Application of the Eurobios Agent-Based Modelling Framework: Joint Simulation of Production and Logistics to Support Plant Selection for a Multi-Site Corrugated Box Company

Anwendung der Agent-basierenden Modellierungs-umgebung von Eurobios: Gemeinsame Simulation von Produktion und Logistik um die Produktionsstandort-entscheidung einer Kartonagenfabrik zu unterstützen

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Zusammenfassung: Produktionsbetriebe mit mehreren Standorten muessen die schwierige Entscheidung treffen, wo welche Produkte produziert werden sollen, unter Beruecksichtigung von Kundenbeziehungen, Produktionsbeschraenkungen und Transportkosten. Eine Anzahl von Komponenten der Agenten-basierenden Modellierungsumgebung von Eurobios wurden kombiniert, um ein einfach zu handhabendes System zur Unterstuetzung von Managemententscheidungen fuer die UK-Niederlassung eines der groessten Europaesichen Kartonagenherstellers, zu entwickeln. Aus verschiedenen historischen und auch technischen Gruenden ist die momentane Kundenverteilung nicht optimal im Sinne einer Minimisierung der Transportkosten. Das von Eurobios entwickelte System bietet dem Management eine einfach zu handhabende Simulation der Produktreallocation. Dem System war es moeglich aufzuzeigen wie ein hoher Gewinn an Transporteffizienz moeglich ist ohne nennenswerte Beeintraechtigung von Produktionszielen wie vollstaendige und zeitgerechte Anlieferung.

Abstract: Multi-site manufacturing companies have to make difficult decisions as where to make different products, taking into account client relationships, production constraints and transportation costs. A number of components from the Eurobios agent-based modelling framework were combined to build an easy-to-use decision support tool for the UK operations of one of Europe's largest corrugated box companies. For various historical and technical reasons the existing distribution of customers is not efficient in the sense of minimising transportation costs. The Eurobios tool provides the management with an easy-to-use simulation of production reallocation. The tool was able to show that a large gain in transportation efficiency is possible without any major disruption of production goals like on-time-in-full delivery.

1 Introduction

Agent-based modelling and simulation, which is based on the discrete-event simulation approach, but emphasises the autonomous decision making capabilities of the individual entities in the model, has proven to be a very effective tool for supply chain modelling and simulation (see for example /1/). And a large part of its success is due to the fact that the interaction between the different agents can be modelled and simulated in great detail. But exactly this strength of the agent-based modelling approach makes it very difficult to develop any useful general-purpose agent-based modelling and simulation applications for production and logistics. To our current knowledge none of the attempts (including the ones undertaken by the Bios Group) to build a general agent-based supply chain tool have produced anything useful for the end-user. While a number of industry strength tools have been developed for coarse grained supply chain modelling, mostly based on equation based modelling or quite general discrete event simulations, any kind of detailed agent-based supply chain model has still to be developed as a bespoke software application. Therefore Eurobios has now turned toward building a library of agent-based modelling components (the agent-based modelling framework), which can be easily combined to develop a highly customized user-friendly modelling and simulation application, capable of modelling almost any supply chain and production set-up in very fine detail.

In this paper we show an application of the Eurobios agent-based modelling framework to a production and transportation problem for a major corrugated box company. We show how an agent-based model of the entire production and distribution process can be built using the framework and how such a model helps the management of the corrugated box company to understand major cost drivers in their supply-chain. We should add that the application currently concentrates on modelling major cost drivers and KPIs like warehouse levels, missed deliveries, delivery distance and time. Some of those values are converted into actual monetary costs using quite rudimentary cost models, but we are working on a much more detailed integration of cost (and pricing) models into the toolkit at the moment.

2 A Corrugated Box Company

The production of corrugated cardboard boxes is a very competitive business with (at least at the high-value end of the industry) a very high demand of flexibility and timeliness on the producer. These demands typically are the effect of a move to just-in-time production on the customer side which translates into the expectation of very precise delivery of the ordered quantities at the exact time specified. Also the highly customized nature of the packaging business makes the sophisticated scheduling of production-runs a necessity in order to minimise warehouse costs and maximize machine-utilisation. This leads to the counterintuitive situation that a production run that might only take a couple of minutes on two or three machines has a practical lead time of several days. This not only results in less than satisfying customer service but increases warehouse costs significantly. Therefore one of the aims of the model, beside the analysis of product allocation inefficiencies, was to help the management to understand what aspect of a single customer's demand makes it necessary to keep large amounts of stock and to only offer multi-day lead times. Once the model showed the detailed effects of the different contractual arrangements and working practices, it turned out to be quite straight forward for the company to remove around 30% of warehouse levels just by selecting their customers more appropriately.

The corrugated-box company studied has a number of production sites all across the UK, with each plant having a slightly different machine set-up and an almost completely different set of customers and products. The measure for corrugated boxes is KSM (thousand square meters) per year and the different plants vary between 20,000 and 100,000 KSM. This equates to between 2,000 and 4,000 product types or between 40,000,000 and 200,000,000 actual corrugated boxes. Each plant has a single corrugating machine that turns either three or five sheets of paper into corrugated carton sheets. Then a number of converting machines print and cut (and optionally fold, glue, stitch) these sheets of corrugated cardboard box into the finished product. Each machine has a specific speed (measured as KSM per seconds, where KSM refers to the size of the sheet that enters the machine) and set-time. Once the boxes come of the last converting machine (reduced in size due to cut-offs) they get put on pallets and are sent to the dispatch area. Once there the pallets wait for a delivery truck to pick them up and deliver them to the customer. Naturally the delivery company tries to optimise the routes and to create multi-leg drop-off routes. But not only due to the locations and delivery times of the customers but also due to the fact that un-reliabilities in the production process make advanced planning sometimes difficult, the routes are sometimes less then optimal in reality.

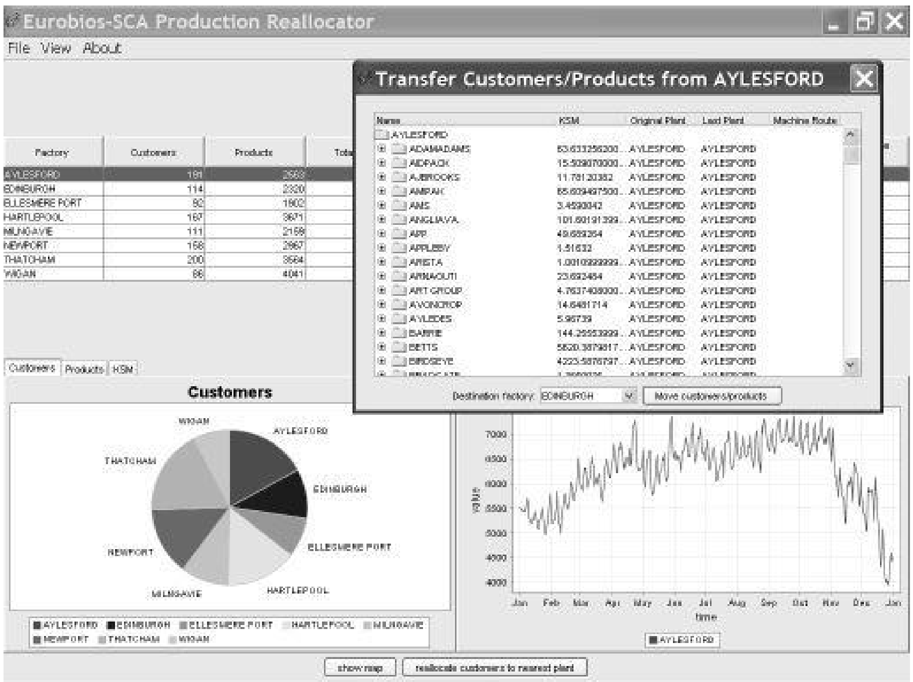

***Figure 1**: Reallocating Customers from one Plant to Another.*

For business-relationship and historic reasons not all products are made at the plant nearest to the customer’s desired delivery location, which results in unnecessary transportation costs. The remit for Eurobios was therefore to build a tool that would allow the management to simulate moving production for one or more customers (or even a subset of a customer’s products) to another plant, which is closer to the required delivery location. Then the model is able to simulate an entire year of production with the additional customer(s) and quantify the changes to key production performance indicators (missed dispatches, machine utilisation, warehouse levels etc.). Parallel to the study of the effect that this product reallocation has on the production process, the tool simultaneously updates the transport delivery routes in order to determine what the new distances are and how much transport costs were reduced by this reallocation.

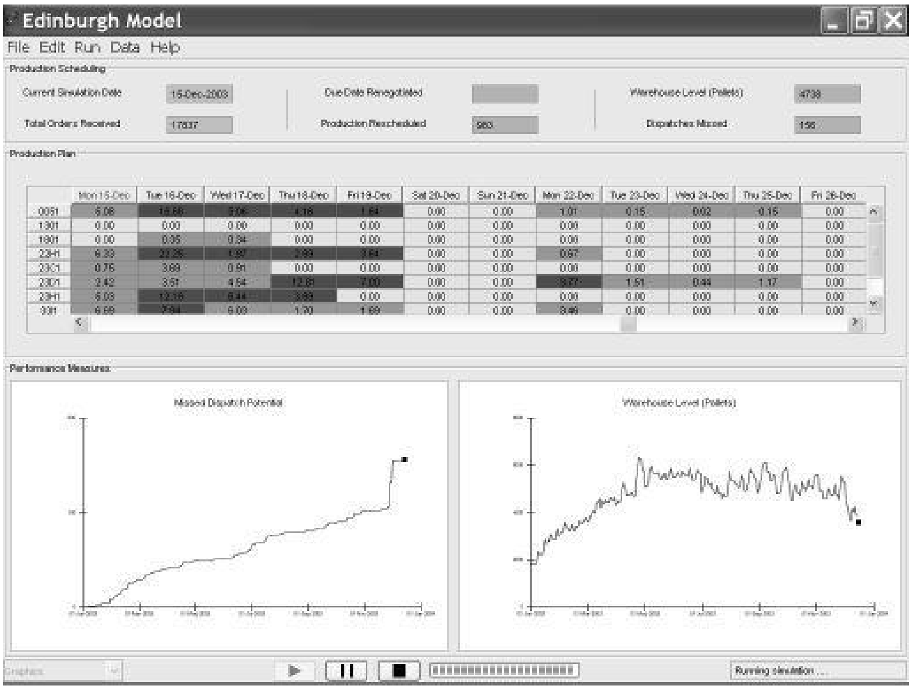

Figure 2: *Simulation of Multi-Stage Production Process.*

Unfortunately, at least from a modelling point of view, transportation for this particular business is done by an outside contractor, so that the corrugated box company itself was not able to provide information on the actual routes taken for each delivery. But since the remit was to find out how much transportation costs can be reduced by a more optimal allocation of customers, a reasonably valid assumption was that a reasonably well-optimized set of delivery routes on any given day would be a very good model for the actual activities of the transportation provider. There are some limitations to this assumption, for example that back-hauling is not included, but as a means of comparing different scenarios it is reasonable (at least if we are taking into account the afore mentioned caveat that we are currently anyway just dealing with distances and not costs directly).

All this leads to quite a long list of demands on the simulation tool in order for the management of the corrugated box company to run all the necessary experiments:

- Simulate an entire year of production for each factory with detailed machine scheduling for each day.
- Collect and visualise relevant production performance indicators.
- Use the data from production to schedule delivery vehicles for the entire year with detailed routes for each vehicle for each day.
- Collect and visualise relevant transportation performance indicators.
- Reallocate any product or customer either automatically to closest delivery location or individually by hand.

3 The Eurobios Agent-Based Modelling Framework

The Eurobios framework is a collection of highly sophisticated components and a flexible development platform which allows for rapid combination of these components to build a customer specific application in a reasonable amount of time, comparing favourably with the time needed to use less detailed tools such as WITNESS™ or PROMODEL™. In this project the “Agent-based Manufacturing Toolkit” was combined with the “Agent-based Transportation Toolkit”, together with a number of visualization components. This was done inside the Eurobios development platform. The only part of the application that had to be custom built was the reallocation capability, which gives the management of the entire company a simple tool to take products form one manufacturing plant and putting them into another. This was accompanied by an automatic reallocation mechanism to be able to reallocate all customers to the nearest factory by simply pressing a button.

3.1 Manufacturing

Our Agent-based Manufacturing Toolkit is an agent-based simulation of the entire manufacturing process. The main entities are warehouse agents, which provide a certain amount of space to store SKUs for a certain amount of time, and transformation agents, which turn a certain number of SKUs into other SKUs. Any kind of manufacturing unit can be modelled as a combination of such warehouse and transformation agents, representing any kind of storage space and machine. These more low-level agents are combined inside business agents to form business units representing customers, production plants and distribution centres. This allows for a straightforward modelling of customers calling the sales department of an individual production plant. The business agent representing this production plant creates an initial machine resource plan inside its sales department. This is then turned into definitive machine-time allocation planning and scheduling by a production planning agent. Once a feasible production plan has been created the goods are produced and sent to dispatch. The toolkit provides various production scheduling algorithms to be used in this process. The production planning agent, which can be used to optimise the scheduling of the jobs on all machines, uses these algorithms to create the production plan. Very great care has gone into designing the flow of information between the different agents with sufficient generality that most kinds of production or supply chain situation can be modelled in sufficient detail (including those with perishable goods, for example). See /2/ for a detailed description of the corrugated box manufacturing simulation.

3.2 Agent-Based Transportation Toolkit

The transportation toolkit simulates transportation of goods from the manufacturing location to the customer location by combining truck allocation with detailed routing using the exact times and distances of the European road network. The transportation toolkit models the transportation fleet consisting of any possible number of tractor and trailer combinations and the delivery schedule with pick-up times and delivery time windows. Based on this model a variety of optimisation algorithms can be used to build the best possible schedule. The classic reference regarding this issue is Clark and Wright /3/.

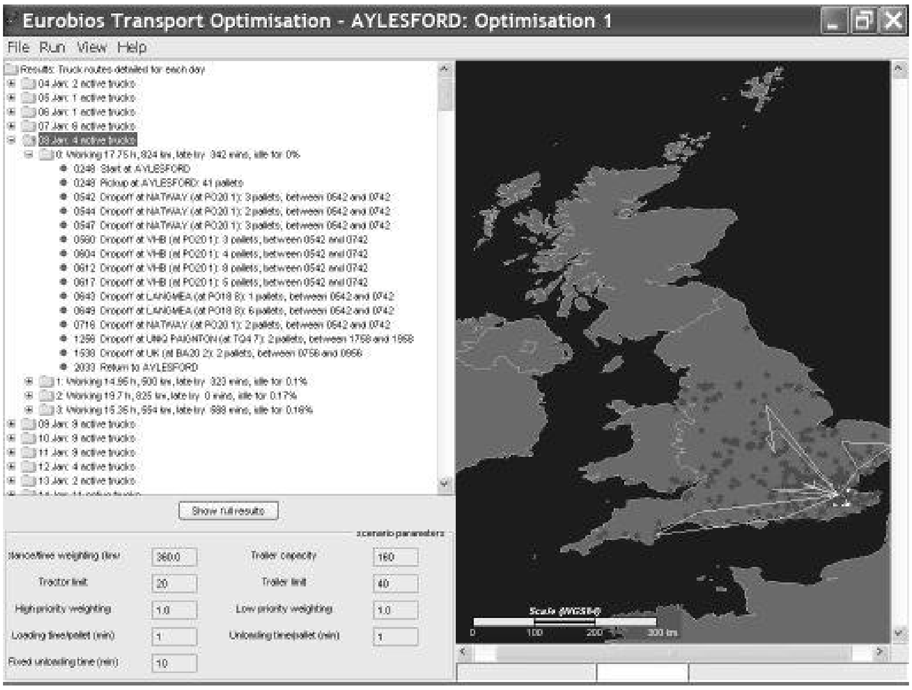

Figure 3: *Simulation of Transportation with Detailed Vehicle Routing Schedule (Using the UK Road Network Even if Grpahic Just Shows Abstract Routes).*

3.3 Reallocation

The components were integrated with each other using a reallocation tool. This central reallocator not only handles all the data-management (loading, saving, connecting to the company's ERP system etc.) but also offers the user the necessary tools to reallocate products or customers from one factory to another and specify the machine compatibility between the different factories. While the data management and the visualisation of the results were easily handled by the Eurobios application platform, the product reallocation was the only part that had to be custom built for this application. The essential part of this reallocation is the definition of machine-to-machine relationships. Any product of any complexity usually goes through a multi-stage production process where it passes through a number of different machines in a certain order. To reallocate such a product from one manufacturing plant to any other it is important to specify which machine route in the former plant should be replaced with which machine route in the latter. This machine-to-machine matching can be edited by the user. It is also possible to create new machines in some of the plants during run-time. Once this machine-to-machine matching has been specified it is a very simple process to select entire customers in one factory and to reallocate them to any of the others, or just to reallocate some of the products of a customer from one factory to another.

4 Results

As a first step the tool provides the possibility to reallocate all customer delivery locations to the factory that is closest to them. There is a slight problem in the fact that some products have several delivery locations, which might be located close to different factories. But due to the individuality of each product it would not be sensible to manufacture a product in multiple locations. Therefore the practical solution is to reallocate the product to the factory that is closest to the delivery location that receives the largest volume.

Unfortunately once this first-stage reallocation is done the production volume is distributed unevenly over the different factories. So while this is a very attractive reallocation from the transport perspective, with delivery distances reduced by over 30%, this is an unfeasible distribution. Therefore the automatic reallocation to the closest factory has to be accompanied by a manual reallocation of some of the customers in order to return the production volume to something similar to the original distribution. But this is actually not an easy task, and does need at least some input from someone with the appropriate domain knowledge. While the tool provides one with all the necessary information about the different machine route of the individual products and the utilisation of the different machines, a domain expert has a much better feel for which products would be best suited to be reallocated in order to get all the individual factories run smoothly again, since not only technical but also customer relations based considerations have to be taken into account here.

Once this reallocation is done it is straight forward to simulate the running of all the different production plants for the entire year and compare the data on various key performance indicators like warehouse levels or missed dispatches. But it is also simple to rerun the entire delivery process and compare the distance that was necessary to make all deliveries. The results were very encouraging and while none of the major KPIs increased significantly (the two major ones of warehouse level and missed dispatches actually decreased) the delivery distance has been reduced by over 25%.

5 Conclusion

In this paper we attempted to show two things: First that while it might still be very difficult to design a general agent-based supply chain application, the approach of building a library of agent-based supply chain components reduces development time for any kind of supply chain application, significantly. Secondly we presented the product reallocation application for a very special situation of a corrugated box company that was built with the elements of this toolkit (and some additional, but small, development efforts). The tool definitely proved its worth by not only giving the management quantitative answers to very difficult questions, but also by now being deployed by this same company to regions outside of the UK.

Biographies

Dr **Peter von Tessin** is Senior Software Engineer at Eurobios UK. He gained a DEA in Mathematical Economics and Econometrics from Pantheon-Sorbonne University in Paris and a Ph.D. in Econometrics from Tuebingen University in Germany. Since graduation the main focus of his work has been in business consulting, quantitative and agent-based modelling and object-oriented software design.

Dr **Vince Darley** is CEO of Eurobios UK. He gained his Ph.D. in Complex Systems from Harvard University, and has degrees in Computer Science and Mathematics from Harvard and Cambridge Universities. He currently manages the growth and strategy of Eurobios UK in applying complex systems modelling techniques to business problems.

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