A DSS SIMULATION MODEL FOR OUTSOURCING STRATEGIES IN LARGE-SCALE MANUFACTURING

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KEYWORKDS
Supply Chain Management, DSS, production planning, outsourcing strategies, production network management.

ABSTRACT

The paper illustrates the design and use of a distributed simulation system for the assessment of competing outsourcing strategies in the context of large scale manufacturing. The work consists in the evaluation of modelling approaches for the systematic assessment of the candidate solutions in terms of their direct production costs and estimated production losses. The paper mainly focuses on the development of a simulation framework to describe a typical production system including a main contractor and several suppliers where jobs are exchanged on a daily basis. A simple application concerning a single contractor and four suppliers was built for testing purposes, the details of this implementation are presented in the paper.

INTRODUCTION

Production planning and control have become increasingly critical activities, as competition in the markets is leveraging on an increasingly large multitude of factors ranging from product quality, to delivery times, pre-sales and after-sales services. Among all of the production and planning activities, scheduling decisions represent the final decision-making phase and typically require the plant and supply chain managers' intervention to accomodate any short noticed changes to maintain satisfactory levels of performance across the entire production system.

In the context of distributed production planning and scheduling, the formulation of suitable outsourcing strategies involves difficult trade-offs between the cost of outsourcing and the reliability of the external production resources. The decision parameters typically include the number of external production resources, the sizes of their operations, and the variability of their committed production capacities. The specification of these decision parameters frequently leads to the identification of multiple competing solutions (De Toni et al., 2000), which need to be systematically assessed and compared. A simulation model capable of supporting this type of analysis should incorporate complex mathematical models representing the details of the suppliers behaviour and the interactions among the different supply chain stakeholders.

Simulation techniques are well-established means to assess and validate scheduling policies and their performance in the manufacturing context (Sargent et Al, 1999) (Chang et Al, 2001). However, nowadays simulation techniques are hardly ever used in the industry to evaluate or improve scheduling performance. In the authors' opinion, this is due manly to two reasons. First, stand alone simulation is not capable of representing large-scale manufacturing enterprises and their distributed operation environment. Second, the development of scheduling software is often commissioned to small software houses, with limited capability to robustly test and validate large scale software solutions.

Only the integration of simulation techniques and scheduling software based on advanced techniques (such as artificial neural networks or other artificial intelligence techniques), into simulation models can properly describe the distributed environments typical of the European production systems and to adequately support modelling for the evaluation of outsourcing strategies.

The development of a full simulation model capable of describing the complexity of the relationships among the main firm and the different suppliers, of reproducing the suppliers behaviour, and of analyzing their performance in terms of the choice of outsourcing strategies, is not a simple task. The key steps required to achieve this goal are illustrated in the paper.

RESEARCH CONTEXT

This research defines modelling approaches for the systematic assessment of the candidate outsourcing solutions in terms of their direct production costs and estimated production losses. The paper proposes a simulation framework for the representation of a typical

Proceedings 19th European Conference on Modelling and Simulation
Yuri Merkuryev, Richard Zobel, Eugène Kerckhoffs © ECMS, 2005
ISBN 1-84233-112-4 (Set) / ISBN 1-84233-113-2 (CD)

environment consisting of a main contractor and several suppliers with jobs being exchanged on a daily basis.

Preliminary research work has provided the statistical basis for estimating the production losses caused by the late completion of the outsourced work. Specifically, a statistical model has been devised for a sub-problem pertaining to the outsourcing of a single batch of intermediate products of a same type to a choice of n different subcontractors (Bandinelli and Orsoni, 2005). The paper illustrates how this statistical model can be integrated with a stochastic, discrete event simulation model of the main production processes to handle the systematic testing of more complex situations. Specifically the research addresses production network performance in the context of multi-product and multi-site manufacturing. The focus is on the assessment of different outsourcing strategies in terms of their direct production costs and of the expected production losses, for a large-scale manufacturer outsourcing intermediate operations to multiple neighbouring/satellite sub-contractors.

In order to evaluate the performance impact of several different strategies, a distributed simulation environment is proposed, which consists of one or more simulation models representing both the main firm's and the suppliers' behaviour to support overall cost estimating. In particular, the stochastic behaviour of the suppliers can be modelled either through the punctual values produced by an external extractor, operating on the relevant probability distributions, or through a simulation model. Either way the information required of the suppliers' models includes their available production capacity, relative to the committed production capacity, as negotiated with the main contractor, and their estimated production rates.

MODELLING FRAMEWORK

Starting from a single simulation model, where both the main contractor and the suppliers are modelled, the authors propose a distributed framework where different simulation packages can be used to model the different stakeholders of the chain. These include the option of externally representing the suppliers through an extractor operating on their statistical distributions.

The idea behind the modelling framework is that, once the information that needs to be exchanged between the main contractor and the subcontractors has been defined, these can be considered as separate shells, and modelled independently. The definition of the information that needs to be exchanged should include all the factors that the main contractor needs to account for, when deciding where to allocate or commission a particular job. It should also include all the factors that the main contractor requires in order to update the scheduling of the main production process, once the supplier has completed the outsourced job.

By isolating the different components it is possible to build a modelling infrastructure which, even though initially developed as a single model, can easily be exported into a distributed environment by means of HLA or other Inter Process Communications (IPC) standard.

Building from previous research, where the effectiveness of job allocation was evaluated based on the direct costs of outsourcing and on the corresponding production losses (Bandinelli and Orsoni, 2005), the proposed framework requires the following exchange of information between the main contractor and the designated suppliers:

- direct production cost
- agreed delivery time
- existing stock of finished product to compensate for late delivery
- current capacity utilization for the subcontractor
- forecast of future main contractors needs for a product of the same type
- a supplier-specific factor, based on historical records, indicating its reliability on the delivery times.

Part of this information, when available, represents a major advantage for the main contractor, while other parts may be an advantage for the suppliers. Information sharing will occur to a certain degree which is linked to the level of affiliation between the suppliers and the main contractor. In any case the model will have to support the exchange of the entire set of information listed above, using the XML format, whereby a standard value will be assigned to all the variables that the different stakeholders may not wish to share.

In the example application described later in the paper, the set of information feeds into a cost function which is briefly characterized in the following section. More information can be obtained in (Bandinelli et al., 2005)

ESTIMATING COSTS AND RISKS: COST FUNCTION DESCRIPTION

Referring to a production unit consisting of a specified batch of production with a specified set of operations that are intended for outsourcing, the total cost of outsourcing can be split into a direct cost, consisting of the actual cost of external processing, and an estimated production loss, associated to the cumulative probability of stock-out events due to late job completion times.

External Processing Costs

For ease of calculation the direct cost of production for the outsourced jobs can be broken down in terms of production capacity and time requirements as indicated in equation 1.

$$C_e = \sum_{ij} Uc_i \times C_i \times T_{ij} \qquad (1)$$

where:

Uc_i is the cost of the job per unit capacity and per unit time for the i-th sub-contractor.

C_i is the capacity committed by the i-th sub-contractor.

Tc_{ij} is the time required for the i-th sub-contractor to complete the j-th operation (it is a stochastic variable).

The unit cost, Uc_i needs to be estimated for each case based on the type of operations required, on the number of sub-contractors involved, and on the capacity of the sub-contractor. A correlation among these variables is currently being established, as part of parallel research, using Artificial Intelligence (AI) techniques based on Neural Networks (ANNs).

Production Losses

The estimation of the production losses caused by the late completion of the outsourced work and possible stock-out events can be addressed building from the probability distributions associated to the production and consumption rates of each subcontractor and of the main contractor, respectively. These can typically be built from historical data for each plant.

A brief description of the equations required to estimate the expected production losses for the general case of a main contractor allocating a batch of a single product type to n subcontractors is provided in the remainder of this section. Further details on the statistical model may be found in some of the referenced work (Bandinelli and Orsoni, 2005).

The total number of units to be externally processed is O_{tot}, of which the i-th subcontractor is allocated a specified quantity O_i . The delivery time associated to each subcontractor is a cumulative function of the production rate and available production capacity over the required processing time. These values may be averaged if the processing time is sufficiently short compared to the time-scale of the other simulated processes.

The expected time of delivery for the entire outsourced quantity, from the perspective of the main contractor, can be estimated as a weighed average of the delivery times calculated for the different subcontractors, where the weights are the sizes of the jobs allocated to the different subcontractors (i.e. the different O_is). It is the particular combination of delivery time and consumption rate at the main contractor's (i.e. the rate at which the intermediate products are used and therefore need to be fed into the main production process) that determines whether a stock-out event may occur and how long it is likely to last. Building from the probability distributions associated to the processing times of the different contractors, including the main contractor, it is possible to determine which combinations of parameters lead to stock-out events and estimate their probability of occurrence. In particular, for each level of consumption rate Cx it is possible to identify the earliest delivery time that will cause a stock-out event, and that is given by equation 2:

$$t(x) = \frac{L - L_{\min}}{C_x} \qquad (2)$$

where:

L is the stock level at main contractor's at the beginning of the time period.

L_{min} is the minimum stock level at the main contractor's

C_x is the consumption rate considered.

By discretizing the probability distributions associated to the consumption rate and to the delivery time for the outsourced production, it is possible to estimate the production losses associated to Cx for each interval of delivery times that may cause a stock-out event, given the unit loss for missed production time (PL_U). The estimated total loss (PL_{TOT}) can be expressed according to equation 3:

$$PL_{TOT} = \sum_x \sum_y PL_U \cdot [t_y - t(x)] \cdot p_y \cdot p_x \qquad (3)$$

where p_y and p_x are the probabilities associated to the y-th arrival time interval (in the vicinity of t_y) and to the x-th consumption rate interval (in the vicinity of C_x), respectively. The sizes of such intervals depend on the criteria used for the discretization of the corresponding probability distributions, which typically are case-specific.

It should be observed that the summation (equation 3) should only be extended to the delivery times (t_y) exceeding t(x) as those are the ones that determine a stock-out event. The difference [t_y – t(x)] represents the duration of the stock-out event.

Given the complexity of the calculations involved in the estimation of the production losses, even for very simple application cases, it is important to automate their computation procedure for its use in the systematic assessment of alternative outsourcing strategies. The modelling framework presented in the next sections of the paper incorporates the cost functions within the core of the simulation model where they can be systematically evaluated at each scheduled parameter update.

MODEL DESCRIPTION

In order to test the modelling framework, a simple model was developed in the Arena® package, distributed by Rockwell. This model represents the behaviour of a main contractor with three different suppliers.

The production process of a single product type is considered, which consists of five phases. The first and the last phase are completed directly at the main contractor's, while the other phases are outsourced to local subcontractors. A flow diagram of the production processes is represented in figure 1. A daily exchange of intermediate parts occurs at fixed times during the day, as long as a threshold batch size requirement is met. If the daily number of parts to be processed is less than the required minimum, the intermediate parts are held in stock until the next day.

In order to choose the most effective combination of scheduling policies and outsourcing strategies, a cost function was introduced as discussed in the previous section. The application of such a function allows to simultaneously assess both the effectiveness of the cost function itself and the performance of the model.

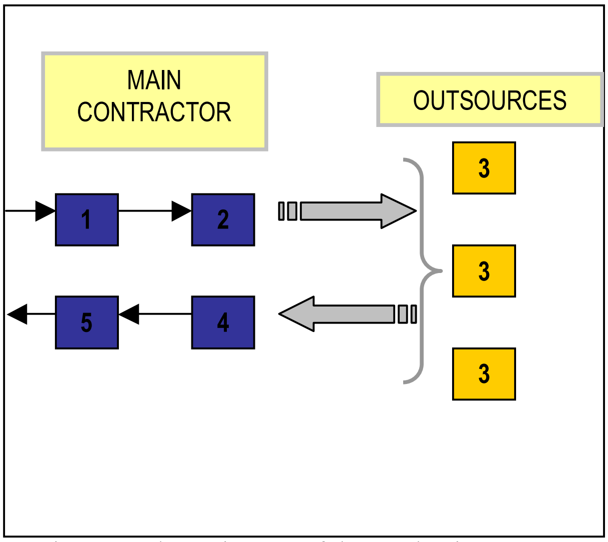

Figure 1: Flow Diagram of the Production Process

The information exchange between the main contractor and the suppliers was represented by means of an Arena® built-in VBA block. By these means the logics for the main contractor and for the different supplier models can be separated, even though they all run within the same software application. In particular the VBA allowed to reproduce the cost function, as described in earlier sections, without characterizing the models specifically for that function.

Information Management

The model, as it stands, is locally run, however the infrastructure for the exchange of information has been designed to be portable for direct use in a distributed environment. Specifically, each shell, whether intended to model the main contractor's or one of the subcontractor's behaviour, includes a "buffer" for intermediate products. While such a zone physically represents a storage facility for in-coming or out-going jobs, waiting to be transferred, it is also used to retain/store the information pertaining to the different stakeholders: it is based on such information that job allocations decisions are made. Specifically, a number of variables have been defined in Arena® for each of the stakeholders: these are the variable that should be re-evaluated and updated whenever a job needs to be allocated for outsourcing.

Because the transfer of intermediate products occurs in a discrete fashion and is performed on a daily basis, subject to meeting a minimum batch size, the relevant information is averaged with respect to the number of jobs of a same type to be externally processed. Once the minimum batch size required for outsourcing has built up in the buffer, the current values of the relevant variables are transferred to the core of the model, where the statistical cost function is implemented and used to evaluate the most effective outsourcing strategy.

The core of the model is also responsible for retrieving the information from the suppliers' side, which is necessary to make actual job allocation decisions (i.e. current stock level, production costs, etc.). Once the information has been retrieved, the core of the model uses it to evaluate the cost function and allocates the job to one of the suppliers. The decision is then communicated both to the main contractor and to the supplier.

The transfer of information is currently handled within the simulation model itself, however the model can be generalized for use in a distributed architecture, where an interaction system is applicable. An example of it, for instance, is HLA. The information discpatched to the two actors involved (i.e. the main contractor and the subcontractor) triggers a status update for all other actors, as well as the allocation of the job for delivery to the designated supplier.

The other information transfers pertaining to the completion of the outsourced jobs are handled exactly in the same way. These events cause the delivery of the processed batches from the supplier to the main contractor, and the update of the corresponding stock levels.

The current version of the model handles the delivery of externally processed jobs from the supplier to the main contractor instantaneously, regardless of the actual batch size. While this way of handling the return of processed jobs to the main contractor may not be generally applicable to different industrial cases and contexts, it is not believed to constitute a limiting assumption for the purposes of testing the effectiveness of the proposed model.

Time management

Time management and event synchronization among the different actors, just as the management of information transfers, have been designed for operability in a distributed environment.

The exchange of batches of intermediate products has been devised to occur on a daily basis and this is just one of the possible assumptions, which does not limit the model functionality in any way.

According to the framework design, the flow of jobs within each shell is independent of external events: it does not depend on external events and does not constrain their occurrence in any way.

Whenever the production cycle for a particular job requires external processing, the job is put on hold until it has been allocated to a particular supplier, and, more generally, until it is ready for the next processing phase.

Considering a model consisting of n independent simulators, time advancement can be based on a time-stepped logic, because the exchange of information between the main contractor and the subcontractors occurs on a daily basis and at fixed times, for instance every morning and every afternoon.

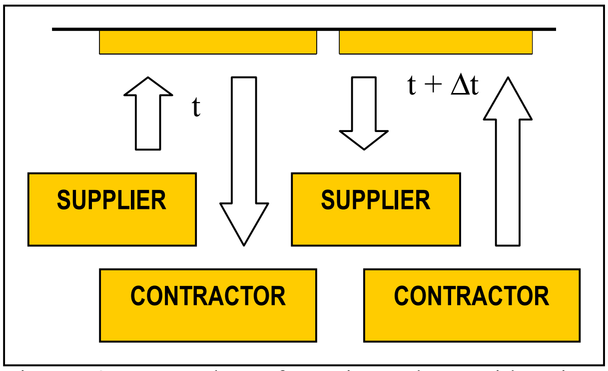

Figure 2: Example Information Flow with Time-Stepped Approach

Figure 2 shows a possible pattern of information flow between the suppliers and the main contractor. At time t (i.e. in the morning of a given day), the supplier updates the main contractor with its available production capacity and stock level. This information is received by the main contractor and used to formulate the outsourcing strategy for the next time step (i.e., the evening of the same day). At time $t+\Delta t$, the information flow is reversed, and the main contractor communicates the new job allocations to the suppliers. However, at time $t+\Delta t$ a status update will still be sent from the subcontractor to the main contractor, as described above, for the allocation of the next jobs.

The definition of the information to be exchanged among the different actors at each stop of the simulation clock depends on the designated IPC standard. When HLA is used, for instance, the reciprocal use of the information exchanged at a particular point in time is not possible, therefore a time-stepped approach is adopted whereby jobs are allocated for outsourcing to the different subcontractors based on their availability evaluated at the previous time step. Another option is to tailor the process of event generation to enable a two-way information exchange prior to the allocation of a job for outsourcing. More details on the use of the Next-Event approach for the generation of dummy events can be found in the referenced literature (Bandinelli et al., 2003).

When using other IPC infrastructures, such as the RMI or the CORBA standard, it is necessary to establish time-advancement logics which are standard-specific. The exchange of information among the different actors in the proposed framework will be the object of further research by the authors.

CONCLUSION & FUTURE WORK

A modelling framework integrating a model based on the process statistics of the main contractor's and of the subcontractors' behaviour has been developed to support the effective choice of outsourcing strategies in large-scale manufacturing. A prototype model representing the suppliers' behaviour and availability, together with the main contractor's model, has been built and tested for performance on a single processor. This way, the main contractor can simulate the process of production scheduling and analyze the effects of competing outsourcing strategies, based on their overall costs. These costs account for process inefficiencies due to stock-out events and late deliveries.

The model was developed in Arena® maintaining the representation of the different supply chain actors independent of one-another. For this purpose a VBA block has been devised to separate the information to be exchanged between the main contractor and the different suppliers. The architecture to support the exchange of such information and their synchronization has also been presented. The model has been locally tested, with the implementation of simple dispatching and allocation rules for job outsourcing purposes. Finally, the cost function based on actual process statistics relevant to the different supply chain stakeholders, has been implemented in the model to support systematic cost estimating for different outsourcing strategies.

This work represent a further step towards the development of a multi-level shell capable of representing different levels of affiliation between the subcontractors and the main contractor, while keeping the same information exchange format and infrastructure. Concurrent research by the authors is looking at Artificial Intelligence (AI) techniques based on Neural Networks (ANNs) for estimating the direct costs of the outsourced jobs. In particular correlations are sought between the unit cost of the outsourced work, the number of sub-contractors potentially available for the job, and the sizes of their production capacities. This will provide a complete DSS aimed at cutting the costs associated to late deliveries and stock-out events, and will effectively support strategic decision making for outsourcing.

DEBITS

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