

HOW MODELLING LIMITS ANALYSIS – THE LONG WAY FROM DISTRIBUTED SIMULATION TO REALITY

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ABSTRACT

This keynote talk reviews the author's experience with simulation at the interface between modelling and analysis. It describes how a research roadmap for the development and application of distributed simulation technology for manufacturing and logistics network design and optimisation, driven by the desire of generating an academic R&D track record, was eventually overruled by the need of industrial relevance. Illustrated by real application scenarios from semiconductor manufacturing and aerospace spare parts logistics network optimisation, an important conclusion is that simulation analysis remains a pure academic exercise as long as the underlying model is not an appropriate representation of the industrial system to be analysed.

1 INTRODUCTION: FROM SIMULATION TO DISTRIBUTED SIMULATION

Discrete Event Simulation (DES) technology has been playing an important role for design and analysis of discrete event systems for more than 40 years. Its power lies in its ability to portray systems that are subject to random effects in order to understand, control and reduce variability in such systems.

Distributed simulation refers to technologies that enable a simulation program to execute on a computing system containing multiple processors that are interconnected by a communication network (Fujimoto 2000). It was originally motivated by needs in the military domain for more effective means to train personnel in distributed virtual environments that mimic actual combat situations (Fujimoto 1998). Subsequently, the availability of synchronisation middleware such as the Runtime Infrastructure of the High Level Architecture (Kuhl et al. 1999) has also inspired research looking at potential application of distributed simulation for modelling and analysis of large-scale,

heterogeneous systems such as communication networks or global supply chains.

In industries such as semiconductor manufacturing and automotive which already have adopted to a large extent a paradigm in which the entire logistics process will be digitally represented and simulated before any investment commitment is made, a natural way to achieve a detailed simulation model that covers all causal relationships between the different areas would be to couple independently designed and developed simulation models (Strassburger et al. 2003). Ultimately, when extending the scope beyond the four walls of a factory to an entire supply chain, the notion of distributed simulation might even become indispensable when the participating organisations are not willing to share detailed model information (Gan et al. 2000).

Distributed simulation in the context of supply chain management has been featured by Lendermann et al. (2003). It has, however, put emphasis on the technology from an R&D prospective rather than the usage of the technology for solving real-world problems.

2 FROM DISTRIBUTED SIMULATION TO AN EVEN MORE "GRAND" VISION

In manufacturing or logistics, simulation has traditionally been used to analyze key performance indicators and refine operations through a steady-state simulation approach using commercial simulation packages in the following manner:

1. Raw material is released at a constant rate and mix into the (simulated) manufacturing or logistics system.
2. After the end of a "warm-up period" (which is required to bring the simulated system from empty state to steady state), collection of KPI-relevant statistics commences. To collect a sufficient number of samples for the required statistical confi-

dence of the result, several replications with different random streams have to be carried out.

3. Depending on the simulation results, system configuration, dispatch rules and other parameters are then refined, and the simulation is repeated to study how the system performance is affected and how it can be enhanced.

In many domains, because of the typically long modelling and validation cycle, analysis is often conducted with rather old system data that does not fully represent any more the operations that are of interest. For this reason, simulation technology has been found to be rather impractical for operational purposes and has therefore been used mainly for tactical and strategic decision support.

At the same time, due to decreasing product lifecycles, increasing number of products and constantly changing demand (quantity and mix), hardly any manufacturing or logistics system still operates in steady state today. In such an environment, a lot of potential benefit that could be gained from simulation analysis can actually not be realised for the real operations. Because of the long modelling-analysis-implementation cycle time, the system would have changed significantly in terms of load, product mix, resource mix by the time measures derived from the simulation analysis can be implemented.

A new paradigm for the application of simulation technology for decision-making in manufacturing and logistics is believed to bear more potential in the future: The latest system status will be used as starting point for a high-fidelity simulation, and the performance evolution will be assessed over a relatively short period of time. Ideally, the simulated time period would correspond with the frequency of making relevant decisions.

This, however, means that – rather than looking at a steady state – the dynamic evolution of the system from a specific point of time (in most cases probably the latest system state) onwards is now of principal interest. In the setting of these paradigm changes, certain conceptual limitations associated with modelling of systems as complex as a large factory or a supply chain must be taken into consideration when talking about real-world issues that decision-makers would like to be able to address.

A simulation model is not a good representation of reality if whatever drives the underlying system is not represented appropriately. In the past, simulation has mostly been applied for design and performance enhancement of systems that are driven by material release into and material availability within the system. In such a system, for example a wafer fabrication facility, once a production lot is available for processing on an appropriate machine that is also available, processing will be executed according to a pre-determined dispatch rule without waiting for any additional demand signal from downstream.

In the downstream supply chain, however, from the completion of wafers onwards operations are not driven

any more by my material release, rather they are driven by customer demand. To enable meaningful representation of reality, not only the generation of customer demand itself but also the translation of customer demand into material release and movement decisions have to be represented.

Once this is done appropriately, not only the time horizon of a simulation can be extended significantly but also the scope can be extended from one individual factory to a multiple echelon supply chain.

As long as the translation of customer demand into material release and movement decisions is primarily software-enabled, it is not impossible to realise such a distributed supply chain simulation. For example, Chong et al. (2006) have demonstrated how a virtual experimentation testbed that comprises not only wafer fab and assembly & test models but also a federate that represents a customer order management system can be used to adjust dispatch priorities in the fab to maximise the on-time delivery of finished ICs.

In fact, an even greater vision to use distributed simulation for decision support in ultra-complex systems, to be enabled by cluster infrastructure and high-fidelity symbiotic simulation capability that allows to extend the application from strategic and tactical to operational decision-making has been described by Lendermann et al. (2007).

3 DISTRIBUTED SIMULATION IN THE LIGHT OF INDUSTRIAL RELEVANCE

Even though it is possible to generate and run distributed supply chain models that also comprise federates such as a customer order management system, the supply chains that are the basis for the analysis of studies such as Chong et al. (2004) are still highly simplified representations of real-world supply networks that are relevant to decision-makers.

In reality, however, because of the heterogeneity of the external drivers and a large number of interfaces, it is hard to imagine that it is actually possible to develop and maintain a high-fidelity simulation model of such a complex system.

Also, many material release and movement decisions in real systems are actually made by humans, especially on the supply chain scale. Humans, however, are not only inherently unstable and unpredictable but also capable of independent actions. The lack of ability to represent such decision-making processes will always be an inherent limitation for generation of high-fidelity models of complex manufacturing and logistics systems.

Moreover, in a distributed simulation, to make sure that causality constraint violations are avoided, lookahead is an important parameter to be considered. The lookahead value has great implications on the runtime of a distributed simulation. If it is large, federates can potentially achieve a high degree of parallelism in processing events. However,

events that have immediate consequences in other federates require near-zero lookahead, resulting in a lot of synchronisation overhead that does not allow much parallelism and therefore can slow down the distributed simulation tremendously. Most contemporary distributed systems do comprise such events, especially if information flow between a physical system component represented by one federate and a software-enabled decision support component represented by another federate is involved.

Ultimately, events requiring near-zero lookahead will always be a major limiting factor for execution speed of distributed simulation of complex systems and therefore for industrial application scenarios.

Since external drivers in this single-echelon system are less heterogeneous compared to the across-echelon supply chain, the specific representation of the within-echelon supply chain coordination and optimisation problem is probably a more promising application scenario for distributed simulation technology. Prominent examples of the within-echelon supply chain problem would be the Borderless Fab of multiple container-terminal seaport operations.

The feasibility of using distributed simulation to study Borderless Fab application scenarios has already been demonstrated. Even with regard to execution time of such distributed Borderless Fab scenarios significant progress has been made through a time synchronisation mechanism that makes use of the manufacturing process flow information (Gan et al. 2007).

4 THE REALITY OF APPLYING SIMULATION AS A DECISIONS-SUPPORT TOOL

In the light of the limitations described in Section 3, and driven by the need to address industrially relevant challenges, the author has changed the focus of his attention from research work of mostly academic nature towards customer driven technology development over the past three years. However, many critical elements of the previously described technology vision are still relevant, as illustrated in the following subsections.

4.1 Simulation for Semiconductor Manufacturing

As discussed in Section 2, in an environment where the product mix changes continuously a wafer fabrication facility basically never operates in a steady-state. In such a setting, critical operational issues to be addressed on a regular basis comprise the question regarding the best configuration and set of dispatch policies, based on the *current* resource availability, factory load, machine state, product mix and demand.

To accomplish this, the underlying simulation model needs to be properly initialised and “warm-started” to the extent that even the percentage of completion for lots currently being processed must be portrayed. This can be done

in a symbiotic simulation framework, based on a simulation model that is synchronised in real-time with the operations. Every time the need for re-configuration arises, an up-to-date snapshot of the real system model will be cloned off and alternative simulation scenarios can be configured automatically and concurrently analysed on a cluster computing infrastructure. This allows to determine rapidly the best re-configuration of dispatch rules or inventory allocations and communicate them back to the Manufacturing Execution System.

4.2 Simulation for Aerospace Spare Parts Logistics

Another interesting application scenario can be found in the aviation industry where a new business paradigm for spare parts management is currently emerging: Rather than selling spare parts to airlines, OEMs (Original Equipment Manufacturers) or Maintenance, Repair and Overhaul (MRO) service providers are now supplying spare parts to airline clients with a guaranteed service level whenever needed. In this setting, new decision support tools are required that are able to portray with high fidelity the dynamic implications of advanced business practices for spare parts management and enable to address questions such as:

- How many spares should be kept where? What is the risk associated with not positioning any spares at certain locations?
- What service levels can be committed with what confidence? How can this be done at minimum cost?
- How to move inventory within the network to minimise risk?
- What is the effect of changes of critical parameters such as delivery time commitment or repair turnaround time?

The associated complex interdependencies of random effects (i.e. component failures), response mechanisms, multi-airline schedules, delivery time constraints and service level commitments to multiple airline operators can only be sufficiently addressed through simulation analysis. At the same time, because of the large number of decision variables a sophisticated optimisation procedure is required that should also be able to leverage the power of a cluster computing infrastructure to maximise the degree of concurrency in a very complex sequence of analysis tasks.

5 CONCLUSIONS: WHAT IS LEFT FROM THE GRAND VISION?

As discussed in this paper, in the light of industrial relevance the application scenarios for distributed simulation are limited because of a number of fundamental modelling issues such as demand-driven input release, human decision-making and the heterogeneity of the systems they are

supposed to represent. However, if there is no appropriate underlying model, analysis remains a purely academic exercise.

This does, however, not mean that there are not many exciting challenges to be addressed such cluster computing or warm-starting of a cloned simulation model. Even distributed simulation may have some future if targeted at industrially relevant application scenarios such as the Borderless Fab.

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