Discrete Event Simulation to Support Production Planning in Real Systems

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Abstract. This article addresses the problem of production scheduling in a single station with unrelated parallel machines, based on a real industrial case. The complexity of the production process is increased by the interrelationship with two additional resources, which requires a high-fidelity modelling approach. Traditional methods often fail in such complex environments, leading in some cases to the integration of classical optimisation techniques with discrete event simulation. In this study, this type of simulation is used to model the real system, incorporating a heuristic that automates the current decision-making process for the factory's production planning. This provides a detailed plan that takes into account all resources and their constraints. Using real production data, the usability of the simulator in this context is validated, demonstrating its effectiveness as a production planning support tool. These results open up significant avenues of research, including reversing the roles of the simulation and optimisation modules, and extending the simulation logic to other stations in the production system.

Keywords: Simulation · Production planning · Scheduling

1 Introduction

Single station production scheduling problems have been studied extensively both in the academic literature and in industry [1, 2]. One of the environments in which such scenarios occur are the Parallel Machine Problems, where different machines are available to process the jobs. One of the variants of these problems is the Unrelated Parallel Machine Problem, where the processing time depends on the speed of the machine, and the speed of the machine depends on the job it is performing [3].

However, such environments, even when the main resource is parallel machines, can be characterised by a high complexity of the developed production process and therefore of its modelling. In these cases, where the inherent complexity and even uncertainty

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of the problem cause traditional methods to fail, it is common to find studies proposing the integration of discrete event simulation along with other classical optimisation techniques [4, 5].

In this work, a production planning problem for a single station and unrelated parallel machines is presented based on a real industrial case. This station, in addition to the machines as the main resource, has a direct interrelation with two other resources that limit its availability and increase the complexity of its modelling. For this reason, after simplifying the problem for its solution in previous studies [6, 7]; this time discrete event simulation is presented as a tool for modelling the system with a high degree of fidelity to reality. The simulator works with a heuristic that automates the factory's current decision-making process and returns a detailed plan that takes into account all the resources involved and their physical constraints.

The structure of this paper is as follows. Section 2 provides a simple description of the production system, including the three main resources involved. Section 3 discusses the use of discrete event simulation for production planning, explaining the simulation logic and its implementation. Section 4 presents the validation of the simulator using real production data and draws conclusions about its effectiveness as a production planning support tool. Finally, the last section lists all the references cited throughout this document.

2 The Production System

In order to understand the complexity of the system and, therefore, the relevance of simulation as a tool to support production planning in real systems, a brief description of the target station is given in this section.

This station has as its main resource independent parallel machines that perform the main activity of the process; hereafter referred to as main machines (MM). The work of these machines is conditioned by the availability of an operator for them, which is the second resource. In addition, the MMs work on several tasks at the same time, but not simultaneously. This is because, for reasons intrinsic to the product, the process performed on each piece includes not only the task performed by the MM, but also requires intermediate downtime for minor setup tasks. Figure 1 shows an example of the total processing time of a part, where the times when the MM is working on the part are shown in light grey and the downtime is shown in dark grey. Since the MMs are the bottleneck of the factory, to maximise their use, whenever a task requires downtime, the MM continues to work on another piece. In this way, each MM can work on up to 3 pieces at the same time, but not simultaneously. The availability of physical space to place these tasks is the third and final resource. The steady-state operation of these MMs is shown in Fig. 2.

Fig. 1. Work sequence for a single task produced in an MM. The light grey bars represent production time, while the dark grey bars represent setup time.

3 Simulation for Production Planning

For the evaluation of the production sequence in each of the MMs, a discrete event simulation logic is used, which allows the concept of time passing to be introduced. This makes it possible to model the use and availability of each of the three resources identified as shared resources, controlled by a mutex that can be in a free or occupied state. Following the same approach, the occupied state of each MM is modelled by identifying each of the different productive sub-processes that make up the industrial process, ensuring that the priority laws inherent to the process are followed in the simulation according to the imposed logic.

Discrete Event Simulation (DES) was chosen because it is the most widely used type of simulation in the development of commercial industrial flow simulators. It allows the evaluation of the evolution of discrete systems described by a series of known states where the environment does not change between events. Thus, an event is interpreted as a change from one known state to another within the simulation, for example the change of a MM state from free to occupied. This saves computational resources by only advancing time when necessary. It also provides control and flexibility by allowing the user to define any known state and the transition rules between them.

The current implementation understands the allocation of products to machines as a service available to the simulator. Thus, the simulator makes a call to the allocation service each time a product is completely finished and the associated resources are released. After re-evaluating the state of the factory at that moment, a new product is assigned to be introduced into the corresponding MM and a new process begins.

4 Validation and Conclusions

In order to validate the simulator as a production planning support tool, a deterministic heuristic has been created to automate the decision-making process currently being developed in the factory. This heuristic is implemented as an allocation service that is called by the simulator whenever a new product-machine allocation is required.

This heuristic is both global and anticipatory, responding not only to the simulator's immediate request but also evaluating the set of pending products and available machines in order to optimise resource utilisation in the medium term. The evaluation considers the suitability of the products to be manufactured in relation to the capabilities of the machines, avoiding assignments that could compromise critical future operations. Ultimately, the product with the highest priority that corresponds to the machine requested by the simulator is selected, based on these criteria. In the event of a tie, the product is chosen randomly among the top-priority ones.

With this, the use of the tool will be systematised and it will be possible to verify whether the real daily activities are developing as predicted by the simulator. Both the simulator and the heuristics have been implemented in Python, based on the Simpy simulation engine, and solved on an Intel® *CoreTM* i7–4790 CPU at 3.60 GHz with 12 GB of RAM using PyCharm Edu 2021.3.2.

As a result, two Gantt charts are shown below. The first shows the direct result of the simulator working with the deterministic heuristic. The second shows the actual planning carried out on the same day. For the sake of simplicity, the codes naming each line show two MMs (*A10* and *A06*) with two associated workspaces (*L1* and *L2*). The codes shown in light grey are the identifiers of the tasks to be carried out at each moment.

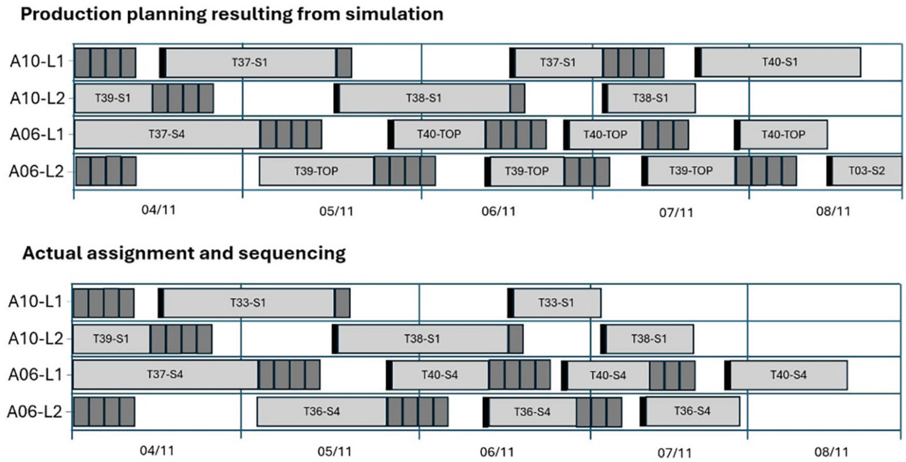

Fig. 2. Gantt chart of the plan resulting from the tool that integrates simulation and production planning (above) and Gantt chart of the actual assignment and sequencing developed in the factory.

It is easy to see from the figure that, although the identifiers of the selected tasks were different in some cases, the evolution of the tasks and their downtimes were identical. This indicates that, although the heuristic may show some discrepancies with the actual planning chosen on the shop floor, the performance of the simulator as a support tool for production planning has given excellent results to continue working with.

These results show a clear development path where the module currently occupied by the deterministic heuristic can be replaced by different metaheuristics that provide better allocation and sequencing results. This would result in a robust tool that not only automates but also optimises the production planning process.

However, calling the heuristic at each demand point can significantly slow down the tool's performance in real-world scenarios involving large volumes of tasks. In light of this, exploring the reversal of the relationship between the simulator and the assignment and sequencing optimisation tool is worthwhile. In other words, the simulator could serve the optimisation module.

Finally, the simulation logic opens the door to linking this single process with others in the complete production system, possibly including transport resources or labour shared between different stages. This would again add robustness, flexibility and realism to the tool.

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