An Industrial Application of Cellular Manufacturing Using African Buffalo Optimization

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Abstract. An industrial case is presented in this paper where the existing job shop layout is converted to a cellular structure using a typical percentage utilization based bi-objective cell formation technique. The aim is the total cell movements. The African Buffalo Optimization (ABO) algorithm is used to obtain the stated cellular structure. The proposed algorithm obtains an initial solution based on random machine cells and part families using percentage utilization. Thereafter, it improves the solutions based on performance metric. The obtained solution shows improved parts movement.

Keywords: Cellular manufacturing, African buffalo optimization, Industrial data.

1 Introduction

Group technology and its application in Cellular Manufacturing Systems (CMS) presents a combined setup of jobshop (diversity) and flowshop (high production) and demonstrates an alternative form of manufacturing [1]. The objective is to manufacture parts and classify them into families based on similarities in processing requirements, time, or sequences, etc. Application of CMS could be a way to reduce the throughput time, the work-in-process, tool requirements, enhance the product quality, and overall control of operations. CMS could possibly make the organisation highly flexible and responsive to customer needs and facilitate low-cost manufacturing of complex production of multiple parts with variable volumes. According to Ref. [2] the aim of CMS is to decompose the production system into several tiny systems (blocks or cells). These are independent and could exploit the processing resemblances of parts on machines. The procedure of allocating part families to the machine cells is termed as the cell formation problem (CFP) and one part family is expected to be assigned to a machine cell. CFP, also termed as machine-part grouping problem,

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exploits the machine-part incidence matrix and attains block diagonal cellular structure to generate cells. Data in CFPs could be classified as, binary data, ratio data, and sequential data. An incidence matrix, packed with '0' and '1' depending upon the machining requirement of parts, is known as 'binary data'. If the '1' elements are replaced with processing time (percentage utilization) of parts, it is termed as 'ratio data', and if the elements present sequential integer numbers, it is called 'sequential data' [3]. An example of simple cell formation based on ratio data could be depicted in Fig. 1. The rows represent machines and columns represent parts. Elements (real valued figures) represent percentage utilization for each part over each machine. After cell formation, block diagonal cells are achieved with part families and respective machines. Elements outside diagonal blocks are known as bottleneck machines (exceptional elements) and empty places inside cells are known as voids.

	P1	P2	P3	P4	P5
M1		0.23	0.11		0.36
M2	0.32			0.43	0.11
M3			0.66		0.28

	P3	P5	P2	P1	P4
M1	0.11	0.36	0.23		
M3	0.66	0.28			
M2		0.11		0.32	0.43

Fig. 1. Incidence matrix for 3x5 example before (left) and after (right)

Binary data are mostly used in the past few decades [4]-[8]. In real world, many other production factors are important. Percentage utilization is one such factor, which is considered as the 'ratio data' in literature.

Ref. [9] first recommended ratio data in a most logical way. Many researchers have considered ratio data subsequently ([3], [10], [11]). Ref. [10] quantified that the workload data and ratio data are identical which is further transformed into an incidence matrix. The total processing time on a machine/work station for any part could be obtained by multiplying its production quantity and its unit processing time. All the '1's in the incidence matrix are then converted to workload values. These would take any value in the ratio scale (0-1) and termed as the ratio level data. However, rarely any past article actually shows the systematic way to obtain the workload value from total processing time. Recently ref. [12] has pointed this out and portrayed a way to attain that goal.

To solve CFPs a sizable number of solution approaches are available in literature of CMS since early 80s. These are exact methods, graph theoretic approaches, mathematical programming, similarity coefficient techniques, clustering algorithms, soft-computing techniques such as neural network, metaheuristics, and fuzzy methods [13]. Particularly the direction of the research indicates towards soft-computing techniques due to their robust convergence properties and ability of handling combinatorial optimization problems with ease. Since the CFPs are NP-Hard (Non-Ploynomially Hard) in nature, obtaining global optimal solution is difficult [14]. These problems could be efficiently solved using meta-heuristic techniques. Therefore, many meta-heuristic techniques are being applied to CFPs for better solutions during past two decades [15]. Ref. [15] demonstrates the usage of hybrid metaheuristics for CFPs since the past decade. Hybrid techniques are improved and prompt while attaining global best solutions.

African Buffalo Optimization (ABO) is a recent addition in the class of metaheuristic algorithms [16], which is highly efficient in solving various optimization problems (details of ABO are portrayed in section 3.3), and it has never been studied for CFPs before. Most of the articles, published in the domain of CMS, have considered theoretical data for evaluation of cell formation models and techniques. However, practical or real-world data-oriented study is rarely available. This research work seals that gap. In this work, an attempt is made to develop the cells using ABO technique considering the percentage utilization of machines. To solve this problem a real-valued matrix is considered from past literature. Further, a novel mathematical formula is proposed which successfully obtains part families minimizing total percentage utilization induced by exceptional elements (EE) or bottleneck machines. Subsequently an industrial case study is presented which is obtained from MSME Tool Room, Kolkata, India. The collected data are used to develop manufacturing cells realistically using the proposed technique.

2 Industrial Data and Problem Formulation

A case study is conducted in MSME (Ministry of Micro, Small and Medium Enterprises) Tool Room (previously known as Indo-German Tool Room), India. This tool room is a government aided company which develops all the special types of tools required by governmental, semi-governmental or quasi-governmental organizations. MSME Tool Room has an existing production floor (Fig. 2) with various machines arranged in jobshop formation (Fig. 3).

Fig. 2. Production Floor of MSME Tool Room, Kolkata

Production flow data are received for the period of one year (2013 – 2014). In this period 368 different types of parts or products are manufactured over 10 different kinds of machines. This company maintains the data in consolidation sheets. An example sheet (scanned) is depicted in Fig. 4. Data sheets are further refined and gathered for historical data acquisition.

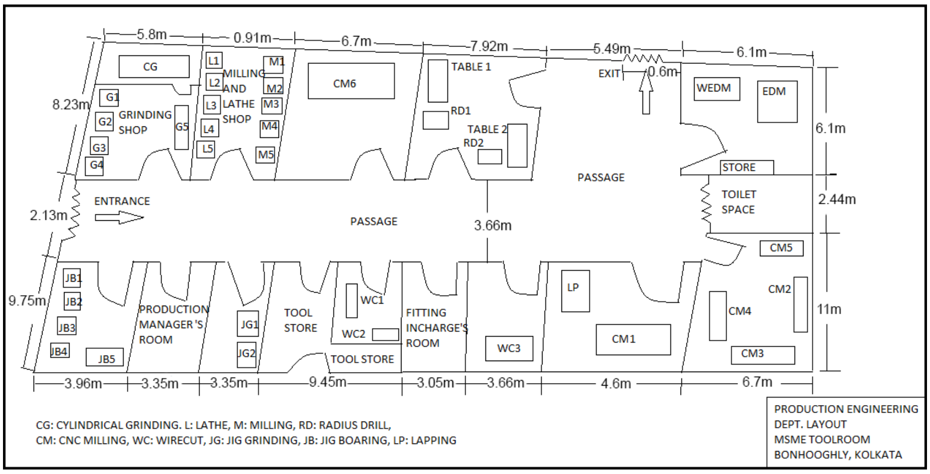
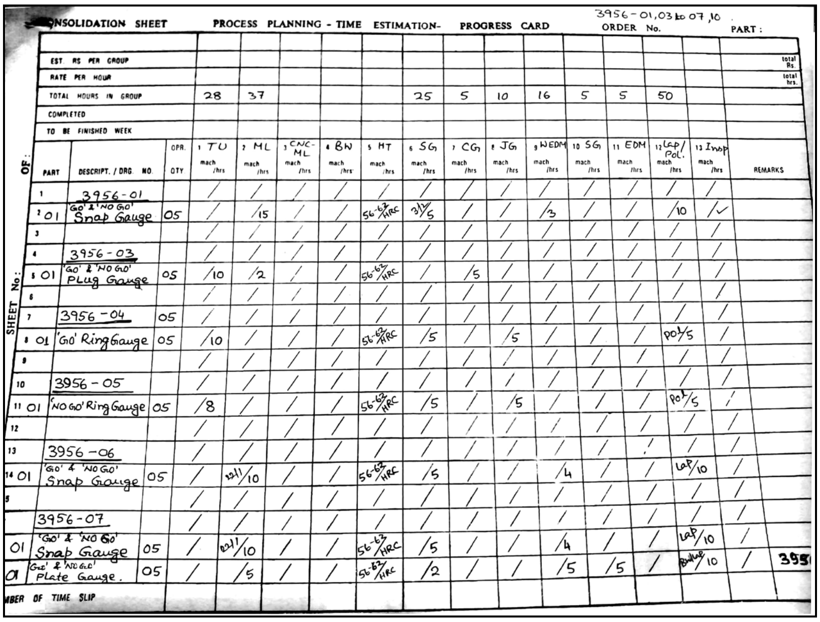


Fig. 3. Arrangement of machines of MSME Tool Room in jobshop structure



CONSOLIDATION SHEET PROCESS PLANNING - TIME ESTIMATION- PROGRESS CARD

ORDER No. 3956-01,03 to 07,10 PART :

SHEET No: OF:

PART	DESCRIPT. / DRG. NO.	OPR. QTY	1 TU mach /hrs	2 ML mach /hrs	3 CNC-ML mach /hrs	4 BW mach /hrs	5 HT mach /hrs	6 SG mach /hrs	7 CG mach /hrs	8 JG mach /hrs	9 WEDM mach /hrs	10 SG mach /hrs	11 EDM mach /hrs	12 Lap/Pol. mach /hrs	13 Insp mach /hrs	REMARKS
EST. RS PER GROUP																total Rs.
RATE PER HOUR																total hrs.
TOTAL HOURS IN GROUP			28	37				25	5	10	16	5	5	50		
COMPLETED																
TO BE FINISHED WEEK																
1	3956-01		/	/	/	/	/	/	/	/	/	/	/	/	/	
2 01	'GO' & 'NO GO' Snap Gauge	05	/	/15	/	/	56-62/HRC	3½/5	/	/	/3	/	/	/10	/✓	
3			/	/	/	/	/	/	/	/	/	/	/	/	/	
4	3956-03		/	/	/	/	/	/	/	/	/	/	/	/	/	
5 01	'GO' & 'NO GO' PLug Gauge	05	/10	/2	/	/	56-62/HRC	/	/5	/	/	/	/	/	/	
6			/	/	/	/	/	/	/	/	/	/	/	/	/	
7	3956-04	05	/	/	/	/	/	/	/	/	/	/	/	/	/	
8 01	'GO' Ring Gauge	05	/10	/	/	/	56-62/HRC	/5	/	/5	/	/	/	Pol/5	/	
9			/	/	/	/	/	/	/	/	/	/	/	/	/	
10	3956-05		/	/	/	/	/	/	/	/	/	/	/	/	/	
11 01	'NO GO' Ring Gauge	05	/8	/	/	/	56-62/HRC	/5	/	/5	/	/	/	Pol/5	/	
12			/	/	/	/	/	/	/	/	/	/	/	/	/	
13	3956-06		/	/	/	/	/	/	/	/	/	/	/	/	/	
14 01	'GO' & 'NO GO' Snap Gauge	05	/	22/1/10	/	/	56-63/HRC	/5	/	/	/4	/	/	Lap/10	/	
15			/	/	/	/	/	/	/	/	/	/	/	/	/	
	3956-07		/	/	/	/	/	/	/	/	/	/	/	/	/	
01	'GO' & 'NO GO' Snap Gauge	05	/	22/1/10	/	/	56-63/HRC	/5	/	/	/4	/	/	Lap/10	/	
01	'GO' & 'NO GO' Plate Gauge.	05	/	/5	/	/	56-63/HRC	/2	/	/	/5	/5	/	[illegible]/10	/	395
NUMBER OF TIME SLIP																

Fig. 4. Example consolidation sheets for production data of MSME Tool Room

Ref. [12] has recently defined Utilization based CFP which is popularly stated as "operational time" or "ratio data" in past literature. This is also named as Machine Part Utilization Matrix (MPUM). After pre-processing and proper transformation, the MPUM is obtained of size 10×368 for the industrial case, which is substantially large.

3 African Buffalo Optimization (ABO)

ABO is a metaheuristic optimization algorithm recently developed [16]. This technique mimics the migratory behaviour of the large herd of African buffalos foraging for food across the plains and forests. They migrate in search of green fields and travel across vast African territory. Depending upon the seasonal differences the buffalos travel continuously across the plains, mountains, and forests in quest of green land. ABO advances with two natural inter-communication strategies among the herd members, (i) the roaring *waaa*, which indicates the sense of risks or scarcity of greenery in present location and directing the herd to move to next location. (ii) The roaring *maaa*, which confirms promising green meadows and suggesting the herd to stay [17]. ABO is being practiced in different problem domains by researchers, such as Travelling Salesman Problem (TSP) and parameter optimization of PID controllers. ABO advances with the i^{th} buffalo and its two natural inter-communication methods among the herd members ($i=1,2,3,\ldots,n$), (i) the roaring *waaa*, denoted by w_i, which helps in exploring the solutions in global search. (ii) The roaring *maaa*, denoted by m_i, which helps in exploiting in the local search space. The values of m and w for $(i+1)^{th}$ buffalo are updated using the following equations,

$$m_{i+1} = m_i + lp_1 \times (bg - w_i) + lp_2 \times (bp_i - w_i)$$

$$w_{i+1} = \frac{(w_i + m_i)}{\lambda}$$

Where lp_1 and lp_2 are learning parameters, bg and bp_i are the best position of the herd and the i^{th} buffalo's best known position respectively, and λ is a prefixed random number. The artificial herd of buffalos is generated with initial herd $x_i = \{x_1, x_2, \ldots, x_n\}_{i \in [1,n]}$ representing the n coordinates for a continuous domain or n vectors for discrete domain. The flowchart of ABO is portrayed in Fig. 5.

4 Results and Discussions

A large dataset (10×368) eventually increases the complexity to find the near-best solution. The ABO is applied on this data and three cells are formed. The result obtained is, UGE: 53.039, TEU 886, Voids: 657 and CPU Time: 2.33 $\times 10^3$ Sec. Further the new cellular structure is made with three distinct cells (Fig. 6). It could further be observed that the material handling is improved in the obtained cell formation. For example, a trimming die would travel from the CNC milling shop to benchwork to jig grinding shop to WEDM shop to benchwork and to surface grinding shop in order to be completely processed. In the existing jobshop formation it would travel 7.3+17.67+27.737+12.49+17.37 = 82.57 meter, but in the proposed cellular shop-floor it would travel around 7.3+12.49+15.85+13.41+15.54 = 64.59 meter. Therefore, material handling cost is reduced by 21.77% approximately.

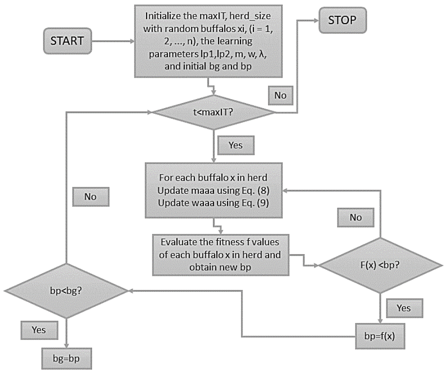


Fig. 5. ABO Flowchart

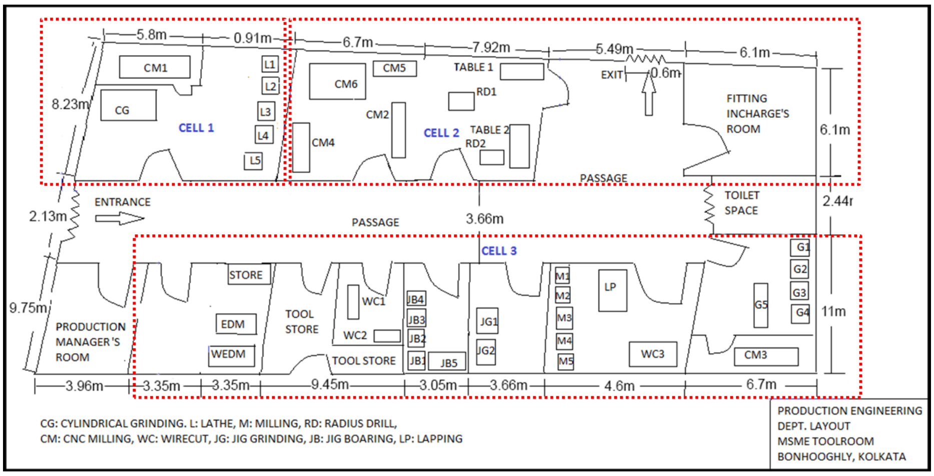


Fig. 6. Proposed arrangement of machines with Cellular configuration

In another example a length gauge would travel from turning to cylindrical grinding to obtain complete processing. In the existing shop-floor it would travel 1.83+2.74 = 4.57 meter, whereas in the proposed cellular shop-floor it is an intra-cell movement in cell 1 which is approximately 1.5 meter, which is 65.6% better than existing arrangement. Therefore, the proposed solution improves the material movement which in turn reduces material handling cost.

5 Conclusions

In this paper the Utilization-based cellular structure is implemented in production toolroom of MSME, India. This is considered as one of the latest NP-Hard problems with an aim to minimize the total cell movements. A latest ABO technique is utilized as a methodology. This proposed technique is shown to obtain promising result. The obtained cellular structure is shown to be more efficient than the existing jobshop formation for the company. This solution could be useful to the operational personnel of the company, who could further decide on material handling costs reduction and production time improvement.

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