A Multi-Agent System Tool for Strategic Planning in Small-Lot Production Environments

by José Barbosa, Paulo Leitão, Udo Inden, and Fosco Mascioni

[Introduction]

The scale of output respectively sales matters in strategic and operations planning because it controls the degression of fixed costs, of learning curve effects (degression of average or per-unit variable costs) or purchasing power that influences prime costs. But what is "small"? There is no clear quantitative definition of "small", except that the minimum is 1. In the use-cases of the ARUM project, airframers and producers of galley appliances, want to sell as much as possible of the same, just limited by the size of the markets for aircrafts and related appliances as well as the interplay of competitive forces [1]. The most sold aircrafts are the Airbus A320 family with an average output of about 180 units per year (6486 in total) [2] and the Boeing 737 family with 230 units per year (8350 in total) [3]. And Iacobuccy HF (IHF) in the long average produced about 1000 galley appliances per year. Compared to car industry that is very small. Compared to the size of the aviation market it is very reasonable. IHF is world marked leader for airworthy coffee makers, On the other side, in the purchasing market also the size of the bill of materials of the product matters. In the cases of the A320 and the B737 that are about 4 million parts per unit, a very big scale, while the galley appliances consist of some hundred parts – a small scale. The differences translate into variations of the leeway of pricing, of market shares and of the profitability. For the purpose of this paper and with regard to the use-case respectively the demonstration scenario it will be sufficient to have a look at the impact of small lots in the sales markets in aviation industry.

In the sales markets for aircrafts, there is a very hard competition between a few strong and politically relevant companies while, in the appliances' market, competition is driven by many smaller players with a far less capital intensive productions (and less political support). But the trends in both markets are similar, since the competition of vendors increases the purchasing power of customers, the airlines. In product design, this translates into requests for customization increase, for more frequent product refurbishments or for earlier uptakes of new technology. Thus, actors in both markets face an increase of variety, shorter life cycles of products, and the problem to earn the return on invest with the decreasing lot-sizes.

Above, in operations, the power of customers drives higher rebates and a request for higher service levels, particularly in terms of a faster response to demand that implies more frequent changes of production cycles and variations of volumes. The consequence are a need for more flexible and complex strategies in capacity management. Below, a scenario will be discussed, that addresses this type of problem. Here, multi-agent systems can provide the required adaptiveness and intelligence. Strategic planning is a good example because chance scenarios can become very complex and solution spaces very large. Our goal is to present an integrated software solution with the goal of responding faster and more correctly to unpredicted events in complex scenes of the production of highly customized products, situations of exceptional peaks of demand, late change requests, or immature technology for processes and products in the ramp-up phase of production.

Within this context, the strategic planner tool addresses the resource allocation (e.g., dependencies and availabilities) that is subject to different criteria (e.g., minimizing the labor or inventory costs) or considering a long planning time horizon. Additionally, the tool should be able to output alternative planning solutions, advising the decision makers with the expected impacts and Key Performance Indicators (KPI) evolution.

Traditional approaches for production planning consider a mathematical solver as a tool to deliver optimal planning solutions for particular sets of constraints. The solver runs specific problem formulation optimization methods for the current context [4]. The optimization methods range from linear programming to meta-heuristics, such as local search methods and evolutionary algorithms. Several solvers are currently available, namely IBM ILOG CPLEX Optimizer, Xpress Optimization Suite, MOSEK, Gurobi Optimizer and KNITRO.[5] In spite of their high optimization levels, these solvers lack the responsiveness to achieve solutions in short term and to dynamically produce different planning solutions by varying the problem constraints, since these alternative planning solutions are usually manually parameterized.

Alternative approaches use the MAS (Multi-Agent Systems) paradigm to implement the optimization algorithm solver. This approach allows an increase of flexibility and robustness in achieving planning solutions but with the cost of a solution optimization decrease. A number of researchers have presented examples of the application of MAS principles in production planning.[6-8]

This work combines the better of the two worlds, particularly an optimization solver to ensure maturity, stability, and optimization and a MAS to provide flexibility to address the complex ramp-up problem. This article briefly describes our view on an ontology-based production management system, giving particular focus on the strategic planning tool, describing its architecture and presenting a use case, where the operability of the tool is demonstrated. The difference between the current approach and the already existing solutions is mainly centered on the use of MAS to provide what-if game simulation to explore different degrees of freedom (DoFs).

DESIGNING AND DEVELOPING A HYBRID PLANNING TOOL

This section describes the architecture for a planning tool that will enable the decision-maker to take strategic decisions. An important question on the design of such strategic planner tool is the selection of the architectural solution that best fits the described objectives and requirements, particularly those of achieving fast planning solutions with optimized results and of enabling the generation of what-if scenarios. Different solutions are considered, including the classical mathematical solvers or the pure agent based approach.

The classical mathematical solver has the advantage of presenting optimized solutions but with the drawback of rigidity of the mathematical model and lower response times in a way that new scenarios may require to manually recode the model. On the other side, a pure agent-based solver overcomes this issue, but can’t reach the optimization performance achieved by the first. Thus, the combination of both approaches, proposing a hybrid solution, seems the most promising choice.

The MAS infrastructure was developed using the Jade framework[9] and comprises four types of agents:[10]

- The *resource agent* maps an enterprise, facility or production line, and represents the physical resources. This agent is responsible for initiating the production planning process.

- The *scenario agent* is responsible for generating the production planning scenarios, exploring different Degrees of Freedom (DoF), such as capacity expansion like the introduction of new shifts or production lines.

- The *planning agent* operates on a strategic, tactical or operational level according to the scope, and is responsible for translating the scenarios to the underlying mathematical model and finding a solution for the planning problem. This agent is responsible for interacting directly with the mathematical solver, which in this implementation uses the ILOG CPLEX Optimization Studio.

- The *simulation agent* is responsible for accessing the production plans through simulation to anticipate the stochastic behavior in the production system.

A graphical agent interaction is depicted in Figure 1**Error! Reference source not found.**, where it is also possible to identify that the SP is divided into two distinct blocks. On the left block, the User Interface (UI) interacts with the aforementioned agent architecture, on the right, exchanging FIPA (Foundation for Intelligent Physical Agents) compliant messages, as defined by the underlying architecture.

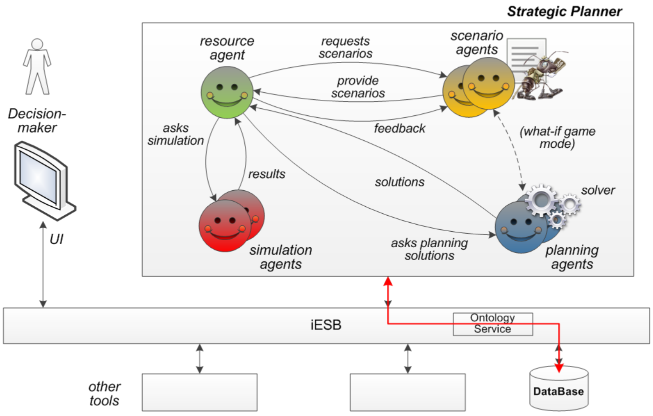
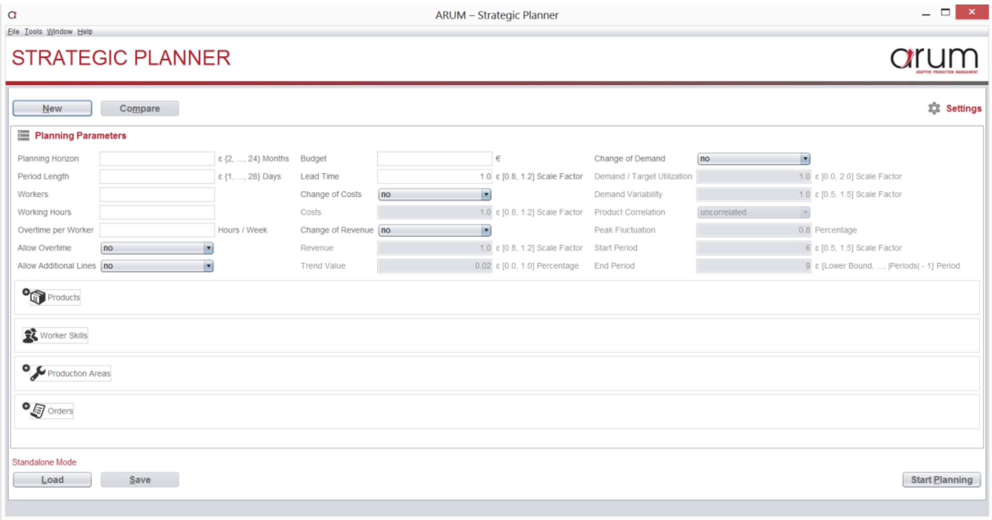


Figure 1. Agent-based strategic planning architecture.

The UI has several screens, where the user can define the scenario to plan (see an example in Figure 2), refine the parameters, such as order details, and output screens, which provide the results in a graphic-based form.



Planning Horizon ε {2, ..., 24} Months
Period Length ε {1, ..., 28} Days
Workers
Working Hours
Overtime per Worker Hours / Week
Allow Overtime no
Allow Additional Lines no
Budget €
Lead Time 1.0 ε [0.8, 1.2] Scale Factor
Change of Costs no
Costs 1.0 ε [0.8, 1.2] Scale Factor
Change of Revenue no
Revenue 1.0 ε [0.8, 1.2] Scale Factor
Trend Value 0.02 ε [0.0, 1.0] Percentage
Change of Demand no
Demand / Target Utilization 1.0 ε]0.0, 2.0] Scale Factor
Demand Variability 1.0 ε [0.5, 1.5] Scale Factor
Product Correlation uncorrelated
Peak Fluctuation 0.8 Percentage
Start Period 6 ε [0.5, 1.5] Scale Factor
End Period 9 ε {Lower Bound, ..., |Periods| - 1} Period

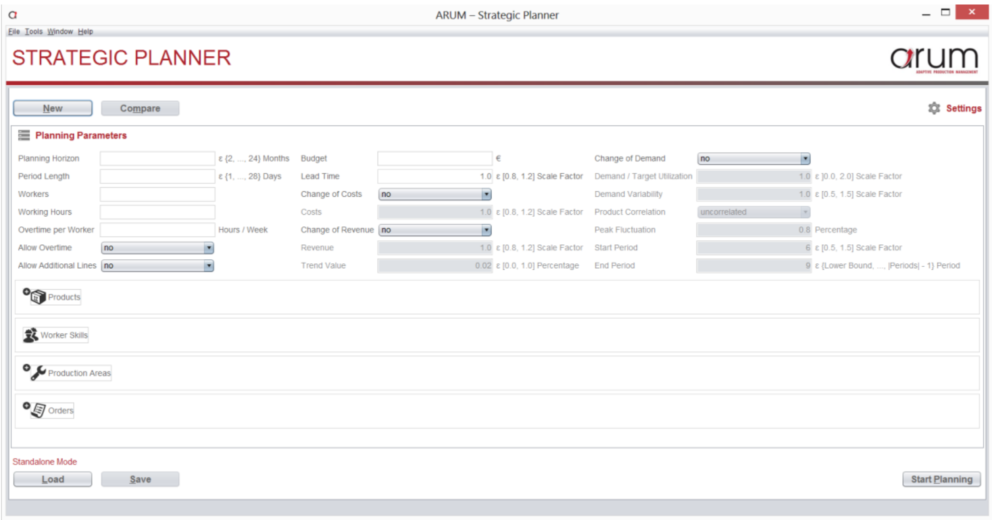


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Figure 2. Strategic Planner scenario definition

After receiving the parameters, the resource agent defines the DoF and asks the scenario agents for exploratory scenarios. The generation of scenarios can also be performed by considering what-if game simulation, exploring capacity expansion possibilities, such as the use of additional production lines or the use of overtime, in order to accommodate the demand fluctuation. In this process, the scenario agents generate alternative scenarios, varying constraints and criteria parameters using learning techniques.[10]

After receiving the scenarios, the resource agent requests the planning agents to solve the problem instances. Each one of these agents interacts with a solver, calculating the planning solution for the specific scenario and considering the problem formulation. The architecture also considers the possibility to use several planning agents simultaneously, allowing the parallelization of the planning process. At the end, the planning agents send the solutions to the resource agent, which evaluates and shows them to the decision-maker in a sorted manner.

The resource agents can also send the planning results to the simulation agents for assessment.

IACOBUCCI HF AEROSPACE - USE CASE DEFINITION

Iacobucci HF Aerospace is a world market leader and one of the most active innovators for the design and production of galley appliances for aircrafts who is facing changes in the demandingness of customers regarding a faster response to demand that imply more complex strategies in mid- and long-term capacity management. In general, strategic planning differs from tactical operations planning and scheduling with respect to the degrees of freedom to adapt the design of products, of production processes or the set of resources, of production capacity, or to new challenges and goals of operations. In the past, strategic planning of IHF was mainly concerned with decisions about (1) the preparation for long-term market developments like changes of aircraft technology or the growth of demand, (2) the deployment and production ramp-up for new products that typically are ambitious in terms of the introduction of new technologies, and (3) about exceptional demands and supply scenarios.

The elaboration of examples of the first and the second class of problems requires drilling deeply into aspects of technology, design and their relations to changing demand in aviation markets. It is expected that the market dynamics will increase and that new and more complex challenges will appear. For instance, in 2014 a coffee maker has been printed by an Italian fab-lab. This is far from being airworthy. But digitalization and 3D printing are technologies that significantly shorten the time from brain to market and accelerate innovation cycles. Thus, strategic planning will have to deal with weighty changes in operations and, partially, of business models.

Trash compactors (TCs) are complex galley appliances used to reduce and store the volume of waste that is produced in inflight services for passengers. The current annual production volume of IHF is on average equal to ten units per month. The scenario deals with a request to deliver 120 trash compactors within a period of 4 months, starting 12 months after conclusion of the contract, a period that refers to the long-term refurbishment planning of the airline. The planning problem is, that here diseconomies of scale apply: The costs to adapt capacity to the peak demand are prohibitive, particularly because it is not predictable whether and when a further demand of that scale will appear. Also the cancellation respectively the rejection of orders from other customers are no valid option at all. I.e., the additional demand is to be accommodated on top of the production for a full order book.

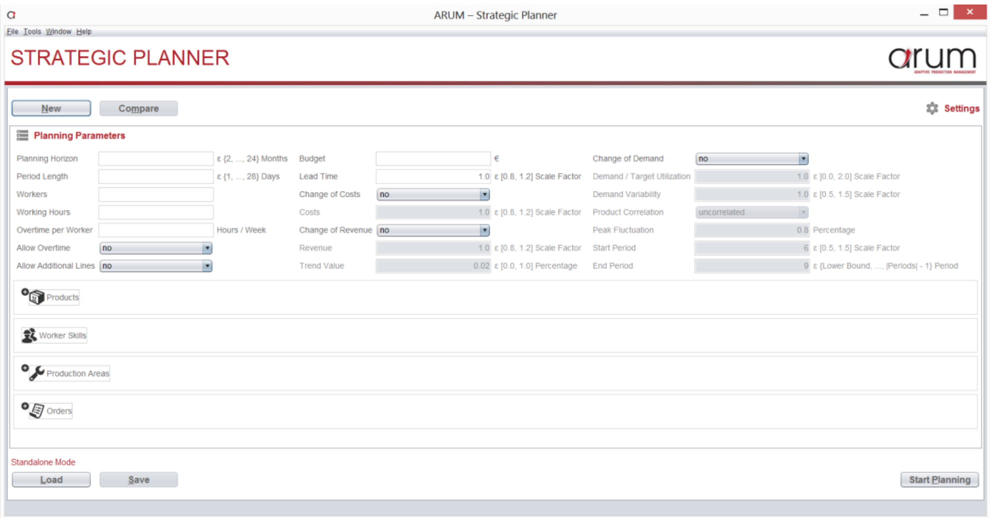
Therefore it needs to find and test strategies that smooth the peak along the available span of time while considering the impact of changing side conditions like the envelops of capacity, of accumulating costs and working capital, or of the leeway for sales to accept further orders from other customers. This can include measures to reduce slack in operations, to introduce extra shifts or train more workers from the CM-line for the TC production. The latter implies that in case of a low demand for CM the workers can contribute the TC production – or vice versa: It is necessary to optimize the whole system, i.e., to consider interaction between the order for different products and the workload on different production lines. Note, that workers with skills for CM and TC will induce dependencies between these lines.

One strategy is to advance the production of trash compactors, and / or of other products (here the coffee makers) within these 12 months. In this respect, the scenario asks to produce finished or partially finished (to be continued later) units on stock. The challenge is to optimize the distribution of the produced stock across products (in the example: CM and TC) and in time. The latter distribution matters because, e.g., the advancing of the production of too many TC (that than will wait for delivery and payment by the customer for many months) will, among others, drive inventory costs. In parallel, resource conflicts (e.g., workers skilled for multiple products), minimizing costs (primarily staff, materials, interest on accumulating capital), or also the calculation of the impact on cash-flow are to be handled.

EXPERIMENTAL RESULTS

A steady increase of the TC production depicts a possible scenario, on which a strategic planning tool may make the difference, allowing the decision-maker to anticipate a future demand increase beforehand. The hypothetical case simulates a 15% year increase of a product, expecting from the decision-maker to verify the best strategy to use if this situation appears.

The expansion of the capacity possibilities helps on accommodating such demand increase, differing on the effective impact and costs the solution may have. To simplify the problem analysis, two of such DoF will be considered, namely the possibility to use extra production lines (note that in the company's case this can be realized simply by introducing a workbench with skilled operators) and the use of daily overtime (considering the possibility of the workers to work, for instance, 2 extra hours a day). Note that the use of the extra production line has 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 use of extra working hours introduces an additional cost related to a percentage increase of the worker's salary. Lastly, the combination of both approaches is also considered, making a two-step analysis on the results. First, the objective is to reduce the product backlog, which increases the company's costs, while having the lowest possible costly measures to implement.



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After inserting the values on the dedicated UI (recall Figure 2**Error! Reference source not found.**) and receiving the planning results from the MAS solver component, the user is presented with the results in a two-fold manner. First, a spider type diagram shows the global, user-selected KPIs making the fast selection of the best candidate solution possible (see Figure 3**Error! Reference source not found.**). In this diagram, several KPIs, such as profit, release quantities, used production lines or used workers, are depicted.

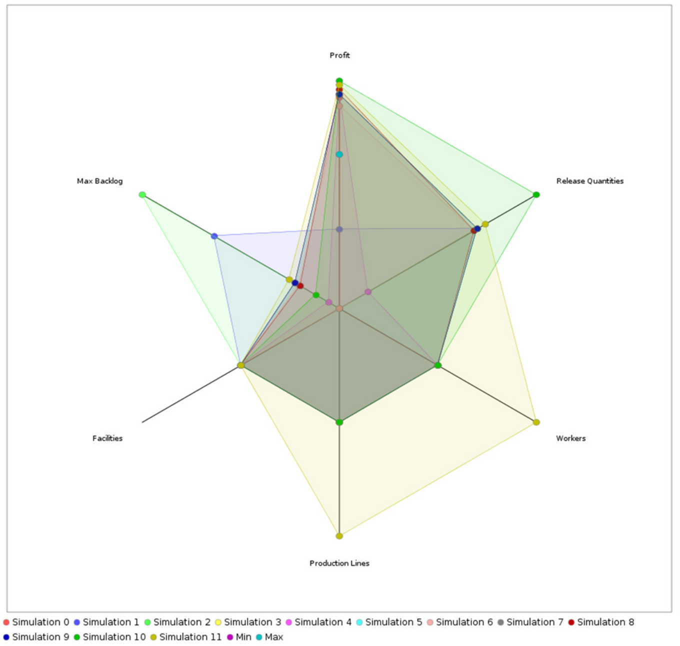

Figure 3. Solutions spider diagram comparison

After this, the user can step into a more detailed solution, where finer-grained details can be analyzed, such as the periodic view of release quantities, the used overtime, the release quantities and the backlog evolution.

In order to have an impact baseline of the demand increase, the decision-maker may reproduce the expected conditions. The backlog evolution for this scenario is depicted in Figure 4, where the backlog evolution can be seen, presenting high levels (maximum value 13). Additionally, we can also observe that the backlog never reaches zero values, which generates additional loss for the company.

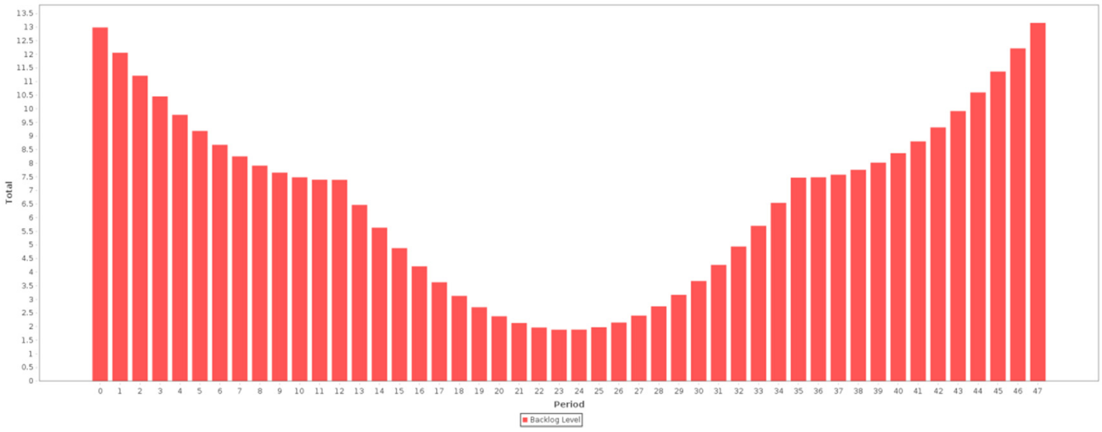

Figure 4. Backlog evolution for the increase demand

The introduction of the possibility to use two extra production lines increases the production capabilities, reducing the backlog levels into a more manageable situation (see Figure 5). Naturally, this solution has an implementation cost of 5.320€.

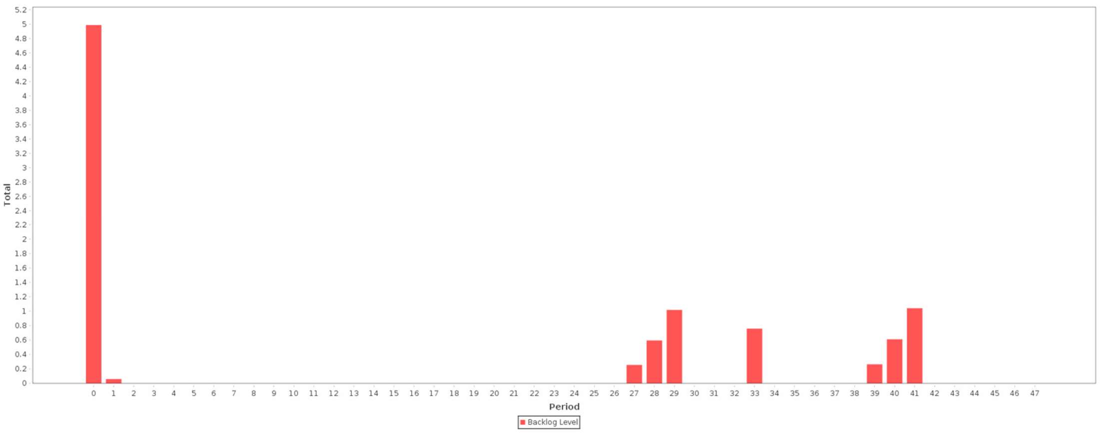

Figure 5. Backlog evolution considering the use of production lines

The second considered DoF is the use of 10h overtime/week (translating in 2h/overtime a day) leading to a backlog evolution depicted in Figure 6. In this situation, the backlog is completely eliminated after the second period, with the associated cost for this solution being equal to 4.406€, which makes this solution the most appropriate to be used.

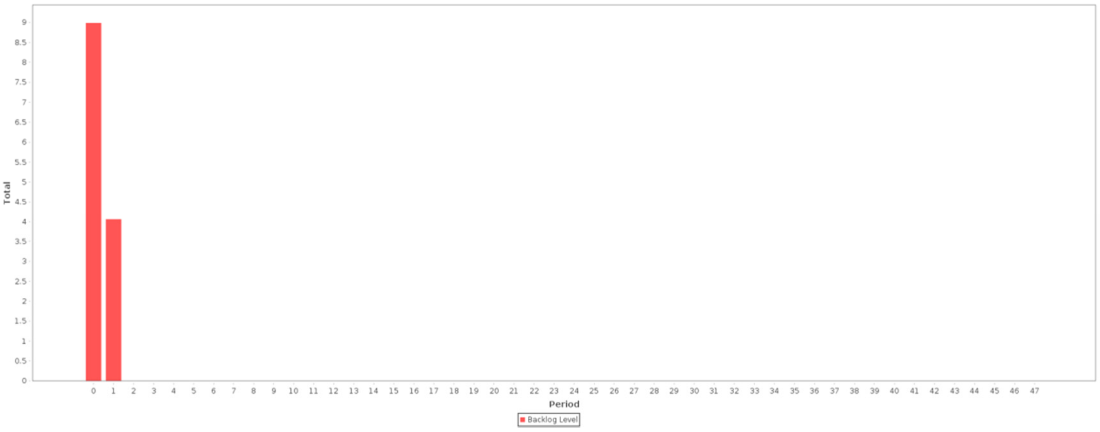

Figure 6. Backlog evolution considering the use of overtime

At this point, the decision-maker may consider continuing this exploratory procedure by trying to find better mitigation strategies or simply by deciding to implement the previous solution considering the expansion of the overtime.

CONCLUSION

Strategic planning assumes a crucial role in companies, helping them on evaluating real case scenarios, such as assessing the impact on a client’s order on their annual production, or on hypothetical scenarios trying to foresee product demand increase or the impact of costs variations.

This article presents a real company use case, where the use of a strategic tool combining MAS principles with an optimization solver supports the impact assessment of a demand increase. The decision-maker, using the available DoFs as expansion possibilities, is able to test different combinations finding the most appropriate one to address the current unexpected situation.

Presently, and as future work, the tool is being automated to generate dynamically and in an intelligent manner the DoF, aiming to release the user from the burden of selecting the most appropriate combination, being only necessary for the user to pre-define the initial acceptable boundaries. In this way, using the agents as the active actuators on the DoF, the decision-maker can focus on what is important for them, which is analyzing and selecting a solution from a set of the best possible ones.

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