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A new approach towards integrated cell formation and inventory lot sizing in an unreliable cellular manufacturing system

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ABSTRACT

This paper presents a comprehensive mathematical model for integrated cell formation and inventory lot sizing problem. The proposed model seeks to minimize cell formation costs as well as the costs associated with production, while dynamic conditions, alternative routings, machine capacity limitation, operations sequences, cell size constraints, process deterioration, and machine breakdowns are also taken into account. The total cost consists of machine procurement, cell reconfiguration, preventive and corrective repairs, material handling (intra-cell and inter-cell), machine operation, part subcontracting, finished and unfinished parts inventory cost, and defective parts replacement costs. With respect to the multiple products, multiple process plans for each product and multiple routing alternatives for each process plan which are assumed in the proposed model, the model is combinatorial. Moreover, unreliability conditions are considered, because moving from "in-control" state to "out-of-control" state (process deterioration) and machine breakdowns make the model more practical and applicable. To conquer the breakdowns, preventive and corrective actions are adopted. Finally, a Particle Swarm Optimization (PSO)-based meta-heuristic is developed to overcome NP-completeness of the proposed model.

1. Introduction

In today's global competitive environment, companies have to deliver low-cost, high quality products to cope with the challenges. Cellular manufacturing system (CMS) is an application of Group Technology (GT) which helps firms to achieve this goal. In spite of CMS, job shop and flow shop manufacturing systems are not able to respond all market requirements, thus CMS is applied as an alternative to overcome today ever growing issues. In designing a CMS, four major decisions are made; 1-cell formation: grouping parts with the closest features into part families, and subsequently, allocating machines to the formed cells, 2-group layout: determining layouts of cells themselves and machines within each cells (intra-cell and inter-cell layouts), 3-group scheduling: planning and managing cell operations, and 4-resource allocation: allocating resources, such as material, workforce and tools to the cells. Some advantages of CMS implementation include production efficiency and system flexibility improvements, simplified material flow, faster throughput, reduced setup times and costs, reduced work-in-process inventory level, reduced intercellular moves, lower cycle times, lower material-handling times and costs, lower product defect rates, lower machine idle times, smaller space requirements, etc. [1,2]. Additionally, many researches have been conducted to point out CMS disadvantages [3–7], among which some can be noted: reduced flexibility compared

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Nomenclature

b	iteration index, $b = 1, \ldots, B$
h	dimension index, $h = 1, \ldots, H$
p	particle index, $p = 1, \ldots, P$
$\varepsilon(b)$	inertia weight in iteration b
$v_{ph}(b)$	velocity at dimension h of particle p in iteration b
$\gamma_{ph}(b)$	position at dimension h of particle p in iteration b
ψ^{p}_{ph}	personal best position (pbest) at dimension h of particle p
ψ^{g}_{h}	global best position (gbest) at dimension h
ψ^{l}_{ph}	local best position (lbest) at dimension h of particle p
δ	uniform random number in [0, 1]
c_p	personal best position acceleration constant
c_l	local best position acceleration constant
c_g	global best position acceleration constant
ρ_{min}	minimum position value
ρ_{max}	maximum position value
$fit(\gamma)$	fitness value of position γ

to a job shop, lower level of machine utilization by dedicating machines to cells, and the effect of machine breakdowns on due date adherence.

There are a few researches that considered main features of a CMS simultaneously. One of these features is production planning in CMSs [8,9] and the other is job sequencing and scheduling alternative process plans in such systems [10,11]. From another point of view, in most research articles, cell formation has been considered under static conditions in which cells are formed for a single-time period with known and constant product mix and demand. In contrast, in a more realistic dynamic situation, a multi-period planning horizon is considered, where the product mix and demand are different in different periods. This occurs in seasonally or monthly production contexts. As a result, the cell configuration in one period may not be optimal in another period, therefore the main focus is nowadays dedicated to dynamic cell formation models [12]. To address this problem, several authors have recently proposed models and solution procedures by considering dynamic cell reconfigurations over multiple time-periods [13–24]. In the mentioned research articles, it is assumed that the demand is equal to production quantity, however, it might not be held for many circumstances and the demand is compensated from inventory or by subcontraction. Hence, production quantity should be calculated from production planning viewpoints and consequently, the calculated production quantities are critical for the cell sizes and number of required machines (cell capacity). Moreover, there is a relation between quantities of sub-assemblies and parts and the quantity of end products based up their Bill Of Materials (BOMs), therefore, product structures are also considered while production planning issues are integrated with cell formation. Thus, dynamic cell formation and production planning are correlative and should be addressed simultaneously [12]. In addition to the above-mentioned research facts, there is another important point which has been neglected. In past decades, it has been assumed that the production facilities work in a reliable state, however, it is not a realistic assumption. Due to technological innovations and scientific developments around the world, manufacturing infrastructure is also changing rapidly. Even though the production facilities are becoming sophisticated day by day, the modern facilities are not free from deterioration due to aging. As a result, machines shift from "in-control" state to "out-of-control" state frequently and machine breakdowns occur during planning horizon.

Another related aspect to the considered problem in this paper is production planning and inventory lot sizing. Many researches have been widely conducted in different manufacturing production planning and inventory control problems. These instances developed various methods and models to solve these problems, which can be found in well-known textbooks of production engineering or manufacturing systems [25,26]. Lots of inventory control models from simple Economic Order Quantity (EOQ) to more complicated Material Requirements Planning (MRP), Kanban and CONstant Work-In-Process (CONWIP) models have been utilized in the relative literature. To review mathematical programming models on Kanban and MRP systems, readers are referred to Price et al. [27]. Also, as stated by Chakraborty et al. [28], the basic Economic Manufacturing Quantity (EMQ) model fits unreliable manufacturing systems well. Therefore, from theoretical and practical viewpoints, the study of EMQ problem for unreliable manufacturing systems is quite significant and meaningful [28]. In order to study system breakdowns, two parallel research paradigms have been carried out in unreliable production systems. In one stream, the production process is assumed to shift from an 'in-control' state to an 'out-of-control' state at any random time where it starts producing non-conforming items. Then, the process continues to produce defective items until the end of the production run. Rosenblatt and Lee [29] and Porteus [30] carried out the seminal works in this direction. On the other hand, Groenevelt et al. [31] initiated another research direction to cope with the unreliable production processes. In this regard, corrective and preventive repair times are all assumed to follow arbitrary probability distributions. However, considerable amount of research has been done focusing separately on the issue of either process deterioration or machine breakdowns