Enterprise Modeling and Simulation Research at HP Laboratories

Our work at HP Laboratories on enterprise modeling and simulation is an outgrowth of the factory modeling project, which began in early 1987. While we were working in the area of robotic automation for manufacturing, we began to appreciate the complexity of the geographically distributed, multientity marketing, manufacturing, and distribution operations necessary for HP to remain competitive. We also realized that there were very few tools available to help understand, design, and operate these complex systems.

Having been involved in product design with the evolving use of CAD and CAE tools, we thought that there was an opportunity of potentially tremendous magnitude for applying similar technologies to the design and operation of the factory and business systems used to market, manufacture, and distribute products. In an effort to capitalize on this opportunity, we began identifying the primary elements of a single factory and building our preliminary order-to-ship model that spanned all major activity from the receipt of an order to its shipment.

Preliminary Order-to-Ship Model

This early model was a vehicle to show the feasibility of applying simulation at a scope larger than a production line, where simulation was beginning to be applied. Developed and proposed for discussion purposes, it was a model to analyze why the order-to-ship time for some products stretched to weeks when the application of modern manufacturing techniques had reduced the build time to a matter of hours. More details on the reasons behind this work are given in references 1 and 2.

Full Order-to-Ship Model

By late 1988 the preliminary model was ready for testing in a real-world context. Data and operational information were provided by a real manufacturing division to help enhance our early model. This process helped to validate the preliminary order-to-ship model and led to the development of the full order-to-ship model.[3] The primary factors considered were order forecast quality, production capacity constraints, supplier lead times, and order filling policies. The primary metrics of interest were order lateness, backlog, and inventory. The model included three distribution centers, one manufacturing entity, and a centralized sales and order entry system. It was configured for one-level bills of materials (BOM), multiline orders, and long life cycle products.

The results of the analysis done with the full order-to-ship model were encouraging; they showed things that were consistent with real-world experiences (e.g., high forecasts led to high inventory and low backlog). The results also provided a view of greater potential by helping to identify areas for future improvement (e.g., the dominant cause of product shortages is long lead time parts coupled with poor forecasts rather than the build time).

While the results of this model were modest, the building and running of this model enabled us to explore some important technologies (i.e., Hierarchical Process Modeling for knowledge acquisition, a discrete event simulation language, SLAM II,[4] and a knowledge-based environment, Knowledge Craft, for system representation and building simulations). Our efforts led to generalized enterprise-level modeling elements and an object-oriented simulator. We also identified some new obstacles (e.g., managing large amounts of simulation data, extracting information) to be overcome in attaining our goals. More details are given in reference 1.

For about a year, no further model development was done, but rather, much effort was put into consolidating what we had learned about the modeling and simulation issues. This effort led to the complete overhaul of our modeling and simulation code while migrating it to the Common Lisp Object System on HP workstations. The power and speed of our system took a quantum leap forward.

Simple Model

With our improved system ready, we were presented with another real-world opportunity to apply our techniques. The Simple Model was proposed as a means of pulling together the main activities, processes and circumstances involved in a manufacturing enterprise. The primary purpose was to understand end-of-life (EOL) inventory and order delivery performance issues. The combined impacts of several environmental factors and operational policies were considered in the analysis. The model, leveraging our earlier work, dealt with a one-level BOM, one factory, one product, and subsequently a family of successive products with common parts and overlapping life cycles.

Our analysis provided some interesting insights, such as certain material procurement and safety stock policies result in EOL inventory even for perfect order forecasts, and with low forecasts, increasing material lead times and planning frequency result in increased EOL inventory. More important, we began to realize that we were onto something that could really have a positive impact for HP. In fact, the business results led to the development of the planning calendar model with the Simple Model as its foundation. We also continued our technical enhancements by connecting the output to S-Plus[5,6] for data analysis and the creation of a Lotus® interface to display output.

Planning Calendar Model

The purpose of the planning calendar model[7,8,9] was to determine the effects of planning cycle times on inventory levels. It required extension of the Simple Model to include production planning and material planning cycle times. It approximated a two-level BOM and multiple assembly sites using a one-level BOM at one site. It used historical forecasts and orders. The primary factors were forecast quality, the length of the planning cycle, and the maximum lead times for parts. The primary metrics of interest were average inventory, delivery performance, and inventory levels at the start of production. The primary technical development was the application of S-Plus data analysis capabilities to the data.

With this model, material lead times had a dominant effect on inventory levels and committed inventory. Historically, forecasts were generally low, so for the historical data given, the planning cycle time used for the particular product had insignificant impact compared to material lead times. There was greater potential for reducing inventory by reducing lead times than by reducing planning time. Low forecasts increased backlogs.

Current Modeling Activities

We are currently finishing an analysis of a single-site manufacturing system where we were looking at how to improve the supplier response time. The challenges in this application include managing a multilevel bill-of-materials and understanding the consequences of long, variable test cycle times. We are also working with sector-level reengineering teams to help understand the consequences of proposed changes and explore alternatives.

Our enterprise modeling and simulation capabilities have evolved considerably from our preliminary order-to-ship model. However, there are still many more interesting challenges to address before we reach our goal of a computer-aided business process design and operation system.

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