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A parallel machine extension to aversion dynamics scheduling

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ABSTRACT

The aversion dynamics research agenda has incorporated within dispatching heuristics a number of real-world observations involving risk mitigation practices used by real schedulers. One such observation is that schedulers occasionally offload risky jobs from a primary machine to otherwise less desirable machine (older, slower) during periods of peak load to avoid the effects the risky job can have on subsequent jobs. This paper examines this situation within the proportional parallel machine environment. Safety time is used to adjust dispatching priorities of risky jobs to reflect the aversion. The effect of various safety time values on performance is studied. Robust safety time values and/or intervals are identified across a variety of experimental factors related to risk level, percent risky jobs in the job stream, and due date distribution.

1. Introduction

The gap between scheduling research and practice has inspired an area that has become known as *aversion dynamics* (McKay et al. 2000; McKay and Black, 2006). Aversion dynamics is based on empirical field studies which reveal how production schedulers incorporate aversion to risk within their daily decisions (McKay, et al. 1995; McKay, 1992). For instance, suppose a scheduler delays assigning a sensitive job to a risky machine until such time the risk subsides. An example of this situation is the period of instability shortly after a major machine upgrade or breakdown. Another example is when a scheduler delays assigning a risky job, perhaps a prototype part, to a machine due to the potential effect it can have on subsequent jobs; the prototype part could destabilize the process, machine settings, or possibly damage the machine. When these strategies are incorporated into the *aversion dynamic* heuristics, the processing time used for prioritization has been inflated beyond the nominal time to reflect the risk (a form of surrogate for the risk assessment), thus affecting sequencing decisions.

To model such risk mitigation strategies, several aversion heuristics have been developed. Averse-1, the initial heuristic, applies to sensitive jobs on risky machines in the single-machine, static arrival

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environment (McKay et al. 2000). It only considers the timeframe after the disruptive event and does a form of selective sub-optimization during the risk interval, returning to a normal state as the risk reduces. Averse-2 extended aversion dynamics to the single-machine, dynamic arrival scenario and considered the timeframe both before (proactive) and after (reactive) the disruptive event (Black et al. 2004; Black, 2001). This allowed work to be pulled ahead of the risk period to mitigate potential damage, as well as alter the sequencing after the potentially risk event. Averse-3 further extended the problem structure to reduce the potential for in-process jobs at the time of the risk event (Black et al. 2005). Other aversion dynamics heuristics have been developed as well, such as risky jobs on sensitive machines (Black et al. 2006), as opposed to sensitive jobs on risky machines. Moreover, anticipatory batch insertion has extended aversion dynamics from the sequencing environment to the lot sizing environment to study the effect of running a small test batch in advance of the main batch to absorb instability from the risk and to stabilize the process prior to running the main batch (Black et al. 2008).

Empirical studies have also shown risk aversion to be practiced within the parallel-machine environment (Aytug et al. 2005). For example, a risky job may be offloaded from a primary machine to an otherwise less desirable (e.g., slower) secondary machine to reduce the disruptive effects it can have on subsequent jobs. For example, prototype jobs often require debugging at the machine before they run efficiently. If such jobs are processed on the primary machine, they can delay subsequent jobs considerably. Offloading them to a secondary, albeit slower, machine (e.g., “prototype machine”) is often employed in practice. Consequently, this paper will extend aversion dynamics from the single-machine to the parallel-machine environment to study this situation. Performance will be examined across a variety of cases involving risk occurrence and level, “safety time” values used in job priorities, job stream composition and due date levels.

2. Literature Search

Various review papers have examined the gap between scheduling research and practice (Aytug et al. 2005; McKay et al. 2002; McKay and Wiers, 1999). A variety of machine configurations, performance measures, dispatching heuristics and arrival patterns have been developed and studied in detail. However, the application of theory in practice is still quite limited. A key reason is the lack of fidelity of the scheduling problem being modeled. Real-world production environments are not static and predictable, but rather dynamic and uncertain. Stochastic scheduling and robust/rescheduling techniques attempt to model such variability to an extent. For example, Dubois et al. (2003) and Kleijnen and Gaury (2003) examined methods for modeling uncertainty. Shafaei and Brunn (1999, 2000) examined schedule robustness measures under uncertainty. Cowling and Johansson (2002) and Ovackik and Uzsoy (1994, 1995) presented techniques for constructing robust schedules. Kanet and Sridharan (2000) and O’Donovan et al. (1999) introduced idle time/schedule slack insertion to absorb variability. However, all such research except O’Donovan et al. (1999) assumed variability is job independent and, thus, applied more to routine manufacturing noise (i.e., random variability) than to any job-dependent phenomena. As review articles have suggested, this assumption is pervasive throughout the literature with few exceptions (Aytug et al. 2005, Cao et al. 2001).

The empirically inspired area of aversion dynamics has introduced job and time dependency into the scheduling problem. Several long-term, longitudinal field studies have shown that 10-15% of scheduling decisions relate to job-dependent issues beyond routine manufacturing noise (McKay, et al. 1995; McKay, 1992). Some risks are predictable in advance (e.g., machine upgrades, engineering changes) and can be proactively addressed; other risks are unpredictable and must be reacted to (e.g., machine breakdowns). Ideally, the production environment after the risk event ends should be the same as beforehand (i.e., time independent). However, McKay, et al. (1995) showed this is often not true. For example, after a machine is repaired, it often requires further time (e.g., calibration, adjustment) until its performance is restored to 100% of its pre-event level. Further, some jobs are more sensitive to these lingering impacts than other jobs. To study this problem of sensitive jobs on risky machines, the *Averse-1* heuristic was developed for the single-machine, static-arrival environment (McKay et al. 2000). Priorities of sensitive jobs were altered after the risk event using a time-based decay principle which resulted in sensitive jobs being delayed in the sequence until such time that the potential impacts associated with the risk declined and performance was restored to its pre-event level. Results were favorable, indicating significant performance gains when the impact occurred as predicted and insignificant losses when it did not.

Although *Averse-1* introduced job dependency and time dependency, it had several limitations. It only considered the static job arrivals and the time after the risk event (i.e., lingering impacts). Consequently, the *Averse-2* heuristic was developed to consider dynamic job arrivals and the time before the risk event (Black et al. 2004; Black, 2001), thus making it possible to apply aversion dynamics in a proactive manner before a perceived risk event (e.g., re-sequencing sensitive jobs in anticipation of a pending machine upgrade). Results again indicated significant performance gains when the risk and impact occurred as predicted and insignificant losses when they did not.

Although Averse-2 attempted to minimize post-event impacts by proactively and reactively re-sequencing sensitive jobs, it made no attempt to avoid an in-process job at the time when the risk event occurs. In-process jobs result in a fragmented processing time profile. Further, they often need to be scrapped and/or the machine needs to be set up a second time for the same job after the risk event. McKay (1992) showed that schedulers seek to avoid such fragmentation in one of two ways. They may intentionally hold the machine idle when a disruption is considered imminent, or they may schedule a lower priority job to bridge the gap between the current time and predicted event time. Consequently, the *Averse-3* heuristic was developed (Black et al. 2005). Linear and exponential priority reduction profiles and a logical constraint were examined in an attempt to minimize in-process jobs. Results showed that fragmentation can be significantly reduced with only minimal impact on weighted tardiness performance.

Aversion dynamics research next considered the complementary problem, namely risky jobs on sensitive machines. Here, the jobs themselves are the risk entities (instead of the machine). Real schedulers have been observed to be averse to scheduling risky jobs on highly loaded (sensitive) machines (Aytug et al. 2005), instead preferring to:
Case 1: Schedule them during quieter (more lightly loaded) periods, or
Case 2: Offload them to an otherwise less desirable machine (e.g., older, slower machine).

Case 1 pertains to the single-machine environment and was investigated by Black et al. (2006). “Safety time” was used to adjust job priorities of risky jobs in order to smooth the effects of processing time variability. Robust safety time values were identified for various objective functions (maximum tardiness, weighted flow time and weighted tardiness) and various experimental conditions related to risk level and due date distribution.

Case 2 pertains to the parallel machine environment and is the subject of this paper. The methodology used to implement this research is discussed in the next section.

3. Methodology

This paper considers a 2-machine proportional parallel machine configuration with a “fast” machine and “slow” machine. The fast machine is the primary machine used to run product. The slow machine is a secondary machine used to supplement the fast machine during periods of high load and also to accommodate risky jobs whenever the schedule is tight. The objective is to examine how various attributes related to job risk, job stream composition and due date affect weighted tardiness performance. Specific variables and settings appear in Section 4.

Parallel machine models require not only sequencing decisions, but routing decisions as well. Fortunately, this particular configuration can be simplified by taking advantage of the fact that there is really just one input queue whose priority sequence needs to be determined to solve the problem (Morton and Pentico, 1993). There exists an optimal solution of the following form: sequence the *n* jobs in an optimal order in a list (method for obtaining the optimum order has not yet been specified) and, in turn, assign each job to the machine that can finish it first.

The methodology used to implement this logic within the static arrival, non-preemptive case is as follows. At each sequencing decision point (i.e., when a machine is empty), assign the highest priority job to the machine that will finish it first. Obviously, if the fast machine is empty, assign the job to it since, by definition, it will always finish it first. However, if the slow machine is empty, it may or may not be able to finish that job first due to the speed differential between the (currently busy) fast machine and the (currently empty) slow machine. In such cases, it is necessary to make a series of temporary job assignments to the fast machine until we find the first job that will finish on the slow machine first. Job priorities are recomputed at each decision point and after each temporary assignment. Once the first job is found that will finish first on the slow machine, it is permanently assigned to the slow machine, all temporary assignments are deleted, and the process is repeated to find the next job to include in the sorted list.

Job priorities are computed using the R&M dispatching rule (Morton et al. 1995; Morton and Pentico, 1993). Also called the "Apparent Tardiness Cost" rule, R&M is a composite rule combining the weighted shortest processing time (WSPT) rule with an additional term used to modify job priority as a function of processing time slack. Since R&M results in dynamic job priorities, it has been shown to be effective in dynamic situations involving job risk that changes over time (Morton et al. 1995; Morton and Pentico, 1993). R&M has the following form:

$$\pi_j = (w_j / p_j^*)\, e^{-S_j^+ / kp_{ave}} \quad . \tag{1}$$

The first term, $\pi_j = (w_j / p_j^*)$, is simply the WSPT rule in which p_j^* represents the planning (estimated) processing time of job j and w_j reflects its weight. R&M appends a second term, $e^{-S_j^+ / kp_{ave}}$, to consider slack. The slack $S_j^+ = \max(d_j - p_j^* - t, 0)$ for each job at time t reflects its urgency relative to its due date d_j. If job j has negative slack, meaning it will be tardy even if selected next, then $S_j^+ = 0$ and R&M reduces to WSPT. However, if $S_j^+ > 0$, then its job priority is exponentially reduced as a function of slack. p_{ave} is the average processing time of all jobs, and k is a tuning parameter empirically derived based upon due date tightness.

We model the scheduler's aversion to risky jobs by applying a *safety time* (ST) factor for prioritization purposes which, in turn, inflates the job processing times used for prioritization (Eq. 1) beyond their nominal times (of course, *actual* processing times are used to drive the simulation). Thus, the final processing time p_j^* used in Eq. 1 for prioritization is as follows:

$$p_j^* = p_j\,[1 + (1 + ST)\,r_j] \tag{2}$$

r_j is the mean risk level. Parameter settings for these variables are provided in the next section.

The objective of this paper is to study and identify robust safety time values for use across a variety of cases involving the experimental factors and risk materialization scenario.

4. Experimental Design

Discrete-event simulation is used to generate the experimental data. The design consists of 4 x 2 x 3 x 3 x 21 = 1512 cases with each case replicated 250 times to provide robust estimates. Specifically, there are four major experimental cases investigated:

- Case 1: Risk-adjusted times (i.e., safety time) used in job prioritization, and the risk actually materializes.
- Case 2: Risk-adjusted times used in job prioritization, but risk does *not* materialize.
- Case 3: Risk-adjusted times *not* used in job prioritization, and risk does *not* materialize.
- Case 4: Risk-adjusted times *not* used in job prioritization, but risk does materialize.

Two mean risk levels r_j are examined: 0.5 for low risk and 2.0 for high risk (non-risky jobs have a risk level of zero).

Three levels (percentage) of risky job levels are examined: 10%, 30% and 50% of the job stream contain "risky" jobs subject to processing time risk. The scheduler is assumed to know which jobs are risky and which jobs are not risky. A 25-job stream is used in all cases.

Three tardiness factor (*TF*) levels are studied: 0.1, 0.4 and 0.7. *TF* represents the expected proportion of tardy jobs (e.g. 40% of jobs expected tardy when *TF* = 0.4). After nominal processing times p_j are generated for each job from a normal distribution with mean 20 and standard deviation 5, the mean of the due date distribution DD_{MEAN} is computed as $(1-TF)*\sum p_j^*$ where $\sum p_j^*$ is the sum of the processing times (i.e., expected makespan). Individual job due dates d_j are then generated from a normal distribution centered at DD_{MEAN}.

21 safety time factors (*ST*) ranging from − 1.0 to +3.0 (in 0.2 increments) are studied. As stated, *ST* is a factor used to model risk aversion behavior. High *ST* values are used when high aversion exists. *ST* = -1.0 corresponds to prioritizing jobs using only their nominal processing times (i.e., no risk aversion). *ST* = 0 corresponds to prioritizing jobs using the mean risk level (e.g., at r_j = 0.5 or 2.0 mean risk levels). *ST* > 0 corresponds to utilizing additional risk time in job prioritization, such as when a scheduler is highly averse to particular risky jobs. Note *ST* only affects priorities for risky jobs; non-risky jobs are prioritized using only their nominal times.

The fast machine is considered to be twice the speed of the slow machine. The performance objective used is weighted tardiness. Job weights are generated from a normal distribution with mean 40 and standard deviation 10.

5. Results and Discussion

Appendix A contains the experimental results. Inner values represent total weighted tardiness across 250 replications for each factor combination. We begin by searching for robust safety time values (*ST*) in aggregate. Fig. 1 displays mean weighted tardiness results for Case 1 across the various safety time values. Recall Case 1 corresponds to when *ST* is used for job prioritization and the job risk actually materializes. Results are aggregated across all risk levels, percent risky job levels and *TF* levels. The *ST* interval yielding the best performance in aggregate is [0, 0.8] with the best value occurring at 0.6.

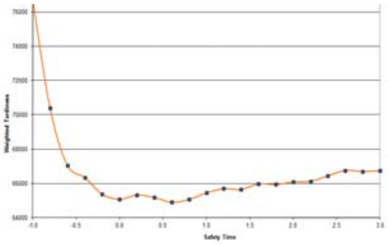

Fig. 1. Performance vs. Safety Time: Aggregate Across Factors (Risk Occurs)

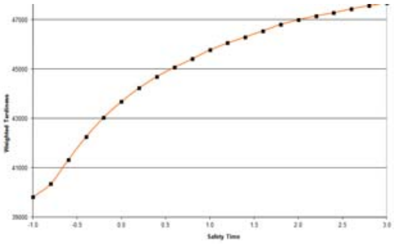

Fig. 2. Performance vs. Safety Time: Aggregate Across Factors (Risk Doesn't Occur)

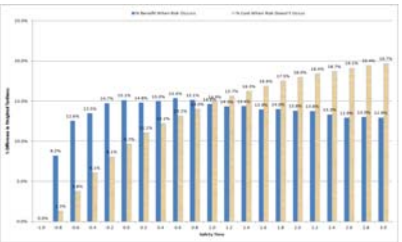

Fig. 3. Performance vs. Safety Time: Aggregate Across Factors

Fig. 2 displays total weighted tardiness results for Case 2. Case 2 corresponds to when ST is used for job prioritization, but the risk does not materialize. These results are shown primarily for confirmatory purposes since it is intuitive that, if the risk does not occur, then including no safety time should yield the best performance. Indeed, this is true since the best ST value occurs at -1.0, which corresponds to prioritizing jobs using only their nominal processing times.

Fig. 3 displays the percent performance increase (Cases 1 vs. 4) and decrease (Cases 2 vs. 3) when risk does and does not occur, respectively. These results are also aggregated across risk, percent risky jobs and tardiness factor levels. Performance gains exceeds losses within the ST interval, $[-0.8, 0.8]$, with $ST = 0.6$ yielding the highest benefit. As expected, the percentage decrease in performance (i.e., "cost") associated with using safety time when the risk does not materialize rises as ST increases. These results are consistent with Fig. 1 and Fig. 2.

Let us now examine benefit-cost tradeoffs at various ST values, which are important when uncertainty exists in whether or not the risk will occur. In such cases, the scheduler may ask, "What can I gain in performance vs. what can I lose?" Obviously, the "best" ST value will depend on the likelihood the risk will materialize. Referencing Fig. 3 at $ST = -0.8$, the benefit (13.5%) is 6.3 times greater than the cost (6.1%). For $ST = -0.4$, the benefit (8.2%) is 2.2 times greater than cost (1.3%). At $ST = 0$, benefit still exceeds cost by a factor of 1.55. Recall $ST = 0$ corresponds to prioritizing jobs using the expected risk times. For example, referencing Eq. 2, if nominal time is 20 minutes and risk level is 0.5, the expected risk time is 20 x 0.5 = 10 minutes (one-half of nominal). If risk level is 2.0, the expected risk time is 20 x 2 = 40 minutes (2 times nominal). If risk level 2.0 and $ST = 1.0$, the planned risk time is 20 x 2 x 2 = 80 minutes (4 times nominal). Consequently, although $ST = 0.6$ provides the greatest percent gain when the risk occurs, $ST =$ □0.6 or -0.8 may be "safer" values to use when uncertainty exists in whether the risk will materialize. These summary results also indicate that, when uncertainty exists, the mean performance gain when the risk occurs will significantly exceed the mean performance loss when it doesn't occur when using ST within the interval $[-0.8, 0]$ (p = 0.000035).

Thus far, we have only analyzed performance in aggregate. We now examine it at specific factor settings. Fig. 4 shows percent benefit-cost at the low risk level ($r_j = 0.5$). Here, performance gains exceed losses within a narrower ST interval $[-0.8, 0]$ than in the aggregate case. Moreover, gains and losses are lower than the aggregate case. It is interesting to note that performance gain when the risk occurs can become negative at very high ST values ($ST \geq 2.4$) implying that, under low risk, using too much safety time can result in worse performance than using none at all.

Fig. 5 shows benefit-cost relationships at the high risk level ($r_j = 2.0$). Performance gains and losses are higher than at the low risk scenario, which is intuitive. Also, gains exceed losses within a wider ST interval, $[-0.8, 1.0]$ than the low risk and aggregate scenarios.

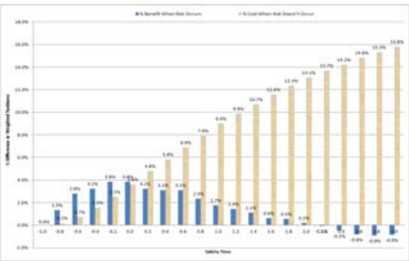

Fig. 4. Performance vs. Safety Time: Low Risk Level

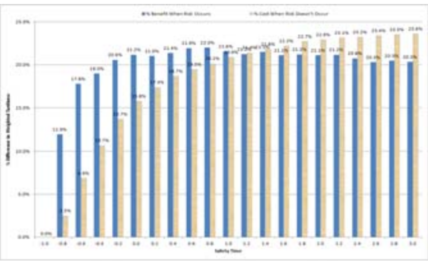

Fig. 5. Performance vs. Safety Time: High Risk Level

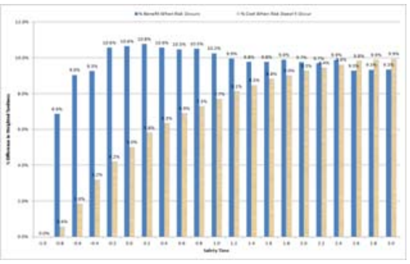

Fig. 6. Performance vs. Safety Time: 10% Risky Jobs Level

Figs. 6-8 display benefit-cost relationships at the three percent risky job levels, 10%, 30% and 50%, respectively. Performance gains and losses are lowest when only 10% of the jobs are risky (on average) and highest when 50% of the jobs are risky, which again is intuitive. However, it is interesting to note the *ST* interval within which gains exceed losses is much wider for 10% risky jobs than for 30% or 50%. At 10% risky jobs, gains exceed losses for any *ST* $\leq$ 2.4. Again, the “best” ST value to use will depend upon the likelihood the risk will materialize.

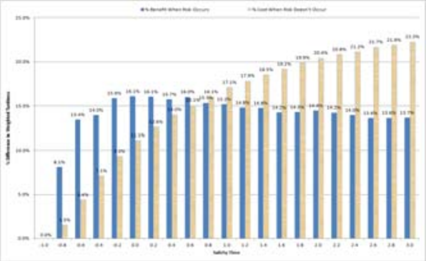

Fig. 7. Performance vs. Safety Time: 30% Risky Jobs Level

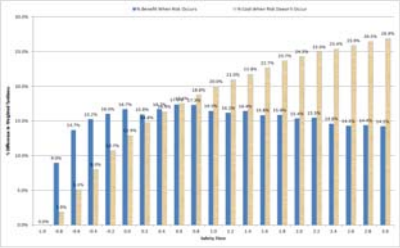

Fig. 8. Performance vs. Safety Time: 50% Risky Jobs Level

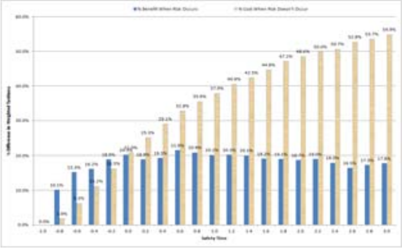

Fig. 9. Performance vs. Safety Time: 0.1 Tardiness Factor Level

Figs. 9-11 display benefit-cost relationships at the three tardiness factor levels, 0.1, 0.4 and 0.7, respectively. In these cases, performance gains and losses are highest under the lowest TF setting (0.1), which is intuitive since more slack exists in the schedule relative to due dates for the R&M rule to re-sequence jobs. However, the *ST* interval within which gains exceed losses is much wider at the 0.7 level (70% tardy jobs on average) than at either the 0.1 or 0.4 levels.

Although weighted tardiness performance has been the focus thus far, we conclude this section by examining the rate at which risky jobs are offloaded to the slow machine. Fig. 12 displays the percent risky jobs processed on the slow machine in the scenarios when safety time is/is not utilized in priority assignments (Cases 1 and 4). In aggregate across all factors, 34.2% of risky jobs are offloaded to the slow machine when safety time was not used (and the equivalent case when ST = − 1). This result is intuitive given the 2:1 speed advantage of the fast machine (i.e., 1/3 of jobs on slow machine and 2/3 jobs on fast machine to balance makespan). When safety time is used, the percent risky jobs assigned to the slow machine increases to 40-45%, depending on safety time.

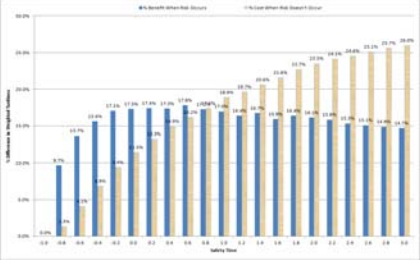

Fig. 10. Performance vs. Safety Time: 0.4 Tardiness Factor Level

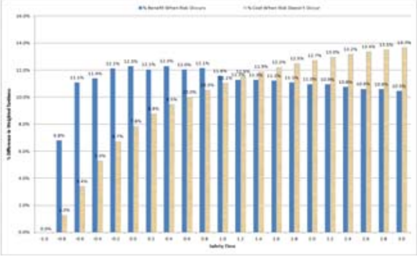

Fig. 11. Performance vs. Safety Time: 0.7 Tardiness Factor Level

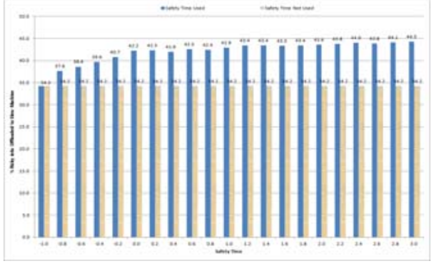

Fig. 12. Percent Risky Jobs on Slow Machine vs. Safety Time: Aggregate Across Cases

Although graphs at specific risk, percent risk job and tardiness factor settings are not shown, the 40-45% rate is fairly consistent across those levels. This rate is reasonable given the proposition used to load the machines (Morton and Pentico, 1993) whereby the highest priority job is assigned to the machine expected to finish it first. Risky jobs are only shifted to the slow machine during times when the schedule is tight (i.e., peak load) and job slack is low.

6. Conclusion and Future Directions

This paper has extended the aversion dynamics research agenda from the single-machine environment to the parallel, proportional two- machine environment to study the effects of empirically observed risk mitigation strategies associated with offloading perceived risky jobs onto a secondary machine. A theoretical proposition (Morton and Pentico, 1993) was used to load the highest priority job on the machine that was expected to finish it first, and the R&M bottleneck dynamics-based heuristic (Morton et al. 1995; Morton and Pentico, 1993) was used to compute job priorities. Four major cases were considered relative to the risk materializing or not and relative to whether or not safety time was applied to processing times within the R&M rule to model risk aversion. Within each major case, two risk levels, three percent risky job levels and three tardiness factor levels were examined across a wide range of potential safety time values. Results indicated that performance gains achieved when risk materializes exceeds performance losses when risk does not materialize within specific safety time intervals. Performance gains and losses were highest at the high risk, high percent risky jobs and/or low tardiness factor settings. Moreover, the *ST* interval within which gains exceed losses is widest at the high risk, low percent risky jobs and/or high tardiness factor settings. Lastly, we examined the percentage of risky jobs that were offloaded to the slow machine. Results indicated a substantially higher percentage of risky jobs were assigned to the slow machine when safety time was used, thus validating the intended risk aversion behavior under consideration.

Future directions in aversion dynamics research can take on various forms (McKay and Black, 2006; McKay, et al. 2002). The subject of this paper, the parallel machine environment, can be extended to consider more than the two machines with multiple speed factors. Further, these concepts can be extended to the general job shop or flow shop environments. Moreover, machine risk can be considered as opposed to job risk, thus placing the focus on specific machines as opposed to specific jobs. Furthermore, extensions to the anticipatory batch insertion research agenda can be pursued as detailed in Black, et al. (2008).

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Appendix A: Summary of Experimental Results

				ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST
Case	Risk	% Risky	TF	-1.0	-0.8	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
1	0.5	10%	0.1	10701	10487	10362	10348	10453	10294	10445	10387	10611	10524	10586	10862	10934	10973	11061	11180	11219	11261	11413	11488
1	0.5	10%	0.4	37917	37369	37143	37000	36310	36263	36325	36513	36576	36793	36978	37163	37287	37277	37235	37321	37339	37552	37547	37562
1	0.5	10%	0.7	84994	84646	83452	83738	83265	83441	83510	83676	83643	83733	84107	84312	84477	84575	84636	84706	84832	84827	85058	85053
1	0.5	30%	0.1	15820	16205	15623	15701	15443	15597	16075	16165	15945	16475	16869	16813	16790	16745	17012	17063	17246	17317	17081	17144
1	0.5	30%	0.4	46205	45030	44314	44002	44462	43902	44436	44458	44856	45307	45849	46051	46267	46536	46507	46887	46830	46781	46794	46888
1	0.5	30%	0.7	95713	94429	93763	93166	92322	92418	92559	92721	92899	93323	94162	94427	94560	95040	95211	95090	95481	95765	96207	96489
1	0.5	50%	0.1	24282	23623	23043	22650	22518	22490	23117	23661	23239	23978	23796	23521	23366	23843	23968	24231	24091	24550	24938	24695
1	0.5	50%	0.4	57720	56588	55313	55050	53749	54427	55151	54947	54881	55604	55839	55696	55638	56496	55871	56161	57006	57370	57796	57957
1	0.5	50%	0.7	108569	107172	105485	104786	104875	104559	104796	104461	104371	104979	105357	106214	107267	107476	107790	108429	108220	108896	109069	109051
1	2.0	10%	0.1	22494	19440	19317	18867	18472	18298	17666	17573	17269	16893	16972	17044	17133	16949	16755	16939	16937	16156	17513	17251
1	2.0	10%	0.4	54306	46147	44346	44359	42282	42146	42036	42632	42791	42900	43013	43187	43365	43358	43087	43070	43061	42992	43169	43169
1	2.0	10%	0.7	102512	93380	90025	89648	89105	89156	89232	89086	89271	89232	89208	89240	89173	89212	89229	89229	89229	89222	89222	89222
1	2.0	30%	0.1	52757	47418	41646	41542	39153	37836	36979	37782	37461	38787	37556	38397	38466	39208	39400	38368	38197	38654	39656	39092
1	2.0	30%	0.4	90358	78596	72252	71965	68166	68795	68528	68760	67588	67338	67597	67718	67525	68128	67476	67567	67868	68083	68428	68501
1	2.0	30%	0.7	144732	127762	118173	117007	115354	115396	115487	115573	115482	116001	115886	116241	116155	116466	116255	116232	116553	116772	116785	116720
1	2.0	50%	0.1	95223	81654	77539	76359	73388	71810	75137	72950	68972	68275	70721	69697	70058	71182	70855	72090	71477	73540	74261	73229
1	2.0	50%	0.4	140851	122317	115619	108194	109517	107960	106574	105943	104559	105725	105558	107464	105792	107521	107235	107490	107540	109058	109207	109715
1	2.0	50%	0.7	194955	174421	159445	159832	157882	156585	157737	156020	157737	155376	158026	158463	157446	156631	157300	157627	157147	157306	157568	157500
2	0.5	10%	0.1	7742	7732	7768	7829	7873	7918	8016	8057	8178	8342	8430	8517	8737	8926	8950	9120	9180	9272	9418	9493
2	0.5	10%	0.4	32676	32702	32741	32872	33050	33242	33475	33751	33934	34231	34470	34666	34905	35132	35237	35515	35618	35817	35926	36004
2	0.5	10%	0.7	79036	79031	79286	79530	79872	80231	80718	81115	81423	81678	81979	82345	82646	82831	82952	83203	83335	83492	83618	83667
2	0.5	30%	0.1	7742	7782	7788	7935	8087	8269	8473	8681	8981	9110	9299	9447	9671	9951	10129	10315	10555	10655	10894	11061
2	0.5	30%	0.4	32676	32709	32904	33287	33674	34185	34679	35145	35600	36146	36747	36926	37368	37812	38238	38677	38889	39088	39382	39607
2	0.5	30%	0.7	79036	79222	79681	80392	81124	81989	82912	83742	84460	85224	85985	86706	87272	87736	88086	88439	88869	89164	89574	89773
2	0.5	50%	0.1	7742	7751	7859	7992	8089	8292	8464	8584	8817	8969	9201	9408	9503	9745	9961	9995	10257	10322	10623	10752
2	0.5	50%	0.4	32676	32765	33062	33371	33790	34430	34918	35326	35883	36502	37050	37475	37730	38221	38819	39212	39512	39838	40145	40564
2	0.5	50%	0.7	79036	79265	79830	80660	81754	82683	83830	84788	85696	86555	87430	88261	88834	89463	90225	90679	91188	91645	91966	92381
2	2.0	10%	0.1	7742	7873	8178	8737	9180	9635	10033	10274	10606	10702	10724	10839	10858	10938	11001	10913	10961	10966	10915	10881
2	2.0	10%	0.4	32676	33050	33934	34905	35618	36085	36499	36705	36985	37050	37295	37520	37515	37657	37792	37790	37854	37788	37967	37967
2	2.0	10%	0.7	79036	79872	81423	82646	83335	83761	84057	84174	84265	84313	84393	84455	84476	84500	84510	84510	84510	84536	84536	84536
2	2.0	30%	0.1	7742	8087	8981	9671	10555	11195	11794	12334	12755	13015	13294	13584	13791	13881	14113	14229	14172	14177	14334	14315
2	2.0	30%	0.4	32676	33674	35600	37368	38889	39888	40672	41454	41895	42291	42829	43158	43315	43497	44019	44182	44304	44403	44549	44568
2	2.0	30%	0.7	79036	81124	84460	87272	88869	90003	90585	91038	91238	91470	91617	91739	91798	91865	91909	91916	91924	91992	91990	91993
2	2.0	50%	0.1	7742	8089	8817	9503	10257	10904	11421	12029	12373	12841	13128	13508	13624	13810	14204	14446	14533	14620	14777	14884
2	2.0	50%	0.4	32676	33790	35883	37730	39512	40720	41848	42939	43441	43931	44687	44882	45695	46093	46509	46788	47220	47272	47325	47645
2	2.0	50%	0.7	79036	81754	85696	88834	91188	92770	93743	94306	94680	94972	95251	95483	95557	95736	95814	95824	95830	95912	95922	95967

				ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST	ST
Case	Risk	% Risky	TF	-1.0	-0.8	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
3	0.5	10%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	0.5	10%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	0.5	10%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
3	0.5	30%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	0.5	30%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	0.5	30%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
3	0.5	50%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	0.5	50%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	0.5	50%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
3	2.0	10%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	2.0	10%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	2.0	10%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
3	2.0	30%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	2.0	30%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	2.0	30%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
3	2.0	50%	0.1	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742	7742
3	2.0	50%	0.4	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676	32676
3	2.0	50%	0.7	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036	79036
4	0.5	10%	0.1	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701	10701
4	0.5	10%	0.4	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917	37917
4	0.5	10%	0.7	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994	84994
4	0.5	30%	0.1	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820	15820
4	0.5	30%	0.4	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205	46205
4	0.5	30%	0.7	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713	95713
4	0.5	50%	0.1	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282	24282
4	0.5	50%	0.4	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720	57720
4	0.5	50%	0.7	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569	108569
4	2.0	10%	0.1	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494	22494
4	2.0	10%	0.4	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306	54306
4	2.0	10%	0.7	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512	102512
4	2.0	30%	0.1	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757	52757
4	2.0	30%	0.4	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358	90358
4	2.0	30%	0.7	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732	144732
4	2.0	50%	0.1	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223	95223
4	2.0	50%	0.4	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851	140851
4	2.0	50%	0.7	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955	194955