Simulation Based Cuckoo Search Optimization Algorithm for Flexible Job Shop Scheduling Problem

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ABSTRACT

The Cuckoo Search Optimization (CSO) is a novel evolutionary algorithm having natural swarm intelligence behavior and suitable for NP-Hard combinatorial problems. This algorithm possesses the features of the way of living of a bird's family, called Cuckoo. Particularly, the system of "egg laying and breeding" of cuckoos is the driving force behind the development of this nature inspired algorithm. The survival endeavor of cuckoos converges to a society in which each cuckoo has same fitness value. Thus, CSO algorithm has been recognized to handle the complex optimization problems, effectively. Therefore, in the present work, simulation based CSO algorithm has been proposed to solve flexible job shop scheduling problem, which is a well-known and real-world problem. The value of fitness function is evaluated through simulation. Simulation is used to calculate value of performance measure as it yields the performance closed to a real system as compare to the mathematical functions. PROMODEL© simulation software has been used to model the shop. Makespan is considered as a performance measure. Results indicates that simulation-based CSO algorithm is effective to optimize the flexible job shop scheduling problem.

CCS Concepts

•Theory of computation → Evolutionary algorithms • Computing methodologies → Planning and scheduling • Computing methodologies → Modeling and simulation • Computing methodologies → Discrete-event simulation

Keywords

Flexible Job Shop Scheduling; Cuckoo Search; Evolutionary Algorithm; Optimization.

1. INTRODUCTION

Production scheduling (sometimes termed manufacturing scheduling or details scheduling) is the important function of a manufacturing business [1]. A good manufacturing system will update the production schedule often, to gratify the large job order of customers, to decrease the cost incurred, to accommodate the changes in resources availability and to increase the overall production efficiency. The production scheduling problem has been classified according to the shop configurations viz., parallel machine shop, single machine shop, open shop, flow shop and job shop manufacturing system [2-3]. The job shop scheduling problem has been recognized as a highest typical class of production scheduling. Therefore, its study provides quality insight into the solution of the scheduling problem faced in complex and real-world manufacturing system. It is a non-polynomial hard problem. The job shop processes several jobs on a given set of machines, in which each job type has a fixed operation sequence to be followed and a machine can process one operation at a given time [4]. In today's competitive world, the manufacturing flexibility is playing crucial rule to sustain in a market, having demand of rapid product delivery at right cost and quality. Also, the machines are available with full flexibility, that can accommodate a variety of processes exclusively. If, a job shop manufacturing system cannot utilize this available advanced machine tool, this incurred a direct loss due to under use of resources. Hence, the job shop manufacturing systems have been turned into flexible job shop systems. So, the scheduling of job shop environment become more tough and it is named as flexible job shop scheduling problem [1]. As mentioned earlier, in job shop scheduling problem, each job is processed with operation sequence without considering substitute machines. This assumption has been relaxed in case of flexible job shop scheduling problem. Thus, in flexible job shop scheduling problem any job may visit any available machine at any instant for its succeeding operation. This scenario is termed as full flexible job shop manufacturing system, which is virtually not possible. Hence, the concept of partially flexibility is most realist and adoptable in present manufacturing systems, which involve the processing of a group of operations of job on the group of alternative machines. Therefore, a flexible job shop scheduling problem comprise two tasks viz., *(i)* assignment of resources (i.e. allocating machine to the operation) and, *(ii)* assignment of sequence of operations of jobs on an individual machine. This problem has been solved for various performance measures (objectives) such as makespan, tardiness, flow time etc. But, the makespan is widely used [5]. Numerous studies have been conducted across the world to solve the flexible job shop scheduling problem but, the efficient algorithm is still not available to find the optimal solution. Thus, the meta heuristic methods are most viable to deal with the problem of combinatorial optimization [6].

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Subsequent sections of this paper present the related literature review, problem formulation, background of cuckoo's search optimization algorithm, adopted methodology to solve the flexible job shop scheduling and results as well as discussion. At the end, conclusion is presented.

2. LITERATURE REVIEW

In literature, the flexible job shop scheduling problem has been solved in two ways; *(i)* by dividing it in two sub problems namely operation sequencing problem and assignment problem and, (ii) by an integrated manner. The detailed review of these approaches has been presented by Chaudhary and Khan [7].

The CSO algorithm has attracted researchers to solve complex engineering problems, due to its effectiveness and robustness to handle global optimization by maintain the balance amid global and local random walks. Zheng and Zhou [8] proposed CSO algorithm based on Gaussian distribution to solve an engineering design optimization problem. Zhou et al. [9], presented CSO with a greedy transform algorithm to solve graph coloring (complexion) problem. Ong [10], presented CSO algorithm for unconstrained optimization. He modified CSO to make it adaptive by changing the step size (α) continuously. Nguyena and Vu [11], proposed CSO algorithm for short term hydrothermal scheduling problem. The modify CSO by making two clusters of eggs, in which top cluster contain eggs having low fitness and abandoned cluster contains other eggs. Also, step size (α) of Levy flights changed corresponding to the iteration number. Singh and Singh [5], presented CSO algorithm to solve job shop scheduling problem to minimize makespan. The proposed to improve the search capability of CSO through the mixing a set of assorted individuals.

3. PROBLEM FORMULATION

A flexible job shop scheduling problem involve the following elements namely jobs, machines manufacturing flexibilities, constrains (assumptions), hypothesis and an objective. Job (J) is equal to (J1, J2, J3…. Jn), i.e. a set of "n" jobs to be scheduled. A job (Ji) possesses a fixed number of operations and any operation (j) of any job (Ji) is represented as Oij. Machine (M) is equal to (M1, M2, M3…. Mm), i.e. a set of "m" machines. A machine is capable to process only one operation at a time. Manufacturing flexibility can be extended from partial to full level. In partial flexibility an operation can be executed on one set of machines, while in full flexibility an operation can be executed on any machine. In present work, partial flexibility has been considered, since it possesses more realistic environment.

The quality of fitness is calculated through the manufacturing simulation software (PROMODEL©). Simulation is considered to find the performance of the system because it gives the performance value near to the real system performance as compare to the mathematical functions. Makespan is considered as the optimization criterion.

The shop is modelled in PROMODEL© simulation software (*student version*). The actual job shop manufacturing system is relatively complex and considering full details of shop configuration increases the modeling complexity, which needs simplifications. Therefore, to streamline the modeling, following assumptions have been made in line with previous studies [12].

- All jobs are independent of each other and available at the zero time.
- Processing time, transportation time and production quantity of each job type are known in advance.
- All machines are independent to each other and available at the time of beginning of operation.
- Operation sequence and machine flexibility for each job type are known in advance.
- Operation and part pre-emption is not allowed, and one machine can process one operation at a time.
- Each machine has infinite buffer capacity to receive each job type in a queue before commencement of processing.
- Incoming and outgoing location is considered to receive and deliver the production order.
- "Shortest processing time" criterion is used as dispatching rule and "first come first serve" rule is used as tie breaker.

4. CUCKOO SEARCH OPTIMIZATION (CSO) ALGORITHM

Figure 1 presents the flowchart of CSO algorithm proposed by Rajabioun [13]. This algorithm is also starts working through the generation of opening population just as if other nature inspired evolutionary algorithms. These opening population of cuckoos emplace the eggs in the nest of host birds. Due to the similarity of eggs of penetrated cuckoos and host birds, the penetrated eggs get the opportunity to nurture and develop the cuckoo. Also, the host birds sensed the remaining eggs and destroy them. Hence, the fitness of nest is based on the growth of eggs in that locality. If the survival rate of the eggs is rising that means the profitability of that vicinity is increasing. Consequently, the location in which the living of eggs is higher will be called that the CSO algorithm leading towards optimization [13].

To increase the survival rate of eggs, the cuckoos quest the fit vicinity to emplace the eggs. Once the eggs nurture and develop as a mature cuckoo they form societies. The habitats are formed to live in these societies and each cuckoo always in search for a better habitat over the entire societies. Hence, the cuckoos immigrate and live near the better habitat. A cuckoo can be bounded with two parameters viz., the number of eggs and the distance to reach at a better habitat. These two parameters determine the "Egg Laying Radii" that means the cuckoo emplace the eggs in randomly selected nests within this radius. Hence, this process works in an iterative manner till the worthy habitat is attained and the population raises within this earnest location [13].

5. ADOPTED METHODOLOGY

Yang and Deb [14] are using the philosophy of CSO algorithm in three conducts viz., *(a)* a cuckoo emplaces one egg in randomly chosen host's nest, at a time, which shows a set of solution; *(b)* some nests having good quality eggs (i.e. best solutions) brings forward in succeeding generation; *(c)* the probability of finding cuckoos eggs (foreigner's egg) by a host bird is 0 and 1, it means, either the host bird abolish the eggs and nest or she relocate to new area and construct another nest. The present work utilizing the CSO algorithm philosophy proposed by Yang and Deb [14]. The flowchart of simulation-based CSO algorithm is shown in figure 2.

5.1 Lévy Flights Equation

There are two types of random walks viz., Lévy walks and Lévy flights. Lévy flights were first used by physicists to define photoconductivity in amorphous materials. Since then, these concepts have been applied in many areas [15]. In Lévy flight the length of a jump/step is defined through the probability distribution having a random direction. In CSO algorithm, the

Lévy flights equation is used for generating new solution [$x^{(t+1)}$] for i^{th} cuckoo, randomly [14]. The equation for new solution is [$x_i^{(t)} + \alpha \oplus$ Lévy (β)]. In which, $\alpha>0$ is the size of a step according to the problem scales. Typically, α is taken as 1. "$\oplus$" represents entry wise multiplication. A random length of a step is drawn from the Lévy distribution [Lévy ~ $u = t^{-\beta}(1 < \beta \leq 3)$], having immeasurable variance value. Basically, the consecutive jumps of a cuckoo comprise the progression of random walk which observe a power law distribution of step length by a hefty tail strength. The fraction (p_a) of worst nests are ruined, and new nests are formed at new places using random walk.

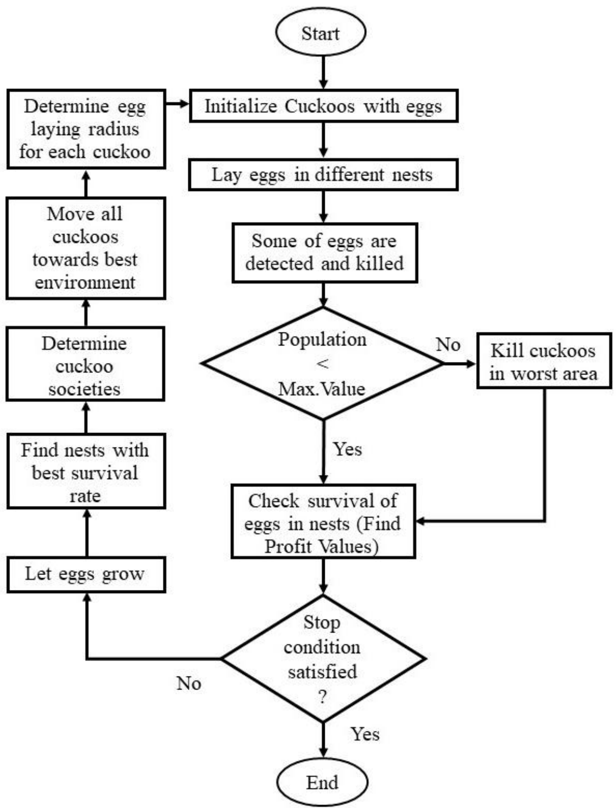

Figure 1. Flowchart of CSO algorithm [13].

In the present work, a modified Lévy flights equation is used to suit the flexible job shop scheduling problem, proposed by Al-Obaidi and Hussein [16]. It helps to enhance the search in discrete space. The equation for a new solution [$x_i^{(t+1)}$] is given by [$x_i^{(t)} + \alpha (x_j^{(t)} - x_i^{(t)}) \times t^{-\beta}$] for t^{th} iteration. Where, [$x_i^{(t)}$] and [$x_j^{(t)}$] are random solutions, [$\alpha(x_j^{(t)} - x_i^{(t)})$] is the deviation from existing solution [$x_i^{(t)}$], [$t^{-\beta}$] represents Lévy Distribution of random steps, [α] is taken as one and the [β] is given by [$\beta_{min} + (\beta_{max} - \beta_{min} / t_{max}) \times t$]. They proposed β_{min}=1.1 and β_{max}= 3, the minimum and maximum value of Lévy Distribution.

5.2 Operators

The operators of Lévy flight such as subtraction, multiplication and addition are revised for discrete production scheduling problem. Flexible job shop scheduling problem is modeled with two vectors viz., machine assignment vector and job permutation combination vector. The subtraction operator works on job vector, in which the comparison is made among two solutions to create a chain of new solution. If, any component of both solutions is matching, then the corresponding component turned as zero while forming a chain of new solution. In case of multiplication, a random number is generated between 0 and 1 for each component of chain and compared with the value of σ. If, random number $\leq \sigma$, then the component of the chain of new solution turned as zero, otherwise no change in the corresponding component. Addition is the last step to form a fresh solution from recent available solution after multiplication operation. In this operation, the jobs with non-zero components are picked from current solution. These components are moved forward and exchange randomly [16].

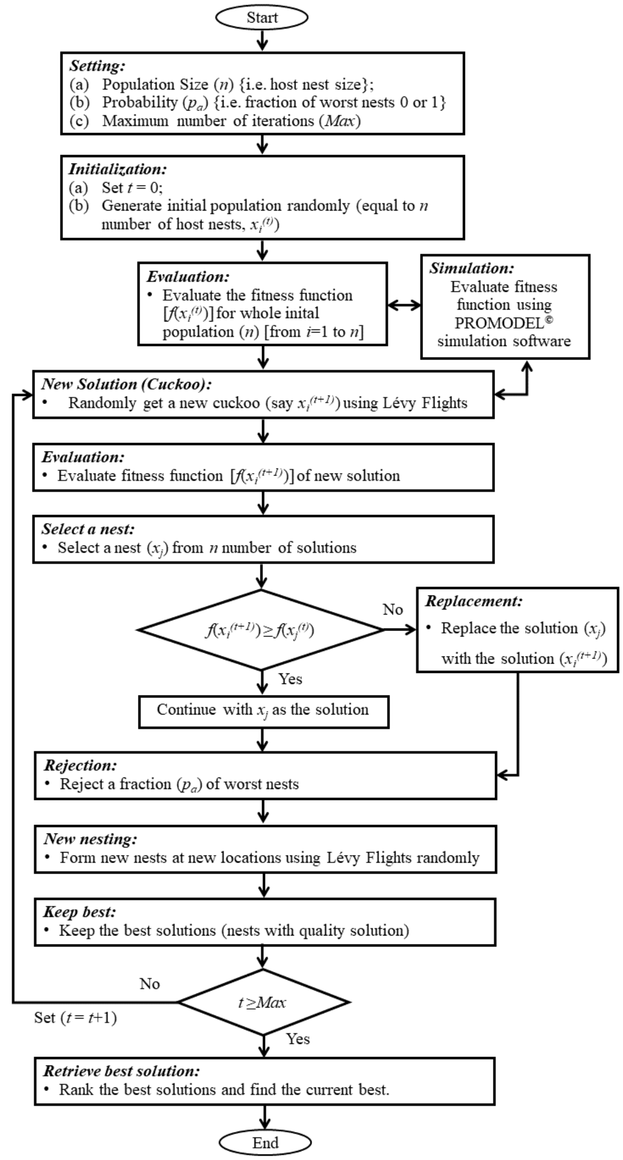

Figure 2. Simulation-based CSO algorithm

5.3 Population Size and Termination Criterion

The CSO algorithm is regulated by various parameters such as number of initial cuckoos, minimum and maximum number of iterations, number of clusters, maximum number of living cuckoos etc. In the present work, parameters of CSO algorithm are adopted from Akbarzadeh and Shadkam [17], because they have proposed the model for minimization. Since, the population size has direct influence on computation time and diversity of the algorithm, therefore, in the present work, the population size (n)

and termination criterion (*Max*) have been linked with the size of problem (i.e. number of machines × number of jobs). Maximum number of iteration is used as a termination criterion for algorithm. As suggested by Al-Obaidi and Hussein [16], for flexible job shop scheduling problem, the population size and termination criterion are [0.5 × (M×N)] and 800, respectively. M is the number of machines and N is the number of jobs.

6. RESULTS AND DISCUSSION

The present work utilize simulation based CSO algorithm methodology, as discussed in section 5. The fitness value is calculated through PROMODEL© simulation software. Simulation is used because it shows the performance near to a real manufacturing system performance as compare to a mathematical function. Makespan is considered as performance measure (objective) for taken job shop. In the present work, a flexible job shop manufacturing system with three jobs and four machines has been considered. This shop has been modelled in the simulation software as shown in the figure 3.

The jobs flow works as follows. The production order is received at incoming location. At the beginning, the raw material (i.e. job) is loaded to a machine or in the que as per the sequence of operation for its first operation. The job will process on machine if the machine is empty otherwise, the job will enter in the waiting queue for handing out. Once the first operation is accomplished, it will transport to the next machine as per the defined sequence of operation for the succeeding operation. Hence, the jobs are travelled to various stations as per the sequence of operations. At last, the job (i.e. finished product) exit the shop from outgoing location [12]. The work flow is illustrated in figure 4.

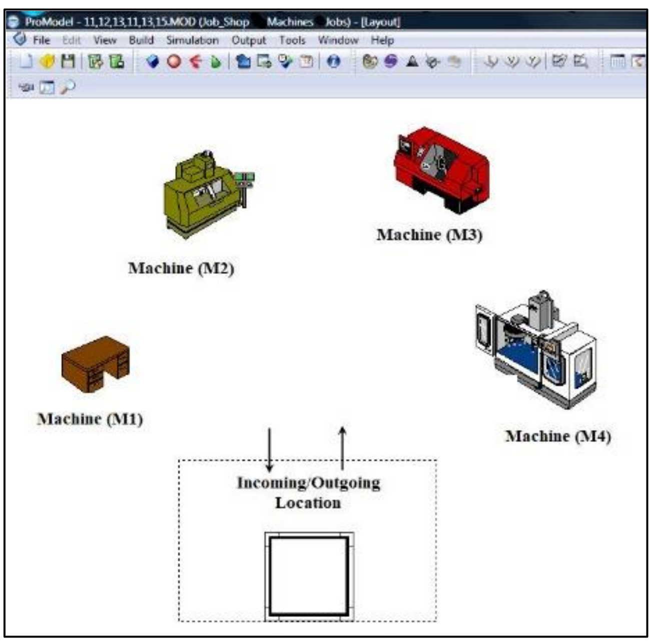

Figure 3. Screenshot of flexible job shop layout consisting of 4 machines modelled in PROMODEL® simulation software.

Table 1 presents the processing time and quantity of each job to be processed in a flexible job shop manufacturing system. Table 2 is showing the transportation time consumed by each job to move from one location to another (including machine to machine and incoming/outgoing location to machines).

The proposed simulation based CSO algorithm has been tested on a sample production order of size three jobs and four machines. Table 3 shows the results obtained. The value of optimized makespan is 158 minutes for the sample problem.

Table 1. Processing time, production quantity and number of operation for taken flexible job shop scheduling problem

Jobs	Machines				Operation Number	Production Quantity
	M1	M2	M3	M4		
J1	5	-	2	-	1st	6
	6	-	5	-	2nd	
J2	-	2	-	3	1st	8
	3	-	-	3	2nd	
	-	3	-	5	3rd	
J3	-	2	-	4	1st	5
	2	-	3	-	2nd	
	-	6	5	-	3rd	

Two case studies are taken from Brandimarte [18] as shown in table 4. Results shows that proposed approach performs better then Brandimarte [18] but, analogous to the results reported by Ho et al. [19]. To compare the performance of proposed approach, the transportation time and production quantity have been not considered during the simulation.

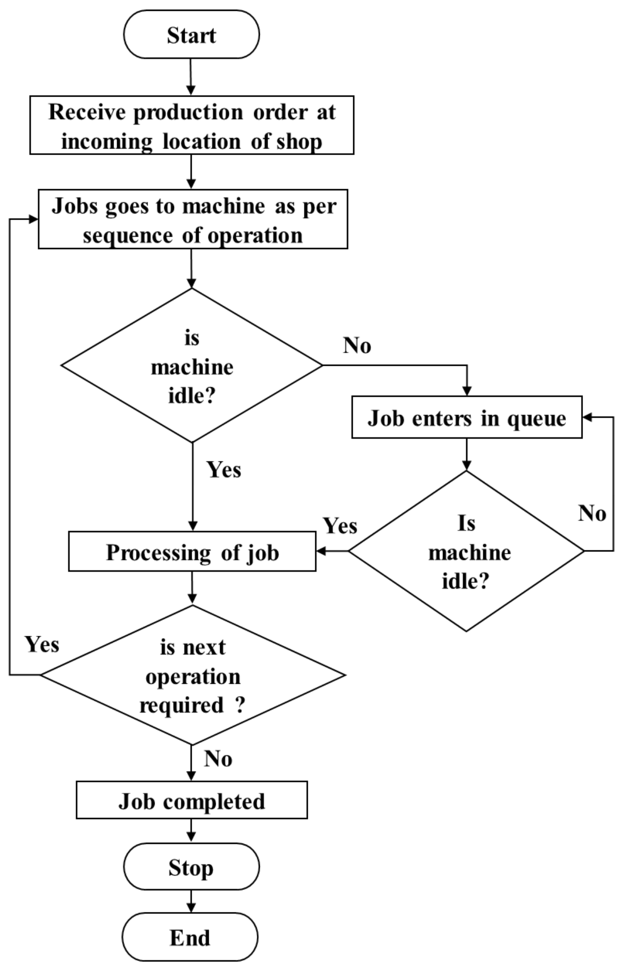

Figure 4. The work flow in modelled job shop.

Table 2. Transportation time from one location to another location.

	M1	M2	M3	M4	I/O Location
M1	0	1	2	2	1
M2	1	0	1	4	3
M3	2	1	0	2	3
M4	2	4	2	0	1
I/O Location	1	3	3	1	0

Table 3. Results of sample problem

Jobs	Operation Sequences	Optimized Makespan
J1	I[1]-M1(5)-[2]-M3(2)-O[3]	158
J2	I[1]-M4(3)-[0]-M4(3)-[4]-M2(3)-O[3]	
J3	I[3]-M2(2)-[1]-M1(2)-[2]-M3(5)-O[3]	

Legends: I – Incoming Location; M – Machine Number; O – Outcoming Location; [-] – transportation time; (-) – processing time.

Table 4. Comparison of results.

PN	J	M	NOP	MPO	PTO	Makespan		
						[18]	[19]	PA
1	10	6	5-7	3	1-7	42	40	40
2	10	6	5-7	6	1-7	32	29	29

Legends: PN – Problem Number; J – Number of Jobs; M – Number of Machines; NOP – Minimum and Maximum Number of Operations Per Job; MPO – Maximum Number of Equivalent Machines Per Job; PTO – Minimum and Maximum Processing Time Per Operation; PA – Proposed Approach.

The adopted methodology has been coded in MATLAB programming language (standard demo given by: Prof. XS Yang [Link]) and processed on "x64-based Window 10 platform" having "Intel® Core™ i5-4210U CPU @ 1.70 GHz".

7. CONCLUSION

The Cuckoo Search Optimization (CSO) is a novel evolutionary algorithm having natural swarm intelligence behavior and suitable for NP-Hard combinatorial problems. It has been recognized to handle the complex optimization problems. In the present work, simulation-based CSO algorithm has been successfully applied to solve flexible job shop scheduling problem, which is a well-known real-world problem. The value of fitness function is evaluated through simulation. Simulation is used to calculate the value of performance measure as it yields the performance closed to real system as compare to the mathematical functions. The algorithm has been tested on a small size problem with transportation time and production quantity. Makespan is considered as a performance measure. Results prove the proposed approach of simulation-based CSO algorithm is effective to optimize the makesapn of flexible job shop scheduling. It has been planned to extend this work for other objectives such as tardiness and flow time etc., as well as, the incorporation of external and internal disturbances on production performance in future.

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