BENCHMARKING ISSUES FOR PRODUCT-DRIVEN DECISION-MAKING

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Abstract:

With the increasing pressure on manufacturing companies to meet business to manufacturing agility, infotronics technologies combined with agent technologies are becoming basic drivers for new decision-making organisational issues in a more heterarchical way. One key point to make these technologies fully adopted by industry is to provide benchmarking environments in order to compare and analyse their efficiency on emulated large-scale industry-led case-studies with regard to current technologies and approaches. This paper propose a generic benchmarking protocol based on LT, OEE and WIP performance indicators in order to evaluate the efficiency of product-driven decision-making. This benchmarking protocol is then applied to an automotive-industry case-study in order to evaluate the impact of making interact the products with the local decision centers.

Keywords:

Intelligent Manufacturing Systems, product-driven control, benchmarking, simulation, HMS, MAS

1. INTRODUCTION

There is a large consensus in the IMS community between holonic control, production management and virtual enterprises [1] that the combination of both agent and infotronics technologies may enable to meet flexibility and adaptability issues as required by the increasing customization of goods and services.

As addressed by Marik [5], there is still a long way to make these heterarchical architectures efficient in real industrial environment. Among many issues to be solved, embedded devices as well as agent technologies are not yet sufficiently reliable and powerful to handle the scalability problems for fully distributing decision-making.

Another issue is then to demonstrate the correct balance between centralized and distributed control capabilities of decision-making agents able to digitally interact ones with the others from the operators throughout the processes down to the products and vice-versa. Simulation seems the only recourse to analyze and compare alternative decision-making scenarios with regards to traditional ones.

After stating in general this decision-making distribution problem in section 2, this paper propose in section 3 a generic benchmarking environment for product-driven decision-making. The related performance evaluation protocol is then applied in section 4 to an automotive-industry case-study. Section 5 address the interpretation of the experimental results and conclusion deals with the perspectives of these on-going works at CRAN for industrial transfer in the area of product-driven logistics for natural-fiber industry.

2. PROBLEM STATEMENT

Comparison between antagonistic control modes, such as market-based and hierarchical control [3], or planning-based and reactive control [2] have been carried out using specifically developed test-beds.

But more generic evaluation tools are needed, enabling to store, share and compare test-cases. Development and definition of such generic evaluation tools has drawn a great deal of interest. An online benchmarking utility has been defined by IMS-NoE special interest group 4 [4] [11] enabling collection and sharing of a wide range of industrial test-cases. On standby of the availability of such a generic service under development at KU Leuven, simulation-based benchmarking of complex manufacturing systems remain the mean to make the proof of the efficiency of plant wide-control organisational issues before their deployment for practical purposes [7].

In fact there is a consensus on the architecture of benchmarking environments putting the emphasis on modularity between the control system (*C*) and an emulated manufacturing process (*P*) in order to provide practitioners with ability to share and compare test cases. Conversely, there is no consensus on emulation modeling issues so that integration between control and emulation model may vary.

Our work is aiming on the one hand at designing a tool fitted to product-driven control by applying a product-driven emulation-based architecture and on the other hand at defining a methodology for emulation models building.

Product-driven control is a way to change the hierarchical integrated vision of plant-wide control for a more interoperable/intelligent one [8], by dealing with products whose information content is permanently bound to their material content and which are able to influence decisions made about them [6].

Therefore product-driven control has an impact on decision-making procedures as well as on information exchange and storage. Among the four possible combinations between modeled or real control and process subsystems [10], two are particularly interesting to study these two impacts of product-driven control :

- the first one use a model (C_m) of the control system that interacts with the emulated industrial process (P_m). Under the hypothesis that product-embedded data are available to decision centers, this approach can be used in order to define what kind of data should be embedded into products and how decision algorithms should use them.
- the second one use the real distributed control system *C* (e.g. a multi-agent system) that controls the emulated process P_m. This testing approach enable to consider more finely distribution issues, such as how products and decision centers should interact to exchange data.

This paper focus on the first experimental step. An industrial case-study dealing with a product-based decision scheme is presented. Previous works on this case have discussed the respective performances of centralized and distributed control [9]. Both decision modes are combined using products: the centralized-made predictive schedule is used to initialize products data whereas distributed decision are based on both product data and local events.

The evaluation environment supports measurement of operational performances of this decision architecture with regard to business and process disturbances and to a classical centralized approach.

3. GENERIC BENCHMARKING ENVIRONMENT

The proposed evaluation environment consists of an emulation modeling framework, a prototype implementing this framework and an experimental protocol.

3.1. Methodology for building emulation models

Our methodology for building an emulation model is based on a systemic vision of the shop-floor system. As we focus on products, we aim at representing their physical evolution. Ac-

cording to systemics, these evolutions can be modeled as shape, space and time transformations.

So the first step of the modeling methodology is a shop floor analysis, in order to determine every physically possible product life-cycle. A state-transition approach is used: states correspond to stables product position and shape while transitions model physically possible spacial and morphological transformations.

In the second step, we aim at modeling actuation on products. Transitions between products states is implemented by shop floor equipments. Therefore we introduce two modeling constructs, *shape* and *space transformations*. These constructs must take into account physical constraints like cycle and setup time, capacity, etc... Moreover a third construct is defined, *time transformation*, dedicated to model products waiting between transformations.

Each shape and space transformation bloc offer an interface, which enable an external system to interactively control it. Control messages enable to request the transformation to setup, or to begin operating. Conversely, reports messages enable to know the transformation current state.

Using these tree kind of modeling constructs, we are able to describe the shop floor structure in a generic way.

Finally, the emulation model would not be complete without a way to observe products. So the third step of the methodology is concerned with product sensing. These modeling constructs includes physical laws like limited scope and sensing accuracy. A RFID transponder is a concrete example of a shop floor equipment modeled as a product sensor.

In conclusion, these modeling constructs enable to build an emulation model from the point of view of logistics. They aim at modeling the physical laws constraining products actuation, transformations and sensing, while offering interfaces to actuators and sensors.

3.2. Implementation of a prototype

A prototype supporting the emulation methodology has been developed using Arena Professional. Each modeling construct is implemented as a template simulation module. Moreover, interaction capabilities were developed into an external library (DLL).

Interaction with emulation modules can be done either from a visual basic program embedded in an Arena model, using direct API calls, or form an external system, sending XML-encoded messages across a TCP socket.

In the first interaction mode, time advances in discrete events mode as the control system is inside the simulation environment. The second interaction mode enable to use more realistic control systems, but emulation must be executed in real time mode as the external control system (such as a multi-agent system) cannot access to Arena events scheduler. These two modes of operation enable incremental development of benchmarking model.

Validation of this prototype was done using first unitary testing to assess that the emulation modules were correctly coded. After modeling of that various realistic cases have been studied. The tool proved to be usable in most situations, as the example presented bellow should demonstrate. One notable limitation is modeling products assembly or disassembly, that is not yet implemented.

3.3. Performance evaluation protocol

First, the physical system is analyzed, modeled, and parametrized with process cycle and setup times. A production scenario is specified in the form of a set of production orders.

Then experimental factors are defined. Specific factors may be used to fit a particular testcase, but tree generic categories can be distinguished. *Control mode* is obviously one of the more important. A reference control system must be included, to provide reference perform-

ance measures. P*rocess disturbances* pertain to the various disrupting events on physical operations (for instance resources failure or product scraping). *Business disturbances* correspond to variation on demand (including rush orders as well as variation in quantity or priority of existing orders).

The third step is concerned with performance indicators. *Overall equipment effectiveness* (OEE), *lead time* (LT)*, work in process level* (WIP), and *tardiness* may be considered.

Finally experiment runs are conducted. Reference performance measures, generated by traditional control system are first used to validate the implementation of alternative control systems. Then standard experiment designs (such as Taguchi tables) may be used to evaluate the effect of each factors and the effects of their interactions.

4. APPLICATION ON AN INDUSTRIAL CASE-STUDY

4.1. Case presentation and parameters

The industrial case of an automotive industry subcontractor is studied. The assembly site can make up to ten thousand products a day, with a product variety of hundred of references. The factory is actually divided into several production cells : each one includes every production step to make a finished product from raw material, and is dedicated to a particular client. One of these cells has been modeled.

The production is divided in two stages. A first set of operations results in semi-finished products. Then, semi-finished products are further assembled on tree independent assembly cells. We assume that each assembly cell cannot work simultaneously on the same reference. The production module therefore includes in addition to the four cells an inventory storing semi-finished products.

We modeled this shop floor using shape transformations for each one of the four cells. Stores were modeled as time transformations, whereas two space transformations were used to move semi-finished products in or out of the store. Finally, some product sensors have been added to the model to trace emulated products.

4.2. Decision-making procedures

The centralized reference control system schedules jobs according to their critical-ratio. This predictive schedule is then implemented by decision centers, jobs being delayed in case of process disturbances. Jobs are re-scheduled when business disturbances happen.

To model product-driven decisions, every product is represented as an object, its attributes representing product-embedded data. A component is dedicated to synchronizing products with their physical counterparts and to enable decision centers to access products.

One of the main product attribute is its priority. At system initialization, the central scheduling procedure is run, and products priorities are assigned according to the schedule. Another attribute of products is their reference, used to setup shape transformations, and their state, enabling to step products through their bill of operations.

We have programmed two modes of product-driven control. In the simpler one local control decisions are only constrained by products priority: When a cell is ready to operate, it scan through the products waiting, and select the one with the highest priority attribute.

In the other one, a more complicated decision algorithm is used, allowing autonomy with regards to products data. This algorithm try to mimic the behavior of an operator, taking into account not only products priorities but also other local parameters, like levels of semi-finished inventory in order to avoid starvation downstream, or the amount of products of the same reference that have been done, to minimize setups.

4.3. Factors and performance indicators

Process disturbances has tree modalities, focusing on resource availabilities. There is either no failure , shorts and frequent failures (uptime=expo(600), downtime=norm(45;6)) or rare and longer failures (uptime=expo(3000), downtime=norm(360,180)). Business disturbances are rush orders, involving small quantities (25) with a very short delay (1.5 time the production time), and also order modifications, where increase in quantity is larger (125), but the delay is longer. The last factor is the control mode, which can be centralized, constrained product-driven or product-driven with autonomy.

Performance indicators are WIP and LT. OEE is correlated with LT and is therefore not shown.

5. EXPERIMENTAL RESULTS AND DISCUSSION

A combinatorial experiment design has been done, each factor combination resulting in 15 simulation run. Figure 1 shows the effects and interaction of each factors.

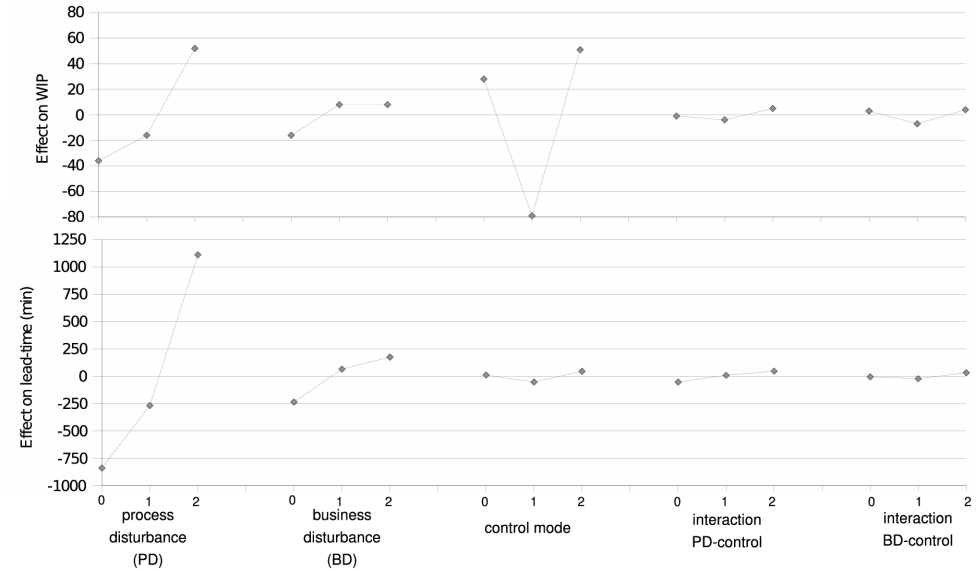


Figure 1: Effects on WIP and lead time

According to experimental results, control-driven control (with autonomy) causes lower WIP levels and a slightly lower lead time than centralized control. Conversely, control driven control without autonomy shows worse performances than centralized control. The last two curves show interactions between perturbations and control. According to these curve we can see that there are interactions (as their slope is not null). This might be explained because of differences of robustness between control modes but further interpretation is difficult.

So existence, and accuracy of local decision-making in a product-driven environment is crucial. Indeed, without autonomous decisions, performance is comparable to centralized control, when there is no perturbation, but performance tends to plunge in a highly perturbed environment. On the contrary, with autonomous decision, product-driven control was sightly less successful in non-perturbed situations, but showed more robustness. Moreover, local decision procedures was certainly far to be optimal nor very ”intelligent”. Therefore applications of product-driven control in a more realistic case where distributed decision procedures

are better (for instance using advanced artificial intelligence, or real human decisions) will certainly perform better.

6. CONCLUSIONS

A modeling methodology based on generic systemic-inspired building blocks has been presented, as well as a prototype allowing an incremental experimental approach. Then, the first experimental stage have been applied on an industrial case-study. Results showed at least feasibility of product-driven decision procedures.

Further experiments are nevertheless required to access the performances of product-driven control, taking into account data exchange issues between products, decision centers and physical equipments.

Moreover, the modeling methodology must be further developed (e.g. to include assembly issues), and its implementation must be continued to improve usability, eventually resulting in the release of a standalone tool.

Perspectives includes using this evaluation environment on model more cases, to study scientific aspects of product-driven control, and also to help transferring product-driven control technologies to industrial partners, in the domain of natural fibers. For these transfers, emulation-based evaluation will be seconded by a physical test-bed to take into account more technological problems like RFID reliability or networking issues.

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