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Variability of completion time differences in permutation flow shop scheduling

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ABSTRACT

Homogeneity of a specific indicator in scheduling has been discussed in several references. Namely, the variance of completion times (completion time variance, CTV) has been addressed by several authors since the 1970ies. However, in contrast to some indications in these papers, CTV does not provide smoothness of jobs' completion times but is more aiming at minimizing the deviation from a common finishing date of all jobs. In this paper, a new objective function is proposed which intends to smooth the differences between the completion times of each two consecutively scheduled jobs in a permutation flow shop setting. We discuss the relevance of respective considerations, define an objective function accordingly and compare some solution approaches by means of examples and a numerical study based on the test instances from Taillard [1, 2]. A main topic of this paper is the discussion of the influence of scheduling decisions on other systems linked to this scheduling system by using our new objective function. This intends to contribute, in a specific and heuristic way, to reduce the gap between the dynamic-stochastic perspective of queuing approaches on one hand and the mostly static-deterministic perspective of job scheduling on the other.

1. Introduction

In job scheduling, usually three categories of objective functions are considered, i.e. utilization-oriented ones (as makespan), material flow/throughput-oriented ones (as flowtime) and due date-oriented ones (as earliness and tardiness or lateness). These categories are described in every respective textbook, see e.g. [[3], pp. 18–9] or [[4], pp. 6–7]. Usually, average or maximum values of the respective indicators are to be minimized.

Only rarely, uniformity related objective functions are discussed in scheduling although uniformity, e.g. of completion times of jobs, might be a relevant issue in manufacturing. To the best of our knowledge, the only objective function addressing similar aspects so far is the minimization of the variance of completion times. Starting with a paper by Merton and Muller in 1972 [5], since then several authors addressed this objective function, implicitly or explicitly aiming at achieving a common completion time of all jobs in a shop (see e.g. [6–8] and the references listed there). Merton and Muller motivate their objective function by an example from computer file organization where it is required to achieve a common/uniform response time to users.

More or less separate from this, during the last decades uniformity (or small non-uniformity) has been identified to be an important issue with respect to the performance of manufacturing and other systems, often referred to in the context of planning and controlling of lean (manufacturing) systems (see e.g. the book by Hopp and Spearman [9]) and intending to smooth material or job flow in a manufacturing system. Based on the fact that in manufacturing contexts or, more general, in each material flow system every deviation from uniformity requires a buffer mix of time, inventory and/or capacity, considering aspects of (non-) uniformity may have a non-negligible influence on the performance of the respective system. In this context, non-uniformity might refer to a diversity of aspects. It might, e.g., be induced by variable demand, variable processing times, times of non-availability of resources etc. Quantifying (non-) uniformity of an indicator is often conducted using the expression *variability* which is well-known as the coefficient of variation from basic statistics. Corresponding considerations can be found in the manufacturing literature. Extended discussion of variability aspects is, e.g., offered in [9]. However, these approaches often refer to (dynamic and stochastic) queuing theory and are not linked to (static-deterministic) scheduling decision problems. In this paper, we contribute

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to heuristically bridging this gap by considering the (non-) uniformity of inter-departure times of jobs from a scheduling system, i.e. the differences between the completion times of each two consecutively scheduled jobs. For simplicity of presentation, we refer to the simple scheduling setting of permutation flow shops.

The sequel of this paper is organized as follows: In Section 2, we present our modeling concept, both with respect to queuing (2.1) and with respect to scheduling (2.2). Section 3 discusses variance and variability as objective functions in scheduling while Section 4 explains our approach by means of a small example and presents some straight-forward improvement approaches. In Section 5, some relationships of variability and traditional objective functions in scheduling are addressed. Section 6 presents a variety of twenty heuristics adapted from the literature for minimization of our variability-related objective function and their evaluation by means of the well-known Taillard test-bed. Also, we numerically compare minimization of makespan, flowtime and the new objective function. Section 7 discusses the influence of scheduling decisions on exposure time in the combined system presented in Section 2.1. The paper ends with an outlook and addressing of future research questions.

2. Heuristically modeling the link between queuing approaches and job scheduling in manufacturing

Since we want to contribute to the analysis of the link between queuing theory approaches and job scheduling in manufacturing, we have to refer to respective models for both. We will only refer to the simplest models to explain the bottom line of our approach here. Nevertheless, any more complicated setting both on the queuing side as well as on the scheduling side might be topic of future work. The link of both approaches will be a heuristic one. We will address this aspect at the end of this section.

2.1. The queuing model

For our queuing considerations, we suppose a setting as described in Fig. 1. Two systems are consecutively coupled where jobs being finished on system 1 are shipped to and further on processed on system 2. Both systems include operations with respective effective processing times $t_e(1)$ and $t_e(2)$ and their effective processing time variabilities $c_e(1)$ and $c_e(2)$. Flow variabilities $c_a(1)$, $c_d(1)$, $c_a(2)$ and $c_d(2)$ refer to the (inter-) arrival and (inter-) departure times of jobs at and from the systems. For simplicity of calculation in the sequel, we use the squared variabilities and for simplicity of consideration we suppose that (a), the departure process from system 1 is identical to the arrival process at system 2 (i.e. $c_d(1)=c_a(2)$) and (b), all jobs in system 1 considered in the sequel are available in front of system 1 simultaneously at time 0 (as supposed in static-deterministic scheduling, see 2.2). Flow variability at the end of system 2 ($c_d(2)$) is not considered here any further.

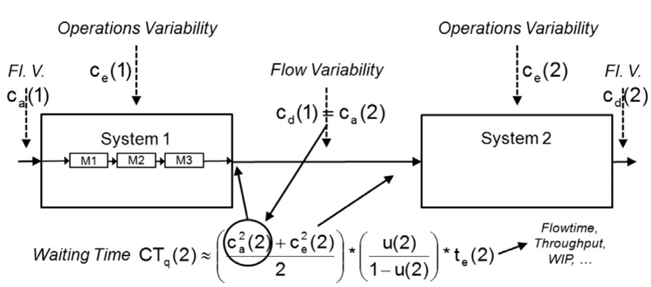

Fig. 1. The system considered from the queuing perspective.

The waiting time in front of machine 2 ($CT_q(2)$) can be approximated by the so-called VUT-formula or Kingman equation (see [[9], pp. 288–91] and [10]). This waiting time depends on four components, namely the variability of departures from system 1 ($c_d(1)=c_a(2)$), the processing times on system 2 ($t_e(2)$) and their variability ($c_e(2)$) as well as on the utilization of system 2 ($u(2)$).

The (expected) flowtime of a job in the overall system is then determined by its time in system 1 (including waiting time before being processed plus processing time) plus its waiting time in front of system 2 (given by $CT_q(2)$) plus its processing time in system 2 ($t_e(2)$). Obviously, the scheduling decision in system 1 influences the departure variability from system 1 (=arrival variability at system 2) and therefore the waiting time in front of system 2.

$$FT_{total,per\ job} = Processing\ Time_{System\ 1} + Waiting\ Time_{1\to 2} + Processing\ Time_{System\ 2} \tag{1}$$

2.2. The scheduling model

While we are not looking into details of system 2 in Fig. 1, we suppose a standard permutation flow shop without any 'specifics' as system 1 (see e.g. [[3], pp. 13–21] for a more detailed description). The scheduling objective functions shall be discussed in the sequel. We will use the following notation:

i	job index, $i=1,\ldots,n$
j	machine index, $j=1,\ldots,m$
$p_{i,j}$	processing time of job i on machine j
seq	given job sequence (permutation, solution)
$[i]$	job in position i of sequence seq
$C_{[i],j}$	completion time of job $[i]$ on machine j, $C_{[i],j} = \max(C_{[i],j-1}, C_{[i-1],j}) + p_{[i],j}$, all indices defined appropriately, $C_{[1],1}=p_{[1],1}$, $C_{[1],j}=C_{[1],j-1}+p_{[1],j}$ $(j=2,\ldots,m)$, $C_{[i],1}=C_{[i-1],1}+p_{[i],1}$ $(i=2,\ldots,n)$
C_i	completion time of job i (on machine m), i. e. $C_i = C_{i,m}$

No job passing is allowed in this simple setting, i.e. even if a job has no operation on a specific machine, this situation is interpreted as if this job has an operation on this machine with processing time 0. In terms of queuing, this induces a strict first-in-first-out (FIFO) discipline in every situation where job queuing appears in the system, which is a consequence of the permutation requirement for the *permutation* flow shop problem.

Considering the overall system from Fig. 1 as described is a heuristic approach to link a static-deterministic scheduling perspective for system 1 with a queuing perspective for the link between the two systems and system 2 itself. We believe that this perspective is fairly close, e.g., to a supply chain interpretation of the system: Information on system 2 in the detailed and deterministic planning and scheduling process of system 1 is usually more or less ignored. However, including the coarse information from system 2 indicated in Fig. 1 into the flowtime calculation according to formula (1) gives at least an indication of the influence of (scheduling) decisions for system 1 on the flowtime of a job in the overall system. (Nevertheless, queuing approaches in general suppose a steady-state situation whereas static-deterministic scheduling usually derives solutions from scratch. This is the main reason why our approach to combine both perspectives is a heuristic one.) We will address this perspective in the sequel of the paper.

3. Variance and variability as objective functions in scheduling

Standard objective functions (to be minimized and meanwhile widely discussed for decades) in scheduling are makespan (which