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Multilayer perceptron for simulation models reduction: Application to a sawmill workshop

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ABSTRACT

Simulation is often used to evaluate supply chain or workshop management. This simulation task needs models, which are difficult to construct. The aim of this work is to reduce the complexity of a simulation model design. The proposed approach combines discrete and continuous approaches in order to construct speeder and simpler reduced model. The simulation model focuses on bottlenecks with a discrete approach according to the theory of constraints. The remaining of the workshop must be taken into account in order to describe how the bottlenecks are fed. It is modeled through a continuous approach thanks to a neural network. In particular, we use a multilayer perceptron. The structure of the network is determined by using a pruning procedure. For validation, this approach is applied to the modelisation of a sawmill workshop.

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1. Introduction

Simulation is used in many goals. One of them is to evaluate supply chain or workshop performance. There are three different ways of measuring this performance: analytical models (queuing theory, etc.), physical experimentation (lab platforms, industrial pilot implementation, etc.), and Monte Carlo methods (simulation or emulation) (Thierry et al., 2008). Analytical methods are generally impracticable because the mathematical model corresponding to a realistic case is often too complex to be solved, and physical experiments suffer from technical and cost-related limitations. Simulation is the better approach to model and analyze performance for large-scale cases. In the simulation model, the number of 'objects' of the model and the number of events can be very large. Consequently, the first problem could be the time needed to build the model and the simulation duration on a computer can be unacceptable for operational use. Thus, it is necessary to reduce the model size (Thierry et al., 2008).

On the one hand, constructing a simulation model is a complex task that can take modelers a lot of time. Effectively, simulation models of actual industrial cases are often very complex and the modelers encounter problems of scale (Page et al., 1999). Thus, numerous authors have expressed interest in using simplest (reduced/aggregated) models of simulation (Ward, 1989; Musselman, 1993; Pidd, 1996; Brooks and Tobias, 2000; Chwif et al., 2006).

On the other hand, to establish and to initialize 'predictive schedule' or 'reactive schedule', the knowledge of the evolution of resources states (WIP (work in process) and queues) are needed. This knowledge can be obtained by using a simulation model. Reduced models can be very useful, because they are quickly parameterized and simulated.

Furthermore, at this level of planning (master production schedule), load/capacity balancing is obtained via the 'management of critical resource capacity' function or 'rough-cut capacity planning' (RCCP), which essentially deals with bottlenecks (Vollmann et al., 1992). Goldratt and Cox (1992) in 'The Goal' put forward the 'theory of constraints' (TOC), which proposes to manage all the workshops by bottlenecks control. Thomas and Charpentier (2005) have shown that a good method to build a simulation model would be to reduce the model according to the TOC.

Moreover, neural networks have been used in all application areas of the manufacturing: scheduling (Akyol and Bayhan, 2007), design of manufacturing process (Cakar and Cil, 2004), etc.

Therefore, the main goal of this work is to propose a design approach for simulation models, which would be less time consuming and simpler for the modelers, and which could be partially automated. This approach is based on the learning capabilities of neural networks and on the TOC.

The rest of the paper is structured as follows. Section 2 contains a brief bibliography overview and Section 3 presents

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the proposed approach of the reduction model and multilayer perceptron. Section 4 is devoted to the validation of the proposed approach in an industrial application, which is a sawmill flow shop case.

2. A bibliography overview

2.1. On supply chain simulations

One main goal of the supply chain simulation is to evaluate the performance of supply chain management in order to support decision-making at three levels:

– strategic level (designing or redesigning a supply chain, localization of factories and warehouses, partners selection, etc.),
– tactical level (validation of the global forecasted production capacities according to forecasted demand), and
– operational level (control policies, scheduling, cooperation policies on the shop floor, etc.).

The simulation model must be constructed according to its use and the supply chain to be modeled.

Kleijnen and Smits (2003) distinguish four simulation types for supply chain management:

– spreadsheet simulation (may be part of production control software),
– system dynamic (may explain the bullwhip effect),
– discrete-event dynamic systems (DEDS) simulation (may predict fill rate values), and
– business game (may educate and train users).

Spreadsheets have been used to implement manufacturing resource planning (MRP), but this type of simulation is often too simple and unrealistic (Kleijnen, 2005).

System dynamic is based on the work of Forrester (1961). In this approach, companies are seen as systems with six types of flows (materials, goods, personnel, money, orders, and information) and different stocks. Managerial control is realized through the changing of rate variables. The feedback principle plays a crucial role in this approach (Kleijnen, 2005).

A DEDS simulation is more detailed than the preceding ones. DEDS concerns the modeling of a system by a representation in which the state variables change instantaneously according to event occurring. Moreover, it takes into account uncertainties (Law and Kelton, 2000).

A business game is a simulated world that may represent a supply chain and its environment. It is used for educational and research goals (Kleijnen, 2005).

The two main difficulties encountered during the design step of a supply chain simulation model are related to the size of the system and the complexity of the control system. A supply chain is composed of a group of enterprises, composed in turn of a group of factories, composed of a group of workshops, etc. Moreover, modeling the behavior of the leading policies of each enterprise and the relationships between them is needed (Thierry et al., 2008). This fact implies that the duration of one simulation may become unacceptably long to be usable. The same difficulty has been highlighted by Thomas and Charpentier (2005) concerning workshop. Therefore, it may be useful to reduce the size of the model. Different ways can be used to perform the model reduction:

– abstraction, which allows the complexity of the model to be reduced and preserves the validity of the results (Frantz, 1995),
– aggregation, which is a form of abstraction where a group of data or variables with common characteristics can be replaced by aggregated data or variables (Aldanondo and Mercé, 1991), and
– reduction of the number of events, where a part of DEDS is replaced by a variable or a formula (Zeigler, 1976).

2.2. On model reduction

Innis and Rexstad (1983) have listed 15 simplification techniques for general modeling. Their approach is composed of four steps: hypotheses (identify the important parts of the system), formulation (specify the model), coding (build the model), and experiments. Based on these works, different approaches have been proposed.

Brooks and Tobias (2000) suggest a 'simplification of models' approach for cases where the indicators to be followed are the average throughput rates. They suggest an eight-stage procedure. The reduced model can be very simple and then an analytical solution becomes feasible and the dynamic simulation redundant. Their work is interesting, but is valid in cases where the required results are averaged and where the aim is to measure throughput. It is not interesting to follow the various events taking place in the work center (WC).

Leachman (1986) has proposed a model for use in the semiconductor industry, which uses cycle time as an indicator. This model has been improved by Hung and Leachman (1999). They propose a technique for model reduction to be applied in large wafer fabrication facilities. They use 'total cycle time' and 'equipment utilization' as decision-making indicators to do away with the WC. In their case, these WCs have a low utilization rate and a fixed service level (they use the standard deviation of batch waiting time as a decision-making criterion).

Tseng et al. (1999) compare the regression techniques applied to an 'aggregate model' (macro) by using the 'flow time' indicator. They suggest reducing the model by mixing the 'macro' and 'micro' approaches, so as to minimize errors in complex models. Here again, for the 'macro' view, they deal only with the estimation of flow time as a whole. For the 'micro' approach, they construct an individual regression model for each stage of the operation to estimate its individual flow time. The cumulative order of flow time estimates is then the sum of the individual flow times. They, then, try to mix the macro and micro approaches. These different approaches simplify the model by using a macroscopic view of the system and by optimizing a macroscopic indicator (total cycle time, flow time, etc.)

Li et al. (2009) propose a reduction model approach based on the aggregation of machines on the production line. They build a complete model of the production line and, if the last two machines correspond to a serial line, they aggregate them. The same is performed with the first two machines if they correspond to a serial line. These aggregation steps may be performed recursively and they denote backward and forward aggregation. If the two machines to be aggregated follow a Bernoulli model or an exponential model, an analytical investigation allows the production rate of the new aggregated machine to be determined. If not, a simulation phase must be performed to determine an empirical formula for the production rate.

Some works (Doumeingts et al., 1987; Hwang et al., 1999) use Petri nets as tool in order to simplify network structures by using macro-places, which represent complex activities associated with function groups.

To simplify models, some works have studied the use of a continuous flow model based on gradient estimation for stochastic

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