_TMax.)-%eval(&Opt_TMax.))/2); *substract the two durations and
divide by 2;
run;
%put The effective project buffer is: &EffectivePBuff.;

data work.eventuated;
      set prob.&NW.&S.&B._&T.;
      if stoch in (&stoch.) and remove = "occur" then buff_use = Pduration;
run;
proc sort data=work.eventuated; by s_start; run;
```

```
*****************************************************************************************************;
*Start options;
*****************************************************************************************************;
/*OPTION #1:  Max Project Buffer*/
data work.eventuated_cum;
      set work.eventuated;
      retain buff_use_cum 0;
      if buff_use ne . then buff_use_cum = buff_use_cum + buff_use;
      if buff_use_cum <= &MaxPBuffer. then t_past = s_start;
run;
proc summary data=work.eventuated_cum;
      var t_past;
      output out=work.t_past max = t_past; *latest point in time where activities have started before the proj buffer was
used up;
run;
data _null_;
      set work.t_past;
      call symput("t_past",t_past);
      call symput("t_past_plus_1",t_past+1);
run;
/*END OPTION #1:  Max Project Buffer*/

/*OPTION #2:  Effective Project Buffer*/
data work.eventuated_cum;
      set work.eventuated;
      retain buff_use_cum 0;
      if buff_use ne . then buff_use_cum = buff_use_cum + buff_use;
      if buff_use_cum <= &EffectivePBuff. then t_past = s_start;
run;
proc summary data=work.eventuated_cum;
      var t_past;
      output out=work.t_past max = t_past; *latest point in time where activities have started before the proj buffer was
used up;
run;
data _null_;
      set work.t_past;
      call symput("t_past",t_past);
      call symput("t_past_plus_1",t_past+1);
run;
/*END OPTION #2:  Effective Project Buffer*/
```

```
/*OPTION #3: Half-Time*/
data _null_;
      set work.t_past;
      call symput("t_past",%eval(&Buff_TMax./2));
      call symput("t_past_plus_1",%eval(&Buff_TMax./2)+1);
run;
/*END OPTION #3:  Half-Time*/

%put The system time to reschedule is: &t_past.;
%put The system time plus one is: &t_past_plus_1.;

data work.tasks_to_reoptimize;
      set prob.&NW.&S.&B._&T.; *start with left-right shifted repaired schedule;
      if s_start > &t_past. then do; *this is the future;
            Pduration = Bduration ; *set Pdur back to Bdur since we don't know if this one will occur or not;
            Pfinish = .; *we want to ask SAS to find us a new finish time for these;
            Pstart = .;
      end;
      if s_start <= &t_past. then do; *this is the past;
            Pfinish = s_finish; *we want to tell SAS these ones are already an actual start time in the past;
            Pstart = s_start;
      end;
run;
*****************************************************************************************************;
* Reoptimize;
*****************************************************************************************************;
proc cpm data=work.tasks_to_reoptimize
out=work.reoptimize
resourceout = work.&NW.&S.&B._rout_check
ressched = work.&NW.&S.&B._ressched_check
resin = NW_Soln.&NW._resources_avail
;
activity activity_num;
duration Pduration;
successor succ1-succ&num_succ.;
resource R1-R&num_R. /  period=date obstype=obstype;* SCHEDRULE = ACTPRTY ACTIVITYPRTY=ACTIVITYPRTY;
actual / A_start = Pstart NOAUTOUPDT timenow = &t_past_plus_1.; *set the actual end time of the tasks in the past - ask
SAS to figure the future ones;
run;    *time now is one time unit past the ones that have already started;
            * NOAUTOUPDT makes it so SAS does not automatically change the start times based on pred relationships;
Code continues at this point with the remainder of schedule eventuation and right-left-shifting repair...
```

Reschedule Times Analysis

Each cell represents the average of 20 networks with the described parameters and assigned eventuation. Resource parameters appear to have an effect on when the re-optimization occurs.

Reopt time divided by MB duration for 20 NW		Early Occurrence		Late Occurrence	
		Network Parameters		Network Parameters	
	Method	**H**	**L**	**H**	**L**
Average Reopt%	Max	28.14%	19.84%	57.86%	46.29%
	Effective	12.27%	13.88%	44.49%	41.25%
	Time	46.35%	47.95%	47.79%	46.63%
Max Reopt%	Max	43.08%	60.38%	78.95%	75.51%
	Effective	36.89%	60.38%	67.52%	75.51%
	Time	56.32%	55.00%	54.74%	53.95%
Min Reopt%	Max	0.00%	0.00%	21.05%	25.00%
	Effective	0.00%	0.00%	21.05%	16.67%
	Time	36.54%	34.38%	40.38%	37.14%

Reopt time divided by MB duration for 20 NW		Early Occurrence		Late Occurrence	
		Stochasticity Level		Stochasticity Level	
	Method	**H**	**L**	**H**	**L**
Average Reopt%	Max	23.51%	24.47%	47.82%	56.33%
	Effective	11.32%	14.83%	36.85%	48.89%
	Time	46.83%	47.47%	46.44%	47.98%
Max Reopt%	Max	43.08%	60.38%	67.02%	78.95%
	Effective	32.00%	60.38%	57.89%	75.51%
	Time	56.32%	51.55%	54.74%	53.13%
Min Reopt%	Max	0.00%	0.00%	25.00%	21.05%
	Effective	0.00%	0.00%	16.67%	21.05%
	Time	34.38%	40.79%	37.14%	37.14%

Reopt time divided by MB duration for 20 NW		Early Occurrence		Late Occurrence	
		Resource Parameters		Resource Parameters	
	Method	**H**	**L**	**H**	**L**
Average Reopt%	Max	32.13%	15.85%	58.90%	45.25%
	Effective	26.15%	0.00%	56.99%	28.75%
	Time	50.04%	44.26%	49.93%	44.50%
Max Reopt%	Max	60.38%	43.08%	75.51%	78.95%
	Effective	60.38%	0.00%	75.51%	48.44%
	Time	56.32%	54.17%	54.74%	50.94%
Min Reopt%	Max	17.20%	0.00%	38.52%	21.05%
	Effective	8.55%	0.00%	38.52%	16.67%
	Time	45.61%	34.38%	45.05%	37.14%

Comparisons of Metric Values With and Without Rescheduling

The following tables contain one cell for each schedule that was repaired with or without one of the rescheduling methods. "None" refers to the right/left-shift repair without any rescheduling, while "Max", "Efftive", and "Time" all refer to rescheduling at the point that is half of the "max" project buffer, "effective" project buffer, or duration of the initial baseline (IB) schedule. All initial baseline schedules were the 50% buffering method. The value in "none" is highlighted if none of the rescheduling techniques have demonstrated improvement on the metric. Otherwise, the rescheduling method that has the best value is highlighted.

Project Duration

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	30.00	30.00	30.00	30.00	78.00	80.00	80.00	80.00	65.00	65.00	65.00	65.00	93.00	93.00	93.00	93.00
		2	32.00	32.00	32.00	32.00	82.00	80.00	80.00	80.00	47.00	47.00	47.00	47.00	95.00	95.00	95.00	95.00
		3	28.00	28.00	28.00	28.00	86.00	86.00	86.00	86.00	62.00	62.00	62.00	62.00	115.00	114.00	114.00	114.00
		4	27.00	27.00	27.00	27.00	76.00	75.00	75.00	75.00	50.00	50.00	50.00	50.00	80.00	80.00	80.00	80.00
		5	24.00	24.00	24.00	24.00	97.00	97.00	97.00	97.00	52.00	52.00	52.00	52.00	87.00	87.00	87.00	87.00
	Late	1	30.00	30.00	30.00	30.00	74.00	74.00	74.00	74.00	53.00	53.00	53.00	53.00	89.00	89.00	89.00	89.00
		2	23.00	24.00	23.00	23.00	96.00	96.00	96.00	96.00	51.00	51.00	51.00	51.00	94.00	94.00	94.00	94.00
		3	29.00	29.00	27.00	29.00	76.00	76.00	76.00	76.00	57.00	57.00	57.00	57.00	95.00	95.00	95.00	95.00
		4	30.00	30.00	30.00	30.00	91.00	91.00	91.00	91.00	52.00	52.00	52.00	52.00	83.00	83.00	83.00	83.00
		5	35.00	35.00	35.00	35.00	100.00	100.00	100.00	100.00	46.00	46.00	46.00	46.00	106.00	106.00	106.00	106.00
Low	Early	1	39.00	39.00	39.00	39.00	106.00	106.00	106.00	106.00	75.00	75.00	75.00	75.00	103.00	103.00	103.00	103.00
		2	41.00	41.00	41.00	41.00	108.00	108.00	108.00	108.00	58.00	58.00	58.00	58.00	114.00	114.00	114.00	114.00
		3	30.00	30.00	30.00	30.00	99.00	99.00	99.00	99.00	76.00	76.00	76.00	76.00	125.00	125.00	125.00	125.00
		4	34.00	34.00	34.00	34.00	97.00	97.00	97.00	97.00	63.00	63.00	63.00	63.00	99.00	99.00	99.00	99.00
		5	35.00	35.00	35.00	35.00	117.00	117.00	117.00	117.00	64.00	64.00	64.00	64.00	114.00	114.00	114.00	114.00
	Late	1	36.00	36.00	36.00	36.00	98.00	98.00	98.00	96.00	76.00	76.00	76.00	76.00	100.00	100.00	100.00	100.00
		2	41.00	41.00	41.00	41.00	110.00	110.00	110.00	110.00	57.00	57.00	57.00	57.00	109.00	109.00	109.00	109.00
		3	35.00	35.00	35.00	35.00	95.00	95.00	95.00	95.00	66.00	66.00	66.00	66.00	120.00	120.00	120.00	120.00
		4	36.00	36.00	36.00	36.00	101.00	101.00	101.00	101.00	64.00	64.00	64.00	64.00	96.00	96.00	96.00	96.00
		5	38.00	38.00	38.00	38.00	122.00	122.00	122.00	122.00	57.00	57.00	57.00	57.00	117.00	117.00	117.00	117.00

Robustness Metric 1

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.034	0.034	0.034	0.034	0.124	0.101	0.101	0.101	0.016	0.016	0.016	0.016	-	-	-	-
		2	-	-	-	-	0.065	0.039	0.039	0.039	-	-	-	-	0.031	0.031	0.031	0.031
		3	-	-	-	-	0.036	0.036	0.036	0.036	-	-	-	-	0.009	-	-	-
		4	-	-	-	-	0.070	0.056	0.056	0.056	0.042	0.042	0.042	0.042	-	-	-	-
		5	-	-	-	-	-	-	-	-	0.020	0.020	0.020	0.020	-	-	-	-
	Late	1	-	-	-	-	0.042	0.042	0.042	0.042	-	-	-	-	-	-	-	-
		2	0.150	0.200	0.150	0.150	0.043	0.043	0.043	0.043	-	-	-	-	-	-	-	-
		3	0.160	0.160	0.080	0.160	-	-	-	-	0.018	0.018	0.018	0.018	0.080	0.080	0.080	0.080
		4	0.034	0.034	0.034	0.034	0.011	0.011	0.011	0.011	-	-	-	-	-	-	-	-
		5	-	-	-	-	0.064	0.064	0.064	0.064	-	-	-	-	0.039	0.039	0.039	0.039
Low	Early	1	-	-	-	-	0.009	0.009	0.009	0.009	-	-	-	-	-	-	-	-
		2	-	-	-	-	0.009	0.009	0.009	0.009	0.018	0.018	0.018	0.018	-	-	-	-
		3	-	-	-	-	-	-	-	-	-	-	-	-	0.053	0.053	0.053	0.053
		4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5	-	-	-	-	-	-	-	-	0.085	0.085	0.085	0.085	-	-	-	-
	Late	1	-	-	-	-	0.089	0.089	0.089	0.067	0.013	0.013	0.013	0.013	-	-	-	-
		2	-	-	-	-	0.028	0.028	0.028	0.028	-	-	-	-	0.052	0.052	0.052	0.052
		3	-	-	-	-	-	-	-	-	0.031	0.031	0.031	0.031	0.081	0.081	0.081	0.081
		4	-	-	-	-	0.019	0.019	0.019	0.019	-	-	-	-	-	-	-	-
		5	0.086	0.086	0.086	0.086	0.034	0.034	0.034	0.034	-	-	-	-	-	-	-	-

Robustness Metric 2

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.111	0.111	0.111	0.111	-	0.026	0.026	0.026	0.204	0.204	0.204	0.204	0.045	0.045	0.045	0.045
		2	0.391	0.391	0.391	0.391	0.068	0.091	0.091	0.091	-	-	-	-	0.044	0.044	0.044	0.044
		3	0.167	0.167	0.167	0.167	0.049	0.049	0.049	0.049	0.240	0.240	0.240	0.240	0.106	0.096	0.096	0.096
		4	0.038	0.038	0.038	0.038	0.084	0.096	0.096	0.096	0.163	0.163	0.163	0.163	0.024	0.024	0.024	0.024
		5	0.111	0.111	0.111	0.111	0.010	0.010	0.010	0.010	0.333	0.333	0.333	0.333	0.112	0.112	0.112	0.112
	Late	1	0.111	0.111	0.111	0.111	0.051	0.051	0.051	0.051	0.019	0.019	0.019	0.019	-	-	-	-
		2	-	0.043	-	-	0.091	0.091	0.091	0.091	0.085	0.085	0.085	0.085	0.033	0.033	0.033	0.033
		3	0.208	0.208	0.125	0.208	0.073	0.073	0.073	0.073	0.140	0.140	0.140	0.140	0.087	0.087	0.087	0.087
		4	0.154	0.154	0.154	0.154	0.096	0.096	0.096	0.096	0.209	0.209	0.209	0.209	0.012	0.012	0.012	0.012
		5	0.296	0.296	0.296	0.296	0.020	0.020	0.020	0.020	0.179	0.179	0.179	0.179	0.082	0.082	0.082	0.082
Low	Early	1	0.083	0.083	0.083	0.083	0.039	0.039	0.039	0.039	0.042	0.042	0.042	0.042	-	-	-	-
		2	-	-	-	-	0.009	0.009	0.009	0.009	0.055	0.055	0.055	0.055	0.036	0.036	0.036	0.036
		3	0.111	0.111	0.111	0.111	0.021	0.021	0.021	0.021	0.226	0.226	0.226	0.226	0.008	0.008	0.008	0.008
		4	0.063	0.063	0.063	0.063	0.040	0.040	0.040	0.040	0.125	0.125	0.125	0.125	-	-	-	-
		5	0.061	0.061	0.061	0.061	0.008	0.008	0.008	0.008	0.164	0.164	0.164	0.164	0.026	0.026	0.026	0.026
	Late	1	-	-	-	-	0.039	0.039	0.039	0.059	0.056	0.056	0.056	0.056	0.029	0.029	0.029	0.029
		2	-	-	-	-	0.009	0.009	0.009	0.009	0.036	0.036	0.036	0.036	0.009	0.009	0.009	0.009
		3	0.296	0.296	0.296	0.296	0.021	0.021	0.021	0.021	0.065	0.065	0.065	0.065	0.032	0.032	0.032	0.032
		4	0.125	0.125	0.125	0.125	-	-	-	-	0.143	0.143	0.143	0.143	0.030	0.030	0.030	0.030
		5	0.152	0.152	0.152	0.152	0.034	0.034	0.034	0.034	0.036	0.036	0.036	0.036	-	-	-	-

Robustness Metric 3

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.094	0.094	0.094	0.094	0.750	0.719	0.719	0.750	0.344	0.344	0.344	0.344	0.250	0.156	0.156	0.156
		2	0.125	-	-	-	0.875	0.875	0.875	0.875	0.156	0.156	0.156	0.156	0.750	0.750	0.750	0.750
		3	0.063	0.031	0.031	0.031	0.688	0.656	0.656	0.656	0.031	0.031	0.031	0.031	0.344	0.219	0.219	0.219
		4	0.156	0.125	0.125	0.125	0.906	0.906	0.906	0.906	0.250	0.250	0.250	0.250	0.406	0.344	0.344	0.344
		5	0.156	-	-	-	0.625	0.656	0.656	0.688	0.125	0.125	0.125	0.125	0.250	0.219	0.219	0.219
	Late	1	-	-	-	-	0.844	0.844	0.844	0.844	0.063	0.063	0.063	0.063	0.250	0.250	0.250	0.250
		2	0.281	0.250	0.250	0.281	0.844	0.844	0.844	0.844	-	-	-	-	0.375	0.375	0.344	0.375
		3	0.594	0.594	0.594	0.594	0.531	0.594	0.594	0.531	0.531	0.531	0.531	0.531	0.406	0.406	0.406	0.406
		4	0.563	0.563	0.563	0.563	0.906	0.906	0.906	0.906	0.250	0.250	0.250	0.250	0.438	0.438	0.438	0.438
		5	0.125	0.125	0.125	0.125	0.844	0.813	0.813	0.813	0.063	0.063	0.063	0.063	0.563	0.563	0.563	0.563
Low	Early	1	-	-	-	-	0.875	0.875	0.875	0.875	0.063	0.063	0.063	0.063	0.313	0.156	0.156	0.156
		2	0.063	-	-	0.031	0.750	0.750	0.750	0.750	0.313	0.313	0.313	0.313	0.500	0.500	0.500	0.500
		3	0.063	-	-	-	0.531	0.531	0.531	0.531	0.031	0.031	0.031	0.031	0.375	0.500	0.500	0.500
		4	0.063	-	-	0.031	0.469	0.531	0.531	0.531	-	-	-	-	0.313	0.281	0.281	0.281
		5	0.188	-	-	-	0.344	0.281	0.188	0.281	0.125	0.125	0.125	0.125	0.406	0.438	0.438	0.438
	Late	1	-	-	-	-	0.781	0.781	0.781	0.781	0.563	0.563	0.563	0.563	0.344	0.344	0.344	0.344
		2	0.156	0.156	0.156	0.125	0.781	0.781	0.781	0.781	-	-	-	-	0.875	0.875	0.875	0.875
		3	0.375	0.375	0.375	0.375	0.563	0.625	0.625	0.563	0.625	0.625	0.625	0.625	0.594	0.594	0.594	0.594
		4	-	-	-	-	0.688	0.688	0.688	0.688	0.031	0.031	0.031	0.031	0.250	0.250	0.250	0.250
		5	0.750	0.750	0.750	0.750	0.719	0.719	0.719	0.719	-	-	-	-	0.375	0.375	0.375	0.375

Robustness Metric 4

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.188	0.188	0.188	0.188	0.313	0.281	0.281	0.281	-	-	-	-	0.344	0.094	0.094	0.094
		2	0.313	-	-	-	0.469	0.625	0.625	0.625	0.063	0.063	0.063	0.063	0.156	0.188	0.188	0.188
		3	0.156	0.188	0.188	0.188	0.313	0.375	0.375	0.375	0.094	0.094	0.094	0.094	0.156	0.125	0.125	0.125
		4	0.281	0.125	0.125	0.125	0.563	0.469	0.469	0.500	0.094	0.094	0.094	0.094	0.313	0.313	0.313	0.313
		5	0.313	-	-	-	0.344	0.250	0.250	0.250	0.031	0.031	0.031	0.031	0.188	0.094	0.094	0.094
	Late	1	-	-	-	-	0.406	0.375	0.375	0.375	0.156	0.156	0.156	0.156	0.313	0.313	0.313	0.313
		2	0.188	0.219	0.188	0.188	0.406	0.438	0.438	0.438	-	-	-	-	0.281	0.281	0.250	0.281
		3	0.125	0.125	0.125	0.125	0.250	0.250	0.250	0.250	0.094	0.094	0.094	0.094	0.281	0.281	0.281	0.281
		4	0.125	0.125	0.125	0.125	0.375	0.406	0.406	0.406	0.250	0.250	0.250	0.250	0.438	0.438	0.438	0.438
		5	0.344	0.344	0.344	0.344	0.438	0.406	0.406	0.406	0.156	0.156	0.156	0.156	0.125	0.156	0.125	0.125
Low	Early	1	-	-	-	-	0.344	0.250	0.250	0.250	-	-	-	-	0.250	0.094	0.094	0.094
		2	0.250	-	-	0.094	0.469	0.438	0.438	0.438	0.031	0.031	0.031	0.031	0.344	0.344	0.344	0.344
		3	0.281	-	-	-	0.281	0.281	0.281	0.281	-	-	-	-	0.156	0.313	0.313	0.313
		4	0.188	-	-	0.031	0.500	0.469	0.438	0.563	-	-	-	-	0.313	0.250	0.250	0.250
		5	0.250	-	-	-	0.375	0.063	0.063	0.094	0.094	0.094	0.094	0.094	0.156	0.250	0.250	0.250
	Late	1	-	-	-	-	0.250	0.250	0.250	0.375	0.063	0.063	0.063	0.063	0.219	0.219	0.219	0.219
		2	0.094	0.094	0.094	0.063	0.500	0.500	0.500	0.500	-	-	-	-	0.313	0.313	0.313	0.313
		3	0.188	0.188	0.188	0.188	0.313	0.344	0.344	0.313	0.063	0.063	0.063	0.063	0.156	0.156	0.156	0.156
		4	-	-	-	-	0.563	0.563	0.563	0.563	0.063	0.063	0.063	0.063	0.156	0.156	0.156	0.156
		5	0.344	0.344	0.344	0.344	0.688	0.625	0.625	0.625	-	-	-	-	0.219	0.219	0.219	0.219

Robustness Metric 5

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.063	0.063	0.063	0.063	0.031	0.250	0.250	0.250	0.031	0.031	0.031	0.031	0.156	0.063	0.063	0.063
		2	0.094	-	-	-	0.125	0.156	0.156	0.125	0.156	0.156	0.156	0.156	0.313	0.188	0.188	0.188
		3	0.063	0.031	0.031	0.031	0.219	0.156	0.156	0.156	0.031	0.031	0.031	0.031	0.125	0.094	0.094	0.094
		4	0.125	0.094	0.094	0.094	0.156	0.219	0.219	0.188	0.063	0.063	0.063	0.063	0.188	0.125	0.125	0.125
		5	0.125	-	-	-	0.094	0.281	0.281	0.250	0.063	0.063	0.063	0.063	0.156	0.125	0.125	0.125
	Late	1	-	-	-	-	0.250	0.219	0.281	0.281	0.063	0.063	0.063	0.063	0.250	0.250	0.250	0.250
		2	0.188	0.156	0.188	0.188	0.313	0.344	0.344	0.344	-	-	-	-	0.219	0.219	0.219	0.219
		3	0.156	0.156	0.063	0.156	0.313	0.344	0.344	0.313	0.094	0.094	0.094	0.094	0.281	0.281	0.281	0.281
		4	0.063	0.063	0.063	0.063	0.219	0.281	0.281	0.281	0.125	0.125	0.125	0.125	0.344	0.344	0.344	0.344
		5	0.125	0.125	0.125	0.125	0.250	0.250	0.250	0.250	0.063	0.063	0.063	0.063	0.094	0.125	0.094	0.094
Low	Early	1	-	-	-	-	0.281	0.313	0.313	0.313	0.063	0.063	0.063	0.063	0.188	0.063	0.063	0.063
		2	0.063	-	-	-	0.188	0.250	0.250	0.188	0.094	0.094	0.094	0.094	0.250	0.156	0.156	0.156
		3	0.063	-	-	-	0.125	0.219	0.219	0.250	0.031	0.031	0.031	0.031	0.156	0.188	0.188	0.188
		4	0.063	-	-	0.031	0.219	0.313	0.313	0.250	-	-	-	-	0.188	0.125	0.125	0.125
		5	0.125	-	-	-	0.125	0.094	0.125	0.063	0.063	0.063	0.063	0.063	0.219	0.188	0.188	0.188
	Late	1	-	-	-	-	0.250	0.250	0.250	0.250	0.063	0.063	0.063	0.063	0.250	0.250	0.250	0.250
		2	0.094	0.094	0.094	0.094	0.125	0.125	0.125	0.125	-	-	-	-	0.219	0.219	0.219	0.219
		3	0.156	0.156	0.156	0.156	0.250	0.281	0.281	0.250	0.125	0.125	0.125	0.125	0.250	0.250	0.250	0.250
		4	-	-	-	-	0.156	0.156	0.156	0.188	0.031	0.031	0.031	0.031	0.156	0.156	0.156	0.156
		5	0.219	0.219	0.219	0.219	0.219	0.188	0.188	0.188	-	-	-	-	0.250	0.250	0.250	0.250

Robustness Metric 6

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	-	-	-	-	0.375	0.156	0.156	0.156	-	-	-	-	-	-	-	-
		2	0.031	-	-	-	0.313	0.063	0.063	0.094	-	-	-	-	-	-	-	-
		3	-	-	-	-	0.188	0.094	0.094	0.094	-	-	-	-	0.094	-	-	-
		4	-	-	-	-	0.250	0.125	0.125	0.125	-	-	-	-	-	-	-	-
		5	0.031	-	-	-	0.375	0.125	0.125	0.188	-	-	-	-	-	-	-	-
	Late	1	-	-	-	-	0.219	0.219	0.156	0.156	-	-	-	-	-	-	-	-
		2	0.031	0.031	-	0.031	0.188	0.156	0.156	0.156	-	-	-	-	0.063	0.063	0.063	0.063
		3	-	-	-	-	0.063	0.094	0.094	0.063	-	-	-	-	0.031	0.031	0.031	0.031
		4	-	-	-	-	0.188	0.156	0.156	0.156	-	-	-	-	-	-	-	-
		5	-	-	-	-	0.156	0.094	0.094	0.094	-	-	-	-	-	-	-	-
Low	Early	1	-	-	-	-	0.156	0.094	0.094	0.094	-	-	-	-	-	-	-	-
		2	-	-	-	-	0.250	0.125	0.125	0.188	-	-	-	-	0.031	0.063	0.063	0.063
		3	-	-	-	-	0.125	0.031	0.031	-	-	-	-	-	0.063	0.063	0.063	0.063
		4	-	-	-	-	0.094	0.031	0.031	0.031	-	-	-	-	-	-	-	-
		5	0.031	-	-	-	0.156	0.125	-	0.156	-	-	-	-	0.031	-	-	-
	Late	1	-	-	-	-	0.219	0.219	0.219	0.094	-	-	-	-	-	-	-	-
		2	-	-	-	-	0.281	0.281	0.281	0.281	-	-	-	-	0.031	0.031	0.031	0.031
		3	0.219	0.219	0.219	0.219	0.094	0.094	0.094	0.094	-	-	-	-	0.031	0.031	0.031	0.031
		4	-	-	-	-	0.250	0.250	0.250	0.219	-	-	-	-	-	-	-	-
		5	-	-	-	-	0.031	0.031	0.031	0.031	-	-	-	-	-	-	-	-

Robustness Metric 7

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	0.074	0.074	0.074	0.074	0.141	0.141	0.141	0.141	0.185	0.185	0.185	0.185	0.045	0.045	0.045	0.045
		2	0.391	0.391	0.391	0.391	0.125	0.125	0.125	0.125	-	-	-	-	0.077	0.077	0.077	0.077
		3	0.167	0.167	0.167	0.167	0.012	0.012	0.012	0.012	0.240	0.240	0.240	0.240	0.096	0.096	0.096	0.096
		4	0.038	0.038	0.038	0.038	0.145	0.145	0.145	0.145	0.116	0.116	0.116	0.116	0.024	0.024	0.024	0.024
		5	0.111	0.111	0.111	0.111	0.010	0.010	0.010	0.010	0.308	0.308	0.308	0.308	0.112	0.112	0.112	0.112
	Late	1	0.111	0.111	0.111	0.111	0.090	0.090	0.090	0.090	0.019	0.019	0.019	0.019	-	-	-	-
		2	0.130	0.130	0.130	0.130	0.045	0.045	0.045	0.045	0.085	0.085	0.085	0.085	0.033	0.033	0.033	0.033
		3	0.042	0.042	0.042	0.042	0.073	0.073	0.073	0.073	0.120	0.120	0.120	0.120	0.154	0.154	0.154	0.154
		4	0.115	0.115	0.115	0.115	0.084	0.084	0.084	0.084	0.209	0.209	0.209	0.209	0.012	0.012	0.012	0.012
		5	0.296	0.296	0.296	0.296	0.041	0.041	0.041	0.041	0.179	0.179	0.179	0.179	0.041	0.041	0.041	0.041
Low	Early	1	0.083	0.083	0.083	0.083	0.049	0.049	0.049	0.049	0.042	0.042	0.042	0.042	-	-	-	-
		2	-	-	-	-	-	-	-	-	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
		3	0.111	0.111	0.111	0.111	0.021	0.021	0.021	0.021	0.226	0.226	0.226	0.226	0.065	0.065	0.065	0.065
		4	0.063	0.063	0.063	0.063	0.040	0.040	0.040	0.040	0.125	0.125	0.125	0.125	-	-	-	-
		5	0.061	0.061	0.061	0.061	0.008	0.008	0.008	0.008	0.073	0.073	0.073	0.073	0.026	0.026	0.026	0.026
	Late	1	-	-	-	-	0.118	0.118	0.118	0.118	0.042	0.042	0.042	0.042	0.029	0.029	0.029	0.029
		2	-	-	-	-	0.018	0.018	0.018	0.018	0.036	0.036	0.036	0.036	0.045	0.045	0.045	0.045
		3	0.296	0.296	0.296	0.296	0.021	0.021	0.021	0.021	0.032	0.032	0.032	0.032	0.105	0.105	0.105	0.105
		4	0.125	0.125	0.125	0.125	0.020	0.020	0.020	0.020	0.143	0.143	0.143	0.143	0.030	0.030	0.030	0.030
		5	0.061	0.061	0.061	0.061	-	-	-	-	0.036	0.036	0.036	0.036	-	-	-	-

Robustness Metric 8

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	4.690	4.690	4.690	4.690	0.909	0.928	0.928	0.928	1.887	1.887	1.887	1.887	1.923	1.923	1.923	1.923
		2	4.690	-	-	-	1.206	1.347	1.347	1.347	3.429	3.429	3.429	3.429	1.244	1.244	1.244	1.244
		3	4.690	4.690	4.690	4.690	1.114	1.072	1.019	1.072	-	-	-	-	2.220	2.278	2.278	2.278
		4	2.888	2.888	2.888	2.888	0.723	0.584	0.584	0.599	3.307	3.307	3.307	3.307	1.598	1.598	1.598	1.598
		5	3.237	-	-	-	1.160	1.152	1.152	1.090	4.690	4.690	4.690	4.690	2.724	2.724	2.724	2.724
	Late	1	-	-	-	-	0.844	0.829	0.878	0.878	-	-	-	-	2.082	2.082	2.082	2.082
		2	1.924	2.547	1.999	1.924	0.748	0.803	0.803	0.803	-	-	-	-	2.017	2.017	2.235	2.017
		3	0.678	0.678	0.668	0.678	1.426	1.157	1.157	1.426	0.895	0.895	0.895	0.895	1.524	1.524	1.524	1.524
		4	0.823	0.823	0.823	0.823	1.366	1.077	1.077	1.077	1.785	1.785	1.785	1.785	1.382	1.382	1.382	1.382
		5	2.605	2.605	2.605	2.605	0.748	0.729	0.729	0.729	-	-	-	-	0.835	0.860	0.835	0.835
Low	Early	1	-	-	-	-	0.966	0.861	0.861	0.861	5.099	5.099	5.099	5.099	1.791	2.128	2.128	2.128
		2	-	-	-	-	1.371	1.371	1.371	1.371	1.622	1.622	1.622	1.622	1.511	1.511	1.511	1.511
		3	-	-	-	-	1.163	1.300	1.300	1.300	5.099	5.099	5.099	5.099	1.544	1.390	1.390	1.390
		4	-	-	-	-	1.480	1.326	1.326	1.409	-	-	-	-	2.054	1.775	1.775	1.775
		5	2.855	-	-	-	2.091	2.091	2.503	2.091	2.824	2.824	2.824	2.824	1.610	1.610	1.610	1.610
	Late	1	-	-	-	-	0.907	0.907	0.907	0.796	0.806	0.806	0.806	0.806	1.581	1.581	1.581	1.581
		2	2.243	2.243	2.243	2.556	1.192	1.166	1.166	1.192	-	-	-	-	0.705	0.705	0.705	0.705
		3	1.485	1.485	1.485	1.485	1.025	0.947	0.947	1.025	0.798	0.798	0.798	0.798	1.039	1.039	1.039	1.039
		4	-	-	-	-	1.430	1.430	1.430	1.416	5.099	5.099	5.099	5.099	2.255	2.255	2.255	2.255
		5	0.641	0.641	0.641	0.641	1.370	1.342	1.342	1.342	-	-	-	-	1.760	1.760	1.760	1.760

Resource Metric 1

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	3.47	3.47	3.47	3.47	2.24	2.19	2.19	2.19	1.72	1.72	1.72	1.72	3.01	3.01	3.01	3.01
		2	2.50	2.50	2.50	2.50	2.77	2.87	2.87	2.87	2.14	2.14	2.14	2.14	3.42	3.42	3.42	3.42
		3	3.14	3.14	3.14	3.14	2.82	2.76	2.58	2.76	1.65	1.65	1.65	1.65	2.65	2.67	2.67	2.67
		4	2.70	2.70	2.70	2.70	3.60	3.62	3.62	3.61	1.91	1.91	1.91	1.91	3.13	3.13	3.13	3.13
		5	2.84	2.84	2.84	2.84	2.37	2.33	2.33	2.33	2.54	2.54	2.54	2.54	3.40	3.40	3.40	3.40
	Late	1	3.57	3.57	3.57	3.57	3.33	3.30	3.25	3.25	1.70	1.70	1.70	1.70	3.32	3.32	3.32	3.32
		2	2.08	2.16	2.29	2.08	3.13	3.05	3.05	3.05	1.72	1.72	1.72	1.72	3.54	3.54	3.41	3.54
		3	2.55	2.55	2.45	2.55	3.55	3.60	3.60	3.55	2.11	2.11	2.11	2.11	3.43	3.43	3.43	3.43
		4	2.50	2.50	2.50	2.50	3.23	3.50	3.50	3.50	2.11	2.11	2.11	2.11	4.04	4.04	4.04	4.04
		5	2.10	2.10	2.10	2.10	2.26	2.22	2.22	2.22	2.85	2.85	2.85	2.85	3.01	3.19	3.01	3.01
Low	Early	1	2.03	2.03	2.03	2.03	2.66	2.52	2.52	2.52	1.21	1.21	1.21	1.21	2.05	2.21	2.21	2.21
		2	1.18	1.18	1.18	1.18	2.47	2.47	2.47	2.47	2.06	2.06	2.06	2.06	3.27	3.27	3.27	3.27
		3	2.15	2.15	2.15	2.15	2.05	2.13	2.13	2.13	2.24	2.24	2.24	2.24	2.76	2.44	2.44	2.44
		4	1.63	1.63	1.63	1.63	2.65	2.64	2.64	3.14	1.81	1.81	1.81	1.81	2.92	2.92	2.92	2.92
		5	2.42	2.22	2.22	2.22	2.42	2.42	1.11	2.42	1.43	1.43	1.43	1.43	2.33	2.33	2.33	2.33
	Late	1	2.42	2.42	2.42	2.42	2.67	2.67	2.67	2.60	1.04	1.04	1.04	1.04	2.61	2.61	2.61	2.61
		2	1.54	1.54	1.54	1.54	2.24	2.27	2.27	2.24	1.27	1.27	1.27	1.27	3.11	3.11	3.11	3.11
		3	1.68	1.68	1.68	1.68	2.61	2.66	2.66	2.61	1.20	1.20	1.20	1.20	3.09	3.09	3.09	3.09
		4	1.82	1.82	1.82	1.82	2.24	2.24	2.24	2.47	1.35	1.35	1.35	1.35	3.26	3.26	3.26	3.26
		5	1.74	1.74	1.74	1.74	2.11	2.11	2.11	2.11	1.83	1.83	1.83	1.83	2.60	2.60	2.60	2.60

Resource Metric 2

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	1.01	1.01	1.01	1.01	0.37	0.54	0.54	0.54	0.96	0.96	0.96	0.96	0.27	0.27	0.27	0.27
		2	1.31	1.31	1.31	1.31	0.24	0.21	0.21	0.21	0.74	0.74	0.74	0.74	0.44	0.44	0.44	0.44
		3	2.27	2.27	2.27	2.27	0.47	0.47	0.47	0.47	0.96	0.96	0.96	0.96	0.39	0.34	0.34	0.34
		4	1.75	1.75	1.75	1.75	0.21	0.26	0.26	0.26	0.94	0.94	0.94	0.94	0.50	0.50	0.50	0.50
		5	1.14	1.14	1.14	1.14	0.64	0.64	0.64	0.64	0.78	0.78	0.78	0.78	0.43	0.43	0.43	0.43
	Late	1	0.67	0.67	0.67	0.67	0.12	0.12	0.12	0.12	0.60	0.60	0.60	0.60	1.11	1.11	1.11	1.11
		2	0.17	0.23	0.17	0.17	0.33	0.33	0.33	0.33	0.51	0.51	0.51	0.51	0.62	0.62	0.62	0.62
		3	0.44	0.44	0.70	0.44	0.60	0.60	0.60	0.60	0.14	0.14	0.14	0.14	0.28	0.28	0.28	0.28
		4	0.42	0.42	0.42	0.42	0.79	0.79	0.79	0.79	0.23	0.23	0.23	0.23	0.98	0.98	0.98	0.98
		5	0.28	0.28	0.28	0.28	0.10	0.10	0.10	0.10	0.70	0.70	0.70	0.70	0.35	0.35	0.35	0.35
Low	Early	1	0.59	0.59	0.59	0.59	0.56	0.56	0.56	0.56	0.34	0.34	0.34	0.34	0.40	0.40	0.40	0.40
		2	0.13	0.13	0.13	0.13	0.25	0.25	0.25	0.25	0.61	0.61	0.61	0.61	0.37	0.37	0.37	0.37
		3	1.68	1.68	1.68	1.68	0.12	0.12	0.12	0.12	0.81	0.81	0.81	0.81	0.10	0.10	0.10	0.10
		4	0.99	0.99	0.99	0.99	0.18	0.18	0.18	0.18	0.65	0.65	0.65	0.65	0.29	0.29	0.29	0.29
		5	1.00	1.00	1.00	1.00	0.24	0.24	0.24	0.24	0.48	0.48	0.48	0.48	0.11	0.11	0.11	0.11
	Late	1	0.45	0.45	0.45	0.45	0.35	0.35	0.35	0.36	0.12	0.12	0.12	0.12	0.44	0.44	0.44	0.44
		2	0.18	0.18	0.18	0.18	0.20	0.20	0.20	0.20	0.42	0.42	0.42	0.42	0.05	0.05	0.05	0.05
		3	0.36	0.36	0.36	0.36	0.35	0.35	0.35	0.35	0.27	0.27	0.27	0.27	0.13	0.13	0.13	0.13
		4	0.09	0.09	0.09	0.09	0.18	0.18	0.18	0.18	0.14	0.14	0.14	0.14	0.34	0.34	0.34	0.34
		5	0.20	0.20	0.20	0.20	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.08	0.08	0.08	0.08

Resource Metric 3

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	-	-	-	-	-	-	-	-	3.00	3.00	3.00	3.00	-	-	-	-
		2	1.00	0.50	0.50	0.50	-	-	-	-	1.50	1.50	1.50	1.50	-	-	-	-
		3	0.50	0.50	0.50	0.50	-	-	-	-	2.50	2.50	2.50	2.50	-	-	-	-
		4	1.00	1.00	1.00	1.00	-	-	-	-	2.50	2.50	2.50	2.50	-	-	-	-
		5	2.50	2.50	2.50	2.50	-	-	-	-	-	-	-	-	-	-	-	-
	Late	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		2	0.50	0.50	1.00	0.50	-	-	-	-	1.00	1.00	1.00	1.00	-	-	-	-
		3	0.50	0.50	0.50	0.50	-	-	-	-	-	-	-	-	-	-	-	-
		4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5	-	-	-	-	-	-	-	-	0.50	0.50	0.50	0.50	-	-	-	-
Low	Early	1	0.25	0.50	0.50	0.50	-	-	-	-	2.00	2.00	2.00	2.00	-	-	-	-
		2	2.00	2.00	2.00	2.00	-	-	-	-	1.50	1.50	1.50	1.50	-	-	-	-
		3	1.00	1.00	1.00	1.00	-	-	-	-	2.50	2.50	2.50	2.50	-	-	-	-
		4	-	-	-	-	-	-	-	-	0.50	0.50	0.50	0.50	-	-	-	-
		5	1.00	0.50	0.50	0.50	-	-	-	-	-	-	-	-	-	-	-	-
	Late	1	-	0.50	0.50	0.50	-	-	-	-	1.50	1.50	1.50	1.50	-	-	-	-
		2	0.50	0.50	0.50	0.50	-	-	-	-	1.50	1.50	1.50	1.50	-	-	-	-
		3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		5	-	-	-	-	-	-	-	-	0.50	0.50	0.50	0.50	-	-	-	-

Resource Metric 4a

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	4.25	8.50	8.50	8.50	12.50	12.00	12.00	12.00	10.50	10.50	10.50	10.50	14.00	14.00	14.00	14.00
		2	6.00	6.50	6.50	6.50	15.50	17.00	17.00	17.00	10.00	10.00	10.00	10.00	13.50	13.50	13.50	13.50
		3	9.00	9.00	9.00	9.00	11.50	11.50	12.00	11.50	8.50	8.50	8.50	8.50	14.00	14.00	14.00	14.00
		4	7.50	7.50	7.50	7.50	12.50	11.00	11.00	11.00	8.00	8.00	8.00	8.00	13.50	13.50	13.50	13.50
		5	10.00	10.00	10.00	10.00	11.50	11.00	11.00	11.50	7.50	7.50	7.50	7.50	15.50	15.50	15.50	15.50
	Late	1	-	5.50	5.50	5.50	10.50	13.00	12.00	12.00	3.50	3.50	3.50	3.50	15.50	15.50	15.50	15.50
		2	6.00	6.00	6.00	6.00	13.50	14.00	14.00	14.00	6.00	6.00	6.00	6.00	10.00	10.00	9.00	10.00
		3	8.00	8.00	6.50	8.00	16.00	15.00	15.00	16.00	6.00	6.00	6.00	6.00	12.00	12.00	12.00	12.00
		4	3.50	3.50	3.50	3.50	9.50	9.00	9.00	9.00	6.50	6.50	6.50	6.50	15.00	15.00	15.00	15.00
		5	8.50	8.50	8.50	8.50	13.00	12.50	12.50	12.50	8.50	8.50	8.50	8.50	14.00	14.50	14.00	14.00
Low	Early	1	2.75	5.50	5.50	5.50	6.50	6.00	6.00	6.00	5.00	5.00	5.00	5.00	7.00	7.00	7.00	7.00
		2	4.50	4.50	4.50	4.50	7.50	7.50	7.50	7.50	7.00	7.00	7.00	7.00	5.50	5.50	5.50	5.50
		3	7.00	7.00	7.00	7.00	6.50	6.50	6.50	6.50	8.50	8.50	8.50	8.50	6.50	7.00	7.00	7.00
		4	4.50	4.50	4.50	4.50	8.50	9.00	9.00	9.00	5.50	5.50	5.50	5.50	5.50	4.50	4.50	4.50
		5	3.00	5.50	5.50	5.50	5.00	5.00	5.00	5.00	2.50	2.50	2.50	2.50	7.50	7.50	7.50	7.50
	Late	1	-	4.00	4.00	4.00	8.00	6.00	8.00	6.50	2.00	2.00	2.00	2.00	7.50	7.50	7.50	7.50
		2	4.50	3.50	4.50	4.50	7.00	6.00	8.00	7.00	2.50	2.50	2.50	2.50	4.00	4.00	4.00	4.00
		3	4.00	4.00	4.00	4.00	7.50	8.00	8.00	7.50	5.50	5.50	5.50	5.50	6.00	6.00	6.00	6.00
		4	3.00	3.00	3.00	3.00	9.00	9.00	9.00	8.00	4.50	4.50	4.50	4.50	7.00	7.00	7.00	7.00
		5	3.50	3.50	3.50	3.50	5.50	5.50	6.00	6.00	4.00	4.00	4.00	4.00	7.50	7.50	7.50	7.50

Resource Metric 4b

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	8.50	17.00	17.00	17.00	67.00	66.50	66.50	66.50	20.00	20.00	20.00	20.00	67.50	67.50	67.50	67.50
		2	11.00	11.00	11.00	11.00	75.50	84.00	84.00	84.00	16.00	16.00	16.00	16.00	68.00	68.00	68.00	68.00
		3	24.00	24.00	24.00	24.00	68.50	69.00	70.00	69.00	19.00	19.00	19.00	19.00	77.00	77.00	77.00	77.00
		4	13.50	13.50	13.50	13.50	59.00	52.50	52.50	53.00	19.50	19.50	19.50	19.50	75.50	75.50	75.50	75.50
		5	21.50	21.50	21.50	21.50	65.50	65.50	65.50	67.50	19.00	19.00	19.00	19.00	82.50	82.50	82.50	82.50
	Late	1	-	14.50	14.50	14.50	43.50	52.00	51.00	51.00	5.50	5.50	5.50	5.50	77.50	77.50	77.50	77.50
		2	7.50	7.50	7.00	7.50	59.00	59.50	59.50	59.50	14.50	14.50	14.50	14.50	59.50	59.50	55.50	59.50
		3	12.50	12.50	12.00	12.50	70.00	67.50	67.50	70.00	9.50	9.50	9.50	9.50	70.00	70.00	70.00	70.00
		4	7.00	7.00	7.00	7.00	58.00	57.50	57.50	57.50	8.00	8.00	8.00	8.00	73.00	73.00	73.00	73.00
		5	13.00	13.00	13.00	13.00	62.00	65.50	65.50	65.50	17.00	17.00	17.00	17.00	73.00	73.50	73.00	73.00
Low	Early	1	6.25	12.50	12.50	12.50	36.00	32.50	32.50	32.50	13.00	13.00	13.00	13.00	35.50	35.00	35.00	35.00
		2	8.50	8.50	8.50	8.50	43.00	43.00	43.00	43.00	13.00	13.00	13.00	13.00	40.00	40.00	40.00	40.00
		3	15.50	15.50	15.50	15.50	34.00	34.00	34.00	34.00	20.00	20.00	20.00	20.00	43.00	41.50	41.50	41.50
		4	8.00	8.00	8.00	8.00	37.50	38.00	38.00	38.50	15.50	15.50	15.50	15.50	34.00	32.00	32.00	32.00
		5	5.50	6.00	6.00	6.00	31.50	31.50	31.00	31.50	6.50	6.50	6.50	6.50	42.00	42.00	42.00	42.00
	Late	1	-	13.50	13.50	13.50	35.50	28.00	35.50	39.00	6.00	6.00	6.00	6.00	41.50	41.50	41.50	41.50
		2	8.00	10.00	8.00	8.00	36.00	26.50	38.00	36.00	7.50	7.50	7.50	7.50	30.50	30.50	30.50	30.50
		3	8.00	8.00	8.00	8.00	38.00	36.00	36.00	38.00	8.00	8.00	8.00	8.00	36.00	36.00	36.00	36.00
		4	3.50	3.50	3.50	3.50	40.50	40.50	40.50	40.00	7.00	7.00	7.00	7.00	38.50	38.50	38.50	38.50
		5	5.00	5.00	5.00	5.00	22.00	22.00	25.50	25.50	3.50	3.50	3.50	3.50	41.00	41.00	41.00	41.00

Resource Metric 5a

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	3.00	6.00	6.00	6.00	5.00	4.00	4.00	4.00	8.50	8.50	8.50	8.50	9.50	9.50	9.50	9.50
		2	8.50	8.50	8.50	8.50	10.50	9.50	9.50	9.50	4.00	4.00	4.00	4.00	15.50	15.50	15.50	15.50
		3	3.00	3.00	3.00	3.00	3.50	5.00	4.50	5.00	8.00	8.00	8.00	8.00	6.00	6.50	6.50	6.50
		4	5.50	5.50	5.50	5.50	16.00	17.00	17.00	17.50	2.00	2.00	2.00	2.00	10.50	10.50	10.50	10.50
		5	2.00	1.50	1.50	1.50	14.00	14.00	14.00	13.50	7.00	7.00	7.00	7.00	9.50	9.50	9.50	9.50
	Late	1	-	7.00	7.00	7.00	15.50	17.00	16.50	16.50	10.00	10.00	10.00	10.00	2.50	2.50	2.50	2.50
		2	4.50	4.50	1.00	4.50	3.50	7.00	7.00	7.00	4.00	4.00	4.00	4.00	5.50	5.50	6.00	5.50
		3	7.50	7.50	8.50	7.50	10.50	10.50	10.50	10.50	3.00	3.00	3.00	3.00	9.50	9.50	9.50	9.50
		4	3.00	3.00	3.00	3.00	10.50	9.00	9.00	9.00	8.50	8.50	8.50	8.50	3.00	3.00	3.00	3.00
		5	6.50	6.50	6.50	6.50	6.00	2.50	2.50	2.50	8.00	8.00	8.00	8.00	24.00	23.00	24.00	24.00
Low	Early	1	1.75	3.50	3.50	3.50	15.00	15.50	15.50	15.50	4.00	4.00	4.00	4.00	6.50	4.00	4.00	4.00
		2	7.00	7.00	7.00	7.00	3.00	3.00	3.00	3.00	8.00	8.00	8.00	8.00	8.50	8.50	8.50	8.50
		3	4.50	4.50	4.50	4.50	5.00	10.00	10.00	10.00	6.50	6.50	6.50	6.50	5.50	6.00	6.00	6.00
		4	4.00	4.00	4.00	4.00	7.50	8.00	8.00	8.00	4.50	4.50	4.50	4.50	9.00	5.00	5.00	5.00
		5	5.50	4.00	4.00	4.00	7.00	7.00	7.00	7.00	8.50	8.50	8.50	8.50	8.00	8.00	8.00	8.00
	Late	1	-	5.50	5.50	5.50	13.00	13.00	13.00	16.00	18.50	18.50	18.50	18.50	7.00	7.00	7.00	7.00
		2	1.50	3.50	1.50	1.50	3.00	1.00	3.00	3.00	8.50	8.50	8.50	8.50	7.00	7.00	7.00	7.00
		3	2.50	2.50	2.50	2.50	3.50	1.00	1.00	3.50	9.50	9.50	9.50	9.50	6.00	6.00	6.00	6.00
		4	8.00	8.00	8.00	8.00	7.00	7.00	7.00	7.00	10.00	10.00	10.00	10.00	2.00	2.00	2.00	2.00
		5	5.00	5.00	5.00	5.00	4.00	6.50	6.50	6.50	9.50	9.50	9.50	9.50	5.50	5.50	5.50	5.50

Resource Metric 5b

			NW 10xx Set				NW 11xx Set				NW 12xx Set				NW 13xx Set			
			None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time	None	Max	Efftive	Time
High	Early	1	16.00	32.00	32.00	32.00	14.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	19.50	19.50	19.50	19.50
		2	38.50	38.50	38.50	38.50	53.00	70.00	70.00	70.00	15.00	15.00	15.00	15.00	90.50	90.50	90.50	90.50
		3	27.00	27.00	27.00	27.00	56.00	30.00	30.00	30.00	17.50	17.50	17.50	17.50	34.00	37.00	37.00	37.00
		4	14.00	14.00	14.00	14.00	42.50	47.50	47.50	47.50	11.00	11.00	11.00	11.00	72.00	72.00	72.00	72.00
		5	13.00	12.00	12.00	12.00	28.00	30.50	30.50	30.50	17.50	17.50	17.50	17.50	34.00	34.00	34.00	34.00
	Late	1	-	54.00	54.00	54.00	19.00	17.50	17.50	17.50	19.00	19.00	19.00	19.00	50.50	50.50	50.50	50.50
		2	7.00	7.00	9.00	7.00	42.00	33.00	33.00	33.00	23.50	23.50	23.50	23.50	41.00	41.00	41.00	41.00
		3	23.00	23.00	29.00	23.00	62.50	62.50	62.50	62.50	14.00	14.00	14.00	14.00	33.50	33.50	33.50	33.50
		4	14.50	14.50	14.50	14.50	63.00	60.00	60.00	60.00	34.00	34.00	34.00	34.00	39.00	39.00	39.00	39.00
		5	33.50	33.50	33.50	33.50	24.50	28.00	28.00	28.00	51.00	51.00	51.00	51.00	105.00	103.00	105.00	105.00
Low	Early	1	10.50	21.00	21.00	21.00	69.50	69.50	69.50	69.50	23.50	23.50	23.50	23.50	41.50	33.50	33.50	33.50
		2	23.50	23.50	23.50	23.50	46.00	46.00	46.00	46.00	42.00	42.00	42.00	42.00	38.50	38.50	38.50	38.50
		3	26.50	26.50	26.50	26.50	14.00	11.50	11.50	11.50	20.50	20.50	20.50	20.50	25.50	25.50	25.50	25.50
		4	2.00	2.00	2.00	2.00	24.00	24.00	24.00	24.00	24.50	24.50	24.50	24.50	31.50	23.50	23.50	23.50
		5	23.50	20.00	20.00	20.00	35.50	35.50	31.00	35.50	52.00	52.00	52.00	52.00	39.50	39.50	39.50	39.50
	Late	1	-	50.00	50.00	50.00	34.00	34.00	34.00	49.00	24.50	24.50	24.50	24.50	34.50	34.50	34.50	34.50
		2	5.00	20.00	5.00	5.00	14.50	13.00	14.50	14.50	17.00	17.00	17.00	17.00	13.50	13.50	13.50	13.50
		3	8.00	8.00	8.00	8.00	30.00	37.50	37.50	30.00	35.00	35.00	35.00	35.00	17.50	17.50	17.50	17.50
		4	2.50	2.50	2.50	2.50	18.50	18.50	18.50	18.50	32.00	32.00	32.00	32.00	11.50	11.50	11.50	11.50
		5	9.00	9.00	9.00	9.00	31.50	30.50	30.50	30.50	46.50	46.50	46.50	46.50	14.00	14.00	14.00	14.00

APPENDIX M: RESULTS FOR RESCHEDULING

GLM Model Results

The following table contains the result of a GLM model for each of the robustness and resource metrics. Here, the dependent variable is the metric value. There are four levels to the factor "reopt", including none (no rescheduling), max (half of "max" project buffer rescheduling time), eff (half of "effective" project buffer rescheduling point), and time ("half-time" rescheduling point). Factors and interactions significant at $\alpha = 0.5$ are highlighted.

Metric	Source	DF	SS Error	F-Val	P-Val
Duration	reopt	3	0.159	0.001	1.000
Duration	res	1	219,922.878	3,204.705	0.000
Duration	reopt*res	3	0.159	0.001	1.000
Duration	net	1	22,028.203	320.994	0.000
Duration	reopt*net	3	0.084	0.000	1.000
Duration	res*net	1	8,518.128	124.126	0.000
Duration	reopt*res*net	3	0.109	0.001	1.000
Duration	stoch	1	15,470.703	225.438	0.000
Duration	reopt*stoch	3	0.134	0.001	1.000
Duration	res*stoch	1	1,276.003	18.594	0.000
Duration	reopt*res*stoch	3	0.084	0.000	1.000
Duration	net*stoch	1	2.628	0.038	0.845
Duration	reopt*net*stoch	3	0.109	0.001	1.000
Duration	res*net*stoch	1	322.003	4.692	0.031
Duration	reopt*res*net*stoch	3	0.084	0.000	1.000
Duration	loc	1	16.653	0.243	0.623
Duration	reopt*loc	3	0.084	0.000	1.000
Duration	res*loc	1	24.753	0.361	0.549
Duration	reopt*res*loc	3	0.134	0.001	1.000
Duration	net*loc	1	306.153	4.461	0.036
Duration	reopt*net*loc	3	0.084	0.000	1.000
Duration	res*net*loc	1	8.778	0.128	0.721
Duration	reopt*res*net*loc	3	0.109	0.001	1.000
Duration	stoch*loc	1	41.328	0.602	0.438
Duration	reopt*stoch*loc	3	0.159	0.001	1.000
Duration	res*stoch*loc	1	55.278	0.806	0.370
Duration	reopt*res*stoch*loc	3	0.159	0.001	1.000
Duration	net*stoch*loc	1	4.278	0.062	0.803
Duration	reopt*net*stoch*loc	3	0.109	0.001	1.000
Duration	res*net*stoch*loc	1	4.753	0.069	0.793
Duration	reo*res*net*stoc*loc	3	0.084	0.000	1.000
Duration	ERROR	256	17,568.000	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric1	reopt	3	0.000	0.058	0.982
Metric1	res	1	0.003	2.546	0.112
Metric1	reopt*res	3	0.000	0.051	0.985
Metric1	net	1	0.011	10.526	0.001
Metric1	reopt*net	3	0.000	0.047	0.986
Metric1	res*net	1	0.000	0.071	0.790
Metric1	reopt*res*net	3	0.000	0.045	0.987
Metric1	stoch	1	0.009	8.647	0.004
Metric1	reopt*stoch	3	0.000	0.054	0.983
Metric1	res*stoch	1	0.000	0.086	0.769
Metric1	reopt*res*stoch	3	0.000	0.043	0.988
Metric1	net*stoch	1	0.018	17.093	0.000
Metric1	reopt*net*stoch	3	0.000	0.046	0.987
Metric1	res*net*stoch	1	0.000	0.286	0.593
Metric1	reopt*res*net*stoch	3	0.000	0.038	0.990
Metric1	loc	1	0.012	11.753	0.001
Metric1	reopt*loc	3	0.000	0.044	0.988
Metric1	res*loc	1	0.000	0.102	0.749
Metric1	reopt*res*loc	3	0.000	0.053	0.984
Metric1	net*loc	1	0.008	7.585	0.006
Metric1	reopt*net*loc	3	0.000	0.037	0.990
Metric1	res*net*loc	1	0.019	17.989	0.000
Metric1	reopt*res*net*loc	3	0.000	0.048	0.986
Metric1	stoch*loc	1	0.000	0.008	0.929
Metric1	reopt*stoch*loc	3	0.000	0.052	0.984
Metric1	res*stoch*loc	1	0.010	9.420	0.002
Metric1	reopt*res*stoch*loc	3	0.000	0.058	0.982
Metric1	net*stoch*loc	1	0.000	0.023	0.880
Metric1	reopt*net*stoch*loc	3	0.000	0.046	0.987
Metric1	res*net*stoch*loc	1	0.010	10.019	0.002
Metric1	reo*res*net*stoc*loc	3	0.000	0.049	0.986
Metric1	ERROR	256	0.267	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric2	reopt	3	0.000	0.009	0.999
Metric2	res	1	0.601	117.968	0.000
Metric2	reopt*res	3	0.000	0.010	0.999
Metric2	net	1	0.000	0.030	0.863
Metric2	reopt*net	3	0.000	0.010	0.999
Metric2	res*net	1	0.001	0.238	0.626
Metric2	reopt*res*net	3	0.000	0.011	0.998
Metric2	stoch	1	0.209	41.005	0.000
Metric2	reopt*stoch	3	0.000	0.007	0.999
Metric2	res*stoch	1	0.017	3.330	0.069
Metric2	reopt*res*stoch	3	0.000	0.009	0.999
Metric2	net*stoch	1	0.000	0.034	0.854
Metric2	reopt*net*stoch	3	0.000	0.008	0.999
Metric2	res*net*stoch	1	0.000	0.042	0.838
Metric2	reopt*res*net*stoch	3	0.000	0.011	0.998
Metric2	loc	1	0.008	1.577	0.210
Metric2	reopt*loc	3	0.000	0.009	0.999
Metric2	res*loc	1	0.007	1.364	0.244
Metric2	reopt*res*loc	3	0.000	0.007	0.999
Metric2	net*loc	1	0.043	8.399	0.004
Metric2	reopt*net*loc	3	0.000	0.011	0.998
Metric2	res*net*loc	1	0.020	3.935	0.048
Metric2	reopt*res*net*loc	3	0.000	0.008	0.999
Metric2	stoch*loc	1	0.008	1.596	0.208
Metric2	reopt*stoch*loc	3	0.000	0.010	0.999
Metric2	res*stoch*loc	1	0.004	0.825	0.365
Metric2	reopt*res*stoch*loc	3	0.000	0.009	0.999
Metric2	net*stoch*loc	1	0.000	0.031	0.860
Metric2	reopt*net*stoch*loc	3	0.000	0.011	0.998
Metric2	res*net*stoch*loc	1	0.013	2.527	0.113
Metric2	reo*res*net*stoc*loc	3	0.000	0.010	0.999
Metric2	ERROR	256	1.303	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric3	reopt	3	0.011	0.099	0.960
Metric3	res	1	12.170	327.365	0.000
Metric3	reopt*res	3	0.002	0.014	0.998
Metric3	net	1	1.749	47.041	0.000
Metric3	reopt*net	3	0.001	0.011	0.998
Metric3	res*net	1	2.117	56.955	0.000
Metric3	reopt*res*net	3	0.011	0.102	0.959
Metric3	stoch	1	0.089	2.398	0.123
Metric3	reopt*stoch	3	0.001	0.008	0.999
Metric3	res*stoch	1	0.002	0.060	0.807
Metric3	reopt*res*stoch	3	0.001	0.008	0.999
Metric3	net*stoch	1	0.258	6.950	0.009
Metric3	reopt*net*stoch	3	0.001	0.008	0.999
Metric3	res*net*stoch	1	0.098	2.631	0.106
Metric3	reopt*res*net*stoch	3	0.001	0.007	0.999
Metric3	loc	1	1.073	28.865	0.000
Metric3	reopt*loc	3	0.012	0.107	0.956
Metric3	res*loc	1	0.111	2.992	0.085
Metric3	reopt*res*loc	3	0.001	0.007	0.999
Metric3	net*loc	1	0.133	3.583	0.059
Metric3	reopt*net*loc	3	0.003	0.024	0.995
Metric3	res*net*loc	1	0.152	4.080	0.044
Metric3	reopt*res*net*loc	3	0.008	0.073	0.974
Metric3	stoch*loc	1	0.100	2.685	0.103
Metric3	reopt*stoch*loc	3	0.001	0.005	0.999
Metric3	res*stoch*loc	1	0.001	0.024	0.877
Metric3	reopt*res*stoch*loc	3	0.001	0.007	0.999
Metric3	net*stoch*loc	1	0.015	0.414	0.521
Metric3	reopt*net*stoch*loc	3	0.001	0.011	0.998
Metric3	res*net*stoch*loc	1	0.042	1.125	0.290
Metric3	reo*res*net*stoc*loc	3	0.001	0.010	0.999
Metric3	ERROR	256	9.517	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric4	reopt	3	0.056	1.783	0.151
Metric4	res	1	3.925	372.830	0.000
Metric4	reopt*res	3	0.009	0.270	0.847
Metric4	net	1	0.930	88.358	0.000
Metric4	reopt*net	3	0.031	0.987	0.400
Metric4	res*net	1	0.216	20.519	0.000
Metric4	reopt*res*net	3	0.023	0.734	0.533
Metric4	stoch	1	0.069	6.522	0.011
Metric4	reopt*stoch	3	0.002	0.048	0.986
Metric4	res*stoch	1	0.078	7.416	0.007
Metric4	reopt*res*stoch	3	0.000	0.007	0.999
Metric4	net*stoch	1	0.001	0.094	0.760
Metric4	reopt*net*stoch	3	0.011	0.335	0.800
Metric4	res*net*stoch	1	0.000	0.019	0.891
Metric4	reopt*res*net*stoch	3	0.004	0.122	0.947
Metric4	loc	1	0.159	15.074	0.000
Metric4	reopt*loc	3	0.055	1.750	0.157
Metric4	res*loc	1	0.000	0.001	0.974
Metric4	reopt*res*loc	3	0.008	0.262	0.853
Metric4	net*loc	1	0.002	0.167	0.683
Metric4	reopt*net*loc	3	0.031	0.970	0.407
Metric4	res*net*loc	1	0.001	0.140	0.709
Metric4	reopt*res*net*loc	3	0.023	0.729	0.536
Metric4	stoch*loc	1	0.000	0.001	0.970
Metric4	reopt*stoch*loc	3	0.001	0.024	0.995
Metric4	res*stoch*loc	1	0.001	0.116	0.733
Metric4	reopt*res*stoch*loc	3	0.000	0.007	0.999
Metric4	net*stoch*loc	1	0.216	20.516	0.000
Metric4	reopt*net*stoch*loc	3	0.009	0.291	0.832
Metric4	res*net*stoch*loc	1	0.047	4.468	0.035
Metric4	reo*res*net*stoc*loc	3	0.004	0.135	0.939
Metric4	ERROR	256	2.695	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric5	reopt	3	0.003	0.240	0.868
Metric5	res	1	1.675	474.913	0.000
Metric5	reopt*res	3	0.007	0.618	0.604
Metric5	net	1	0.035	9.906	0.002
Metric5	reopt*net	3	0.005	0.499	0.683
Metric5	res*net	1	0.014	3.881	0.050
Metric5	reopt*res*net	3	0.038	3.607	0.014
Metric5	stoch	1	0.021	5.963	0.015
Metric5	reopt*stoch	3	0.001	0.056	0.983
Metric5	res*stoch	1	0.002	0.540	0.463
Metric5	reopt*res*stoch	3	0.001	0.072	0.975
Metric5	net*stoch	1	0.004	1.185	0.277
Metric5	reopt*net*stoch	3	0.001	0.111	0.953
Metric5	res*net*stoch	1	0.005	1.457	0.229
Metric5	reopt*res*net*stoch	3	0.001	0.141	0.936
Metric5	loc	1	0.171	48.575	0.000
Metric5	reopt*loc	3	0.005	0.459	0.711
Metric5	res*loc	1	0.022	6.254	0.013
Metric5	reopt*res*loc	3	0.002	0.177	0.912
Metric5	net*loc	1	0.002	0.631	0.428
Metric5	reopt*net*loc	3	0.004	0.375	0.771
Metric5	res*net*loc	1	0.061	17.174	0.000
Metric5	reopt*res*net*loc	3	0.027	2.548	0.056
Metric5	stoch*loc	1	0.023	6.576	0.011
Metric5	reopt*stoch*loc	3	0.000	0.004	1.000
Metric5	res*stoch*loc	1	0.040	11.439	0.001
Metric5	reopt*res*stoch*loc	3	0.000	0.033	0.992
Metric5	net*stoch*loc	1	0.003	0.943	0.333
Metric5	reopt*net*stoch*loc	3	0.000	0.040	0.989
Metric5	res*net*stoch*loc	1	0.018	5.134	0.024
Metric5	reo*res*net*stoc*loc	3	0.000	0.038	0.990
Metric5	ERROR	256	0.903	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric6	reopt	3	0.027	4.503	0.004
Metric6	res	1	0.416	205.175	0.000
Metric6	reopt*res	3	0.021	3.461	0.017
Metric6	net	1	0.393	194.156	0.000
Metric6	reopt*net	3	0.022	3.575	0.015
Metric6	res*net	1	0.259	127.620	0.000
Metric6	reopt*res*net	3	0.016	2.652	0.049
Metric6	stoch	1	0.000	0.072	0.789
Metric6	reopt*stoch	3	0.005	0.860	0.463
Metric6	res*stoch	1	0.005	2.550	0.112
Metric6	reopt*res*stoch	3	0.004	0.685	0.562
Metric6	net*stoch	1	0.000	0.183	0.669
Metric6	reopt*net*stoch	3	0.003	0.481	0.696
Metric6	res*net*stoch	1	0.011	5.257	0.023
Metric6	reopt*res*net*stoch	3	0.002	0.355	0.786
Metric6	loc	1	0.011	5.248	0.023
Metric6	reopt*loc	3	0.017	2.773	0.042
Metric6	res*loc	1	0.000	0.013	0.908
Metric6	reopt*res*loc	3	0.013	2.208	0.088
Metric6	net*loc	1	0.010	4.904	0.028
Metric6	reopt*net*loc	3	0.013	2.083	0.103
Metric6	res*net*loc	1	0.000	0.002	0.969
Metric6	reopt*res*net*loc	3	0.010	1.615	0.186
Metric6	stoch*loc	1	0.015	7.167	0.008
Metric6	reopt*stoch*loc	3	0.003	0.511	0.675
Metric6	res*stoch*loc	1	0.001	0.434	0.511
Metric6	reopt*res*stoch*loc	3	0.002	0.410	0.746
Metric6	net*stoch*loc	1	0.032	15.983	0.000
Metric6	reopt*net*stoch*loc	3	0.002	0.259	0.855
Metric6	res*net*stoch*loc	1	0.008	3.917	0.049
Metric6	reo*res*net*stoc*loc	3	0.001	0.182	0.908
Metric6	ERROR	256	0.519	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric7	reopt	3	0.000	0.000	1.000
Metric7	res	1	0.322	58.105	0.000
Metric7	reopt*res	3	0.000	0.000	1.000
Metric7	net	1	0.001	0.213	0.645
Metric7	reopt*net	3	0.000	0.000	1.000
Metric7	res*net	1	0.001	0.103	0.748
Metric7	reopt*res*net	3	0.000	0.000	1.000
Metric7	stoch	1	0.216	38.947	0.000
Metric7	reopt*stoch	3	0.000	0.000	1.000
Metric7	res*stoch	1	0.019	3.433	0.065
Metric7	reopt*res*stoch	3	0.000	0.000	1.000
Metric7	net*stoch	1	0.002	0.437	0.509
Metric7	reopt*net*stoch	3	0.000	0.000	1.000
Metric7	res*net*stoch	1	0.002	0.390	0.533
Metric7	reopt*res*net*stoch	3	0.000	0.000	1.000
Metric7	loc	1	0.010	1.782	0.183
Metric7	reopt*loc	3	0.000	0.000	1.000
Metric7	res*loc	1	0.004	0.808	0.370
Metric7	reopt*res*loc	3	0.000	0.000	1.000
Metric7	net*loc	1	0.013	2.416	0.121
Metric7	reopt*net*loc	3	0.000	0.000	1.000
Metric7	res*net*loc	1	0.014	2.590	0.109
Metric7	reopt*res*net*loc	3	0.000	0.000	1.000
Metric7	stoch*loc	1	0.020	3.599	0.059
Metric7	reopt*stoch*loc	3	0.000	0.000	1.000
Metric7	res*stoch*loc	1	0.000	0.058	0.809
Metric7	reopt*res*stoch*loc	3	0.000	0.000	1.000
Metric7	net*stoch*loc	1	0.002	0.317	0.574
Metric7	reopt*net*stoch*loc	3	0.000	0.000	1.000
Metric7	res*net*stoch*loc	1	0.004	0.637	0.426
Metric7	reo*res*net*stoc*loc	3	0.000	0.000	1.000
Metric7	ERROR	256	1.418	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
Metric8	reopt	3	1.130	0.277	0.842
Metric8	res	1	2.255	1.656	0.199
Metric8	reopt*res	3	0.930	0.228	0.877
Metric8	net	1	24.976	18.345	0.000
Metric8	reopt*net	3	1.149	0.281	0.839
Metric8	res*net	1	0.061	0.045	0.833
Metric8	reopt*res*net	3	0.910	0.223	0.880
Metric8	stoch	1	3.853	2.830	0.094
Metric8	reopt*stoch	3	0.248	0.061	0.980
Metric8	res*stoch	1	6.160	4.524	0.034
Metric8	reopt*res*stoch	3	0.224	0.055	0.983
Metric8	net*stoch	1	12.377	9.091	0.003
Metric8	reopt*net*stoch	3	0.299	0.073	0.974
Metric8	res*net*stoch	1	32.658	23.987	0.000
Metric8	reopt*res*net*stoch	3	0.188	0.046	0.987
Metric8	loc	1	37.448	27.506	0.000
Metric8	reopt*loc	3	1.077	0.264	0.852
Metric8	res*loc	1	16.950	12.450	0.000
Metric8	reopt*res*loc	3	1.248	0.306	0.821
Metric8	net*loc	1	12.298	9.033	0.003
Metric8	reopt*net*loc	3	1.036	0.254	0.859
Metric8	res*net*loc	1	8.238	6.051	0.015
Metric8	reopt*res*net*loc	3	1.301	0.318	0.812
Metric8	stoch*loc	1	10.065	7.393	0.007
Metric8	reopt*stoch*loc	3	0.233	0.057	0.982
Metric8	res*stoch*loc	1	10.892	8.000	0.005
Metric8	reopt*res*stoch*loc	3	0.292	0.072	0.975
Metric8	net*stoch*loc	1	2.663	1.956	0.163
Metric8	reopt*net*stoch*loc	3	0.245	0.060	0.981
Metric8	res*net*stoch*loc	1	5.920	4.348	0.038
Metric8	reo*res*net*stoc*loc	3	0.276	0.068	0.977
Metric8	ERROR	256	348.531	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric1	reopt	3	0.033	0.064	0.979
RMetric1	res	1	52.092	301.115	0.000
RMetric1	reopt*res	3	0.036	0.070	0.976
RMetric1	net	1	0.293	1.696	0.194
RMetric1	reopt*net	3	0.021	0.040	0.989
RMetric1	res*net	1	15.609	90.228	0.000
RMetric1	reopt*res*net	3	0.025	0.049	0.986
RMetric1	stoch	1	30.071	173.820	0.000
RMetric1	reopt*stoch	3	0.024	0.046	0.987
RMetric1	res*stoch	1	0.639	3.692	0.056
RMetric1	reopt*res*stoch	3	0.015	0.029	0.993
RMetric1	net*stoch	1	0.919	5.313	0.022
RMetric1	reopt*net*stoch	3	0.027	0.052	0.984
RMetric1	res*net*stoch	1	0.698	4.037	0.046
RMetric1	reopt*res*net*stoch	3	0.022	0.042	0.988
RMetric1	loc	1	0.132	0.765	0.383
RMetric1	reopt*loc	3	0.034	0.065	0.978
RMetric1	res*loc	1	3.484	20.139	0.000
RMetric1	reopt*res*loc	3	0.022	0.042	0.989
RMetric1	net*loc	1	0.146	0.845	0.359
RMetric1	reopt*net*loc	3	0.039	0.075	0.974
RMetric1	res*net*loc	1	0.055	0.317	0.574
RMetric1	reopt*res*net*loc	3	0.029	0.056	0.982
RMetric1	stoch*loc	1	0.451	2.607	0.108
RMetric1	reopt*stoch*loc	3	0.021	0.041	0.989
RMetric1	res*stoch*loc	1	0.087	0.502	0.479
RMetric1	reopt*res*stoch*loc	3	0.023	0.044	0.988
RMetric1	net*stoch*loc	1	0.364	2.106	0.148
RMetric1	reopt*net*stoch*loc	3	0.011	0.021	0.996
RMetric1	res*net*stoch*loc	1	1.806	10.437	0.001
RMetric1	reo*res*net*stoc*loc	3	0.014	0.027	0.994
RMetric1	ERROR	256	44.287	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric2	reopt	3	0.001	0.005	1.000
RMetric2	res	1	6.608	93.863	0.000
RMetric2	reopt*res	3	0.001	0.002	1.000
RMetric2	net	1	0.656	9.321	0.003
RMetric2	reopt*net	3	0.002	0.007	0.999
RMetric2	res*net	1	1.617	22.963	0.000
RMetric2	reopt*res*net	3	0.001	0.003	1.000
RMetric2	stoch	1	5.945	84.440	0.000
RMetric2	reopt*stoch	3	0.001	0.005	1.000
RMetric2	res*stoch	1	0.199	2.834	0.094
RMetric2	reopt*res*stoch	3	0.000	0.002	1.000
RMetric2	net*stoch	1	0.004	0.057	0.811
RMetric2	reopt*net*stoch	3	0.002	0.008	0.999
RMetric2	res*net*stoch	1	0.408	5.794	0.017
RMetric2	reopt*res*net*stoch	3	0.001	0.003	1.000
RMetric2	loc	1	6.794	96.501	0.000
RMetric2	reopt*loc	3	0.000	0.002	1.000
RMetric2	res*loc	1	9.000	127.843	0.000
RMetric2	reopt*res*loc	3	0.001	0.005	1.000
RMetric2	net*loc	1	1.754	24.919	0.000
RMetric2	reopt*net*loc	3	0.001	0.003	1.000
RMetric2	res*net*loc	1	0.503	7.145	0.008
RMetric2	reopt*res*net*loc	3	0.002	0.008	0.999
RMetric2	stoch*loc	1	0.065	0.929	0.336
RMetric2	reopt*stoch*loc	3	0.001	0.002	1.000
RMetric2	res*stoch*loc	1	0.917	13.025	0.000
RMetric2	reopt*res*stoch*loc	3	0.001	0.005	1.000
RMetric2	net*stoch*loc	1	0.602	8.555	0.004
RMetric2	reopt*net*stoch*loc	3	0.001	0.003	1.000
RMetric2	res*net*stoch*loc	1	0.004	0.059	0.809
RMetric2	reo*res*net*stoc*loc	3	0.002	0.007	0.999
RMetric2	ERROR	256	18.023	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric3	reopt	3	0.002	0.002	1.000
RMetric3	res	1	50.205	162.381	0.000
RMetric3	reopt*res	3	0.002	0.002	1.000
RMetric3	net	1	5.317	17.198	0.000
RMetric3	reopt*net	3	0.002	0.002	1.000
RMetric3	res*net	1	5.317	17.198	0.000
RMetric3	reopt*res*net	3	0.002	0.002	1.000
RMetric3	stoch	1	0.164	0.531	0.467
RMetric3	reopt*stoch	3	0.005	0.006	0.999
RMetric3	res*stoch	1	0.164	0.531	0.467
RMetric3	reopt*res*stoch	3	0.005	0.006	0.999
RMetric3	net*stoch	1	0.002	0.006	0.940
RMetric3	reopt*net*stoch	3	0.005	0.006	0.999
RMetric3	res*net*stoch	1	0.002	0.006	0.940
RMetric3	reopt*res*net*stoch	3	0.005	0.006	0.999
RMetric3	loc	1	15.642	50.593	0.000
RMetric3	reopt*loc	3	0.021	0.023	0.995
RMetric3	res*loc	1	15.642	50.593	0.000
RMetric3	reopt*res*loc	3	0.021	0.023	0.995
RMetric3	net*loc	1	0.930	3.008	0.084
RMetric3	reopt*net*loc	3	0.021	0.023	0.995
RMetric3	res*net*loc	1	0.930	3.008	0.084
RMetric3	reopt*res*net*loc	3	0.021	0.023	0.995
RMetric3	stoch*loc	1	1.411	4.564	0.034
RMetric3	reopt*stoch*loc	3	0.002	0.002	1.000
RMetric3	res*stoch*loc	1	1.411	4.564	0.034
RMetric3	reopt*res*stoch*loc	3	0.002	0.002	1.000
RMetric3	net*stoch*loc	1	1.099	3.553	0.061
RMetric3	reopt*net*stoch*loc	3	0.002	0.002	1.000
RMetric3	res*net*stoch*loc	1	1.099	3.553	0.061
RMetric3	reo*res*net*stoc*loc	3	0.002	0.002	1.000
RMetric3	ERROR	256	79.150	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric4a	reopt	3	2.790	0.310	0.818
RMetric4a	res	1	1,302.095	433.608	0.000
RMetric4a	reopt*res	3	3.902	0.433	0.729
RMetric4a	net	1	7.970	2.654	0.105
RMetric4a	reopt*net	3	3.365	0.374	0.772
RMetric4a	res*net	1	0.957	0.319	0.573
RMetric4a	reopt*res*net	3	3.602	0.400	0.753
RMetric4a	stoch	1	1,683.613	560.657	0.000
RMetric4a	reopt*stoch	3	0.619	0.069	0.977
RMetric4a	res*stoch	1	275.653	91.795	0.000
RMetric4a	reopt*res*stoch	3	0.153	0.017	0.997
RMetric4a	net*stoch	1	18.050	6.011	0.015
RMetric4a	reopt*net*stoch	3	0.294	0.033	0.992
RMetric4a	res*net*stoch	1	13.203	4.397	0.037
RMetric4a	reopt*res*net*stoch	3	0.041	0.005	1.000
RMetric4a	loc	1	96.251	32.052	0.000
RMetric4a	reopt*loc	3	0.009	0.001	1.000
RMetric4a	res*loc	1	84.563	28.160	0.000
RMetric4a	reopt*res*loc	3	0.121	0.013	0.998
RMetric4a	net*loc	1	6.757	2.250	0.135
RMetric4a	reopt*net*loc	3	0.115	0.013	0.998
RMetric4a	res*net*loc	1	0.020	0.007	0.936
RMetric4a	reopt*res*net*loc	3	0.252	0.028	0.994
RMetric4a	stoch*loc	1	9.113	3.035	0.083
RMetric4a	reopt*stoch*loc	3	0.781	0.087	0.967
RMetric4a	res*stoch*loc	1	0.003	0.001	0.974
RMetric4a	reopt*res*stoch*loc	3	0.191	0.021	0.996
RMetric4a	net*stoch*loc	1	0.613	0.204	0.652
RMetric4a	reopt*net*stoch*loc	3	0.544	0.060	0.981
RMetric4a	res*net*stoch*loc	1	0.028	0.009	0.923
RMetric4a	reo*res*net*stoc*loc	3	0.053	0.006	0.999
RMetric4a	ERROR	256	768.750	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric4b	reopt	3	23.927	0.262	0.853
RMetric4b	res	1	131,432.711	4,322.445	0.000
RMetric4b	reopt*res	3	22.862	0.251	0.861
RMetric4b	net	1	1,023.344	33.655	0.000
RMetric4b	reopt*net	3	34.754	0.381	0.767
RMetric4b	res*net	1	369.263	12.144	0.001
RMetric4b	reopt*res*net	3	17.416	0.191	0.903
RMetric4b	stoch	1	26,740.899	879.431	0.000
RMetric4b	reopt*stoch	3	9.705	0.106	0.956
RMetric4b	res*stoch	1	14,161.177	465.720	0.000
RMetric4b	reopt*res*stoch	3	9.408	0.103	0.958
RMetric4b	net*stoch	1	134.875	4.436	0.036
RMetric4b	reopt*net*stoch	3	5.710	0.063	0.979
RMetric4b	res*net*stoch	1	174.419	5.736	0.017
RMetric4b	reopt*res*net*stoch	3	5.735	0.063	0.979
RMetric4b	loc	1	1,870.903	61.529	0.000
RMetric4b	reopt*loc	3	7.663	0.084	0.969
RMetric4b	res*loc	1	137.485	4.521	0.034
RMetric4b	reopt*res*loc	3	4.576	0.050	0.985
RMetric4b	net*loc	1	0.086	0.003	0.958
RMetric4b	reopt*net*loc	3	6.849	0.075	0.973
RMetric4b	res*net*loc	1	139.458	4.586	0.033
RMetric4b	reopt*res*net*loc	3	7.158	0.078	0.972
RMetric4b	stoch*loc	1	218.213	7.176	0.008
RMetric4b	reopt*stoch*loc	3	5.954	0.065	0.978
RMetric4b	res*stoch*loc	1	17.931	0.590	0.443
RMetric4b	reopt*res*stoch*loc	3	7.366	0.081	0.970
RMetric4b	net*stoch*loc	1	49.024	1.612	0.205
RMetric4b	reopt*net*stoch*loc	3	4.874	0.053	0.984
RMetric4b	res*net*stoch*loc	1	0.727	0.024	0.877
RMetric4b	reo*res*net*stoc*loc	3	6.915	0.076	0.973
RMetric4b	ERROR	256	7,784.200	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric5a	reopt	3	3.012	0.062	0.980
RMetric5a	res	1	316.510	19.699	0.000
RMetric5a	reopt*res	3	2.388	0.050	0.985
RMetric5a	net	1	95.977	5.974	0.015
RMetric5a	reopt*net	3	7.815	0.162	0.922
RMetric5a	res*net	1	231.625	14.416	0.000
RMetric5a	reopt*res*net	3	0.447	0.009	0.999
RMetric5a	stoch	1	71.489	4.449	0.036
RMetric5a	reopt*stoch	3	0.177	0.004	1.000
RMetric5a	res*stoch	1	288.325	17.945	0.000
RMetric5a	reopt*res*stoch	3	0.697	0.014	0.998
RMetric5a	net*stoch	1	13.305	0.828	0.364
RMetric5a	reopt*net*stoch	3	1.512	0.031	0.993
RMetric5a	res*net*stoch	1	94.885	5.906	0.016
RMetric5a	reopt*res*net*stoch	3	3.101	0.064	0.979
RMetric5a	loc	1	0.396	0.025	0.875
RMetric5a	reopt*loc	3	1.190	0.025	0.995
RMetric5a	res*loc	1	157.150	9.781	0.002
RMetric5a	reopt*res*loc	3	1.591	0.033	0.992
RMetric5a	net*loc	1	42.596	2.651	0.105
RMetric5a	reopt*net*loc	3	0.415	0.009	0.999
RMetric5a	res*net*loc	1	33.638	2.094	0.149
RMetric5a	reopt*res*net*loc	3	4.316	0.090	0.966
RMetric5a	stoch*loc	1	6.399	0.398	0.529
RMetric5a	reopt*stoch*loc	3	0.387	0.008	0.999
RMetric5a	res*stoch*loc	1	25.453	1.584	0.209
RMetric5a	reopt*res*stoch*loc	3	0.676	0.014	0.998
RMetric5a	net*stoch*loc	1	53.424	3.325	0.069
RMetric5a	reopt*net*stoch*loc	3	0.999	0.021	0.996
RMetric5a	res*net*stoch*loc	1	11.916	0.742	0.390
RMetric5a	reo*res*net*stoc*loc	3	2.413	0.050	0.985
RMetric5a	ERROR	256	4,113.150	0.000	-

Metric	Source	DF	SS Error	F-Val	P-Val
RMetric5b	reopt	3	118.000	0.136	0.938
RMetric5b	res	1	15,792.200	54.613	0.000
RMetric5b	reopt*res	3	230.838	0.266	0.850
RMetric5b	net	1	1,920.800	6.643	0.011
RMetric5b	reopt*net	3	182.938	0.211	0.889
RMetric5b	res*net	1	292.612	1.012	0.315
RMetric5b	reopt*res*net	3	157.300	0.181	0.909
RMetric5b	stoch	1	5,176.153	17.900	0.000
RMetric5b	reopt*stoch	3	6.334	0.007	0.999
RMetric5b	res*stoch	1	6,417.153	22.192	0.000
RMetric5b	reopt*res*stoch	3	4.084	0.005	1.000
RMetric5b	net*stoch	1	1.653	0.006	0.940
RMetric5b	reopt*net*stoch	3	10.309	0.012	0.998
RMetric5b	res*net*stoch	1	7,040.628	24.348	0.000
RMetric5b	reopt*res*net*stoch	3	23.884	0.028	0.994
RMetric5b	loc	1	193.753	0.670	0.414
RMetric5b	reopt*loc	3	107.509	0.124	0.946
RMetric5b	res*loc	1	867.903	3.001	0.084
RMetric5b	reopt*res*loc	3	53.309	0.061	0.980
RMetric5b	net*loc	1	222.778	0.770	0.381
RMetric5b	reopt*net*loc	3	63.959	0.074	0.974
RMetric5b	res*net*loc	1	517.653	1.790	0.182
RMetric5b	reopt*res*net*loc	3	91.234	0.105	0.957
RMetric5b	stoch*loc	1	3,200.450	11.068	0.001
RMetric5b	reopt*stoch*loc	3	22.113	0.025	0.994
RMetric5b	res*stoch*loc	1	132.612	0.459	0.499
RMetric5b	reopt*res*stoch*loc	3	15.575	0.018	0.997
RMetric5b	net*stoch*loc	1	285.013	0.986	0.322
RMetric5b	reopt*net*stoch*loc	3	1.925	0.002	1.000
RMetric5b	res*net*stoch*loc	1	22.050	0.076	0.783
RMetric5b	reo*res*net*stoc*loc	3	7.263	0.008	0.999
RMetric5b	ERROR	256	74,026.400	0.000	-

ANOVA Results

For all preceding ANOVA table results, the degrees of freedom for the model are 3, error is 16, and the corrected total is 19. The rows of the ANOVA tables are highlighted where the p-value is less than 0.05 (α level) and therefore rejects the null hypothesis, indicating a significant factor or interaction effect.

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE10	Duration	-	147.200	-	1.000
HE10	Metric1	(0.000)	0.004	-	1.000
HE10	Metric2	0.000	0.292	0.000	1.000
HE10	Metric3	0.018	0.045	2.091	0.142
HE10	Metric4	0.084	0.129	3.481	0.041
HE10	Metric5	0.012	0.024	2.673	0.082
HE10	Metric6	0.001	0.001	2.667	0.083
HE10	Metric7	0.000	0.312	0.000	1.000
HE10	Metric8	9.424	69.948	0.719	0.555
HE10	RMetric1	(0.000)	2.320	-	1.000
HE10	RMetric2	-	4.231	-	1.000
HE10	RMetric3	0.038	14.600	0.014	0.998
HE10	RMetric4a	3.384	43.100	0.419	0.742
HE10	RMetric4b	10.838	531.400	0.109	0.954
HE10	RMetric5a	0.938	116.800	0.043	0.988
HE10	RMetric5b	33.750	2,052.200	0.088	0.966
HE11	Duration	0.150	1,132.400	0.001	1.000
HE11	Metric1	0.001	0.025	0.127	0.943
HE11	Metric2	0.001	0.023	0.129	0.941
HE11	Metric3	0.001	0.223	0.013	0.998
HE11	Metric4	0.000	0.332	0.002	1.000
HE11	Metric5	0.026	0.057	2.422	0.104
HE11	Metric6	0.125	0.043	15.366	0.000
HE11	Metric7	0.000	0.077	0.000	1.000
HE11	Metric8	0.001	1.109	0.004	1.000
HE11	RMetric1	0.006	4.912	0.006	0.999
HE11	RMetric2	0.005	0.535	0.052	0.984
HE11	RMetric3	-	-	-	-
HE11	RMetric4a	0.100	86.700	0.006	0.999
HE11	RMetric4b	2.138	1,638.000	0.007	0.999
HE11	RMetric5a	0.050	506.500	0.001	1.000
HE11	RMetric5b	0.938	6,721.200	0.001	1.000
HE12	Duration	-	987.200	-	1.000
HE12	Metric1	0.000	0.005	0.000	1.000
HE12	Metric2	0.000	0.240	0.000	1.000
HE12	Metric3	0.000	0.230	0.000	1.000
HE12	Metric4	0.000	0.027	0.000	1.000
HE12	Metric5	0.000	0.042	0.000	1.000
HE12	Metric6	-	-	-	-
HE12	Metric7	0.000	0.224	0.000	1.000
HE12	Metric8	0.000	51.219	0.000	1.000
HE12	RMetric1	0.000	2.062	0.000	1.000
HE12	RMetric2	(0.000)	0.183	-	1.000
HE12	RMetric3	-	22.800	-	1.000
HE12	RMetric4a	-	26.800	-	1.000
HE12	RMetric4b	-	39.200	-	1.000
HE12	RMetric5a	-	124.800	-	1.000
HE12	RMetric5b	-	122.800	-	1.000

Group	Metric	SS Model	SS Error	F-Val	P-Val
HE13	Duration	0.150	2,628.400	0.000	1.000
HE13	Metric1	0.000	0.003	0.024	0.995
HE13	Metric2	0.000	0.023	0.003	1.000
HE13	Metric3	0.015	0.864	0.090	0.964
HE13	Metric4	0.018	0.135	0.706	0.562
HE13	Metric5	0.018	0.047	1.999	0.155
HE13	Metric6	0.001	0.007	1.000	0.418
HE13	Metric7	0.000	0.021	0.000	1.000
HE13	Metric8	0.001	5.283	0.001	1.000
HE13	RMetric1	0.000	1.551	0.000	1.000
HE13	RMetric2	0.000	0.134	0.014	0.998
HE13	RMetric3	-	-	-	-
HE13	RMetric4a	-	10.800	-	1.000
HE13	RMetric4b	-	646.800	-	1.000
HE13	RMetric5a	0.037	175.200	0.001	1.000
HE13	RMetric5b	1.350	13,999.600	0.001	1.000
HL10	Duration	0.950	285.600	0.018	0.997
HL10	Metric1	0.002	0.103	0.090	0.965
HL10	Metric2	0.002	0.180	0.050	0.985
HL10	Metric3	0.000	1.107	0.001	1.000
HL10	Metric4	0.000	0.253	0.003	1.000
HL10	Metric5	0.001	0.084	0.075	0.973
HL10	Metric6	0.000	0.002	0.333	0.801
HL10	Metric7	0.000	0.142	0.000	1.000
HL10	Metric8	0.055	18.743	0.016	0.997
HL10	RMetric1	0.002	5.604	0.002	1.000
HL10	RMetric2	0.009	0.614	0.081	0.969
HL10	RMetric3	0.038	1.700	0.118	0.948
HL10	RMetric4a	4.050	94.900	0.228	0.876
HL10	RMetric4b	30.238	252.700	0.638	0.601
HL10	RMetric5a	6.538	102.200	0.341	0.796
HL10	RMetric5b	490.200	4,627.600	0.565	0.646
HL11	Duration	-	2,220.800	-	1.000
HL11	Metric1	0.000	0.011	0.000	1.000
HL11	Metric2	0.000	0.016	0.000	1.000
HL11	Metric3	0.001	0.292	0.010	0.999
HL11	Metric4	0.000	0.086	0.000	1.000
HL11	Metric5	0.003	0.032	0.452	0.719
HL11	Metric6	0.004	0.038	0.587	0.632
HL11	Metric7	0.000	0.008	0.000	1.000
HL11	Metric8	0.038	1.049	0.191	0.901
HL11	RMetric1	0.003	4.566	0.003	1.000
HL11	RMetric2	(0.000)	1.471	-	1.000
HL11	RMetric3	-	-	-	-
HL11	RMetric4a	0.200	95.100	0.011	0.998
HL11	RMetric4b	14.650	915.300	0.085	0.967
HL11	RMetric5a	0.050	407.500	0.001	1.000
HL11	RMetric5b	15.000	6,512.200	0.012	0.998

Group	Metric	SS Model	SS Error	F-Val	P-Val
HL12	Duration	-	251.200	-	1.000
HL12	Metric1	0.000	0.001	0.000	1.000
HL12	Metric2	0.000	0.093	0.000	1.000
HL12	Metric3	0.000	0.753	0.000	1.000
HL12	Metric4	0.000	0.136	0.000	1.000
HL12	Metric5	0.000	0.034	0.000	1.000
HL12	Metric6	-	-	-	-
HL12	Metric7	0.000	0.092	0.000	1.000
HL12	Metric8	0.000	10.203	0.000	1.000
HL12	RMetric1	0.000	3.472	0.000	1.000
HL12	RMetric2	-	0.948	-	1.000
HL12	RMetric3	-	3.200	-	1.000
HL12	RMetric4a	-	50.800	-	1.000
HL12	RMetric4b	-	358.800	-	1.000
HL12	RMetric5a	-	147.200	-	1.000
HL12	RMetric5b	-	3,447.200	-	1.000
HL13	Duration	-	1,156.800	-	1.000
HL13	Metric1	0.000	0.020	0.000	1.000
HL13	Metric2	0.000	0.025	0.000	1.000
HL13	Metric3	0.000	0.206	0.004	1.000
HL13	Metric4	0.000	0.190	0.011	0.998
HL13	Metric5	0.000	0.129	0.006	0.999
HL13	Metric6	0.000	0.013	0.000	1.000
HL13	Metric7	0.000	0.060	0.000	1.000
HL13	Metric8	0.007	4.357	0.008	0.999
HL13	RMetric1	0.010	2.135	0.025	0.994
HL13	RMetric2	(0.000)	2.186	-	1.000
HL13	RMetric3	-	-	-	-
HL13	RMetric4a	0.237	91.500	0.014	0.998
HL13	RMetric4b	2.638	835.000	0.017	0.997
HL13	RMetric5a	0.237	1,230.200	0.001	1.000
HL13	RMetric5b	0.600	13,507.600	0.000	1.000
LE10	Duration	-	299.200	-	1.000
LE10	Metric1	-	-	-	-
LE10	Metric2	0.000	0.027	0.000	1.000
LE10	Metric3	0.020	0.020	5.214	0.011
LE10	Metric4	0.131	0.058	12.021	0.000
LE10	Metric5	0.014	0.009	8.660	0.001
LE10	Metric6	0.000	0.001	1.000	0.418
LE10	Metric7	0.000	0.027	0.000	1.000
LE10	Metric8	1.223	6.521	1.000	0.418
LE10	RMetric1	0.006	3.201	0.009	0.999
LE10	RMetric2	(0.000)	5.222	-	1.000
LE10	RMetric3	0.009	9.350	0.005	0.999
LE10	RMetric4a	4.134	24.050	0.917	0.455
LE10	RMetric4b	6.834	239.100	0.152	0.927
LE10	RMetric5a	0.009	38.150	0.001	1.000
LE10	RMetric5b	7.350	1,550.900	0.025	0.994

Group	Metric	SS Model	SS Error	F-Val	P-Val
LE11	Duration	-	1,012.800	-	1.000
LE11	Metric1	0.000	0.000	0.001	1.000
LE11	Metric2	0.000	0.004	0.000	1.000
LE11	Metric3	0.001	0.878	0.008	0.999
LE11	Metric4	0.031	0.366	0.459	0.715
LE11	Metric5	0.010	0.110	0.478	0.702
LE11	Metric6	0.027	0.059	2.470	0.099
LE11	Metric7	0.000	0.007	0.000	1.000
LE11	Metric8	0.019	3.789	0.027	0.994
LE11	RMetric1	0.363	2.481	0.781	0.522
LE11	RMetric2	-	0.466	-	1.000
LE11	RMetric3	-	-	-	-
LE11	RMetric4a	-	34.700	-	1.000
LE11	RMetric4b	1.450	349.500	0.022	0.995
LE11	RMetric5a	5.400	334.400	0.086	0.967
LE11	RMetric5b	5.100	7,741.600	0.004	1.000
LE12	Duration	-	1,003.200	-	1.000
LE12	Metric1	0.000	0.022	0.000	1.000
LE12	Metric2	0.000	0.094	0.000	1.000
LE12	Metric3	0.000	0.247	0.000	1.000
LE12	Metric4	-	0.027	-	1.000
LE12	Metric5	0.000	0.020	0.000	1.000
LE12	Metric6	-	-	-	-
LE12	Metric7	0.000	0.099	0.000	1.000
LE12	Metric8	0.000	78.862	0.000	1.000
LE12	RMetric1	(0.000)	2.928	-	1.000
LE12	RMetric2	-	0.496	-	1.000
LE12	RMetric3	-	17.200	-	1.000
LE12	RMetric4a	-	81.200	-	1.000
LE12	RMetric4b	-	382.800	-	1.000
LE12	RMetric5a	-	65.200	-	1.000
LE12	RMetric5b	-	3,038.000	-	1.000
LE13	Duration	-	1,688.000	-	1.000
LE13	Metric1	0.000	0.009	0.000	1.000
LE13	Metric2	0.000	0.004	0.000	1.000
LE13	Metric3	0.000	0.299	0.003	1.000
LE13	Metric4	0.000	0.142	0.005	0.999
LE13	Metric5	0.012	0.038	1.682	0.211
LE13	Metric6	-	0.017	-	1.000
LE13	Metric7	0.000	0.012	0.000	1.000
LE13	Metric8	0.001	1.183	0.006	0.999
LE13	RMetric1	0.004	3.294	0.007	0.999
LE13	RMetric2	-	0.330	-	1.000
LE13	RMetric3	-	-	-	-
LE13	RMetric4a	0.037	22.100	0.009	0.999
LE13	RMetric4b	2.400	294.800	0.043	0.988
LE13	RMetric5a	5.400	52.900	0.544	0.659
LE13	RMetric5b	38.400	822.400	0.249	0.861

Group	Metric	SS Model	SS Error	F-Val	P-Val
LL10	Duration	-	91.200	-	1.000
LL10	Metric1	0.000	0.024	0.000	1.000
LL10	Metric2	0.000	0.243	0.000	1.000
LL10	Metric3	0.000	1.604	0.000	1.000
LL10	Metric4	0.000	0.339	0.002	1.000
LL10	Metric5	0.000	0.148	0.000	1.000
LL10	Metric6	0.000	0.153	0.000	1.000
LL10	Metric7	0.000	0.242	0.000	1.000
LL10	Metric8	0.015	16.250	0.005	1.000
LL10	RMetric1	-	1.851	-	1.000
LL10	RMetric2	-	0.328	-	1.000
LL10	RMetric3	0.037	1.100	0.182	0.907
LL10	RMetric4a	2.150	15.800	0.726	0.551
LL10	RMetric4b	30.638	226.100	0.723	0.553
LL10	RMetric5a	6.238	110.400	0.301	0.824
LL10	RMetric5b	483.750	4,637.800	0.556	0.651
LL11	Duration	0.600	1,947.200	0.002	1.000
LL11	Metric1	0.000	0.016	0.025	0.994
LL11	Metric2	0.000	0.005	0.057	0.981
LL11	Metric3	0.001	0.100	0.041	0.988
LL11	Metric4	0.001	0.391	0.016	0.997
LL11	Metric5	-	0.057	-	1.000
LL11	Metric6	0.004	0.180	0.108	0.954
LL11	Metric7	0.000	0.035	0.000	1.000
LL11	Metric8	0.003	0.879	0.018	0.997
LL11	RMetric1	0.002	0.974	0.014	0.998
LL11	RMetric2	0.000	0.155	0.001	1.000
LL11	RMetric3	-	-	-	-
LL11	RMetric4a	2.538	23.200	0.583	0.635
LL11	RMetric4b	79.050	701.900	0.601	0.624
LL11	RMetric5a	6.238	362.500	0.092	0.964
LL11	RMetric5b	20.138	1,860.100	0.058	0.981
LL12	Duration	-	984.000	-	1.000
LL12	Metric1	0.000	0.003	0.000	1.000
LL12	Metric2	0.000	0.031	0.000	1.000
LL12	Metric3	0.000	1.644	0.000	1.000
LL12	Metric4	0.000	0.019	0.000	1.000
LL12	Metric5	0.000	0.044	0.000	1.000
LL12	Metric6	-	-	-	-
LL12	Metric7	0.000	0.036	0.000	1.000
LL12	Metric8	0.000	73.202	0.000	1.000
LL12	RMetric1	0.000	1.412	0.000	1.000
LL12	RMetric2	-	0.254	-	1.000
LL12	RMetric3	-	9.200	-	1.000
LL12	RMetric4a	0.000	33.200	0.000	1.000
LL12	RMetric4b	-	50.800	-	1.000
LL12	RMetric5a	-	271.200	-	1.000
LL12	RMetric5b	-	1,982.000	-	1.000

Group	Metric	SS Model	SS Error	F-Val	P-Val
LL13	Duration	-	1,732.800	-	1.000
LL13	Metric1	0.000	0.023	0.000	1.000
LL13	Metric2	0.000	0.003	0.000	1.000
LL13	Metric3	0.000	1.005	0.000	1.000
LL13	Metric4	0.000	0.066	0.000	1.000
LL13	Metric5	-	0.027	-	1.000
LL13	Metric6	0.000	0.005	0.000	1.000
LL13	Metric7	0.000	0.024	0.000	1.000
LL13	Metric8	0.000	5.935	0.000	1.000
LL13	RMetric1	0.000	1.524	0.000	1.000
LL13	RMetric2	-	0.472	-	1.000
LL13	RMetric3	-	-	-	-
LL13	RMetric4a	-	34.800	-	1.000
LL13	RMetric4b	-	322.000	-	1.000
LL13	RMetric5a	-	68.000	-	1.000
LL13	RMetric5b	-	1,403.200	-	1.000

Tukey Tests

In the following tables, means with the same letter in the columns labeled "Tukey Grouping" are not significantly different. Additionally, a 1 indicates no pair-wise difference. Zeros, indicating significant pair-wise differences are highlighted, and a note is made if at least one of the rescheduling methods shows improvement over repairing a schedule using right/left-shift with no rescheduling.

Group	Metric	Tukey Grouping		Mean	Reopt Meth	None	Re-Scheduling Max	Eff	Time	None vs Reopt
HE10	Metric4	A		0.250	None	1	1	1	1	**No diff btwn Reopt and None**
HE10	Metric4	A		0.100	max	1	1	1	1	
HE10	Metric4	A		0.100	eff	1	1	1	1	
HE10	Metric4	A		0.100	time	1	1	1	1	
HE11	Metric6	A		0.300	None	1	0	0	0	**At least one Reopt differs from None**
HE11	Metric6	B		0.113	max	0	1	1	1	Improvement
HE11	Metric6	B		0.113	eff	0	1	1	1	Improvement
HE11	Metric6	B		0.131	time	0	1	1	1	Improvement

Group	Metric	Tukey Grouping		Mean	Reopt Meth	None	Re-Scheduling Max	Eff	Time	None vs Reopt
HE11	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HE11	RMetric3	A		0.000	max	1	1	1	1	
HE11	RMetric3	A		0.000	eff	1	1	1	1	
HE11	RMetric3	A		0.000	time	1	1	1	1	
HE12	Metric6	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HE12	Metric6	A		0.000	max	1	1	1	1	
HE12	Metric6	A		0.000	eff	1	1	1	1	
HE12	Metric6	A		0.000	time	1	1	1	1	
HE13	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HE13	RMetric3	A		0.000	max	1	1	1	1	
HE13	RMetric3	A		0.000	eff	1	1	1	1	
HE13	RMetric3	A		0.000	time	1	1	1	1	
HL11	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HL11	RMetric3	A		0.000	max	1	1	1	1	
HL11	RMetric3	A		0.000	eff	1	1	1	1	
HL11	RMetric3	A		0.000	time	1	1	1	1	
HL12	Metric6	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HL12	Metric6	A		0.000	max	1	1	1	1	
HL12	Metric6	A		0.000	eff	1	1	1	1	
HL12	Metric6	A		0.000	time	1	1	1	1	
HL13	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
HL13	RMetric3	A		0.000	max	1	1	1	1	
HL13	RMetric3	A		0.000	eff	1	1	1	1	
HL13	RMetric3	A		0.000	time	1	1	1	1	
LE10	Metric1	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LE10	Metric1	A		0.000	max	1	1	1	1	
LE10	Metric1	A		0.000	eff	1	1	1	1	
LE10	Metric1	A		0.000	time	1	1	1	1	
LE10	Metric3		A	0.075	None	1	0	0	1	**At least one Reopt differs from None**
LE10	Metric3	B		0.000	max	0	1	1	1	Improvement
LE10	Metric3	B		0.000	eff	0	1	1	1	Improvement
LE10	Metric3	B	A	0.013	time	1	1	1	1	
LE10	Metric4	A		0.194	None	1	0	0	0	**At least one Reopt differs from None**
LE10	Metric4	B		0.000	max	0	1	1	1	Improvement
LE10	Metric4	B		0.000	eff	0	1	1	1	Improvement
LE10	Metric4	B		0.025	time	0	1	1	1	Improvement

Group	Metric	Tukey Grouping		Mean	Reopt Meth	None	Re-Scheduling Max	Eff	Time	None vs Reopt
LE10	Metric5	A		0.063	None	1	0	0	0	**At least one Reopt differs from None**
LE10	Metric5	B		0.000	max	0	1	1	1	Improvement
LE10	Metric5	B		0.000	eff	0	1	1	1	Improvement
LE10	Metric5	B		0.006	time	0	1	1	1	Improvement
LE11	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LE11	RMetric3	A		0.000	max	1	1	1	1	
LE11	RMetric3	A		0.000	eff	1	1	1	1	
LE11	RMetric3	A		0.000	time	1	1	1	1	
LE12	Metric6	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LE12	Metric6	A		0.000	max	1	1	1	1	
LE12	Metric6	A		0.000	eff	1	1	1	1	
LE12	Metric6	A		0.000	time	1	1	1	1	
LE13	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LE13	RMetric3	A		0.000	max	1	1	1	1	
LE13	RMetric3	A		0.000	eff	1	1	1	1	
LE13	RMetric3	A		0.000	time	1	1	1	1	
LL11	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LL11	RMetric3	A		0.000	max	1	1	1	1	
LL11	RMetric3	A		0.000	eff	1	1	1	1	
LL11	RMetric3	A		0.000	time	1	1	1	1	
LL12	Metric6	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LL12	Metric6	A		0.000	max	1	1	1	1	
LL12	Metric6	A		0.000	eff	1	1	1	1	
LL12	Metric6	A		0.000	time	1	1	1	1	
LL13	RMetric3	A		0.000	None	1	1	1	1	**No diff btwn Reopt and None**
LL13	RMetric3	A		0.000	max	1	1	1	1	
LL13	RMetric3	A		0.000	eff	1	1	1	1	
LL13	RMetric3	A		0.000	time	1	1	1	1	

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