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Technical paper

Lot streaming in [N-1](1)+N(m) hybrid flow shop

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ABSTRACT

This paper deals with N-stage hybrid flow shop (HFS) lot streaming problem to develop a schedule that minimises the makespan. The HFS considered consists of one machine in each of the first (N-1) stages and m machines in stage N. A mixed integer linear programming (MILP) model is proposed and solved using LINGO solver. For large size problems, the LINGO solver takes longer time and hence an algorithm is proposed. The heuristic approach consists of splitting the lots and then sequencing. The lot splitting is based on the average processing time of jobs in the first (N-1) stages and cycle time of stage N. The sum of processing time of all jobs in each stage of the first (N-1) stages is considered for sequencing. Numerical illustrations are carried out to show the percentage deviation of solution obtained using the algorithm from the MILP model. The results show that the algorithm gives near optimal solution to the problems within a very small computational time compared to the MILP model.
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1. Introduction

Hybrid flow shop (HFS) is a generalization of the flow shop and parallel machines environment [1]. In HFS, jobs have to be processed through all stages in the same order and that there is at least one stage with multiple machines. This kind of environment is generally used in industries such as textile, computer manufacturing, paper, photographic film manufacturing, etc. [1,2] and hence attracts many researchers worldwide. The performance of flow shop is poor when processing time of jobs in some stages is higher than the processing time of some other stages. Parallel machines can be utilized in those stages with higher processing time, to improve makespan and production rate, and to reduce work-in-process (WIP) inventory. The HFS is also called multi-processor or flexible flow shop [3].

Lot streaming was introduced by Reiter in 1966 [4]. It involves splitting a production lot into number of sub-lots and then scheduling these sub-lots on machines in order to have the better performance of the production system. Without lot streaming, the whole lot is transferred to the next stage for processing as per the schedule. When a lot is processed on a machine, the completed units have to wait in the output buffer of the machine until the whole lot is completed. Hence the downstream machine might be idle. By splitting the lot into sub-lots, finished sub-lots can be transferred to the successive machine for processing, and thus overlapping the processes. Most researchers have considered the number and the size of sub-lots as decision variables in lot streaming problems [5–16]. Chang and Chiu [17], Glock et al. [18], Cheng et al. [19] present the review of the literature in lot streaming. Potts and Van Wassenhove [20] present a classification based on the main dimensions of lot streaming and on seven sub-dimensions as well. They point out that division of a lot into sub-lots will improve the service of the production system to the customer and also improves the performance of the multi-stage production system by overlapping the processes. Lot streaming can be easily accommodated in an existing production line without any need in change of facilities and production processes. Truscott [21] presented some advantages of lot streaming. They are: (i) reduction in manufacturing lead times, (ii) reduction of WIP inventory and associated WIP costs, and (iii) reduction of material handling system capacity.

In a lot streaming problem, the sub-lot size may vary from machine to machine or maintained constant. When the sub-lot size remains constant, the problem is called consistent sub-lot problem and when the sub-lot size varies from machine to machine, the problem is called variable sub-lot problem. A special case of consistent sub-lot problem is called equal sub-lot problem, where all the sub-lot sizes of a lot (job) are equal. The sub-lot sizes can be continuous or discrete. In continuous sub-lot sizes, the value of the sub-lot can be any real value. In discrete sub-lot size, the value of the sub-lot can have only integer value. The lot streaming problems can also have intermingling allowed or not allowed. In the scheduling problems with intermingling allowed, before all the sub-lots of a lot are processed on a machine, a sub-lot of another job is processed on the same machine, where as in the problems with intermingling not

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Table 1
Features of hybrid flow shop (HFS) lot streaming papers addressed in the literature.

Sl. No.	Author	Production system configuration	Lot streaming factors		Multi-Product/Single product	Modelling/solution approach	Decision variable(s)	Performance measure(s)
			CS/VS/ES*	WI/WOI**				
1	Kim et al. [27]	$[1](nk)+2(m)$	ES	WOI	Multi-Product	Algorithm similar to Johnson's algorithm	Number of sub-lots, Sub-lot size and Job schedule	Makespan
2	Tsubone et al. [28]	$[1](1)+2(m)$	ES	WOI	Multi-Product	Mathematical programming model	Number of sub-lots, Sub-lot size and Job schedule	Total flow time, Makespan, Capacity utilization, Maximum WIP
3	Zhang et al.[29]	$[1](nk)+2(1)$	ES	WOI	Single product	Local search heuristic	Number of sub-lots and Sub-lot size	Mean Flow time
4	Zhang et al. [30]	$[1](nk)+2(1)$	ES	WOI	Single product	Mathematical programming model and Local search heuristic	Number of sub-lots and Sub-lot size	Mean Completion time
5	Liu [31]	$[1](nk)+2(1)$	ES	WOI	Single product	Local search heuristic	Number of sub-lots and Sub-lot size	Makespan
6	Cheng and Sarin [32]	$[1](nk)+2(2)$	CS	WOI	Multi-Product	Mathematical programming model and Local search heuristic	Number of sub-lots, Sub-lot size and Sub-lot allocation	Makespan, Mean completion time
7	Cheng and Sarin [33]	$[1](nk)+2(2)$	CS	WOI	Single product	Mathematical programming model	Number of sub-lots and Sub-lot size	Makespan
8	Nejati et al. [34]	$[N\text{-}1](nk)+N(m)$	CS	WOI	Multi-Product	Mixed integer non-linear programming, Simulated annealing and Genetic Algorithm	Number of sub-lots, and Sub-lot size	Weighted mean completion time
9	Nedari and Yazdani [35]	$[N\text{-}1](nk)+N(m)$	CS	WOI	Multi-Product	Mixed integer linear programming and Imperialistic Competitive Algorithm	Job sequence and Sub-lot schedule	Total tardiness
10	Nejati et al. [36]	$[1](nk)+2(m)$	CS	WOI	Multi-Product	Mixed integer non-linear programming, Simulated annealing and Genetic Algorithm	Machine allocation, Job sequence, Number of sub-lots, Sub-lot size, Completion time of jobs, and jobs as WIP	Weighted mean completion time

* CS/VS/ES – Consistent sub-lot (CS), Variable sub-lot (VS) and Equal sub-lot (ES).
** WI/WOI – With intermingling (WI) and Without intermingling (WOI).

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