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Bees Algorithm for multi-mode, resource-constrained project scheduling in molding industry

Ercan Oztemel [1], Ayse Aycim Selam [2,*]

Department of Industrial Engineering, University of Marmara, Turkey

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ABSTRACT

In a resource-constrained environment project planning and scheduling becomes an extremely complex problem. For real life project schedules multi-mode resource requirements remarkably increase the complexity of and enlarge the respective solution spaces. Therefore schedulers require systematic methodologies compatible with the real world implementations in order to generate cost effective schedules. Similarly, plastic injection molding is known to be a "make-to order" process. The manufacturing of the mold which is a unique and essential component of plastic injection is considered kind of a project. The aim of this study is set to investigate the possibility of utilizing Bees Algorithm for single-resource, multi-mode, resource-constrained mold project scheduling in order to generate a systematic approach to solve the problems of this nature. A Bee-Based Mold Scheduling Model is therefore proposed and employed on a set of problems with different dimensions for the proof of concept. Detail description of an injection molding project together with respective performance analysis is also provided. After the implementation of the proposed methodology, it is well proven that, even for high number of activities and limited resources, the proposed method generates suitable schedules for the projects of this kind the implementation and respective modelling is explained and the results are discussed in detail within the text.

1. Introduction

Project planning and scheduling is well known and an extremely complex problem due to the limited amount of resources to be scheduled. Especially multi-mode resource requirements remarkably increase the complexity of real life project schedules and enlarge the respective solution spaces. Generating cost effective schedules therefore require systematic methodologies coherent to the real world implementations. The aim of this study is set to investigate the possibility of utilizing Bee Colony Optimization for single-resource, multi-mode, resource-constrained project scheduling in order to generate a systematic approach to solve the problems of this nature. A Bee-Based Scheduling Model is therefore proposed and employed on a set of problems with different dimensions for the proof of concept. Detail description of an injection molding project is provided together with respective performance analysis is also provided.

A project can be considered as failed if it is not completed on-time, with the allocated budget, and with satisfying the contracted specifications. This clearly implies that the success of a project can be improved through a cost effective project schedule. As well known, the project scheduling is considered to be a complex task having a significant effect on project completion time. Generating a schedule which is complying with the specified project plan is therefore one of the most important issues in sustaining cost effective project management. The project scheduling requires significant amount of effort to prioritize project activities assuring the best performance in terms of completion time as well as other predefined criteria. It is heavily employed by various disciplines where projects in various sizes are carried out. The implementation is carried out in various domain including software development, construction, production, computer technologies, civil engineering, machine design, environmental and urban design, etc.

In order to schedule a project, the respective environment must be well understood. Since there is always scarce of resources, most of the time generating the project schedule under limited resources is the main problem. Note that there are usually more than one way to perform the project activities such as utilizing

* Corresponding author.
E-mail addresses: eoztemel@marmara.edu.tr (E. Oztemel), aselam@marmara.edu.tr (A.A. Selam).

[1] The author was enrolled for a Prof. Dr. (Industrial Engineering) degree in the Department of Industrial Engineering, University of Marmara.

[2] The author was enrolled for a PhD (Industrial Engineering) degree in the Department of Industrial Engineering, University of Marmara.

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alternative machinery or subcontracting. The problem, therefore, is to select an effective single mode to complete the project on time with satisfying the contracted specifications. The selection of a single activity mode among the alternatives in this way is characterized as the Multi-mode Project Scheduling Problem (PSP). This study provides a new methodology to solve this type of problems utilizing an intelligent meta-heuristic algorithm called Bee Colony Optimization (BCO).

There have been several studies on creating intelligent algorithms and heuristics for planning and scheduling of the projects in the literature. Some of them may include Ant Colony Optimization (ACO) (Li & Zhang, 2013; Xiao, Ao, & Tang, 2013) Swarm Intelligence (Pacini, Mateos, & Garino, 2014; Salem & Hassine, 2015), Genetic Algorithms (Afshar-Nadjafi, Rahimi, & Karimi, 2013; Barrios, Ballestin, & Valls, 2011; Okada, Zhang, Yang, & Fujimura, 2010; Van Peteghem & Vanhoucke, 2010; Xia, Li, & Gao, 2016), priority rule-based heuristics (Buddhakulsomsiri & Kim, 2007), classical and nonstandard meta-heuristics (Banaszak & Zaremba, 2006; Van Peteghem & Vanhoucke, 2014). There are also some user-friendly computer programs such as Microsoft Project, Primavera, or ZOHO Projects which were developed and marketed for this purpose. But, the studies employing these tools indicate that most of these are not designed to concentrate enough on changing environmental requirements and they are naturally not sensitive to sudden changes of resources that has to be utilized.

Furthermore, "ready to use" software tools do not seem to effectively facilitate the variation of solution procedures and are not capable of utilizing alternative solutions in different stages of the project execution. This is quite understandable as the main motivation behind these tools is rather to visualize the project activities. Additionally, they also require high amount of inputs to be provided to the project scheduler, which may not always be readily available. Yet another problem is that the huge amount of time is required to solve the problems, and the applicability, efficiency and accuracy of the methods employed are questionable in this respect.

Since, scheduling problems are highly dynamic, complex and require extra resources as well as satisfy a set of various but inevitable constraints, it is obvious and well known that generating the solution algorithms is not easy. Since most of the time, it is not even possible to find out the optimum solution, the project scheduling problems are considered to be "np-hard problems" (Lanchester & Ozbayrak, 2007). Some domain dependent and specifically designed solution algorithms as well as some procedures based on domain related assumptions are required for generating "good enough" solutions. Moreover, the difficulty of changing the schedules based upon the changes on resources, durations or respective activities is yet another problem requiring systematic attention and solution procedures.

In order to overcome some, if not all, of these problems, some methodologies such as Critical Path Method (CPM), Project Evaluation and Review Technique (PERT) and Graphical Evaluation and Review Technique were already proposed and great number of traditional engineering models and algorithms are implemented. They mainly take centralization aspects into account (California Technology Agency, 1997; Shumsky, 2003).

On the other hand, plastic injection molding is known to be a "make-to order" process in a job-shop environment and considered to be an NP-hard problem (Jong & Lai, 2015; Jong, Lai, & Lo, 2014; Xiong, Fan, Jiang, & Li, 2016). However, each mold to be manufactured is unique, custom-designed and require a set of activities to be processed in a limited (predefined) time. With this point of view, each molding process is usually assumed to be a "project" in a make-to order environment (Alfieri, Tolio, & Urgo, 2012). That is the reason for defining and solving mold manufacturing problems using the project scheduling methodology in this study. Note that, a Bees Algorithm (BA) based project scheduling algorithm is proposed for scheduling plastic injection mold manufacturing. The main motivation behind this is that; various natural systems (social insect colonies) such as bees or bacteria (Escherichia coli bacteria) indicate that very simple individual organisms can create systems which are able to perform highly complex tasks by dynamically interacting with each other and adopting social foraging behavior (Tang, Nouri, & Motlagh, 2011; Teodorovic, Lucic, Markovic, & Dell'Orco, 2006).

It is proven that the BCO is well-proven to be able solve complex optimization problems (Akay & Karaboga, 2012; Karaboga & Akay, 2010; Nakrani & Tovey, 2004; Pham et al., 2005, 2006). The algorithm is inspired by the food foraging behavior of honey bees and could be regarded as belonging to the category of "intelligent" optimization tools (Pham et al., 2006). Note that it is a meta-heuristic and well known search algorithm capable of locating good enough solutions. This biologically inspired approach is currently being employed especially for;

- solving continuous optimization problems,
- utilizing training efficiency in neural networks,
- optimizing mechanical and electronic component design,
- sorting out combinatorial optimization problems such as job shop scheduling and
- generating solutions to famous Traveling Salesman Problem (TSP), etc. (Nakrani & Tovey, 2004).

The literature review as highlighted above indicates the lack of studies on minimizing the completion times of molding projects. The main idea behind carrying out this study is to show that a metaheuristic algorithm can be used for project management purpose. The BCO is particularly selected due to its novelty among the other possible approaches. Since this study indicate the success in this implementation, the comparison of other metaheuristics should be considered. That is surely the topic of the future studies along this line. The discussion and conclusion sections of this paper highlight the results of the study.

2. Scheduling mold manufacturing process as a project

A mold is a vital element affecting the quality of the plastic products. Mold manufacturing involves the collaboration of various internal and external functions, where every party involved requires different information to facilitate their work (Leung, Choy, & Kwong, 2010). One of these is the complex and variable machining processes (Jong et al., 2014). Also, many types of parts are to be processed and assembled together to constitute the mold (Jong & Lai, 2015). The manufacturing systems of mold industry can therefore be considered as make-to-order projects where planning is critical because of uncertainty in product specifications (Xiong et al., 2016) and project scheduling rules can be implemented. When the specifications vary during processing phase the scheduling environment becomes dynamic (Corti, Pozzetti, & Zorzini, 2006). In this dynamic and complex environment, it is also significant to track each mold on its own for the customer.

A mold manufacturing process can be formulated as a project which is typically defined as the following (Gray & Larson, 2008):

"*A complex, non-routine, one-time effort limited by time, budget, resources, and performance specifications designed to meet process needs.*"

This definition implies the following major characteristics of the mold manufacturing as a project:

- The established objective is to complete the mold and the mold manufacturing project is to assign respective activities (tasks or jobs) that have to be performed for the sake of this.