

An Agent Based Approach for Multi-Objective Optimization in Production Scheduling for Turbine Engine Blade Manufacturing

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ABSTRACT

With the development of many new technologies in aircraft manufacturing area and the increasing competition of the global market, aircraft manufacturing enterprises have to reduce their production time and increase the cost-efficiency, with the consideration of high speed response to the changes inside enterprises or in the environment. Production scheduling is a significant process in manufacturing, especially for complicated part or component processing. This paper proposes an agent based multi-objective optimization approach for production scheduling based on Genetic Algorithms. It aims to minimize the total production cost and simultaneously reducing the emission released during production, and the delivery time and equipment constraints are satisfied as well. The new approach is tested in a virtual plant for turbine blade manufacturing. Experimental results show that a group of Pareto optimal solutions are obtained, which can be provided to the decision maker of the manufacturer to select according to different actual conditions.

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INTRODUCTION

With the economic globalization, today's manufacturing companies and organizations are facing a dynamic market with increasingly changing customer requirements and strong business competition. The ability of manufacturing organizations to reduce their production cost and to achieve shortest production time becomes an essential issue for them to survive in the current business environment and raise their competitiveness. Meanwhile, the use of energy in all organizations recently becomes a critical factor for multiple reasons. The political pressure for companies to reduce manufacturing emissions is currently an area of focus that affects public opinion of the company and its products. It may also bring benefits from financial incentives offered by governments.

Turbine engine blade production is one of the most difficult processes in aircraft manufacturing. There can be 40 to 60 different production operations for a single blade manufacturing [1]. Many researchers and engineers have been working on the technical process improvement to enhance various kinds of engine performance, but fewer of them considered the improvement of the production scheduling of turbine blades. Recently, it was reported that Boeing planned to increase its production capability to 47 per month in 2017. Thus, the turbine blade suppliers need to change their manufacturing strategy that the production efficiency and productivity of their product, which is one of the most important components of the engine and of the aircraft, needs to be improved. Production

scheduling is a key function in manufacturing. Several different operations of a product are allocated to limited resources in the system and the appropriate processing time needs to be decided. A good scheduling plan can help manufacturers increase the production efficiency.

This paper proposes a multi-objective optimization approach based on agent techniques for reducing both production cost and the amount of manufacturing emissions with the constraints of job due dates and equipment capabilities. Agents and multi-agent systems (MAS) have been successfully applied in many different academic and industrial fields, where individual entities with the abilities of communication, coordination and making autonomous decisions are simulated to achieve a global goal or a set of goals. The proposed approach is employed into a plant for aircraft turbine engine blade manufacturing. In the next section we identify and formulate the problem that needs to be solved. In [section 3](#), some related previous works are reviewed. [Section 4](#) introduces the multi-objective optimization method based on agent iterative bidding process and Genetic algorithms. Numerical tests and results are shown in [Section 5](#) and the last section states the conclusion and future work.

PROBLEM FORMULATION

After a customer order containing n sub-jobs (or operations) enters into a manufacturing system, these operations are then allocated to resources by the system manager according to the

job precedence constraints. Each job is assigned a due date as the latest finishing time. In the manufacturing system, there are m resources with different technical abilities for carrying out different types of job operations. Some of the resources have multiple capabilities which enable them to perform more than one type of operation, and each resource is able to perform at most one job operation at the same time. Additionally, there may be a job buffer for a resource containing a list of unprocessed jobs from previous orders. Therefore, in this problem, it should be decided which resource will carry out which job operation, and the processing sequence of each operation in resource buffers. The main objective of this problem is to find the optimal or near-optimal allocation of a production job containing a sequence of operations to a pool of resources in the system in order that the entire job can be finished within a given due date at the minimum production cost and releasing the least manufacturing emissions with the system constraints.

When a job operation i is being processed in a resource j , it needs a processing cost C_{pij} and a lead time T_{pij} and maybe another setup cost C_{sij} and time T_{sij} before processing. Unprocessed jobs are stocked in resource buffers, so there is a waiting cost C_{wij} and time T_{wij} if the resource is not idle when the new job arrived. Before the operation, the job is transported from another resource where the previous operation is processed, so a transporting cost C_{tij} and time T_{tij} is needed. After a new job operation is loaded to the resource buffer, it has to be decided that the new job is arranged in which position in the buffer queue, since there has been some existing jobs already waiting for processing. If the new job is not put at the end of the queue, it will affect other previous jobs' waiting cost and time. In that case, there will be an additional cost C_{rij} paid by the current job for rescheduling others in the waiting list. Otherwise, if the new job is set to the end of the buffer queue, C_{rij} will be 0. The whole operational cost and lead time for completing a single operation i are:

$$T_{ij} = T_{tij} + T_{pij} + T_{sij} + T_{wij} \quad (1)$$

$$C_{ij} = C_{tij} + C_{pij} + C_{sij} + C_{wij} + C_{rij} \quad (2)$$

On the other side, the amount emission E released when producing an entire job can be calculated:

$$E_{ij} = \psi \sum_{i=1}^n (e_{pij} \cdot T_{pij} + e_{wij} \cdot T_{wij} + e_t \cdot l_{jj*}) \quad (3)$$

where n is the total number of the required job operations. e_{pij} represents the quality of electricity power used per time unit when the job operation i is being processed in machine j , e_{wij} represents the electricity power used per time unit when the job is waiting in the machine j 's buffer, and e_t represents the electricity power used per distance unit when the job is being transported between two machines. T_{pij} is the total processing

time of operation i in machine j . T_{wij} is the waiting time of operation i in the buffer of machine j , which is determined by the number of unprocessed jobs whose process priorities are higher than j . l_{jj*} is the distance between the locations of the machine j^* processing the previous operation and the machine j for carrying out the current operation. The unit of energy can be liters or grams of fuel for generating electricity used in production activities and transportation, and one kilowatt-hour of electricity produced results in 900 grams of CO_2 emitted into the atmosphere. The value of coefficient ψ can then be assigned as 0.9 kg/kh[2].

To sum up, the problem that the manufacturing system faces is to allocate each job operation to a proper resource in order to achieve optimal routing and sequencing solution, i.e. to find an allocation with both minimal production cost and emission with satisfied due date.

$$\begin{aligned} & \text{Min} \sum_{i=0}^n \sum_{j=0}^m C_{ij} y_{ij} \\ & \text{Min} \sum_{i=0}^n \sum_{j=0}^m E_{ij} y_{ij} \\ & \text{subjected to} \quad \sum_{i=0}^n \sum_{j=0}^m T_{ij} y_{ij} \leq D \\ & y_{ij} \in (0, 1) \quad \text{for } i \in [0, n] \\ & \sum_{j=0}^m y_{ij} = 1 \quad \text{for } i \in [0, n] \\ & TF_i < TS_{i+1} \quad \text{for } i \in [1, n] \end{aligned} \quad (4)$$

where C_{ij} and E_{ij} represent the total cost and total emission for resource j processing the operation i and D is the due date of the job order. y_{ij} equals to 1 if resource j is selected to process operation i and equals to 0 if it is not selected. Note that for each operation i , there is only one resource can be selected. This problem belongs to NP-hard (Non-deterministic polynomial-time hard) problems and it is not practicable to list all possible allocation plans and select the best one. Therefore, it is necessary to find an efficient method to accelerate the searching speed and reduce the computational complexity.

Additionally, in this problem, the total production cost and the total emission are expected to be minimized simultaneously. When a problem has two or more objectives to optimize, it belongs to the multi-objective optimization problems. In such problems, a single optimal solution cannot be found. Instead, there is a set of non-dominated optimal solutions which are called Pareto-optimal set, or Pareto front. The system decision maker is provided the set of solutions and chooses the preferred one according to the relative importance of different objectives.