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SIMULATION AS A SUPPORT OF DESIGN AND VALIDATION OF A PRODUCT DRIVEN CONTROL SYSTEM

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Abstract: This work is part of a research project on product-driven automation that makes the product active for business and manufacturing purposes. The paper focuses on the design and the simulation of a product-driven control system to ensure better synchronization between informational and physical flows. Feasibility of the product-driven concept is evaluated by the development of an industrial test-bed from Trane Company. Main results show benefits for product traceability and cost & time reduction thanks to a better synchronization and anticipation between the manufacturing, assembly and supplying lines of the Trane plant.

Keywords: Manufacturing plant control, discrete event simulation, Distributed production control.

1. Introduction

Since 1990 s, the mode of production in enterprises has changed from the traditional mass production mode led by products into the mass customization production mode to facilitate increasing global market competition. Consequently research in manufacturing system control has moved away from traditional centralized approaches based on MPCS Manufacturing Planning and Control System (Vollman, et al., 1988) where decision making is hierarchically broadcasted from the higher decisional levels down to the operational units to more distributed architectures. Hierarchical architectures promote production control by distributing every decision capacities in autonomous entities, without any centralised view of the shop floor status. In Order to ensure consistency of decision making, more pragmatic approaches are based on hybrid control which combines the predictability of the centralized control with the agility and robustness against disturbances of the heterarchical control. Holonic Manufacturing Systems (HMS) has been suggested as a concept for these future manufacturing systems (Kostler, 1967). This concept advocates that the product can be an association between two parts, a physical part and an informational one.

This work is a part of a research project on product-driven system (PDS). The PDS is a Holonic paradigm specialization which postulates as Mc Farlane research at the University of Cambridge (Mcfarlane, et al., 2003), that the product can be an active actor throughout its life cycle. In fact, the PdS paradigm aims to investigate challenges, trends and opens issues related to the potential active role of the product into the cybernetic loop. This paradigm emerged from the increasing capabilities of infotronics technology (RFID, wireless …).

As addressed by Marik (Marik and Lazansky, 2006), there is still a long way to make these heterarchical architectures efficient in real industrial environment. Many issues have to be solved; such as methodological approaches that are needed to evaluate the PDS technical feasibility and its efficiency. Indeed, traditional methodologies to implement centralized control system as ERP can not be used in “PDS” context. There are two major ways to implement ERP systems according to enterprise strategy. One extreme is the big-bang deployment where at once all the old systems are upgraded to the new one. The other extreme is phased rollout where the system component is brought on-line serially and

operated and observed before moving on to implementation of the next phase.
In the context of product driven control system the decisions are made in detailed levels (a product or part) conversely of centralized systems where decisions are made in manufactured order level. Thus, it is necessary to evaluate the PDS interactions with the whole physical system by keeping centralized framework defined by the ERP (Enterprise resource planning).

.This evaluation cannot practically be done "on line" without safety and financial impacts on the plant.
In this context, there have been numerous efforts to use modelling and simulation tools and techniques to improve manufacturing control efficiency over the last four decades. While an increasing number of manufacturing system decisions are being made based on the use of simulation models, their use is still sporadic in many manufacturing environments.

In order to evaluate PDS feasibility and efficiency, collaboration has been initiated with a firm called Trane Company witch provides indoor comfort systems and comprehensive facility solutions for residential, commercial and industrial building needs. In this context, we propose a methodological approach to integrate a PDS within the Trane legacy system. This approach moves from the customer requirement and identification of efficiency metrics to the design and implementation of PDS solutions to improve production processes currently based on the Demand Flow Technology (DFT) (Costanza, 1996).
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This paper focuses on the design phase where two types of Discrete Event Simulation are used (Isermann, *et al.,* 1999) "software in the loop" simulation to progressively build the PDS control and "hardware in the loop" emulation to validate the real PDS control before implementation.

The section 2 provides the basics of understanding the DFT concept and in particular, how a product driven system can be integrated to fill the lacks of the DFT. The section 3 explains the use of simulation to better design a Product driven system infrastructure and how to validate the real control system. Application of the proposed methodology to Trane Company is discussed on the section 4. We conclude with synthesis of achieved works, limits and perspectives.

2. DFT AND PRODUCT DRIVEN SYSTEM

2.1 Demand Flow Technology

The demand flow technology is a Just in Time methodology which leads to have strictly similar assembly line organization (Fig. 1). The objective is to optimize production through processes standardization. The production context is as follows: the shop floor is organized in pull production, and each finished product is assembled on a main assembly line.
To be sure that a needed component (semi-finished) arrives at the right time and thus avoids shortage there is some inventory between assembly line and each feeder (called in process Kanban –IPK-).).

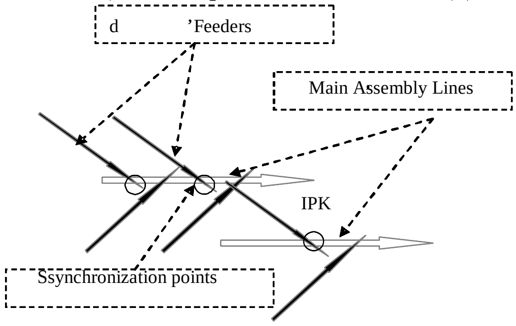


Fig. 1. DFT architecture

The others components are managed by the Kanban method (Card, empty Bin, In Process Kanban (IPK) on plant floor). In addition, the control management must respect the objectives defined monthly by the tactical planning suggested by the ERP

To summarise this part, although, this organization allows a great flexibility and reactivity on the level of materials flow it has many challenges: the first one, is how to better synchronise assembly lines and their feeder i.e how to minimize IPKs, the second, is how to give more visibility on the informational systems for example how will be the actual consumption of component because today 80% of components are managed by kanban and consequently the consumption of inventories is realised by backfluching. The third question is how to improve reactivity in case of disturbance? And the last one, is the PDS concept can answer those problems?

The study focuses on the design and implementation of a product-driven control system in order to ensure better synchronization between different flows: informational flows with physical ones for traceability and two or more physical flows for cost & time reduction.

2.2 Product Driven System

As developed in the introduction, nowadays the best practices in manufacturing management field is to combine both hierarchical and hierarchical flow control approaches. The aim is ensuring a global optimum while keeping the hierarchical systems reactivity. One of the major representations of this concept is Holonic Manufacturing Systems (HMS) (Morel, et al., 2007)
The Holon concept was suggested by Koestler to describe a basic unit of an organisation in biological or social systems. Every identifiable unit of organisation consists of more basic units while at the same time forming a part of a larger unit of organisation.

Comparison between different control modes, such as market-based and hierarchical control, or planning-based and reactive control have been carried out using specifically developed test-beds.
But more generic evaluation tools are needed, to enable storing, sharing and comparing test cases. Development and definition of such generic evaluation tools has drawn a great deal of interest.

IMS-NoE a special interesting group (Cavalieri, *et al.*, 2003) (Valckenaers, *et al.*, 2006) has defined a benchmarking utility to enable the collection and the 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.

3. PDS DESIGN AND SIMULATION

The development of a test bed PDS control must be first based on a clear definition of performance indicators that PDS is expected to improve. This requires to understand the customer's requirements and to identify what level of performance is required to satisfy and even delight the customer. In the case of Trane PDS benchmark, the six-sigma method (Antony and Banuelas, 2002) is used to capture user's requirements related to PDS and define metrics in terms of CTQs (Critical to Quality). Those CTQ are supposed to be the foundations of the design and simulation phases (Fig. 2.)

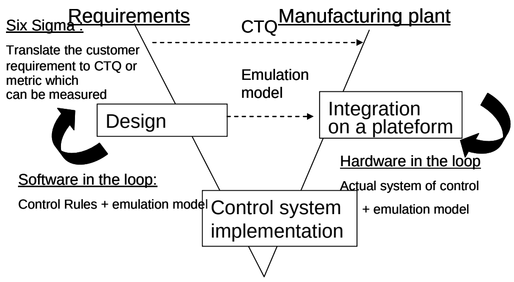


Fig. 2. Methodological approach for PDS evaluation

3.1 *Software in the loop*

Software-in-the-loop simulation consists on coupling control models with plant models in order to evaluate the accuracy of the proposed control rules.
In the area of production system modelling, there is a consensus on the architecture of benchmarking environments which puts 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. In the particular context of PDS control, we have proposed a systematic modelling of (Elhaouzi, et al., 2007):

– elementary physical entities that only focuses on transformations on the product flows, i.e. the manufacturing process
– control heuristic and algorithms that represents the centralized decisions
– local decisional entities having both physical and logical behaviour.

The Problem of PDS design is to identify which, when and where product information and events can contribute to improve test performance indicators given by CTQ. The proposed modelling constructs provide the ability to simulate interactions between control, product information/event and physical processes and, consequently, to evaluate many PDS scenarios.

3.2 *Hardware in the loop*

Hardware in the loop simulation consists on validating the behaviour of a real system within its emulated environmental context. Emulation runs on a controller board that mimics the target hardware. In the context of control validation, the main advantage is that the validation can be carried in a virtual platform without using the real physical system; that decreases the time of development and implementation.

In the context of PDS, implantation is based on various technologies such as multi-agent (Cavalieri, *et al.*, 2000), web applications, etc. Consequently, hardware in the loop simulation requires developing communication interfaces between the selected technology and the emulation models.

4. TRANE BENCHMARK

4.1 *Pilot presentation*

The six-sigma approach has leaded to translate the different internal customer requirements to CTQs then a Trane pilot was chosen to evaluate the Product Driven System hypothesis according to those CTQ. In this context, the CTQ are the lead time and the cost. The pilot called PilotAB is composed by an assembly line and with 4 workstations and a feeder with 4 workstations also. This feeder must feed the main assembly line on site A and to satisfy the need for another production site called B (managed by basic Kanban) (Fig 3). To summarize this part the need for the site A is managed on demand and in kanban for the site B. We must satisfy in priority the need of the site A and to be able to produce all the kanban requirements per day for the site B.

Nowadays, the synchronisation of one assembly line and its feeders is realized using the shop packet. These documents (line and feeders) are edited and scheduled in the same way. To summarize, the factory is considered as a black box where the only available information are the projected schedule of the assembly line and its expected components. Being sure that the right component is manufactured

at the right moment is the operator responsibility. Concerning feeder's management, the component manufacturing is anticipated to make sure that the assembly line does not stop because of a missing component. This fact creates a huge stock. This kind of management is in the opposite of the main objective of DFT which is to decrease inventories.
Implementing an auto-id system will answer many objectives:

- Manufacturing will be on demand: the product arrival on a particular process in the assembly line gives a signal trigger of the components manufacture. This fact decreases inventories due to a large time of anticipation.
- The manufacturing information related to feeder trigger will correspond exactly to the expected component. Consequently the production quality will be improved.

The remaining question is what will be the best moment in the assembly line to send a manufacturing signal to the feeder, to be sure that the expected component arrives at the right moment and to ensure that this kind of control does not involve delays on the assembly lead time.

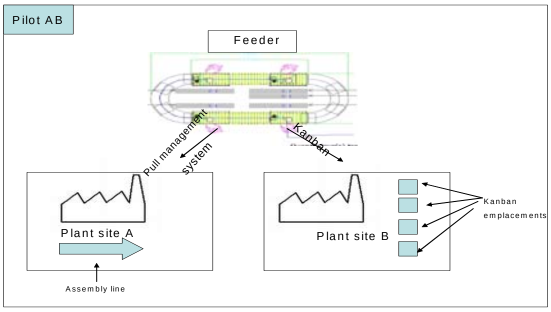


Fig. 3: Pilot AB view

Discrete Event Simulation was chosen as the key question required assessment of process cycle time and queuing time. Arena was selected due to its ease of use and ability to deploy the model for future operational use with no addition cost. Indeed the Arena software makes it possible to simulate the behaviour of an assembly line and the statistics generated give to the engineer's good indicators to integrate an effective system of traceability and control. Although, this tool is powerful for simulation, its use remains very complex, even impossible for no data processing specialist. We develop a generic tool to facilitate the use of Arena and to automate the modelling of assembly lines. Moreover, the problem was the evaluation of an existing control system on different physical systems.

4.2 Software in the loop simulation

Arena models were developed without any information and decision rules. Three models are necessary to represent the feeder and the two assembly lines in the two production sites (Fig3). Thanks to arena, two types of the results are provided: i) physical flow animation and ii) statistic sheet useful for planning optimisation.

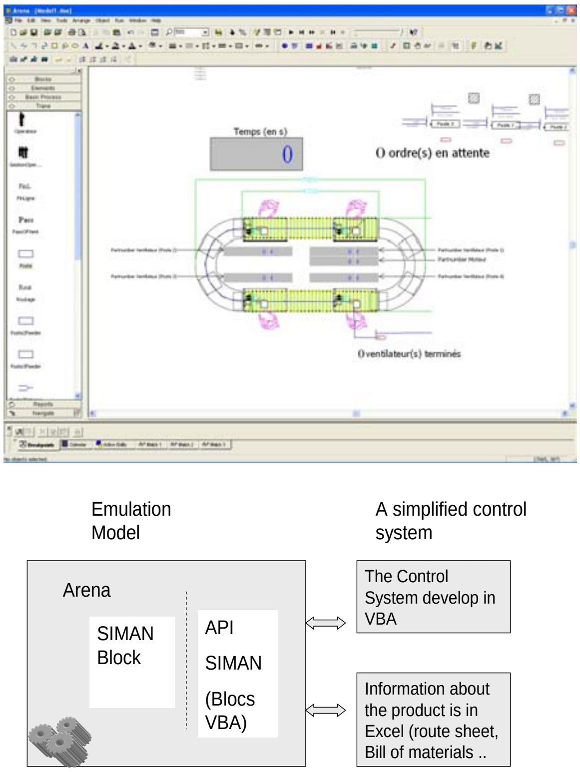


Fig 4: The simulation models

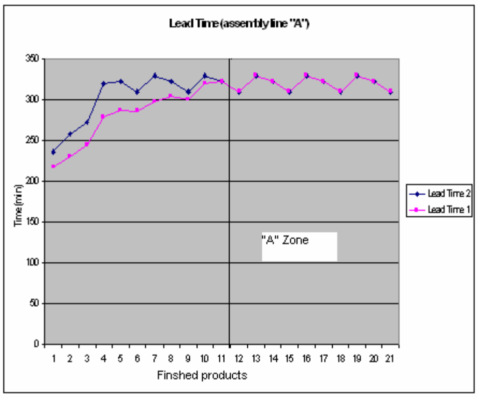
In the first phase of the simulation process, the flow of the "PilotAB" factory was defined and estimated data was established by experts. The table 1 presents major input parameters for the simulation model.
It presents a sample of a standard MPS. We find there the orders priorities, the references, and the number of the components waited from the feeder "f", and operational times on the 4 assembly line workstations (twsi). A similar table provides operational times of the feeder components.

Priority	Reference	Component Number	N° Orders	tws1	tws2	tws3	tws4
1	C2	14	10	60	40,8	40,8	75,5
2	C1	14	20	55	40,8	41,8	73,4
3	D	12	30	37	64,3	27,5	69,4
4	C2	14	40	60	40,8	40,8	75,5
5	C1	14	50	55	40,8	41,8	73,4
6	D	12	60	37	64,3	27,5	69,4
7	C2	14	70	60	40,8	40,8	75,5

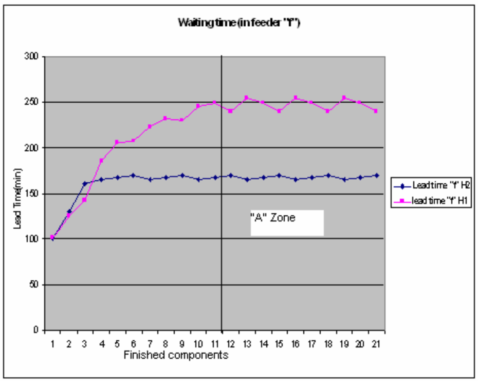
Table 1. Master of Production planning (MPS) (inputs of simulation model)

In the second step, the various scenarios of the readers' implementation are defined. Hypothesis 1 "H1" the reader is implemented in the workstation "ws1" i.e. the signal of manufacture sent to the feeder in the beginning of the assembly line "a". Hypothesis 2 "H2": the reader is implemented at the workstation 2 "ws2"… etc.

To summarize the most important points in our statistical analysis, the figure 6a shows the lead time in minutes per finished component on the feeder and the figure 6b shows the lead time in minutes per finished product. The comparison between the different hypotheses is only considered when the production line has reached its steady functional state (A zone in both figures 6a, 6b). Concerning the assembly line there is no lead time differences between H1 and H2 and they both satisfy plant sites' A and B needs.



a. hypothesis 1



b. hypothesis 2

Fig. 6. Statistical analysis

Concerning the feeder, figure 6a shows that the waiting time in the feeder is minimal for H2. This can be explained by the fact that a too important anticipation of the trigger tends to overload the IPK capacity (between the feeder and assembly line) the product arrivals frequency (consequently triggering signal in H1).

To conclude, the solution "H2 has better results on both metrics lead times and inventories. Hypothesis 3 is voluntarily omitted because when the first product arrives at "ws4" it waits about 60 min before having its 14 components (shortage case).

This study enables to validate the profit in term of time and cost for better synchronizing an assembly line and its feeders. In particular, it leads to design and validate a prototype of the control system based on product driven system concept. After this step, we build a control system using ".net" facilities.

This system must be validated before the implementation on the shop floor.

4.3 Hardware in the loop simulation

In this phase we use the same emulation model developed with ARENA. The control system is composed by a communication system connected with Oracle and the ERP (manufacturing orders and information traceability) and users interface to help human operator in his work by displaying the method sheet and the bill of materials (Fig4).

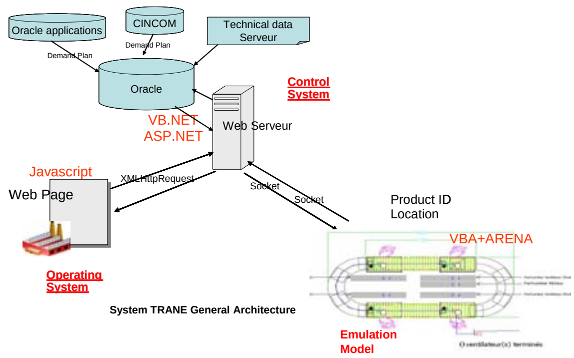


Fig. 7. General architecture of the emulation test-bed

4.4 Control system description

The control system is developed as a web application with ASP .Net and VB.Net. Concerning the pilot, the industrial aim is to produce "fans" assembled on different work stations. To ensure product traceability and control material flow between the two sites, the web application is connected to an Oracle data base.

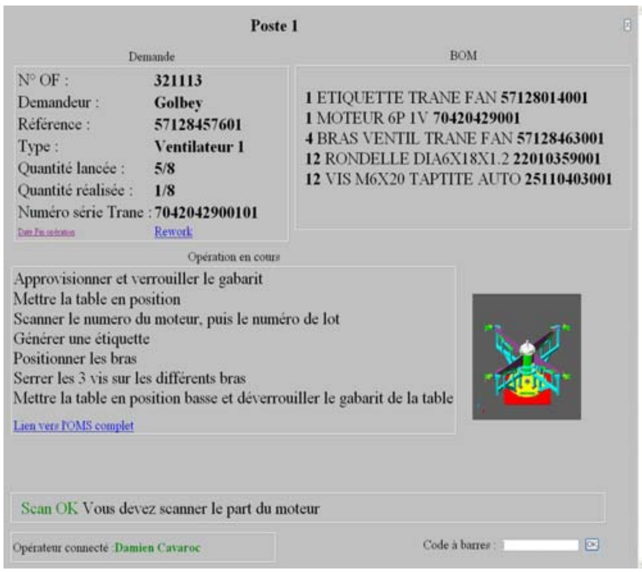


Fig. 8. Operating system user interface

The operator screen (see fig 8) proposes the following information:

- Information specifying the demand (Work Order Number, item part number, quantity, etc…)
- Bill of Material (these data come from the ERP)
- OMS (Operation Manufacturing Sheet) it is the description of the operations
- Information zones useful in case of breakdown in bar code or RFID tag scanning.

4.5 *Communication interface*

The web application sends the OF parameter to Arena which creates entities with the received attributes then, the emulation model (Arena) "emules" the item "bar code scan" and sends, via a socket the scanned information (Trane reference number, WO number, etc…). When Arena data are receipt, in the meantime operator work center send a request (via a XMLHttpRequest object), the control system store them in the data base.
As soon as Web application is launched, it sets up a server socket thanks to SocketClient DLL. Socket is the only communication way between Arena models and Control system and XMLHttpRequest objects are the only ones between work centers and Control system. (See fig 8)

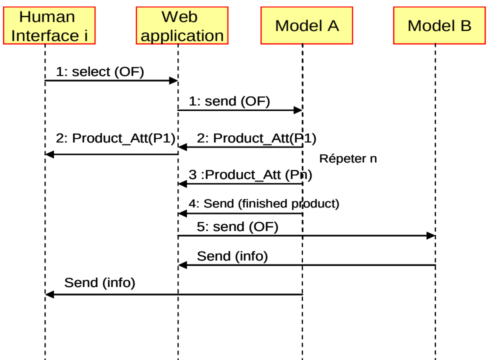


Fig. 8. A UML diagram for communication protocol

5. CONCLUSION

In this paper, we defined an approach where two types of Discrete Event Simulation are used. "Software in the loop" simulation to progressively build the PDS control and "hardware in the loop" emulation to validate the real PDS control before implementation. In the last part, we presented the use of the whole approach in a case study. The results help manager to validate PDS profitability and feasibility in Trane Company. The main weakness of this proposition lays in the fact that the time schedule periods are different in emulation model (Arena) and the web application.
The future work will be aiming to improve the time management between emulation model and a real control system using a more standard approach as High Level Architecture (IEEE, 2003)

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