

Agent-Based Factory Modelling

Eurobios and SCA Packaging A Case Study

1. Introduction

This case study presents an application of agent-based modelling (ABM) to the management and optimisation of a corrugated-box manufacturing plant. SCA Packaging, a leading international manufacturer in the corrugated-box market, turned to Eurobios to provide an agent-based solution to explore different strategies for reducing stock levels without compromising delivery times, as well as evaluating consequences of changes in its customer base. In order to operate successfully in a highly competitive market, SCA Packaging found itself under growing pressure to maintain a high quality of customer service and delivery times, as well as plant efficiency and reduced inventories of finished goods. An agent-based tool was developed by Eurobios to model and simulate plant operations at SCA Packaging. The tool was developed in 2001 and was used by SCA Packaging to make strategic decisions on the customer base and plant capacity. As a result, SCA Packaging experienced a reduction of warehouse levels by over 35% while maintaining delivery commitments.

2. SCA Packaging

SCA Packaging was established in 1929 and originally comprised ten forest industry companies producing sawn goods and paper pulp in northern Sweden. SCA has since grown and diversified into three main businesses, delivering hygiene products, forest products and packaging. In the packaging domain, SCA is Europe's leading provider of customer-specific packaging. It has operations in 30 countries and production at 320 plants worldwide [3], and its business covers the whole supply chain, from the production of raw material (containerboard), to the high quality finished packaging product.

3. Eurobios

Eurobios is a company specialising in commercial applications of complexity science and complex adaptive systems for business optimisation problems. Eurobios uses agent-based technology to build simulations and optimisations of very complex business systems, with a strategic focus on optimising the supply chain. The company builds on the expertise of an international team of 15-20 scientists/developers, experienced in all stages of software development, from algorithm design through to implementation. This expertise has been built up through an extensive portfolio of successful projects with clients such as Unilever, BP, Post Danmark, SCA Packaging, Kappa Packaging, Peugeot, Ferrovial, Deutsche Post World Net, as well as through subcontracting on large-scale projects for vendors like CapGemini and BCG.

In the case of SCA Packaging, an extensive collaboration with Eurobios resulted in a suite of agent-based tools to simulate, analyse and optimise supply chain operations (e.g. transport optimisation and production reallocation, replenishment policy tuning, etc.). The use of agent-based modelling was beneficial because agents have the potential to capture the complexity of real world problems. With agents, complex operations and entities in the supply chain can be modelled in great detail, while the complexity of supply chain problems emerges bottom-up from the interactions between agents.

4. Modelling and simulation of a corrugated-box plant at SCA Packaging UK

In the corrugated-box plant, customer orders arrive simultaneously for a large variety of boxes, each with its own colour scheme and specific printing, and often to be delivered at very short notice. Plant managers have to deal with varying lead-times, varying seasonality and overlapping production pathways, while trying to avoid weekend shifts and overtime, keeping the warehouse stock levels down, and ensuring on-time and in full delivery [2]. The complexity of plant processes, combined with the difficulty of predicting customer behaviour and machine failure, makes managerial decisions difficult. Thus the problems and the trade-offs arising in the management of the plant require a detailed understanding of the relationships between

customer order patterns, factory capacity, machine speeds, order batching and warehouse size, (to mention just a few of the variables of plant management), which can only be achieved through the use of sophisticated simulation technology.

5. The agent-based model

The simulation model developed by Eurobios combined agent technology with discrete event simulation; agents represent interacting entities with behaviour rules and decision capabilities attached, while the simulation of the processes is achieved using events, occurring concurrently or consecutively.

5.1 The problem

The main objective of the model was to understand the impact of changes in the plant setup, and changes in some of the main characteristics of the customer orders, on the running of the factory. Two key factors were used to analyse the impact on the plant. The first was On-Time-In-Full (OTIF), an important quality measure, representing the number of orders delivered to the customer on time and in full quantity. The second factor was the warehouse stock level, which is a combination of the finished goods stock (kept by agreement with some customers) and the goods deposited temporarily in the dispatch area before transport. However, the two measures (the OTIF and warehouse level) cannot both be optimised at the same time, in that it is difficult to reduce finished good stocks without compromising On-Time-In-Full delivery. To maximise plant efficiency, a detailed scheduling of operations on machines is usually required, in order to ensure permanent high machine utilisation. However, the more detailed the production plan, the more sensitive (and therefore the less robust) it is to disturbances like machine failure, customer order irregularities (peaks and troughs), or unpredictable changes in orders, resulting in last-minute changes to the production plan. As a result, dispatches can be delayed or delivered in less quantity than required, thus negatively affecting the OTIF of the plant.

Delaying or missing dispatches can also have a major negative impact on customer satisfaction, as well as negative financial implications. While it is difficult to establish exactly the cost of missed dispatches, it is, instead, easier to compare it with the cost of inventory. In this case, being able to reduce inventory levels while keeping the OTIF (i.e. the inverse of the cost of missed dispatches) constant is one of the means of plant optimisation. For this reason the trade-off between the OTIF and warehouse levels is a good operational measure of the efficiency of the plant and therefore for testing the agent-based model.

5.2 The model

In the Eurobios model, software agents represent different entities, ranging from functional and physical departments to plant machines and humans, while the physical flow of goods and customer orders are represented by information flow between the communicating agents. One of the key agent types in the model is the customer, which aims to model the handling of incoming orders, where an order is described by the product and quantity, delivery location and delivery data and time. The products themselves have several different parameters (such as box size, unique print design and colour-scheme, number of boxes per pallet shipped, agreed stock level for that product and guaranteed lead-time), and each customer has a number of such products for which it places orders of various amounts over the year.

Orders from the customer arrive at the plant through the sales agent (representing the salesperson), which deals with an incoming order by performing a pre-defined action associated with the type of that order. For example, if the order is a request for a certain quantity of a product from pre-agreed warehouse stock, then the stock level is checked, the requested quantity is shipped to the customer, and a stock-replenishment order is triggered. The quantity that must be shipped is then moved to the dispatch area, which is also represented as an agent, and is the location where finished goods are temporarily deposited while waiting to be loaded and transported to the customer. However, if there is no stock, a production order is triggered instead. Production orders are then slotted into the current production-plan according to different order handling policies and lead-time agreements.

The behaviours of the agents are constructed as parameterised ‘if-then’ rules encoding the behaviours observed in the factory. Thus, the agents representing the machines (e.g. corrugated board machines, converters, gluers, stichers, palletisers) have deterministic behaviours, characterised by parameters such as speed and set-time, while the behaviours of the agents modelling the humans mimic the formalised or unformalised “if-then” rules that salespeople and factory managers use daily. Part of the simulation for the agents then consisted of modifying the ‘if-then’ rules in relatively simple ways, such as, changing their priorities (for example, how willing an operations manager is to work a weekend shift), or changing the strategy according to which production orders are slotted into the production plan (for example, simple planning strategies can be used, like slotting the production order nearer the time at which the customer order arrives or nearer the due-date of delivery, or more complex strategies can be used to make machine utilisation more uniform or to optimise the transportation schedule).

The simple rule-based modelling approach that mimics human behaviour was preferred to sophisticated dynamic optimisation techniques. The assumption was that the knowledge of people with 20 years hands-on experience in the plant is invaluable when dealing with complex plant operations and unpredictable customer behaviour. Furthermore, rules of thumb are often the basis for decisions taken by plant operators, making statistical approaches irrelevant.

6. Business case and project management framework

The project was commissioned by senior management at SCA Packaging, drawing on Eurobios’ reputation of successful implementations of agent-based systems. In particular, the extensive experience of Eurobios with supply chain optimisation using agents was valuable in convincing managers at SCA Packaging about the feasibility of using the technology. In the first instance, however, problems at SCA plants were largely ill-defined, and it was therefore necessary to establish exactly what needed to be addressed. While many solutions to improving plant operations could be implemented, finding the areas where the ABM approach was appropriate and where ABM tools could help was critical.

The project therefore started with a six-month exploratory phase, during which Eurobios and SCA Packaging collaborated in carrying out a feasibility assessment. This assessment involved choosing between two SCA plants to focus on, by analysing existing plant problems and ways of improving them. The first option was a plant located in the South-East of England, which was largely underperforming due to a series of known problems that could be solved through solutions simpler than agent-based modelling. The second option, which was chosen, was a plant located in Edinburgh, with higher performance than the previous plant, but where optimisation was more challenging and thus had the potential to emphasise more clearly the benefits of using agent technology to SCA managers.

Development was then split into three phases in order to better monitor the progress and manage the risk, and each phase lasted for one month. During the first phase, a basic model of the plant was built and the model was run with real company data. The objective of this phase was to provide a preliminary demonstration of how the plant works, so the realism of the model and the level of detail of the data were less important. During the second phase the model was further elaborated to add more realism and more detailed data, while the objective of the third phase was to make the model as realistic as possible and to perform ‘what-if’ analyses based on different simulation scenarios. The model was thus developed iteratively, so that the level of complexity and detail were increased at each iteration. The final, complete model was then calibrated, by running it with real data (e.g. customer orders) and by comparing the results of the simulation with the real values of variables like warehouse inventory levels and cost.

7. Demonstration scenario

As a strategy tool, the agent-based simulation was used to make decisions on the choice between two important customers. One of the customers (Customer A) was a high margin customer (i.e. high profit margin per box), with short lead times (shorter than the average plant lead time) and with high levels of stock. By contrast, the second customer (Customer B) was a low profit margin customer, but allowed for large contractual lead-times and with little stock of its products. A choice between these customers had to be made when Customer B decided

to bring a new product to the UK market and required a large production volume (approximately 20% of the volume of the SCA plant). Making the right strategic decision in this difficult situation required accurate and fast analysis of the cost of serving these customers versus the amount of orders and therefore the revenue brought in by the customers.

Using the simulation results from the agent-based tool, a series of options were evaluated in order to deal with the cost and capacity problems. The options ranged from refusing business from a number of small existing customers to taking on a limited number of orders from Customer B, or completely rejecting all orders from Customer A. Despite expectations, the model offered a clear solution to the problem, which was to stop working for Customer A completely, and to accept all orders from Customer B, resulting in a drop of 40% in warehouse stock levels and an increase in OTIF and overall production efficiency.

The reason for this choice was a subtle difference in order patterns between Customer A and Customer B. It was found that Customer A would often 'abuse' its already short lead-time by requesting even shorter lead-times on its orders, while Customer B would instead accept even longer lead-times than specified in the contract. In addition, Customer B would tend to place its orders on Mondays, Tuesdays or Wednesdays, while Customer A would do so only on Thursdays. This hidden order pattern often resulted in having to shift orders from Thursday to Friday or even to the following Monday, and thus having to allocate orders over the weekend in order to avoid changing other customers' delivery agreements, which in turn incurred extra labour costs.

Through what-if simulation, the model made visible certain customer order patterns and the propagation of events across the plant as a result of the arrival of orders. It was found that the relationship between the days of the week when the orders of Customer A and Customer B were placed, the utilisation of the machines during those days and the lead-time requested for those orders were crucial for the cost incurred for the two customers. The observed pattern was useful for efficiently managing other customers as well, and therefore strategically valuable for SCA.

8. Lessons and experiences

8.1 Knowledge engineering

Knowledge engineering was necessary for data acquisition, model building (rule formalisation) and model validation (validating the rules and correcting missing or wrong values in the data). In order to produce changes at an operational level, such as changing how people make decisions in the day-to-day running of the plant, a high level of realism was necessary both for the model and the data. To ensure this realism, Eurobios collected more data and in more detail than strictly required by the model, reducing the chances of inconsistencies between the model and reality, but also adding to the knowledge acquisition and validation effort.

Implementations of systems for business performance optimisation can sometimes require significant data acquisition effort, particularly in companies where data is spread between different enterprise applications. For example, with the advent of Enterprise Resource Planning (ERP) systems, a higher level of data integration has been achieved across companies, and therefore, in companies with ERP systems in place, the knowledge acquisition effort is less significant. This acquisition effort is also sometimes due to the nature of the business applications generating the data. For example, some of these systems are mainly transactional and not designed for storing intermediate states of information between the transactions or the events that model the business processes, nor for storing other types of information like the time of generating the data, or what-if analysis information. Furthermore, the effort of eliciting data of sufficient quality and detail can sometimes be underestimated because software engineers and business people have a different understanding of what it is that constitutes good data.

In the case of SCA, however, Eurobios found that the acquisition effort was slightly less significant than for other companies, and data was made available more easily to the developers, so that the model could be run with real data from the very first stage of development.

Benefits of the knowledge engineering task went beyond the realm of software development. For SCA, an add-on benefit was the insight into different departments' work practices, which were sometimes unformalised or ad-hoc, based on an everyday understanding of different

events, such as customer order fluctuations. For example, an agreement between plant managers and one customer to change delivery dates during a very busy period to avoid unwanted delays and customer dissatisfaction, but resulting in changes in stock levels, remained unknown to top management and was not included in the agent-based model, creating discrepancies between the simulation results and real warehouse stock levels. By encouraging different departments to talk to each other in the process of eliciting plant information, some of the communication barriers between functional departments and between plant management and top management were eliminated.

8.2 Validation

For a model of the complexity of the SCA plant, validation through extensive tests was mandatory. Diagnosing problems and tracking system behaviour was important not only for validating the model, but also to explain to SCA how the system works and to eliminate issues related to plant operations that were not properly understood. However, the task proved challenging for several reasons. First, agent-based systems may explore realms of behaviour outside people's expectations and often yield surprises [1]. Second, there was a lack of control over the input data, combined with a lack of access to the company servers storing that data. Every optimisation was done over data collected from company systems in real time through a multi-step, interactive process, (based around stock replenishment, optimising stock policies for warehouses, etc.), and there was no simple mechanism for recording the input data for each run. In consequence, each simulation run was irreproducible, which made diagnosis and debugging more difficult.

8.3 The trade-off between design and implementation

Eurobios experienced a dilemma in determining the time and effort required for the design and that for the implementation of the agent-based tool. While spending considerable time in advance to ensure sufficient data accuracy and designing the application to ensure reusability, quality and robustness was important, it was found that only through simulations during the model calibration and validation stages did certain issues surface that would not have been discovered at design time. Because of the complexity of the model, there was a point after

which spending time in design brought no further value to the final system because there was a chance that what was being designed would later be invalidated.

9. Summary

An agent-based system was developed by Eurobios to model a corrugated-box plant for SCA Packaging. The complexity of such a manufacturing plant, caused by a large number of different products, tight deadlines and a multi-pass production process, make the optimisation of plant efficiency and the reduction of cost difficult. The agent-based model offered SCA Packaging an improved understanding of the consequences of possible changes to the customer base on the way the plant is run. As a result, the plant management was able to take decisions that led to a reduction in warehouse levels by over 35% without compromising on-time-in-full delivery. The successful implementation in the Edinburgh plant led SCA to commission Eurobios to develop similar implementations for several other plants across the UK.

References

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