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Integrating optimisation and simulation to solve manufacturing scheduling problems

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Abstract

In this research paper, a novel approach to solve manufacturing scheduling problems based on the integration of optimisation and simulation tools is proposed. The advantages of this approach are illustrated with reference to a manufacturing scheduling case study. The initial optimisation model is formulated as an adaptation of the Capacitated Lot-Sizing Problem (CLSP). Then, a Discrete Event Simulation (DES) software is employed to verify the optimised solution and analyse its robustness taking into account uncertainties in the processing times and arrival rates, and a heuristic method is applied to improve the initial solution.

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Keywords: Scheduling; Simulation; Optimisation; Mathematical programming; Discrete event simulation; Capacitated lot-sizing problem;

1. Introduction

Nowadays, manufacturing systems entail complex decisions concerning short term issues (e.g. daily production) as well as long term investment strategies (e.g. the introduction of new machines, new products, etc.), that can be effectively supported by tools of different nature, such as simulation models and mathematical programming techniques.

As a matter of fact, several simulation software tools have been developed in recent years to support complex decision-making situations. These tools allow to setup a digital model of a real manufacturing system providing detailed information on its behaviour within several different scenarios, without intervening on the physical level. Simulation tools are able to take into account uncertainties that may characterise real systems, such as faults of machines, delays, scraps, etc. In this way, it is possible to evaluate the most relevant performance indicators for each problem and obtain valuable data that suggest potential reconfigurations or improvements to enhance the system. However, although simulation models are a useful tool to verify given scenarios, if used alone they are not able to help in the research of the optimal (or near-optimal) solutions to a given problem.

On the other hand, mathematical programming models serve the aim of determining optimal (or near-optimal) solutions for decision variables by formally describing problems in terms of objective function and constraints to be satisfied. Nevertheless, the drawbacks of these models are related to their complexity and the difficulty to involve uncertainties in their formulation.

Therefore, it could be useful to combine the different features of the two approaches by defining an integrated conceptual framework able to exploit the feedbacks provided by the joint use of these diverse tools in order to enhance their performance.

In the recent literature, there is a growing number of studies in which optimisation and simulation tools have been employed together to solve complex problems, especially in different industrial environments: in most cases, one of the tools is used as first and the obtained results are then fed to the second tool [1-5]. In few cases,

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a third software tool is introduced to connect optimisation and simulation tools and realise their integration to deal with industrial case studies [6].

In this research paper, a novel approach integrating optimisation models and simulation techniques and tools through the automatic implementation of a closed loop in which information and data are mutually exchanged in an effective way is proposed. In practice, a valid integration of the optimisation and simulation models can help the search of a good solution characterized by a major robustness in terms of sensitivity to uncertainties.

2. Simulation-Optimisation integrated approach

The aim of this research paper is to define a novel approach where optimisation and simulation models are integrated and combined through the implementation of a feedback loop involving the mutual exchange of information, according to the scheme of Fig. 1.

Starting from an optimisation model, able to determine an optimal or suboptimal solution to a given problem, the approach proceeds with the employment of simulation tools, able to produce information concerning the system behaviour and reaction to different inputs.

In fact, the solution generated by (exact or heuristic) optimisation techniques is used as input of a simulation model with the aim to verify the actual feasibility and robustness of the found solution through the generation of different scenarios able to take into account several kinds of uncertainties which are typical of real systems.

The results of the simulation experiments, allowing an evaluation of the system performance, can support the detection of the current solution weaknesses and the identification of suitable modifications concerning the ingredients of the initial problem formulation.

The feedback loop is then realised going back to the optimisation phase with the new information generated by the simulation model. This information is used to improve the initial optimal solution, e.g. through heuristic techniques or changes in the problem formulation. This approach allows to connect the evaluation of the relevant system performance indicators to the decision making process on the optimal solution.

3. Modelling of Manufacturing Scheduling Problems

The novel approach presented in this research work is implemented with particular reference to the solution of manufacturing scheduling problems, that can be briefly described as follows.

Lots of units belonging to different part numbers, produced by various upstream processes, are delivered according to a specified arrival rate to a manufacturing cell. Here, parallel machines able to process all the part numbers according to different cycle times are available.

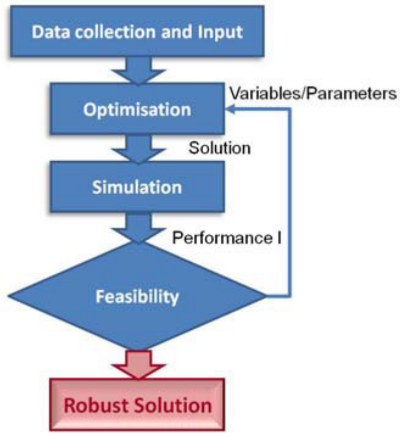

Fig. 1. Simulation-Optimisation integrated approach

A typical objective to be optimized in manufacturing scheduling problems is represented by the makespan, i.e. the maximum completion time considering the items to be processed. When a time window to perform the operations is given, a proxy of the makespan can be represented by the number of items in queue at the end of the time window.

In the following, a possible formulation of the introduced problem in terms of mathematical programming is described.

3.1. Formulation of the problem

The time window T is divided in N periods of equal length indexed by t=1...N. Then, the following formulation is adopted:

$$z = \sum_j \sum_t h_j I_{jt} + s_t B_t \qquad \text{Min!} \qquad (1)$$

subject to:

$$I_{jt} = I_{j(t-1)} + d_{jt} - q_{jt} \qquad j = 1...J;\ t = 1...N; \quad (2)$$

$$\sum_j p_j q_{jt} \le l B_t \qquad j = 1...J;\ t = 1...N; \quad (3)$$

$$I_{jN} = 0 \qquad j = 1...J; \quad (4)$$

$$q_{jt}, I_{jt}, B_t \ge 0 \qquad j = 1...J;\ t = 1...N; \quad (5)$$

$$B_t \in N \qquad j = 1...J;\ t = 1...N; \quad (6)$$

The following notation has been adopted:

- J: set of part numbers to be processed;
- p_j: average processing time for part number j;
- d_{jt}: arrival rate of part number j in period t;
- h_j: queue holding cost for a unit of j in period t;
- q_{jt}: units of part number j to be processed in period t;
- I_{jt}: queue level of part number j at the end of period t;