AGENT-BASED STRATEGIC PLANNER FOR THE PRODUCTION OF SAMLL LOTS OF COMPLEX PRODUCTS: THEORETICAL AND PRACTICAL PERSPECTIVES

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Abstract
This paper presents a strategic planner that assists the decision-makers to take strategic decisions on short term to respond faster and efficiently to unexpected events in the ramp-up production of complex and highly customized products, namely in situations of peak of demand, late change requests and immature technology. This tool combines the flexibility of multi-agent systems with the optimization capability of mathematical optimization solvers. The application of the strategic planner is illustrated by playing iterative what-if games supporting implementation of mitigation strategies addressing a real use case of a peak demand of a specific product.

1. Introduction

The ARUM (Adaptive Production Management) project [1] is addressing the challenging problem of the production planning and control in the ramp-up production of complex and highly customized products, particularly in small lot sizes, as in aircraft and shipbuilding industries. In fact, the daily occurrence of unexpected events creates significant risks during the initial phase of the production of a series, e.g. in situations of peak of demand, late change requests and immature processes and technology. This problem becomes hardly to be handled when the products are made in short series, since learning from these events becomes difficult and slow.

Having this in mind, the challenge is to consider innovative real-time decision-support tools that provide optimized solutions to respond faster and efficiently to these unexpected events, incorporating in a short notice the learning from these unexpected events. An example of such tools is the strategic planner that supports the decision-makers to take strategic decisions by producing and analysing alternative planning solutions for situations where unexpected events may provoke strong impact on the running plans. The traditional approach for the production planning problem considers a classical mathematical solver that runs an optimization method for a particular problem formulation using the current context [2]. In spite of the optimization levels, this approach lacks the responsiveness to achieve solutions in short term, which is crucial in industrial environments that are usually subject to condition changes. An alternative is to consider a distributed approach, e.g. using the Multi-Agent Systems (MAS) paradigm, to implement the optimization method, allowing to achieve better flexibility, robustness and responsiveness. However, the optimization level reached is degraded.

This paper introduces a hybrid approach for the production planning problem, combining the maturity, robustness and optimization provided by a classical solver and the flexibility and responsiveness provided by MAS solutions. The application of the proposed strategic planner is illustrated by playing iteratively the tool for a real use case related to the peak production demand for a specific product, allowing to foresee in advance the best strategy to mitigate the demand increase.

The rest of the paper is organized as follows: Section 2 overviews the current architectural approaches to develop strategic planning solutions and Section 3 presents the architecture of the agent-based strategic planning tool as part of the ARUM system. Section 4 describes the implementation of the planning tool and the case study scenario used for experimental validation. Section 5 illustrates the use of the strategic planning tool by playing what-if games simulation for a case study scenario of a peak product demand. Finally, Section 6 rounds up the paper with the conclusions.

2. Existing Approaches to Strategic Planning Decision

The production planning problem is traditionally faced by using a mathematical optimization solver. The solver is a software application that runs an optimization algorithm to solve a mathematical problem determining the optimum solution for given constraints. Solvers may implement different optimization algorithms, ranging from linear programming to meta-heuristics, such as local search methods and evolutionary algorithms, being possible to choose the algorithm according to the problem type. Several solvers are currently available, e.g., IBM ILOG CPLEX Optimizer, Xpress Optimization Suite, MOSEK, Gurobi Optimizer, KNITRO and Choco (see [3] for a comparative analysis).

These solvers are usually mature and robust computational applications that provide optimal solutions for the strategic planning problem. However, the majority of these solutions are commercial and lacks flexibility in situations of iterative rounds. In fact, in situations of re-parameterization of constraints and criteria, the decision-maker must manually introduce the new parameters making this solution to be hardly managed and very time consuming (i.e. sequential achievement of solutions).

An alternative is to implement the optimization method for the production planning using a distributed approach, e.g. considering the MAS principles. MAS paradigm [4] advocates the use of a set of distributed and autonomous entities, called agents, to solve complex problems. In such solutions, the agents representing the system components (e.g. orders and resources) interact with each other trying to achieve an optimized solution in a more robust, flexible and agile manner. Examples of the application of MAS principles in the production planning are [5-7].

In addition to the robustness and responsiveness, other potential advantage of the MAS based solver is the possibility of adaptive re-scheduling that increases the reaction time in case of small changes in the input data. This allows the strategic planner to analyze more exploratory options in a given time frame. In spite of these benefits, this approach presents several disadvantages, namely the need to develop the solver from scratch, the missing maturity of the approach, the non-optimal solution reached, and the missing scalability of MAS technology for a huge size of the problem search.

An alternative solution is to consider the best features of the previous described approaches, i.e. integrating a classical mathematical solver into an agent based infra-structure. This hybrid approach combines the maturity, robustness, stability and optimization of the solver with the MAS principles to explore the achievement of alternatives solutions for the strategic planner. Some works considering these ideas are reported in the literature, e.g. [8-9].

3. Agent-based Strategic Planning Architecture

A hybrid approach combining a mathematical solver and a MAS infrastructure is used to design the strategic planning addressing the ramp-up problem of production of small batches of complex and highly customized products. The main innovation regarding the similar approaches is centred on using the MAS principles to provide a what-if game simulation to explore different Degrees of Freedom (DoF), e.g., the different possibilities to expand the capacity to accommodate the demand fluctuation.

The MAS infrastructure is established to manage the exploration of alternative planning solutions supporting the decision-makers to take strategic decisions. This ecosystem comprises the following classes of agents, as illustrated in Figure 1 [10]:

- *Resource agent* (enterprise, facility or production line according to the scope), representing the physical resources in the enterprise, being responsible for the interaction with the decision-maker (to insert simulation data and visualization of alternative planning solutions) and to initiate the production planning process.

- *Scenario agent*, responsible to generate scenarios for the production planning, exploring different DoF.
- *Planning agent* (strategic, tactical or operational according to the scope), responsible to calculate the solutions for a planning problem (formulated as a mathematical model), considering a certain scenario and applying an optimization method. This agent integrates a commercial solver, e.g., IBM ILOG CPLEX Optimizer, which implements optimization algorithms, e.g. the Mixed Integral Programming technique.
- *Simulation agent*, responsible to assess the achieved production plans through simulation to anticipate the stochastic behaviour in the production system.

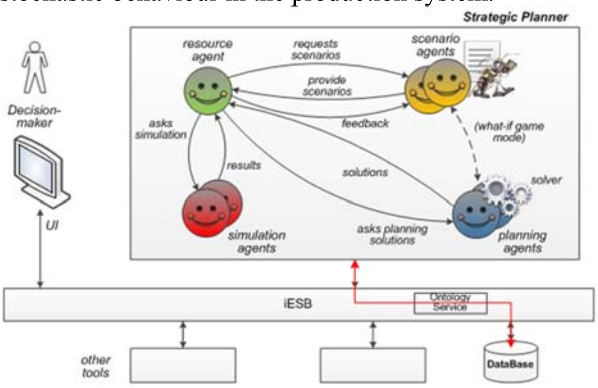

Figure 1 – Agent-based architecture for the strategic planning architecture [10].

The global system behaviour emerges from the interactions among the individual agents according to proper cooperation processes. Initially, the resource agent defines the set of DoF that can be handled to find alternative planning solutions and asks the scenario agents for exploratory scenarios that can be used for a specific situation (that includes the product demand and the production system capacity). The generation of scenarios explores the possibilities of capacity expansion to accommodate the demand fluctuation.

After receiving the generated scenarios, the resource agent requests the planning agents to solve the planning problem. The planning agent, using the mathematical formulation for the planning problem and the set of criteria defined by the resource agent, triggers the solver to run an optimization method. Several planning agents can run simultaneously aiming to parallelize the planning process to achieve faster the alternative solutions.

The resource agent compiles the alternative planning solutions provided by the planning agents and performs a pre-evaluation analysis by filtering and sorting these solutions according to pre-defined Key Performance Indicators (KPIs). In particular, the resource agent, articulated with the decision-maker, can iteratively modify the criteria and ask new solutions to the planning agents or to decide accepting one planning solution to be implemented. Optionally, the resource agent may send the alternative planning solutions for the simulation agents for assessment and sends the simulation results to the scenario agents for classification and posterior usage in the generation of scenarios.

This agent-based solution allows the implementation of what-if games simulation supporting the strategic decision-making based on the analysis of exploratory alternative planning solutions.

4. Instantiating the Strategic Planning for the Use Case

The described strategic planner architecture was applied to a real case study related to a manufacturing company that produces modular equipment used during the airplanes' flights.

4.1 Description of the Use Case

The company produces coffee machines, trash compactors, ovens and trolleys. Four production lines are dedicated to produce around 20 coffee makers per week. Each production line is composed by two working places, equipped with the necessary tools and accessories, where two skilled workers are performing the assembly steps.

The planning problem considered in this study is related to a situation occurred in 2012, where a major customer asked to deliver within only four months a number of coffee makers that almost exceeded the annual production volume. The time to confirm or decline the request was very short, while any possible response strategy required complex decisions about deep changes of current production and capacity plans, including the need to abandon a significant volume of orders from other customers respectively for other products. In this way, the problem of a peak of 100% in the production demand for the coffee makers during the weeks 15 and 30 requires a strategic decision about how to balance the production to fulfil the book of orders with the limited resources.

The strategic planner will assist the decision-makers to anticipate, assess and prepare mitigation strategies to for this kind of problem. Several DoF are used to mitigate the demand increase, namely considering additional production lines and extra working hours [10]. The first one refers to the possibility to add new production lines comprising skilled workers, which implies additional costs, composed by a fixed term related to the setup of the working bench, and a variable cost related to the workers' salary. The second DoF refers to the possibility to extend the daily working hours, which introduces an additional cost related to a percentage increase of the worker's salary.

4.2 Implementation of the Strategic Planner

The strategic planning tool was developed using the JADE [11] agent-based development framework to implement the MAS infra-structure. The communication between the agents is performed over the Ethernet network using the TCP/IP protocol, with the messages encoded using the FIPA-ACL (Foundation of Intelligent Physical Agents - Agent Communication Language). The planning agents use the ILOG CPLEX Optimizer solver to run the optimization techniques that solves the planning problem. The connection between the planning agent and the solver is performed through the ILOG Java API.

Several User Interfaces (UIs) were developed as desktop applications built on top of the NetBeans platform, being the several charts used to display the outputs of the planner developed using the JFreeChart API.

5. Playing with the Strategic Planning Tool

The decision-maker interacts with the strategic planner through a UI (User Interface), particularly to introduce input data, pre-select alternative scenarios to explore, and to visualize the alternative planning solutions, as illustrated in Figure 2. In order to achieve this, the component comprises several screens. After inserting the input data related to the mathematical model, the planning process is started by clicking the "*Start Planning*" button. The alternative planning results can be visualized as bar charts, navigable in several dimensions (e.g., production lines or products). The evaluation of the planning solutions can be performed according to several KPIs. In this work, the analysis considers the backlog control since the non-deliveries have significant impact for the company.

Considering the peak demand and the current operational configuration, i.e. 4 production lines and 40 working hours, the backlog is shown in Figure 3, ending the year with a total amount of 87 products. This backlog level is unaffordable and consequently some mitigation measures must be taken.

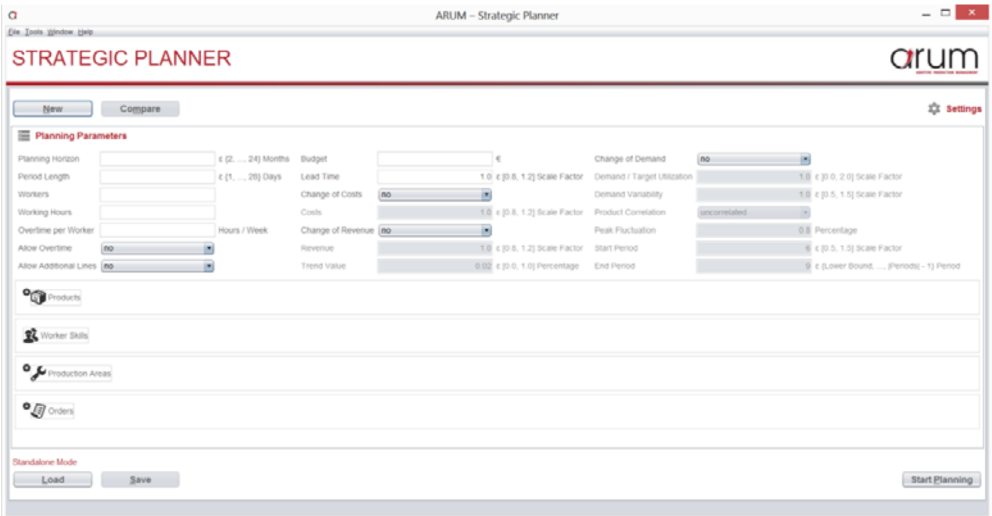

Figure 2 – UI for the input of data.

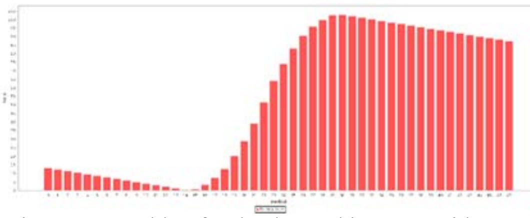

Figure 3 – Backlog for the demand increase without acting in DoF (max value: 102.8).

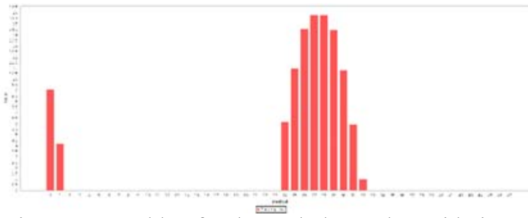

Figure 4 – Backlog for the peak demand considering 10h of overtime hours (max value: 15.8).

Considering the previously described DoF, the decision-maker can play with the possibility of have more overtime hours of work and/or allowing additional production lines. The first possibility could be to use 10hours/week of overtime for each production line, which allows to reduce the majority of backlog, remaining only the backlog concentrated in the peak demand period (see the planning solution illustrated in Figure 4). Additionally, the decision-maker can also play with the DoF related to the production lines, e.g., considering the use of two additional production lines allows reducing the backlog (see Figure 5). Acting individually on these DoF allows to reach acceptable backlog values, having each one an additional production cost (16.224€ for the first case and 15.880€ for the second one).

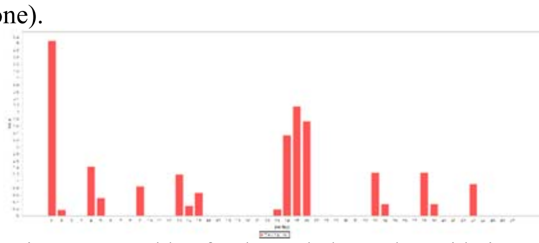

Figure 5 – Backlog for the peak demand considering 2 extra production lines (max value: 5.1).

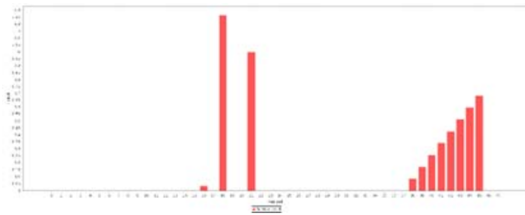

Figure 6 – Backlog for the demand increase considering both DoF (max value: 1.3).

The backlogs are now under control but the decision-maker may decide to analyse other mitigation strategies, e.g. extend the overtime to the weekend (i.e. working at Saturdays) and even consider the combination of both DoF. As example, the combination of 2 additional production line with 10 weekly overtime hours have further reduced the backlog with an additional cost of 7.720€ for the use of the extra production line and 21.418€ for the overtime, giving an overall price of 29.138€. As illustrated in Figure 6, the scattered backlog is now completely residual, which naturally requires the use of more financial resources.

Playing the iterative what-if games, the decision-maker can foresee in advance the better strategies to mitigate the impact of the unexpected event and take the proper actions to solve the problem.

6. Conclusion

This paper describes a strategic planning solution that combines the reliability and optimization of mathematical optimization solvers with the flexibility, robustness and responsiveness of MAS principles, supporting decision-makers to take strategic decisions on short notice with a high level of confidence for unexpected events, such as peak of product demand.

The agent-based strategic planner was implemented using the JADE framework and integrates the ILOG CPLEX Optimizer solver. The application of the strategic planner solution was illustrated by considering a real use case problem related to the peak product demand, where what-if games can be iteratively played to explore the impact of acting on different DoF related to the capacity expansion possibilities (in this case extra production lines and working hours) to minimize the backlog.

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