Assessing the performances of a market-like model through an experimental comparison with dispatching rules

S. Cavalieri, M. Garetti, M. Macchi, M. Taisch
Dipartimento di Economia e Produzione, Politecnico di Milano
Piazza Leonardo da Vinci, 32 - I-20133 Milano
Tel: ++39-02-2399.2729
Fax: ++39-02-2399.2700
e-mail: sergio.cavalieri@polimi.it

Abstract

In the last few years, changes in the manufacturing environment have increasingly driven enterprises towards the research of new ways to manage and reorganise their production systems. In particular, as regards operations management and control, research is progressively shifting from hierarchical to heterarchical architectures which are founded on distributed decision-making entities interacting through particular cooperative mechanisms.

These architectures should be more deeply investigated to gather more information on the real behaviour of the mechanism of the algorithms. The result of this study will be important to correctly address in the future the right design issues of new and more sophisticated systems.

Moreover, the performances of this kind of architectures have not yet been deeply investigated by researchers and, therefore, there is no evidence of the real benefits coming from their industrial implementation.

In order to give a contribution in this direction, in this paper one of the most well-known heterarchical architectures, the market-like model, is first compared in its manufacturing performances with dispatching rules within a job-shop environment. Then, an analysis of some of the tuning parameters of the architecture is carried out.

Keywords

Scheduling and Control, Multi-agent architectures, Contract-Net, Dispatching rules.

1 INTRODUCTION

Refusing the traditional idea of a central planning and scheduling system which establishes a manufacturing plan for all the machines and work orders, the multi-agent control architectures assume the presence of several decision-making entities which interact and cooperate with each other in order to achieve optimal global performances. The hypothesis at the basis of these models is that from the local, autonomous and often conflicting behaviours of the single decision-making units, a global behaviour of the manufacturing system emerges, coherently with the requested characteristics of reactivity and flexibility that centralised production control systems normally lack (Cavalieri *et al.*, 1998).

A second alternative approach to centralised production control systems is represented by dispatching rules that have been extensively investigated by researchers and are widely applied in industry, having demonstrated their real applicability and efficiency especially in complex production systems (Blazewicz *et al.*, 1996).

In this paper, results of an experimental comparison carried out between a heterarchical multi-agent architecture and two different dispatching rules are reported. After a short description of the market-like model and of its algorithms (par. 2), the test-bed and the experimental campaign will be described (par. 3). Results are then compared and analysed (par. 4) and conclusions are finally drawn (par. 5).

2 DESCRIPTION OF THE MARKET-LIKE MODEL

The model, referring to the architecture proposed by Solberg and Lin (1992), is one of the most complete and detailed examples of an architecture based upon information treatments and decision-making processes distributed in a heterarchical system. This production control system takes its inspiration from the negotiations carried out in a marketplace where sellers aim to sell their goods at the highest price, while buyers try to buy goods of the desired types and of the required quality at the lowest prices.

In this market-like model, each manufacturing entity is represented by an agent with a high decision-making autonomy: two main typologies of agents, the *part agent* and the *resource agent*, are available.

The *part agent* is the informative model of a production lot or a single manufacturing part. It contains all manufacturing information (part code, process plan, etc.), managerial information (goals, objective function, etc.) as well as the state (bid, currency, etc.) and the algorithms for the negotiation.

On the other hand, a *resource agent* is the logical representation of any of the production resources of the shop-floor system. As in the part agent, the resource agent collects all the manufacturing and managerial information related to the negotiation tasks of the resource itself.

The resource agent sells a service at a fixed price P_i , which is a weighted mean value of the prices of the already committed – but not yet processed - tasks and of all the announced tasks so far broadcast. This price charging mechanism - that increases price when a resource is highly demanded and, conversely, decreases price when its service demand is lowering - can guarantee a right balance between resource utilisation and resource reactivity.

Each part agent tries to fulfil the processing requirements to achieve its own set of objectives (due-date, quality, costs, etc.). For this purpose, it is endowed with a budget per operation to negotiate a resource. The budget is assigned proportionally to a coefficient of priority of the production lot and to the expected prices charged by each type of machine:

$$\text{Budget}_{ij} = C_{\text{prior}} * \frac{\bar{P}_i}{a_i} \quad (1)$$

where:

- C_{prior} is the coefficient of priority of the j -th production lot, which is assigned according to the degree of urgency of production lots according to their expected due date;
- $\bar{P}_i$ is the mean price charged by the type of machines required by the i -th operation when the production lot is loaded;
- a_i is a coefficient which considers how the current utilisation rate of the resources diverges from the expected mean profile of their workloads (over a larger time window).

The allocation of resources to the production lot (i.e. negotiation between part and resource agents) is based on the contract-net protocol with a combination of price and objective mechanism. The protocol works as follows: after the beginning of the current operation, the part agent evaluates, according to its process plan, which production resources have the necessary technological capability to carry out the next operation. Then it broadcasts a task announcement, indicating the type of operation to be assigned and providing other information, both technical (e.g. tolerance, kind of tool) and managerial (e.g. expected due-date of the operation) as well as a proposal regarding the purchase price of the requested service.

Figure 1 shows how the negotiation process between part and resource agents is accomplished. A resource agent evaluates task demands periodically at every monitoring time interval (Δ_{tMON}) and selects those task requests whose purchase prices are above its current price threshold P_i . On the other hand, at every fixed time interval (Δ_{tBE}), the part agent evaluates bids eventually awarded by resource agents. This way, considering processing time (Δ_{tPT}) of the current operation; the negotiation process can be iterated at best $\Delta_{\text{tPT}}/\Delta_{\text{tBE}}$ times in shadow time; for this reason, given a fixed value of the parameter Δ_{tBE} , with short-lasting operations lower chances to negotiate in shadow time are assigned.

Figure 1 The negotiation process.

The negotiation process concludes with the selection of the task offer considered by the part agent the most coherent with its own objectives, and with the task commitment between the contracting parts, consisting in the forwarding of a final bid award by the part agent and in the transmission to the selected resource agent of all the technical information and data related to the assigned operation.

3 DESCRIPTION OF THE TEST BED AND THE EXPERIMENTAL DATA SET

The test bed adopted for the experimental evaluation of the multi-agent model is a job-shop plant with a single bottleneck resource. The plant is made up of four types of machines, a transport system and a system buffer (see Figure 2). Each type of machine provides a different technological capability, since it can execute a single type of operation (i.e., op1, op2, op3, op4). At least two machines per type are present, thus enabling routing flexibility for the scheduling of each single operation. The transport times are set to zero.

Figure 2 Layout of the machining system used as test-bed.

The plant also contains other kinds of auxiliary resources. Each machine has its own input and output buffers which act as de-coupling points between machine processing and transport system service. The system buffer performs the same functionality with respect to the outer environment. Loading and unloading stations

are only modelled respectively as points where production orders are created and disposed.

The job-shop problem proposed is characterised by:

- products with a fixed process plan constituted by four non-preemptable and non-overlapping operations (one for each type of machine);
- each operation with deterministic and constant processing times (not dependent on the job being processed);
- a static bottleneck resource with a 90% mean saturation rate;
- size of production orders uniformly distributed;
- due dates assigned randomly over a full range of flow allowances, thus identifying jobs with a tight due date as well as jobs with a loose due date.

Performance measures have been purposely chosen in order to enhance the different behaviour of the multi-agent controlled system with the outcomes of two alternative types of dispatching rules. In particular, the following indicators have been recorded:

- *mean flow time* - thus allowing a direct comparison with the Shortest Processing Time (SPT) dispatching rule which is more oriented to the optimisation of this variable;
- *mean lateness, mean tardiness, number of jobs on delay* - in this case using the Earliest Due Date (EDD) dispatching rule as a good benchmark of the multi-agent system.

4 THE EXPERIMENTAL RESULTS

Table 1 reports the main results in terms of mean value and standard deviation of the flow times of the multi-agent model and the SPT rule.

Table 1 Experimental comparison between market-like model and SPT rule: minimisation of flow time.

	<i>Mean flow times</i>	<i>Std. dev. of flow times</i>
Market-like model	39.84	19.26
SPT dispatching rule	38.52	29.37

As it is evident, given the high dispersion of the data, it is not possible to draw final conclusions regarding the comparative behaviours of the market-like model and the SPT dispatching rule. On one hand, as it is expected from literature (Baker, 1974), the SPT rule, which sequences jobs according to their processing times, performs relatively better in terms of mean flow time, but it is affected by a high

value of standard deviation. Conversely, since price-based negotiation encompasses heterogeneous information related to the utilisation rate of the production resources (through their charging price) and to lot priorities (with the budget allocation mechanism), the market-like model can guarantee a more consistent and less divergent behaviour from the system's point of view. This feature is quite important, since in many production contexts the main criticality is given by the need to smooth the effects of uncertainties and high variability on the performance variables of the system.

Table 2 outlines the main outcome of the multi-agent model and the EDD rule assumed as benchmark for evaluating its efficiency in terms of respect of job due-dates.

Table 2 Experimental comparison between market-like model and EDD: respect of expected job due dates

	<i>Mean Lateness</i>	<i>Std. dev. Lateness</i>	<i>Mean Tardiness</i>	<i>Std. dev Tardiness</i>	<i>% of lots on delay</i>
Market-like model	-12.40	25.86	5.13	10.89	30.79
EDD dispatching rule	-12.69	21.52	2.95	6.59	28.74

The EDD dispatching rule performs distinctively better in terms of entity of delays. In fact, jobs are finished generally earlier than due date (mean lateness), thus minimising mean and standard deviation of tardiness. Conversely, the market-like model clearly achieves a higher percentage of lots on delay. In this case, delayed lots are the ones whose representative agents have been overtaken in the market competition by economically stronger agent parts.

As regards the latter result, it is worthy to point out the way the market-like system can distinguish and give different importance to the single jobs according to their relative priorities (given for example by their tardiness or inventory costs). These priorities are counted within the coefficient of priority C_{prioj} (eq. (1)) multiplying the budget initially released to the job. The higher the value of C_{prioj} , the better the chance to get service from production resources. From the analysis of figure 3, it is evident how, unlike the indiscriminating behaviour of the SPT rule, the market-like model can guarantee system performances more consistent with the real priorities of the production lots. Figure 3 shows also the high sensitivity of the model upon the different values assigned to this design parameters. By changing the order of magnitude of the relative priorities of the jobs, the performance of the production system can be highly variable (MM-NP vs. MM-PP). This feature can obviously be a point of strength, since it guarantees high flexibility and reconfigurability of the model according to the required performance. On the other hand, it implies a very tough and long-lasting preliminary tuning activity of all the parameters included within the model.

Figure 3 Mean flow time (time units) registered with market-like model and no relevant job priorities (MM-NP), with market-like model and relevant job priorities (MM-PP) and with SPT rule (SPT).

A second design issue which has been investigated is the ratio $\Delta_{t_{PT}}/\Delta_{t_{BE}}$. As already claimed in paragraph 2, it represents the number of possible renegotiations a part agent can carry out without affecting its own flow time. The results of the simulation runs have shown a high correlation of the system performance to this ratio for values from 1 to 5, whilst no significant improvement in the system performances has been recorded for values higher than 5.

5 CONCLUSIONS AND FURTHER RESEARCH

In this paper an experimental benchmarking between a multi-agent architecture and two different typologies of dispatching rules is reported and analysed. This comparison has been conducted under steady conditions of the production system. The results demonstrate how the multi-agent architecture does not perform better than dispatching rules, but they indeed show a similar behaviour.

These results should be considered promising. In fact, while no improvements can be done on dispatching rules, a lot of work should be still carried out on the design and implementation of more efficient and better performing multi-agent algorithms. Hence, future research will aim at studying more thoroughly the distributed decision-making mechanisms of the adopted multi-agent system by enriching also experimental conditions with more disruptive situations (considering events as machine breakdowns or rush orders) and in presence of more complex production systems.

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7 BIOGRAPHY

Sergio Cavalieri is Ph.D. in Management and Production Engineering at Politecnico di Milano, where he now works as researcher. His main research interests have been mainly focused on the design and development of advanced techniques (GA, ES, ANN) in manufacturing and process fields. He is currently working on the design and implementation of distributed production systems.

Marco Garetti is professor of industrial technology at the Politecnico di Milano. His actual fields of interests are design of production systems, production management, simulation and computer integrated manufacturing. He is a senior member of CASA/SME, a member of IFIP W.G. 5.7 and Book Reviews Editor of *Production Planning and Control*.

Marco Macchi, M.Sc., is a researcher at Politecnico di Milano, where he now works in the area of the design and implementation of agent-based system to shop floor control and simulation as a design technique for manufacturing systems.

Marco Taisch is senior researcher at Politecnico di Milano, where he works in the area of design and management of production systems. His research interests are intelligent manufacturing systems, soft computing techniques for production planning and control and reactive scheduling. He is co-ordinator of the IFIP WG 5.7 Special Interest Group on Advanced Techniques in Production Planning & Control.

The article is the result of the joint work of the authors. In particular, Sergio Cavalieri wrote paragraph 4, Marco Garetti wrote paragraph 1, Marco Macchi wrote paragraph 2 and Marco Taisch wrote paragraphs 3 and 5.