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**Non-Exhaustive Family Based Dispatching Heuristics –  
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# Non-Exhaustive Family Based Dispatching Heuristics – Exploiting Variances of Processing and Set-Up Times

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## ABSTRACT

Group Technology exploits similarities in product and process design to effectively meet the diversity of customer demand. In this paper we consider one of the implementations of this concept – heuristics for family based dispatching. Intrinsic to family based dispatching is the grouping of similar types of products for joint processing. Hence the number of set-ups may be reduced. Consequently, lead-time performance of the shop can be improved. Unfortunately, variances of processing and set-up times – as found in practice – have received little attention in heuristics' construction and testing. To address this issue we propose several new, non-exhaustive heuristics. Whereas existing exhaustive heuristics set batch contents equal to all products available for a family, non-exhaustive heuristics allow for switching families, even when the current family queue is not empty. An extensive simulation study shows how this flexibility in batch composition improves shop performance, especially in case of high variances of processing and set-up times.

## KEY WORDS

Family based dispatching, Group Technology, Simulation

*Non-Exhaustive Family Based Dispatching Heuristics***1 INTRODUCTION**

Companies nowadays try to meet customers' demands, the competition, and their own performance standards, by redesigning their plants according to the lean manufacturing concept. Essentially, this concept aims at flexible and efficient manufacturing systems by reducing waste in all forms, such as, production of defective parts, excess inventory, unnecessary processing steps, and unnecessary movements of people or materials (Womack et al. 1990, Goldman et al. 1995). Group Technology (GT) may enable waste reduction by exploiting similarities in product and process design to effectively meet the diversity of customer demand. Motivated by several case studies (Nomden and Slomp 2006, Bokhorst et al. 2008, Nomden and Van der Zee 2008, Nomden et al. 2008) we address GT by studying one of its implementations, i.e., family based dispatching heuristics for shop floor control.

Family based dispatching rules strive to improve lead time performance by reducing set-up time. This is realised by grouping products that share similar requirements with respect to system set-up, i.e. families, for joint dispatching (Vaithinathan and McRoberts 1982). The application of these rules is considered particularly beneficial in small batch discrete parts manufacturing (Hyer and Wemmerlov 2002, Wisner and Sifer 1995). In these environments frequencies of set-ups tend to be high, while set-up times may be lengthy.

Clearly, exploiting similarities in set-up requirements may present a good starting point in decomposing the product sequencing problem. Effectively, it reduces the problem to a batch sequencing problem. This seems rewarding from the perspectives of computational efficiency, clarity of reasoning, and lead time reduction. Remainder decisions for the dispatcher concentrate on a further decomposition of batches, and their sequencing. The possibility to further decompose batches is reflected in the notion of "non-exhaustive" policies. Whereas *exhaustive policies* only change their choice of job family if there are no jobs left within the current family, *non-exhaustive policies* allow for switching to other job

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3 families, even when the current family queue is not empty (Mosier et al. 1984, Russell and  
4 Philipoom 1991, Mahmoodi and Dooley 1991, and Ponnambalam et al. 1999). In this article  
5 we will re-assess construction and evaluation of non-exhaustive family based dispatching  
6 heuristics for the single machine case.  
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12 So far, non-exhaustive heuristics tend to be rather unsuccessful in terms of flow time  
13 performance (Lockwood et al. 2000). Existing non-exhaustive heuristics, however, rely on  
14 static parameters, in terms of pre-set time fences (Russell and Philipoom 1991) or batch sizes  
15 (Mosier et al. 1984, Ruben et al. 1993), or link the choice of batch size to queue length at the  
16 decision moment (Mosier et al. 1984). They do not consider local data on processing times in  
17 their decision to split a batch. This is surprising, as exploiting such information seems  
18 worthwhile in case variance of processing times is significant. After all, under these  
19 circumstances, isolating a partial batch of products with short processing times within a  
20 product family, may enable an early start for another product family.  
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34 As far as heuristics' testing is concerned, the distributions of processing and set-up times  
35 are not included as experimental factors in most of the studies (Frazier 1996). Moreover,  
36 coefficients of variation of the chosen distributions may differ significantly over the studies.  
37 This is surprising, as batch priority setting for family based dispatching heuristics strongly  
38 relies on set-up times and processing times (Frazier 1996, Nomden et al. 2008). Obviously,  
39 this may hinder a fair comparison of rules, and – hence – an adequate guidance in rule  
40 selection.  
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50 In conclusion, we observe how variances in processing and set-up times are hardly  
51 exploited in rule construction and testing. We address the issue by proposing several new  
52 non-exhaustive heuristics for the single machine case. Rule development and testing is  
53 supported by an extensive simulation study. The study is meant to demonstrate the potential  
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of the new and existing heuristics for a large variety of system configurations, including alternative distributions for processing and set-up times.

The paper is structured as follows. In Section 2, we review existing heuristics for family based dispatching. In Section 3 we discuss shop characteristics, and introduce a decision framework for its control. The framework is used as a generic format for describing heuristics for family based dispatching in terms of an ordered set of decisions. Next, we design an extensive simulation study for evaluating the potential of the new and existing heuristics, and analyze the results. Finally, main conclusions are summarized in Section 6.

## 2 LITERATURE REVIEW

Scheduling with set-up times plays an important role in today's manufacturing and service environments. This has also been reflected in research, where the notion of set-up times has received significant attention. It is recognized that processing items with similar manufacturing requirements consecutively can improve flow performance significantly. As such setup reduction should be included in continuous improvements programs in manufacturing and service industry (Allahverdi and Soroush 2008).

So far, the main focus has been on the deterministic rules, which start from the idea that all jobs are known beforehand. For an overview, see Allahverdi et al. (1999, 2008). Unfortunately, practice often requires a dynamic approach that is capable of dealing with limited information, and allows for regular updates of the job list. Moreover, rules should allow for timely answers. Analytic approaches, like those implemented for deterministic rules, often do not work out under these circumstances, due to problem size, and complexity. Therefore, one often relies on heuristic approaches (McKay et al. 1988, Stuber 1998).

In this section we will review literature for family based dispatching heuristics. More specifically, we will consider those heuristics, which adopt the minimization of mean flow

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3 time per job as an objective. Overviews of heuristics adopting alternative, due date related,  
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time per job as an objective. Overviews of heuristics adopting alternative, due date related, criteria, can be found in Frazier (1996), and Nomden et al. (2006).

Family based dispatching starts from the idea that products can be grouped in families based on their similarities with respect to set-up requirements. As such it is linked to Group Technology, in particular Virtual Cellular Manufacturing (VCM). VCM starts from the idea that grouping efficiencies can be realized using family-oriented scheduling/dispatching rules, instead of physical rearrangements of machinery on the shop floor – as in Cellular Manufacturing (Nof 1982, Kannan and Ghosh 1996, Nomden et al. 2006).

Family based dispatching heuristics may be characterized by three ordered decisions (Mosier et al. 1984):

- (a) When to select a new family of jobs for servicing.
- (b) Which of the families to select – assuming the decision to change has been made, cf. (a).
- (c) Which job is to be selected from the chosen queue.

Alternative heuristics for family based dispatching are characterized by their choice of rules for implementing each decision.

Most heuristics for family based dispatching may be classified as exhaustive, i.e., they *select a new family* at the moment the queue for the current family is empty. Alternatively, several authors study the relevance of non-exhaustive heuristics, which allow switching families, even when the queue for the current family is not empty. Mosier et al. (1984) supply two examples of truncation rules for non-exhaustive family based dispatching, Highest AVErage priority over all families (AVE) and ECONomic trade-off between changing queues (ECON). AVE restricts process batch size for a family to the number in queue at the time of its

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3 selection. ECON allows for family selection after every job completes processing. Its  
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5 decision builds on a comparison of queue lengths and expected set-up times for the current  
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7 and alternative families. Mosier et al. show how AVE is outperformed by ECON and an  
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9 exhaustive heuristic. Several authors, however, report poor performance for ECON (Frazier  
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11 1996, Mahmoodi et al. 1992, Russell and Philipoom 1991). Ruben et al. (1993) modify  
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13 ECON by including a threshold value on queue length. This modified rule is also beaten by  
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15 an exhaustive rule. i.e., the Minimum Set-Up Shortest Processing Time heuristic (MSSPT).  
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17 However, in their concluding remarks Ruben et al. suggest an undeveloped potential for non-  
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19 exhaustive heuristics, by mentioning that “other non-exhaustive group scheduling heuristics  
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21 with more sensitive switching procedures could overcome some of the weaknesses.”  
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27 Russell and Philipoom (1991) consider several truncation rules for batch formation. Next  
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29 to due date related truncation rules, they discuss a rule introduced by Sawicki (1973).  
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31 According to this rule the processing family is changed when either a specified amount of  
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33 time has elapsed or the family is exhausted. However, they realize best results for an  
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35 exhaustive heuristic. Mahmoodi and Dooley (1991), and Ponnambalam et al. (1999) study  
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37 truncation rules for job shop environments. Unfortunately, the non-exhaustive heuristics  
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39 studied primarily address due date related criterions. This hinders their fair comparison for  
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41 flow time performance.  
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48 In a recent article (Nomden et al. 2008) we give an overview of existing *priority rules for*  
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50 *family selection* adopting a flow time criterion. A basic rule, often used as a benchmark, is the  
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52 First Come FAMily rule (FCFAM), see Flynn (1987). This rule shows similarities with the  
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54 well-known First Come First Serve rule (FCFS). It prioritizes families by considering the  
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56 earliest entry moment of the jobs available in queue for a family. Most definitions for family  
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58 priority setting aiming at flow time performance can be related to the concept of the weighted  
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3 shortest processing time rule (WSPT). This well-known dispatching rule sequences jobs by  
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5 considering workload for a job relative to its weight (see, for example, Pinedo 1995). For  
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7 family based dispatching this concept is extrapolated towards composite jobs, i.e., the sets of  
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9 jobs available for specific families. Alternative rules differ with respect to the way workload  
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11 for a batch is estimated and weighted, using data on set-up times, processing times, and queue  
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13 lengths. Nomden et al. (2008) test the potential of large number of heuristics for a wide range  
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15 of shop configurations. Among others, their study confirms earlier results (Jensen et al. 1998,  
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17 Shambu et al. 1996) suggesting that no single rule performs best over all configurations.  
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21 Starting from the single machine case, priority rules have been extended to deal with  
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23 forecast data on future jobs (Kannan and Ghosh 1996; Mahmoodi and Martin 1997; Reddy  
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25 and Narendran 2003; Nomden et al. 2008), and parallel machines (Kannan and Ghosh 1996;  
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27 Jensen et al. 1996, 1998).  
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31 Typically, conventional dispatching rules like First Come First Serve (FCFS), Shortest  
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33 Processing Time (SPT), Earliest Due Date (EDD) etc. are used to *choose among individual*  
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35 *jobs*, see Blackstone et al. (1982) or Chang et al. (1996) for overviews.  
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43 From our literature review we derive two observations:  
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- 45 • The best policy for batch formation studied so far is an exhaustive strategy. This strategy  
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47 suggests selecting a new family at the moment the queue for the current family is empty.  
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49 Alternative, non-exhaustive, strategies tend to rely on static decision parameters, i.e.,  
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51 threshold values for queue length or family related time fences, and/or do not exploit  
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53 local information in batch formation. More specifically, they do not attempt to make good  
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55 use of information on processing times for products in queue.  
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- Wemmerlov (1992) indicates that variance of processing times is an important determinant for the success of family based dispatching heuristics. Quite surprisingly, we found no evidence of more recent studies including alternative distributions for processing times as an experimental factor, also see Frazier (1996), Shambu et al. (1996). Moreover, settings for this factor tend to differ significantly over the studies, implying coefficients of variation for processing times ranging from, for example, nearly zero (Kannan and Ghosh 1996), to one (Jensen 1998). Similar comments can be made with respect to the coefficient of variation for the set-up times. Clearly, this may hinder a fair and adequate testing and comparison of rules. Hence, opportunities arise for improving guidance for the dispatcher in his choice of heuristics for family based dispatching.

In this article we seek to exploit variances of processing and set-up times in family based dispatching. We address this issue in two ways by:

- Proposing several new non-exhaustive heuristics addressing the single machine case.
- Testing the new and existing heuristics for a wide range of configurations. More specifically, we consider variances of processing and set-up times as experimental factors.

### **3 FAMILY BASED DISPATCHING HEURISTICS**

In this section we describe characteristics of the single machine shop, and define a decision framework for shop control. In line with Mosier et al. (1984) the framework captures the general structure of the control system for family based dispatching in terms of an ordered set of decisions, cf. Section 2. It is meant to clarify the way existing and new heuristics are composed of alternative rules for implementing the respective decisions. An overview of the notation and the heuristics introduced in this section, can be found in Appendices A and B.

*Non-Exhaustive Family Based Dispatching Heuristics***3.1 Shop description**

The shop consists of a single machine and a buffer. Incoming products are stored in the buffer until the time they are released to the machine and processed. We associate each job with a single product. The buffer is assumed to have an unlimited storage capacity. Each job belongs to a certain family  $j \in J$ . Total number of jobs in queue for each family  $j$  equals  $q_j$ . Each product family requires a specific, sequence dependent, machine set-up. This so-called major set-up is associated with a set-up time  $s_{j_0,j}$ . Length of the set-up time is determined by the current set-up – for family  $j_0$  – and the required set-up for family  $j$ . Obviously,  $s_{j_0,j} = 0$  for  $j = j_0$ . Product related, so-called minor set-ups, are assumed to be included in job processing times ( $p_{i,j}$ ), with  $i$  identifying individual jobs being available within a family  $j$ .

**3.2 A decision framework**

Let us now discuss a framework for family based dispatching. The framework relates rule construction for family based dispatching heuristics to the decision hierarchy suggested by Mosier (1984), see Section 2. As an objective we consider the minimisation of mean flow time per job in the long run. Given  $N$  processed jobs, mean flow time per job ( $MFT$ ) is defined as:

$$MFT = \frac{\sum_{j \in J} \sum_{i=1,2,\dots} ft_{i,j}}{N} \quad [1]$$

with

$$ft_{i,j} = w_{i,j} + p_{i,j}$$

$$N = \sum_{j \in J} \sum_{i=1,2,\dots} 1$$

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In computing flow time for a job  $i$  belonging to family  $j$  ( $ft_{i,j}$ ) we distinguish between waiting time ( $w_{i,j}$ ) and job processing time ( $p_{i,j}$ ). Note how waiting time includes set up times ( $s_{j_0,j}$ ).

In line with Mosier et al. (1984), our decision framework distinguishes between three ordered decisions:

- (a) When to reconsider job family selection for servicing, i.e. decision moments.
- (b) Which of the families to select, i.e. family priority setting.
- (c) Which job is to be selected from the chosen queue, i.e. job priority setting.

Below we will typify the decisions to be made. Moreover, we illustrate alternative choices of rules for implementing decisions, by considering existing heuristics.

#### Decision moments

Essentially, two types of events govern shop dynamics: job arrivals and job completions. As such they correspond to elementary *decision moments* ( $t_0$ ), at which a planner may be triggered to make a decision on the selection of the job family to be processed next. Next to the aforementioned moments, a planner may decide to intervene in shop operations, given, for example, new information on upcoming jobs or planning procedures (Fowler et al. 1992, Van der Zee et al. 1997, Nomden et al. 2008).

Typically, family based dispatching rules consider a subset of decision moments. *Exhaustive* policies only allow decision making in case the current job family has been processed, including job arrivals. Alternatively, *non-exhaustive* policies enable decision-making in case jobs available for the current job family have not been fully processed.

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So far, several non-exhaustive policies have been studied, see Section 2. The AVE policy (Mosier et al. 1984) relates the next moment for family selection to restrictions on batch size, i.e., queue length at the decision moment. The ECON policy (Mosier et al. 1984) allows a switch of family after every job completion. A switch is motivated by expected set-up times and queue lengths for product families. Ruben et al. (1993) modify ECON by including a threshold value on queue length. Russell and Philipoom (1991) adopt time fences for processing a specific family. After this preset time period has elapsed, a new decision is triggered. Where the trade-off in ECON includes a new choice of family, this policy does not make such a decision. Similar to the aforementioned threshold values on queue length, time fences are estimated by executing (many) test runs.

Family priority setting

Several rules for family priority setting have been developed. Nomden et al. (2008) show how most of these rules may be related to the concept of the Weighted Shortest Processing Time Rule (WSPT), see Pinedo (1995). An important example of such a rule is adopted by the exhaustive Minimum Average Set-up and Processing time rule (MASP) heuristic, see (Russell and Philipoom 1991). According to this rule, system set-up is related to the choice of family  $j^*$  for which a minimum weighted workload is foreseen. Hereby workload is estimated by the sum of family set-up time ( $s_{j_0,j}$ ) and cumulative processing time ( $\sum p_{i,j}$ ).

Weights are related to queue length ( $q_j$ ):

$$j^* = \arg \min_{j \in J; q_j > 0} \frac{s_{j_0,j} + \sum_{i=1}^{q_j} p_{i,j}}{q_j} \quad [2]$$

Alternative rules following the WSPT scheme are typically found by leaving out shop data from the above equation. For example, priority rules for the MAP, and MAS heuristics

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(Mosier et al. 1984, Nomden et al. 2008) can be found by omitting set-up times, and processing times respectively. Finally, we mention the FCFAM rule (Flynn 1987). It prioritizes families by considering the earliest entry moment ( $t_{i,j}$ ) of the jobs ( $i$ ) available in queue for a family ( $j$ ). Similar to the well-known FCFS rule, this rule is often used as a benchmark:

$$j^* = \arg \min_{j \in J; q_j > 0} t_{i,j} \quad [3]$$

Job priority setting

The job release order typically follows conventional dispatching rules, such as, the First Come First Serve rule (FCFS) and the Shortest Processing Time rule (SPT). In line with the objective best performance is realized by applying the SPT rule (Wemmerlov 1992).

For the single machine case Nomden et al. (2008) showed how the heuristics MASP, and MAS performed best over a wide range of configurations. Although both rules indicate the same performance for many settings, MASP tends to outperform MAS in case of low set-up to run-time ratios, while MAS shows better performance in case of high set-up to run-time ratios and high system utilization. The good performance of MAS – despite being less informed – indicates that under these circumstances set-up efficiencies should be preferred over short term gains, i.e., short processing times. Similar observations have been made for the field of parallel batching, see, for example Fowler et al. (1992), Weng and Leachman (1993), and Van der Zee (2004, 2007).

**3.3 New heuristics**

Starting from the decision framework defined above, we introduce three new non-exhaustive heuristics. All three heuristics are extensions of the exhaustive MASP heuristic, see above.

*Non-Exhaustive Family Based Dispatching Heuristics*MASP\_GA

The GAted Minimum Average Set-up plus Processing time (MASP\_GA) extends the exhaustive MASP heuristic by restricting batch size to queue length at the decision moment. As soon as the respective number of jobs has been processed, the dispatcher is triggered for a new decision on the job family to produce next. A “gated” policy is also known for controlling polling systems (Takagi 1989). MASP\_GA is similar to the AVE heuristic (Mosier et al. 1984). AVE differs from MASP\_GA by neglecting set-up times in family priority setting.

MASP\_AD

Several authors indicate the relevance of exploiting processing time variance in dispatching, see, for example, Cao et al. (2005) and Mandelbaum and Reiman (1998). Selective grouping of products based on their processing times may benefit flow time performance, in the presence of set-up times or parallel machines. Here we will consider the exploitation of processing time variance by defining the ADaptive Minimum Average Set-up plus Processing time (MASP\_AD).

MASP\_AD extends MASP by allowing for alternative choices of batch size. MASP\_AD bounds batch size by considering the highest priority partial batch:

$$F_{MASP\_AD} = \arg \min_{j \in J; k = k_{\min} \dots q_j; q_j > 0} \frac{s_{j_0, j} + \sum_{i=1}^k P_{i, j}}{k} \quad [4]$$

with

$$F_{MASP\_AD} = (j^*, k^*)$$

$$k_{\min} = \text{round}(s_{j_0, j} / (\lambda - \hat{T}))$$

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Formation of partial batches is realized by setting the batch size ( $k$ ). The highest priority batch ( $F_{MASP\_AD}$ ) is characterized by the choice of family ( $j^*$ ), and the choice of batch size ( $k^*$ ).

A series of test runs indicated that for high work loads application of MASP\_AD may result in excessive flow times. This follows from its allowance for smaller batch sizes, which causes an increase of set-up frequency relative to exhaustive heuristics. Ultimately, set-up frequencies are bounded by system utilization. If system utilization is too high, additional set-ups may “eat capacity away”, hence causing poor performance. Therefore we suggest a lower bound to batch size ( $k_{min}$ ). It relates set-up time ( $s_{j_0,j}$ ) to the mean job arrival interval ( $\lambda$ ) and mean processing time per job over all families ( $\hat{T}$ ). This bound is motivated by the idea that the choice of batch size should not violate long term restrictions on maximum work load (100%).

MASP\_HY

The Minimum Average Set-up plus Processing time Hybrid (MASP\_HY) seeks to further improve set-up efficiencies relative to MASP\_AD. It is characterized by a three stage approach. The initial stage is an application of MASP\_AD.

The second stage for MASP\_HY addresses the possibility for increasing set-up efficiency by extending batch size for the chosen family ( $j^*$ ):

1. Set  $m = k^*$ .
2. Determine the priority ( $P^2$ ) for the next best family:

$$P^2 = \min_{j \in J; j \neq j^*; k=1..q_j} \frac{s_{j_0,j} + \sum_{i=1}^k p_{i,j}}{k} \quad [5]$$

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3. If  $m < q_{j^*}$  then set  $m = m + 1$  else go to 6.
4. Determine priority ( $P_m^1$ ) for family  $j^*$  and batch size  $m$  :

$$P_m^1 = \frac{s_{j_0, j^*} + \sum_{i=1}^m P_{i, j^*}}{m} \quad [6]$$

5. If  $P_m^1 < P^2$  then go to 3 else  $m = m - 1$  ; go to 6.
6. Set  $k^{*ex} = m$ .

The above procedure checks whether a further increase of the batch in the same family ( $j^*$ ) is possible (step 3), and priority found for the next-best family ( $P^2$ ), cf. steps 2,4,5. This is reflected in the choice of batch size ( $k^{*ex}$ ), cf. step 6.

Finally, in the third stage, a decision is made on whether an exhaustive policy is followed or not. Note, how MASP\_HY may be classified as a hybrid heuristic by allowing to switch between an exhaustive policy and a non-exhaustive policy. A temporarily switch to an exhaustive policy is related to the choice of batch size ( $k^{*ex}$ ). In case the (extended) batch size ( $k^{*ex}$ ) is equal to queue length for the chosen family ( $j^*$ ), an exhaustive policy is adopted. In all other cases the next decision moment is determined by the partial batch size, similar to MASP\_AD.

For all three heuristics an SPT ordering is assumed. Note how new job arrivals may force an updating of the current batch, i.e., the (partial) batch which was composed as a net result of the dispatching decision. Products arriving during batch processing will be added to the current batch if their processing time is smaller than the longest processing time found within this batch. However, adding a product to a batch, implies that the product with the longest processing time is omitted from the batch.

## 4 DESIGN OF THE SIMULATION STUDY

A simulation study was designed to consider the potential of the new non-exhaustive family based dispatching heuristics. In this section we discuss research questions, the experimental design, and simulation details.

### 4.1 Research issues

In our simulation study we aim to:

- I. Gain an insight in the potential of new and existing heuristics for family based dispatching under low and high variances of processing and set-up times.
- II. Study heuristics' workings by considering their capabilities of exploiting variances in processing and set-up times, respectively.

In (I) the *potential* of family based dispatching heuristics is studied, in terms of their relative performance for system configurations with high and low processing and set-up time variances. More specifically, we consider added value of the new non-exhaustive heuristics. Finally, in (II) we try to further detail insights on heuristics' performance by studying relative performance of rules for alternative choices of distributions for processing and set-up times.

### 4.2 Shop configurations

As a starting point for discussion of the experimental design, we use Table 1 to specify fixed factors, and experimental factors. We consider a single machine shop with an unlimited buffer, see Section 3. Jobs are assumed to arrive according to a negative exponential distribution. For all shop configurations, jobs belonging to the same family are ordered according to shortest processing time (SPT). Further, all product families have an equal share in the product mix. Product processing and set-up times are drawn from a Gamma distribution, with mean of 1. Assumptions with respect to product family, mix and arrival

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3 distribution are in line with the previous research in this field (e.g., Jensen et al. 1996, and  
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5 Wemmerlov 1992).  
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10 [insert Table 1 about here]  
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15 In line with our choice of research issues we chose to set up an extensive simulation study.  
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17 The study covers most experimental factors and their ranges found in literature on family  
18 based dispatching. Choices of factors and ranges are largely based on the reviews by Frazier  
19 (1996), Shambu et al. (1996), and Nomden et al. (2005).  
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25 Alternative settings of parameters for processing, and set-up times follow from the ranges  
26 for the respective coefficients of variation. Here respective ranges reflect alternative choices  
27 made in the literature. For example, Wemmerlov and Vakharia (1991) assume processing  
28 times to be almost constant, while Reddy and Narendran (2003) adopt a negative exponential  
29 distribution for setting processing times. In a similar way, Russell and Philipoom (1991), and  
30 Jensen et al. (1996), consider constant set-up times, while Mosier et al. (1984) assume an  
31 exponential distribution for set-up times. Other researchers hold intermediate positions, see,  
32 for example, Mahmoodi et al. (1997).  
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43 The set-up to run-time ratio equals mean set-up time divided by mean processing time.  
44 Set-up times are drawn every time a set-up is executed. For the set-up to run-time ratio four  
45 settings are considered: 0.125, 0.25, 0.5, and 1.0. Many other authors adopt similar settings;  
46 see, for example, Wemmerlov (1992), Frazier (1996), Russell and Philipoom (1991), Andrés  
47 et al. (2005). The relevance of this factor follows from its foreseen impact on set-up  
48 frequency, see Section 4.1. The number of families ranges from 4 to 16. This range is in  
49 conformity with many other studies, see, for example, Jensen et al. (1996), Marsh et al.  
50 (1999), and Wemmerlov (1992).  
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*Non-Exhaustive Family Based Dispatching Heuristics*

Alternative shop load levels are chosen by adapting the mean inter-arrival time. They have been determined using a shop configuration with 8 product families, and FCFAM as a control rule. This benchmark configuration was used to determine three levels of shop load for each setting of the set-up to runtime ratio. The levels correspond with 60%, 75%, and 90% shop utilization, respectively, which includes both processing and set-ups. Previous research indicates that shop load has a major impact on (relative) performance of family based dispatching heuristics (Wemmerlov and Vakharia 1991).

Seven rules for family based dispatching are included in the study. The exhaustive policies MASP and MAS are considered, because of their good overall performance in our previous work (Nomden et al. 2008). For MASP this is confirmed in earlier research by Russell and Philipoom (1991). MAS is a new rule, introduced by Nomden et al. (2008). Three new non-exhaustive rules are studied: MASP\_GA, MASP\_AD, and MASP\_HY, see Section 3. Finally, FCFAM, and SPT serve as bench mark rules. FCFAM concerns an extension of the well-known FCFS rule, see Section 3. SPT is included for its relevance in case of small set-up to run-time ratio, see Wemmerlov (1992).

### 4.3 Simulation modelling

Plant Simulation (Plant Simulation<sup>TM</sup> 8.2, Tecnomatix, Stuttgart) was used to carry out the simulation experiments. The principles of object oriented design underlying this language make it a flexible and efficient tool for model building. The performance for each heuristic was estimated using the replication deletion method (Hoover and Perry 1986, Law and Kelton 2000). A total of 60 runs were considered for each experiment. The length of the warm-up period was determined using the Welch procedure (Law and Kelton 2000). In accordance with the outcomes of the procedure the warm up period and run length were set at 10,000 and 110,000 time units, respectively.

## 5 ANALYSIS OF SIMULATION RESULTS

In this section we will analyse the outcomes of the simulation study, starting from the research issues identified in Section 4.

### **5.1 Potential of new and existing heuristics for family based dispatching under low and high processing and set-up time variances.**

The first research issue concerns the potential of new and existing heuristics for family based dispatching under low ( $CV = 0.33$ ) and high ( $CV = 1.00$ ) processing and set-up time variances, see Tables 2a,b. The tables rank heuristics for their flow time performance across all shop configurations. Results for best performing heuristics are underlined. Performance differences for the heuristics have been tested for statistical validity using a paired t-approach, cf. Law and Kelton (2000). The tests pointed out that differences greater than 0.25% should be considered significant.

[insert Tables 2a,b about here]

Tables 2a,b show that best results cannot be related to a single heuristic. Typically, the heuristics' rankings differ for each setting of work load and set-up to run-time ratio. However, rankings tend to display a specific pattern. This pattern is identified by cell colours in Tables 2a,b. For low work loads and set-up to run-time ratios best performance is indicated for greedy rules with a short term focus on exploiting processing time similarities, i.e., conventional dispatching rules (SPT), and adaptive non-exhaustive rules (MASP\_AD). Alternatively, for high work loads and set-up to run-time ratios, MAS, with its long term focus on set-up efficiencies, displays best performance. MASP\_HY holds an intermediate position.

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4 The pattern displayed in Tables 2a,b, i.e., relevance of heuristics for specific shop  
5 configurations, may be explained by a “fit” between system parameters – here work load, and  
6 set-up to run-time ratio – and rule construction, being either more focussed on short term  
7 gains by exploiting processing time variances, or tailored towards long term set-up  
8 efficiencies. Note how the pattern holds, but shifts for alternative settings of variances of  
9 processing and set-up times. The shift is expected, as high variances create more room for  
10 exploiting processing time variance (MASP\_AD). In turn low variances reduce such room,  
11 thereby forcing a shift towards exhaustive strategies, especially MAS. The number of product  
12 families tends to act as a moderator in this shift. Typically, a higher number of product  
13 families, implies the need for more set-ups, and – hence – a minor change of preference to  
14 exhaustive heuristics.

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Results of the simulation study indicate how the choice of rule makes a difference. Many  
authors already indicated how intelligent heuristics clearly outperform the non-intelligent  
FCFAM rule, see, for example Frazier (1996). However, performance differences may be  
great among intelligent rules,, ranging from 0 to about 30% of mean flow time. Potential for  
non-exhaustive heuristics – especially MASP\_AD – is largest for low set-up to run-time  
ratios, and moderate and high work loads. Under these circumstances performance gains –  
relative to exhaustive heuristics – of up to 20% are possible. Further, results indicate how  
adaptive, non-exhaustive heuristics (MASP\_AD) tend to outperform the less intelligent non-  
exhaustive heuristics (MASP\_GA), which consider queue length, but not queue contents in  
their batch size decision. Finally, SPT appears to be only relevant for low work loads, set-up  
to run-time ratios and variances. Although MASP\_AD indicates somewhat better  
performance under these circumstances, SPT may be preferred for its simplicity.

## 5.2 Heuristics capabilities in coping with set-up and processing time variances.

The second research issue addresses heuristics' capabilities in exploiting variances in either set-up or processing times. Therefore, we cluster outcomes of the simulation study according to alternative settings for the respective variances, see Figure 1. Results for the SPT rule are not included in the figure, because of its poor performance, i.e., 12 to 20 time units on average.

[insert Figure 1 about here]

A first finding from Figure 1 is that higher variances for set-up and processing times deteriorate the performance of FCFAM. This is not surprising given its similarity with the well-known FCFS rule. Typically, given a FCFS policy, (approximate) queueing models tend to indicate a deterioration of performance under higher variances, see, for example, Hopp and Spearman (2000). Note how variance of the processing time accounts for most of the performance differences.

Where FCFAM indicates a worsening of performance, the performance of the intelligent heuristics indicate how they may exploit variances in processing times (CVP) and set-up times (CVS). Typically, a higher variance of set-up times allows for an improvement of performance (CVP=1; CVS=1 vs. CVP=1; CVS=3). For higher variances of processing time only part of the "potential" is realized – as indicated by results of FCFAM for alternative settings of the variance of processing times. Note how the validity of the aforementioned patterns holds over all intelligent heuristics.

Not surprisingly, Figure 1 indicates how MAS, which aims at set-up efficiencies only, realizes good performance for high set-up time variances. On the other hand, MASP\_AD

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performs best under high variances for both processing and set-up times. As expected, MASP\_HY holds an intermediate position, see Section 5.1.

Note that mean performance figures for the respective heuristics unhide both potential (compare FCFAM), and heuristics' capabilities in exploiting processing and set-up time variances. However, specific settings for other system parameters may shift preference to other heuristics.

## 6 CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

In this article we studied family based dispatching heuristics for shop floor control. Unfortunately, variances of processing and set-up times have received little attention in heuristics' construction and testing. More specifically, we found that existing heuristics do not exploit processing time variances, both in process batch formation, and their sequencing. Therefore we proposed several new "non-exhaustive" heuristics for family based dispatching. Non-exhaustive heuristics prioritize partial batches within a product family, for which processing times are small. This distinguishes them from many existing exhaustive heuristics, which select a new family at the moment the queue for the current family is empty.

To demonstrate potential of both new and existing heuristics we set up an extensive simulation study. The results indicate how both variances of processing and set-up times are relevant for system performance, and heuristics' relative performance. Results of the simulation study indicate:

- There is no single heuristic that performs the best under all experimental conditions. The new non-exhaustive MASP\_AD heuristic performs well under low set-up to run-time ratios, while existing heuristics should be preferred in the presence of high set-up to run-time ratios. The new MASP\_HY heuristic holds an intermediate position. Differences are explained by heuristics' construction, being tailored either to short term gains, i.e., small processing times, or to long term set-up efficiencies.

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- The choice of heuristic makes a difference. Intelligent heuristics, exploiting set-up and processing times in dispatching decisions, clearly outperform the benchmark FCFAM rule – which does not use such information. However, among intelligent heuristics performance differences of up to 30% may be found. More specifically, our results indicate how the new non-exhaustive heuristics may improve system performance up to about 20%, relative to existing exhaustive heuristics.
- Both new and existing heuristics exploit variances of processing and set-up times. Not surprisingly, existing exhaustive heuristics with a restricted focus on realizing set-up efficiencies perform well when set-up time variances are high. On the other hand, the new non-exhaustive heuristics perform well when variances of processing times are high.

Several interesting directions for future research are foreseen. Meta heuristics may help in constructing a rule which indicates best performance for a wide(r) range of shop configurations. Further, insights obtained in heuristics construction, may be supportive in developing and improving heuristics with due date related performance objectives.

## Non-Exhaustive Family Based Dispatching Heuristics

## APPENDIX A: NOTATION

## Indexes

$i$	job identifier = 1,2,... for jobs in the system, ordered by arrival time
$j$	family identifier = 1,2,...
$k$	batch size, i.e., number of products included in the batch
$m$	batch size, i.e., number of products included in the batch

## Parameters

$j_0$	current family, i.e., the family for which the machine has been set-up
$j^*$	family for which a minimum weighted work load is foreseen
$k_{\min}$	lower bound for batch size
$k^*$	batch size for which a minimum weighted work load is foreseen
$k^{*ex}$	maximum batch size for weighted work load is less than $np$
$J$	set of job families
$N$	total number of jobs processed over all families
$t_0$	decision moment, i.e., the moment the dispatcher is triggered to make a decision
$p_{i,j}$	processing time of job $i$ belonging to family $j$
$q_j$	numbers of jobs in queue for family $j$ at $t_0$
$s_{j_0,j}$	set-up time required for changing the current set-up for family $j_0$ to meet requirements for family $j$
$\hat{T}$	mean processing time per job over all families $j \in J$
$\lambda$	job arrival rate

## Variables

$MFT$	mean flow time per job
$ft_{i,j}$	flow time for job $i$ belonging to family $j$
$P^2$	priority, i.e., minimum weighted work load, for the next best family $j \in J$ with $j \neq j^*$
$P_m^1$	priority, i.e., weighted work load, for the best family $j^*$
$w_{i,j}$	waiting time for job $i$ belonging to family $j$

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**APPENDIX B: OVERVIEW OF DISPATCHING HEURISTICS**

[insert Table B1 about here]

For Peer Review Only

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<b>Fixed factors</b>				
Family mix	Equal share per family			
Inter-arrival time distribution	Negative exponential			
Set-up time distribution	Gamma(Mean=1.00)			
Processing time distribution	Gamma(Mean=1.00)			
Job selection	SPT			
<b>Experimental factors</b>				
Number of product families	4;8;16			
Set-up to runtime ratio*	0.125;0.25;0.50;1.00			
	S			
	0.125	0.25	0.5	1.0
Mean inter-arrival times for S	1.83 <sup>a</sup>	2.01 <sup>a</sup>	2.36 <sup>a</sup>	2.04 <sup>a</sup>
	1.46 <sup>b</sup>	1.59 <sup>b</sup>	1.84 <sup>b</sup>	2.35 <sup>b</sup>
	1.19 <sup>c</sup>	1.28 <sup>c</sup>	1.44 <sup>c</sup>	1.83 <sup>c</sup>
				FCFAM
				MASP
				MASP_GA
Family based dispatching rules				MAS
				MASP_AD
				MASP_HY
				SPT
CV processing time (P)	0.33;1.00			
CV set-up time (T)	0.33;1.00			

\* mean set-up time divided by mean processing time

<sup>a</sup> 60% shop load with rule =FCFAM, number of product families = 8

<sup>b</sup> 75% shop load with rule =FCFAM, number of product families = 8

<sup>c</sup> 90% shop load with rule =FCFAM, number of product families = 8

**Table B1 Overview of fixed and experimental factors**

Non-Exhaustive Family Based Dispatching Heuristics

(a) Low variances for processing and set-up times (CV = 0.33)

Rule		Set up to run time ratio												
		0.125			0.25			0.50			1.00			
		Products			Products			Products			Products			
		4	8	16	4	8	16	4	8	16	4	8	16	
Work load	60%	FCFAM	1.8929	1.9797	2.0346	1.9812	2.1299	2.2279	2.1970	2.4554	2.6342	2.6996	3.1581	3.4907
		MASP	1.8546	1.9028	1.9279	1.9449	2.0505	2.1117	2.1560	2.3548	2.4767	2.6375	2.9885	3.2078
		MASP_GA	1.8474	1.9003	1.9272	1.9507	2.0561	2.1153	2.1696	2.3654	2.4825	2.6475	2.9962	3.2139
		MAS	1.8803	1.9512	1.9911	1.9591	2.0768	2.1455	2.1603	2.3591	2.4779	2.6363	2.9801	3.1907
		MASP_AD	1.8434	1.8970	1.9251	1.9553	2.0605	2.1186	2.1773	2.3733	2.4876	2.6516	2.9999	3.2156
		MASP_HY	1.8528	1.9010	1.9270	1.9446	2.0509	2.1125	2.1568	2.3561	2.4780	2.6375	2.9884	3.2084
		SPT	1.8550	1.9071	1.9344	1.9971	2.1001	2.1538	2.3022	2.5039	2.6119	2.9640	3.3669	3.5896
	75%	FCFAM	2.5541	2.7609	2.9217	2.5779	2.9082	3.1880	2.7587	3.2944	3.7915	3.2522	4.1165	4.9960
		MASP	2.4706	2.5786	2.6439	2.5024	2.7227	2.8785	2.6729	3.0500	3.3395	3.1233	3.7109	4.1614
		MASP_GA	2.4615	2.5797	2.6477	2.5282	2.7462	2.8945	2.7148	3.0863	3.3635	3.1514	3.7321	4.1785
		MAS	2.5206	2.6722	2.7721	2.5230	2.7546	2.9137	2.6711	3.0307	3.2855	3.1138	3.6743	4.0788
		MASP_AD	2.4660	2.5824	2.6484	2.5642	2.7861	2.9261	2.7535	3.1343	3.4084	3.1667	3.7492	4.1931
		MASP_HY	2.4628	2.5706	2.6384	2.5039	2.7272	2.8841	2.6745	3.0559	3.3454	3.1232	3.7120	4.1634
		SPT	2.5113	2.6239	2.6833	2.7292	2.9591	3.0869	3.2209	3.7152	4.0188	4.2471	5.3380	6.0867
	90%	FCFAM	4.7098	5.5164	6.4812	4.2282	5.3271	6.7859	4.1560	5.7413	8.1423	4.3164	6.3309	9.5287
		MASP	4.5434	5.1204	5.7057	4.0901	4.9322	5.8875	3.9711	5.0964	6.4733	4.0428	5.2761	6.6602
		MASP_GA	4.5607	5.1975	5.7850	4.2377	5.0983	6.0338	4.1642	5.2959	6.6541	4.1399	5.3731	6.7428
		MAS	4.5958	5.1211	5.6083	4.0653	4.7447	5.3971	3.9157	4.8378	5.7671	4.0124	5.1287	6.2216
		MASP_AD	5.0494	5.8368	6.4220	4.8033	6.0520	7.2771	4.4906	5.9327	7.6541	4.2106	5.4794	6.8762
		MASP_HY	4.5433	5.2048	5.8482	4.1269	5.0660	6.1421	3.9770	5.1231	6.5311	4.0395	5.2526	6.6042
		SPT	5.6461	6.5757	7.1804	6.8315	9.8002	12.7100	12.5300	∞	∞	19.0800	∞	∞

(b) High variances for processing and set-up times (CV = 1.00)

Rule		Set up to run time ratio												
		0.125			0.25			0.50			1.00			
		Products			Products			Products			Products			
		4	8	16	4	8	16	4	8	16	4	8	16	
Work load	60%	FCFAM	2.3676	2.5153	2.6143	2.3880	2.6056	2.7600	2.5413	2.8852	3.1401	3.0405	3.6156	4.0705
		MASP	2.2108	2.2053	2.1900	2.2456	2.3006	2.3215	2.3913	2.5329	2.6009	2.8354	3.0956	3.2305
		MASP_GA	2.1281	2.1628	2.1691	2.1936	2.2745	2.3079	2.3752	2.5250	2.5970	2.8486	3.1045	3.2318
		MAS	2.3233	2.4081	2.4503	2.3117	2.4210	2.4762	2.4149	2.5751	2.6585	2.8331	3.0922	3.2236
		MASP_AD	2.0700	2.1161	2.1401	2.1606	2.2446	2.2879	2.3637	2.5116	2.5872	2.8506	3.1020	3.2280
		MASP_HY	2.1858	2.1815	2.1740	2.2284	2.2831	2.3084	2.3831	2.5227	2.5912	2.8291	3.0871	3.2183
		SPT	2.0848	2.1376	2.1649	2.2057	2.3111	2.3666	2.4972	2.7091	2.8218	3.2190	3.6612	3.8981
	75%	FCFAM	3.3833	3.7275	4.0112	3.2443	3.7229	4.1570	3.2850	3.9804	4.6739	3.7282	4.8018	5.9527
		MASP	3.0425	3.0131	2.9616	2.9496	3.0385	3.0674	2.9833	3.1941	3.3058	3.3244	3.6701	3.8495
		MASP_GA	2.8479	2.9238	2.9225	2.8463	2.9938	3.0489	2.9614	3.1937	3.3111	3.3660	3.7001	3.8654
		MAS	3.2733	3.4344	3.5154	3.0664	3.2468	3.3388	3.0092	3.2319	3.3502	3.3097	3.6242	3.7788
		MASP_AD	2.6812	2.7640	2.8061	2.7569	2.8936	2.9631	2.9295	3.1327	3.2391	3.3681	3.6693	3.8214
		MASP_HY	2.9327	2.9010	2.8792	2.8862	2.9613	2.9972	2.9449	3.1349	3.2367	3.3059	3.6253	3.7921
		SPT	2.7221	2.8252	2.8782	2.9071	3.1170	3.2345	3.3743	3.8272	4.0961	4.4798	5.5355	6.2438
	90%	FCFAM	6.6047	7.8022	9.1755	5.5348	6.9659	8.8246	5.0476	6.9156	9.6783	4.9617	7.2426	10.7900
		MASP	5.7946	5.9946	6.1197	4.8999	5.3479	5.7170	4.4213	4.9984	5.4739	4.2039	4.7458	5.0985
		MASP_GA	5.1229	5.7402	6.0552	4.6401	5.3011	5.7650	4.4266	5.0921	5.5842	4.3208	4.8483	5.1726
		MAS	6.2587	6.6856	6.8983	5.0487	5.4261	5.6126	4.3761	4.7502	4.9400	4.1286	4.5266	4.7319
		MASP_AD	4.6099	4.8664	4.9936	4.3737	4.6650	4.8158	4.2801	4.6100	4.7822	4.2899	4.6634	4.8539
		MASP_HY	5.1306	5.1046	5.1206	4.5513	4.7130	4.8230	4.2144	4.5248	4.7177	4.1150	4.5352	4.7761
		SPT	5.1146	5.7584	6.1678	5.9481	7.8617	9.6486	9.7490	∞	∞	15.2000	∞	∞

Legend

- Adaptive non-exhaustive heuristics
- Hybrid heuristics
- Exhaustive heuristics

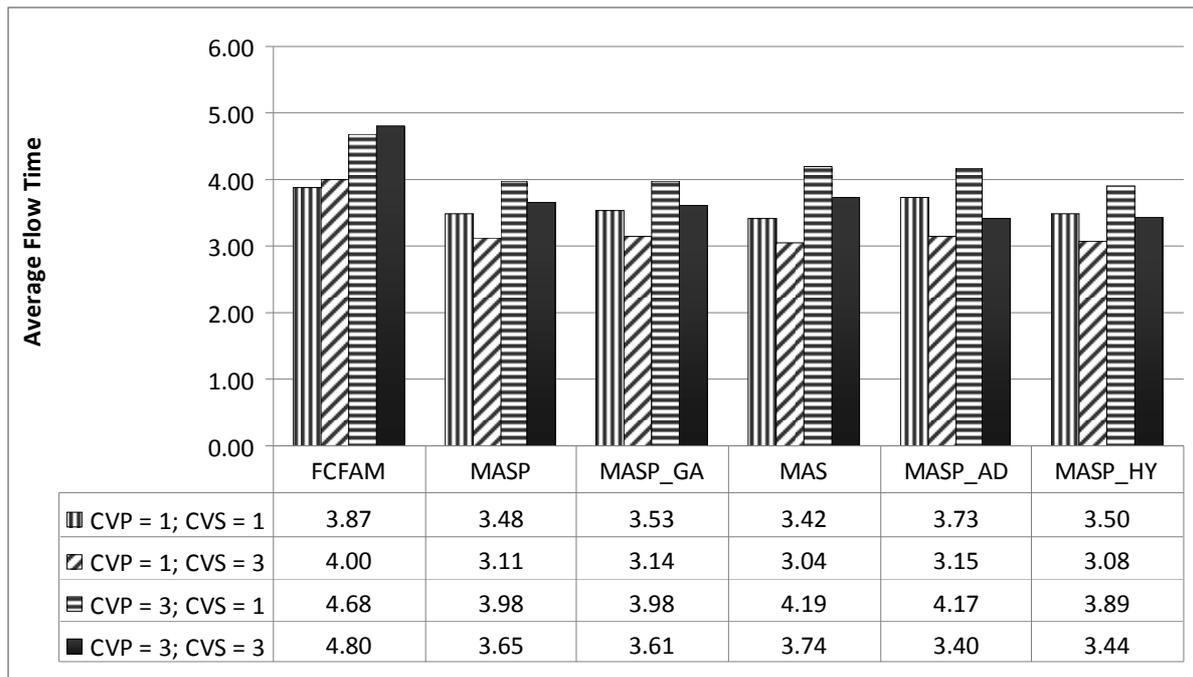
Tables 2a,b Estimating potential of heuristics for high and low variances of processing and set-up times.

*Non-Exhaustive Family Based Dispatching Heuristics*

Name	Explanation	Type*	Exhaustive	Reference	Remarks
AVE	Highest AVErage priority over all families	FBD	yes	Mosier et al. (1984)	Heuristic is quite similar to MASP_GA. AVE, however, does not include set-up times in family priority setting.
ECON	ECONomic trade-off between changing queues	FBD	no	Mosier et al. (1984), Ruben et al. (1993)	
EDD	Earliest Due Date	DP	-	Blackstone et al. (1982)	
FCFAM	First Come FAMily	FBD	yes	Flynn 1987	Often used as benchmark
FCFS	First Come First Serve	DP	-	Blackstone et al. (1982)	
MAS	Minimum Average Set-up time	FBD	yes	Nomden et al. (2008)	
MASP	Minimum Average Set-up plus Processing time	FBD	yes	Jensen et al. (1996)	
MASP_AD	ADaptive Minimum Average Set-up plus Processing time	FBD	no	This paper	Extension of MASP. It allows for alternative settings of batch size within product families
MASP_GA	GAted Minimum Average Set-up plus Processing time	FBD	no	This paper	Extension of MASP. Bounds batch size by queue length at the decision moment
MASP_HY	HYbrid Minimum Average Set-up plus Processing time	FBD	no	This paper	Extends MASP_AD by considering possibilities to further improve set-up efficiencies. It allows for a temporary shift towards an exhaustive policy.
SPT	Shortest Processing Time	DP	-	Blackstone et al. (1982)	
WSPT	Weighted Shortest Processing Time	DP	-	Pinedo (2005)	

\* FBD = Family based dispatching heuristic, DP = Conventional dispatching rule

**Table A Overview of dispatching heuristics**

*Non-Exhaustive Family Based Dispatching Heuristics*

**Figure 1** Relative performance of heuristics for alternative coefficients of variation of processing and set-up times.