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Artificial Bee Colony with Random Key Technique for Production Scheduling in Capital Goods Industry

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Abstract. Scheduling is one of the core business operations especially in capital goods industry, in which the complex products are highly customised and therefore manufactured with low volume in make/engineer-to-order basis. Effective production scheduling must be met the customer due date with considering the limited resource constraints and allocations. Scheduling is classified as a Non-deterministic Polynomial (NP) hard problem, which means that the amount of computation required increases exponentially with problem size. This work presents the application of Artificial Bee Colony with Random Key (ABC+RK) technique for solving production scheduling in capital goods industry. The comparative study on the proposed techniques was carried out using scheduling datasets from a company engaged in capital goods industry. The analysis on the computational results indicated that the ABC+RK performed better than the conventional ABC especially for extra large-size problems.

Keywords: Scheduling, capital goods, bee colony, random key technique.

1. Introduction

Scheduling is one of the core business operations especially in manufacturing industry since companies seek to deliver products based on the Just in Time philosophy and simultaneously achieve high resource utilisation. There is an abundant literature on production scheduling, the majority of which has focused on single machine, flow-shop and job-shop scheduling [1]. Classical job/flow shop scheduling problems generally consist of a set of independent tasks. This is a single stage scheduling [2] which means that there are no precedence constraints among operation and assembly requirements [3]. This is impractical for manufacturing company engaged in capital goods industry.

Capital goods such as steam turbines or large boilers have unique production scheduling characteristics [4]. These products have very complex and deep product structures with many levels of assembly, which gives rise to assembly precedence constraints. Many components have complex processing requirements and are manufactured on many non-identical machines with long routings. Thus operation precedence constraints are another important issue. All resources have finite capacity constraints and deadlock within schedules needs to be avoided. The highly constrained nature of these problems means that a large proportion of schedules produced by stochastic search methods are infeasible.

The research related to the capital goods company is relatively rare compared with the classical job/flow shop scheduling problem. The objectives of this paper are to: i) propose the modified Artificial Bee Colony that embedded the Random Key technique (ABC+RK) for scheduling capital goods; ii) benchmark and compare the performance of the proposed algorithm with the conventional method in terms of the quality of the solutions achieved with the same amount of search and computational time required to solve four industrial cases.

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The remaining sections of this paper are structured as follows. The next section briefly presents the characteristics and the assumptions of scheduling problem for manufacturing capital goods. Section 3 describes the Artificial Bee Colony with random key technique proposed to solve the complex scheduling problems adopted from a capital goods company. Section 4 presents the numerical study and followed by the conclusions in section 5.

2. Scheduling in capital goods company

Sequencing commonly determines the order of operations or tasks to be performed on processor(s) or resource(s). The sequencing process is sometimes constrained by precedence relationship and assembly precedence. It does not initially involve timing. Scheduling is defined as the allocation of resources over time to perform a collection of tasks [5] and usually aimed to optimise one or more measures of performance such as delivery performance, work in process inventory or machine utilisation. An optimum schedule for capital goods needs to co-ordinate the supply of components to meet assembly requirements and also ensure that finite capacity constraints are not exceeded [6].

Capital goods industry represents a very important industrial sector. Production planning in these companies is different from other industrial sectors. In order to meet customer requirement with a wide variety of high quality products at a competitive prices, capital goods companies has to establish a very close interact relationship with customers. Goods produced by these companies are highly customised and produced in Make-To-Order (MTO) and Engineer-To-Order (ETO) manufacturing systems. ETO companies are heavily involved in the product design, manufacture and construction of capital equipment. These products have a very complex product structure (e.g. many levels of manufacturing operations, subassembly and assembly on many machines) and they are produced in a low volume. Typical products are large oil rigs, turbine generators, cranes, ships and large boilers. These goods contain a very diverse range of components. Some of these components are required in very low volume, whereas some others are required in medium or large quantities. Certain components are highly customised whilst others are standardised [7].

A typical product structure of a capital goods is shown in Figure 1. The root node represents the final product that requires many assemblies. The leaf nodes correspond to the components, each of which requires manufacturing operations on various machines.

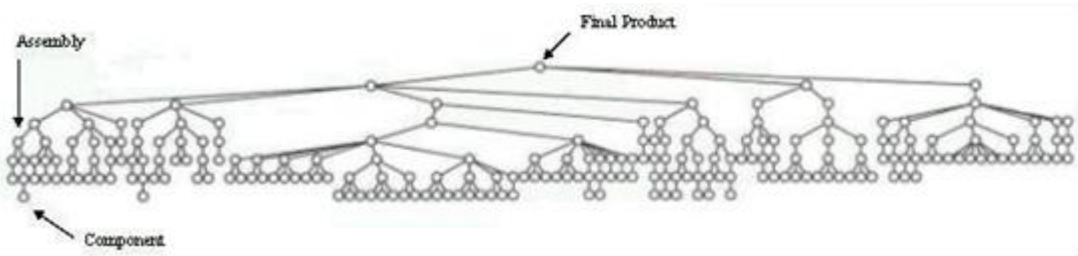

Fig. 1: A product structure of a capital good [4].

Various assumptions have been made in order to simplify, formulate and solve scheduling problems [8-9]. In this work, the following common assumptions were made: a successor operation is performed immediately after its predecessor has finished, providing that the machine is available; each machine can handle only one operation at a time; each operation can only be performed on one machine at a time; there is no interruption of operations; there is no rework; each operation on machine requires setup and transfer times.

In capital goods companies, delivery performance is considered to be especially important [10]. The measure of scheduling performance considered in this present work was based on the Just in Time philosophy, in which the early completion of the components, assemblies and finished goods leads to the holding cost related to the products and work-in-process inventory. Late delivery will also result in severe penalty due to contractual terms. The total costs related to the early completion and the tardy delivery were minimised in this work using the Artificial Bee Colony with Random Key technique.

3. Artificial Bee Colony with Random Key technique

Since nature is always a source of inspiration, there has been increasing interests in development of computational models or methods that iteratively conduct stochastic search process inspired by natural intelligence. Many optimisation algorithms have been recently designed and developed in the last few decades by adopting a form of biological-based swarm intelligence including Artificial Bee Colony (ABC) Algorithm [11].

The pseudo code of ABC algorithm applied to solve the production scheduling problem is shown in Figure 2. It can be seen that the performance of the conventional ABC depends on three control parameters including i) the number of food sources, which is equal to the population size (S) of employed or onlooker bees; ii) the predefined value of limit (L) for unimproved loop in the case that if a position cannot be improved then food source is assumed to be abandoned; and finally iii) the maximum loop for searching food (M). Enhancing the algorithm’s performance can be basically accomplished by the use of the appropriate parameter setting, which can be systematically investigated and statistical identified via the experimental design and analysis [12-13]. Due to the nature and complexity of the problem domains, it has been suggested that the appropriate parameter setting can be varied across problem sizes and/or problem domains. Most research work related to the application of nature-inspired algorithms e.g. Genetic Algorithm has set it parameters and operators in an ad hoc fashion [14].

1: Define population size (S), loop (M) and unimproved loop (L)
2: Initial the population of schedules (X_i); $i = 1, 2, 3, \ldots, S$.
3: Evaluate the population
Set *loop* = 1
Repeat
4: Produce new schedules (V_i) using Random Key technique as the employed bee and evaluate them
5: Apply greedy selection process for the employed bees
6: Calculate the probability value (P_i) for schedules (X_i)
7: Produce V_i as the onlookers from X_i selected depending on P_i and evaluate them
8: Apply greedy selection process for the onlookers
9: Determine the abandoned solution for the scout according to L, if exists, replace it with a new schedule
10: Update the best achieved so far solution
loop = *loop* + 1
Until *loop* = M

Fig. 2: Pseudo code of the ABC with RK technique for creating employed bee.

Random Key encoding technique, which can be used to transform a position in RK continuous space to a discrete space, has been introduced by Lin et al. [15]. Since the vector operations specified within some algorithms (e.g. Particle Swarm or Bee Colony) can therefore be a difficulty for its application to solve combinatorial optimisation problems such as scheduling (all possible schedules in the solution space are discrete), this particular technique can be applied to overcome the difficulty. The basic concept of this technique is by assigning an identical random number associated with each element in a particular schedule. Any mathematical vector operation related to the corresponding elements can be calculated via the associated random numbers. More explanation and example of the RK technique refer to Lin et al. [15]. In this work, the RK technique is applied in the process of producing employed bees as mentioned in step 4 of the pseudo code shown in Figure 2. The ABC based scheduling program has been coded in modular style using a general purpose programming language called TCL/TK programming language. The computational study on the developed program conducted on a 2.2 GHz CPU with 2 GB DDRII RAM notebook is presented in the next section.

4. Computational Study

In this work, four sizes of industrial scheduling problem (detailed in Table 1) including production schedules, product structure relationships, process plans and resource loading information were obtained from a collaborating company engaged in make/engineer-to-order capital good industry. The first (small) problem, for example, involved two different products (245 and 451), with a combined requirement of twenty-five machining operations on eight resources with nine assembly operations. The small scheduling problem was so called two-product eight-machine four-stage scheduling problem. Regarding to the number of operations components and resources involved, the remaining problems are relatively medium and large, respectively. The large problem involved 118 machining and 17 assembly operations on 17 resources. There were more interactions and contentions on resources.

Table 1 Industrial scheduling problem.

Problem size	Part number	Characteristics of Scheduling Problems				
		Number of Products	Number of Components	Machining / Assembly Operations	Number of Resources	Levels of product structure
Small	245 & 451	2	6	25/9	8	4
Medium	229 & 451	2	8	57/10	7	4
Large	4 & 228	2	12	118/17	17	4
Extra large	227	1	46	229/39	25	6

The computational experiment on the ABC based scheduling program for each problem size using conventional ABC and the ABC+RK technique was carried out with 30 replications with assigning different random seed numbers. The computational results obtained from a total of 240 runs were analysed and illustrated in Table 2.

Table 2 Total penalty cost associated with the schedules obtained from each problem size [Unit in currency (x1000)].

Problem size	Method	Best so far (BSF) solution	Average BSF	Standard Deviation	Average loop that found BSF	Average execution time (min.)
Small	ABC	15	15.0	0	7.20	0.415
	ABC+RK	15	15.0	0	8.13	0.455
Medium	ABC	51	54.2	1.5	31.67	0.918
	ABC+RK	52	54.4	1.5	29.43	0.969
Large	ABC	221.5	254.1	15.0	45.47	2.633
	ABC+RK	**219.5**	254.8	15.1	44.57	2.633
Extra Large	ABC	7,981.5	8,879.4	541.9	49.03	11.749
	ABC+RK	**7,516.5**	8,777.9	546.2	49.10	9.530

It can be seen that the penalty cost of the best so far (BSF) solutions and its average obtained from both conventional Artificial Bee Colony (ABC) and the proposed ABC with Random Key (ABC+RK) technique were close for the small and medium size problem. However, the proposed ABC+RK produced BSF schedules with lower penalty cost than the conventional ABC for the large and extra-large size problems. The average execution times taken by both methods with the same amount of search were marginal. An example of Gantt chart produced by the proposed ABC+RK is illustrated in Figure 3.

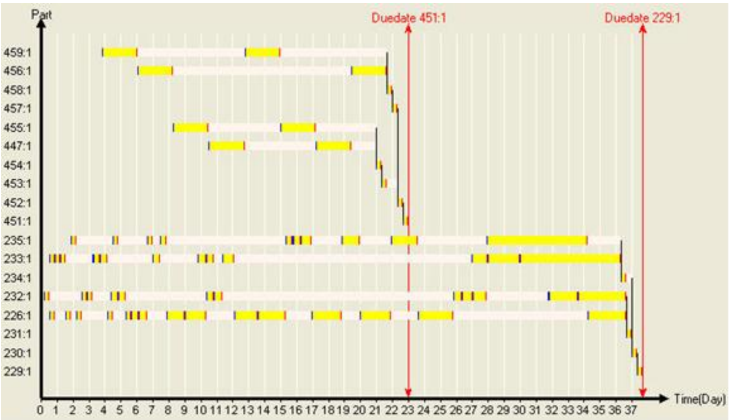

Fig. 3: An example of Gantt chart of the best schedule obtained.

5. Conclusions

This work describes the development of scheduling program, in which the Artificial Bee Colony with Random Key (ABC+RK) technique was applied to solve production scheduling in capital goods industry. The comparative study between the proposed techniques and the conventional method was carried out using scheduling datasets from a capital goods company. The analysis on the computational results indicated that the ABC+RK performed better than the conventional ABC especially for extra large-size problems.

6. Acknowledgements

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