Four Loops Supervisory Control for Virtual Enterprise

A. CURAJ , A.M. STĂNESCU , S.I. CARAMIHAI and [1]M. CHIRCOR

Politehnica University Bucharest, Human Resource Training Center
132 Calea Grivitei., Sector 5, Cod 78122, Bucharest, Romania
tel. +4013111661, fax.+4013111794, e-mail: adi@cncsis.ro
[1]University Ovidius,
B-dul Mamaia 124, Constanta, Romania
e-mail: mchircor@univ-ovidius.ro ;

Abstract: *The desired improvement in performance and the realisation of global enterprise objectives require a tight integration of the units of the enterprise. The close monitoring of the operational performance of various plants, manufacturing shops-floor/cells/machines, as well as their associated instrumentation and control is seen to be of increasing strategic importance. Failures can lead to increased costs, reduced product quality, consistency and production, plant shutdown, an increased environmental impact. It is a real need for the advanced monitoring technologies to be applied, and their potential demonstrated, on complex industrial plants. The planning and scheduling of manufacturing systems integrated in Virtual Enterprise architecture request for new General Master Production Planning and Scheduling techniques and Supervisory Control and Data Acquisition (SCADA) functions implementation. The paper discusses some key issues concerned with the four loop supervisory control for Virtual Enterprise.*

Keywords: *Virtual Enterprise, Fabricator, eEnterprise, SCADA*

1. INTRODUCTION

The various sintagmas for different views of the new manufacturing paradigm are describing the global research effort focusing on the digital era requirement challenge. The ***NGMS*** (Next Generation Manufacturing Systems) (Kosanke 1998), the ***ADMS*** (Advance Manufacturing Systems), (Fabian 1998), the ***DEE***- Dynamic Extended Enterprise, (Browne 1998), the ***IMS*** - Intelligent Manufacturing Systems, (Brussel 1999) or the ***CE***- Concurrent Enterprise, (Pallot 2000) are based on the new models: agile (Kidd 1994), holonic (Arai 1999), fractal (Bischoff 1998), bionic (Hatono 1999), virtual (Smirnov 2001). The future manufacturing systems will be the result of both provoking emerging Information and Communication Technology (ICT) and the new management science approach. They will have in common some characteristic proprieties: autonomy, co-operation, multidisciplinary team work, integrated approach for product-process-system design, re-thinking of humans position and role, will be agile as organisation and virtual as geographic distribution and alliance. An important requirement for all post-CIM manufacturing systems is the ability to capture knowledge from multiple disciplines and store it in a form that facilitates re-use, sharing, and extensibility. The convergence of disciplines around the extended control domain involves real time control, embedded control, networking control (Metakides 2001), mobile communication (Antoniac 2001) (e.g. M2M-machine to machine), multi-modelling and simulation driven design for complex automation systems. The ITC emerging platforms have opened the challenging way to develop the flexible industrial integrative platform based environments for SCADA system configuring and development. The SCADA system may be used to control of advanced manufacturing cells (involving more and more intelligent functions) and also to control of various plants that could be seen as Internet enabling intelligent manufacturing “cell” (Stanescu 2000), figure 1.

The important contribution brought into scientifically community attention by University Novo de Lisbon is concerned with an ICT support platform for Virtual Enterprise (VE). Considering a VE as a temporary and dynamic (i.e. with variable ”geometry”) organisation that appears in response to a business opportunity and disbanded on the completion of this business process (Camarinha 2000) a number of both base and auxiliary facilities&service can be identified. Potential partners' selection and negotiations agreements could be supported by the contract-net approach of the Distributed Artificial Intelligence community. Also the network topology definition and co-ordination approach, for auxiliary functionality to monitor and parameterise the network behaviour are supported by PRODNET II, ESPRIT Project

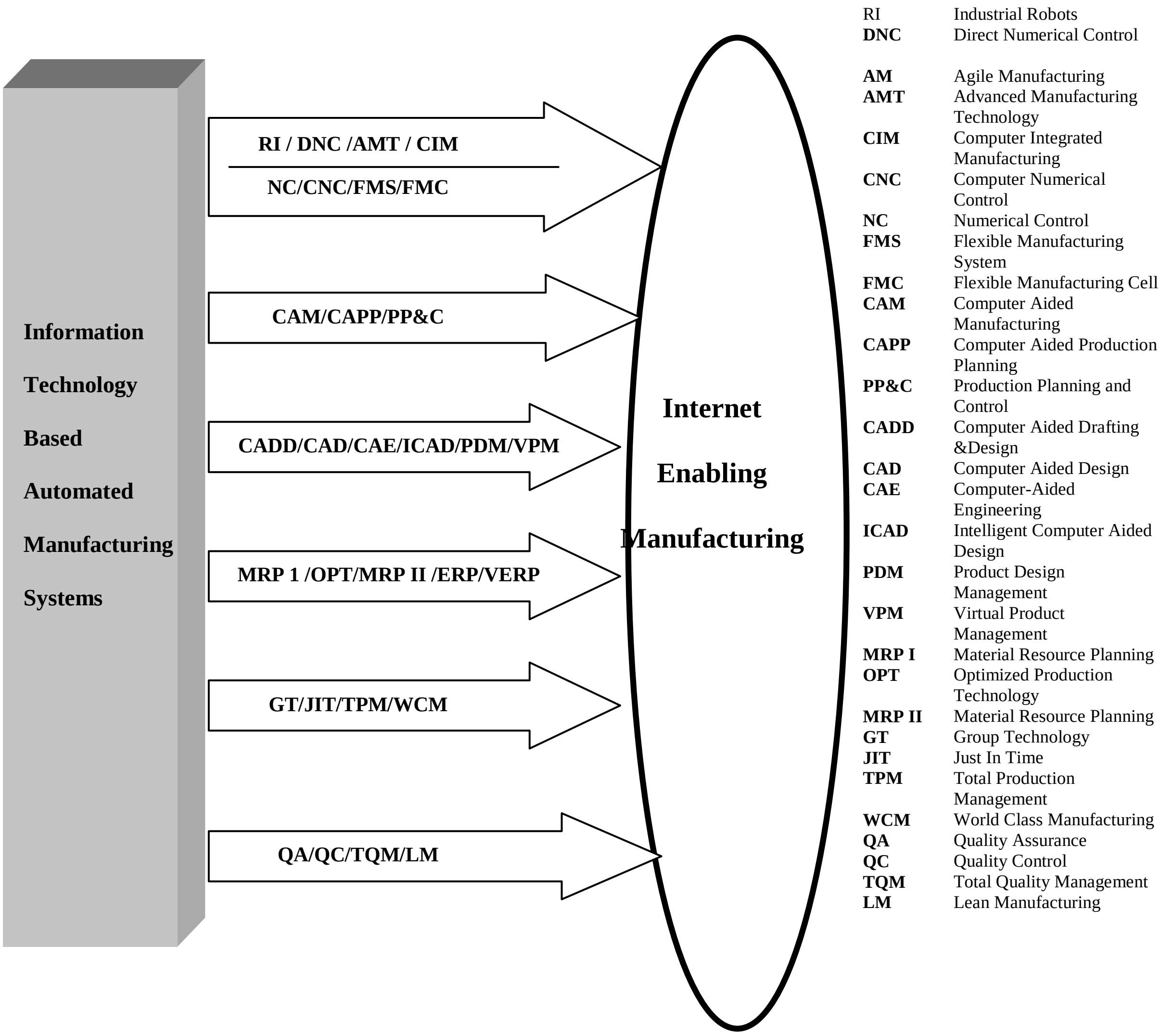

Figure 1. Manufacturing systems history.

16. One of the important issues here is the identification of “who will perform this function” in this “democratic” value chain (Katzy 2000).

During operation of a VE, by Web interconnection among partners from e-commerce to points of sales and crossing all intermediate nodes: manufacturers and distribution centres, there are some important goals to be achieved: the efficiency of orders flow, follow-up of orders evolution, management and exchange of order information among partners, distributed and dynamic scheduling, quality information even distance learning. Starting with the general requirements, the main contributions are directed to a model-based architecture. These architectures are focused on a single enterprise entity, do not fit with needs of virtual enterprises, but they can be useful in both giving a general overview of the global structure, in its multiple views, of a generic industrial enterprise (a potential node in the virtual enterprise) and suggesting an approach for VE Reference Architecture.

Some of them are still sustainable like CIM. OSA/Open System Architecture for Computer Integrated Manufacturing (Kosanke 1998), PERA – Product Enterprise Reference Architecture, GRAI – Integrated Methodology, GERAM-IFIP/IFAC Generic Enterprise Reference Architecture Methodology, GLOBEMAN 21 (Vesteragen 2000).

In the specific area of Virtual Enterprise some attempts have already being done in order to establish Reference Architectures. The most significant is NIIIP (National Industrial Information Infrastructure Protocols).

2. FROM VIRTUAL ENTERPRISE TOWARDS eENTERPRISE

One could evaluate this new type of distributed networked enterprises as a business integrator, having a specific life cycle of business duration. Each node has to perform a dedicated set of tasks, based on their core competence (Katzy 2000). This new type of organisation, VE, is faster reactive for facing the business process finite horizon opportunity better than well-known traditional organisations (large enterprise or SMEs). The Virtual Enterprise is the most appropriate concept due to its basic meta-system features:

- **business integrator**, allowing both the vertical and horizontally integration of SMEs (Santoro 1997);
- cyber space **friendly user** e- business approach for market place;
- multi-agent based internal **co-ordinator**, implementing Production Planning and Control (PP&C) within wide-area-network of heterogeneous platforms;
- extended concurrent engineering oriented **designer** for product/ process / production system facilities.

The materialisation of the paradigm of virtual enterprise (VE) requires for definition of the reference architecture and the development of a supporting platform and appropriate protocols for open system architecture.

A VE alliance has a certain lifecycle that starts with the initial phase, (capturing of market opportunities, sales forecast, customer orders, partners’ profiles establishing and preliminary selection of partners). These activities are primarily concentrated within management of the further VE. The market conditions and core competencies of potential partners, Fabricators, are part of the environment for a VE development.

The next phase, configuration phase, is dealing with the VE building including “final” selection of partners, formal agreements, legal issues, etc. At the end of this phase the VE is able to operate on market. The actual presence on market, concerning business progress is done in VE functioning phase. VE is under a continuing reconfiguration process, based on business performances and the actual status of partners. Actions are taken to improve the VE efficiency, by developing of every actor capabilities and even by removing/adding new partner by outsourcing decision. All these phases have to be supported by a Global Re-engineering Knowledge Network

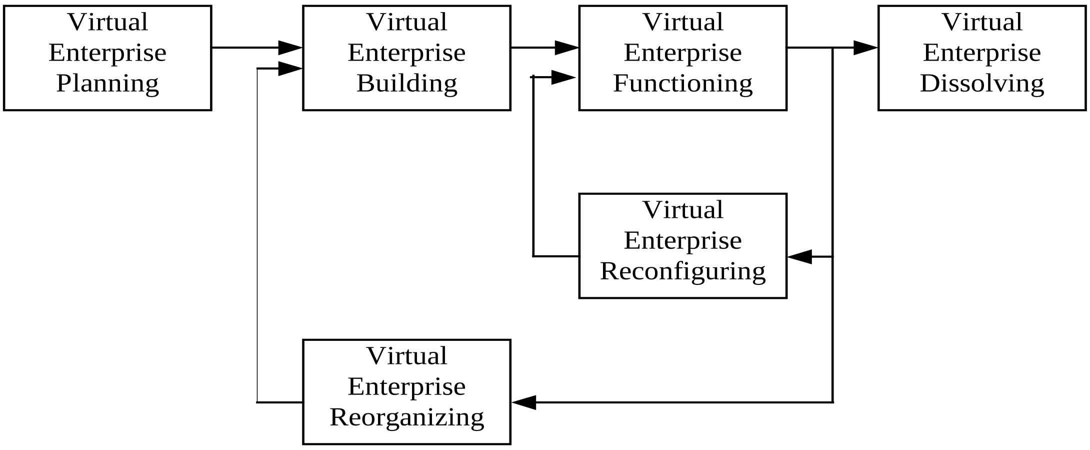

Figure 2. Virtual Enterprise Lifecycle.

(Curaj 1998) an integrated approach of two “networks”, Global Engineering Network (Sauer 1996) and Global Partner Network (Curaj 1998).

When the VE has completed its mission it will be faced with the dissolving phase.

During the panel discussion from the 8th International conference on Concurrent Enterprising (ICE’2001-held at the BIBA at University Bremen, June 29th, 2001) the authors proposed a provoking concept as further research goal: *e*Enterprise beyond the Concurrent Enterprising / Virtual Enterprise state of the art:

$$\mathcal{E}=\mathrm{f}(\mathcal{M}_{\mathcal{P}},\mathcal{M}_{O},\mathcal{M}_{a},\mathcal{M}_{\mathcal{R}}, \mathcal{M}_{\mathcal{K}}, \mathcal{M}_{\mathcal{A}}, \mathcal{G})$$

where:

1. $\mathcal{M}_{\mathcal{P}}$ = set of processes (manufacturing, desgn, business, a.s.o.)
2. $\mathcal{M}_{O}$ = set of transformation objects encapsulating
3. $\mathcal{M}_{a}$ = set of intelligent agents (both natural and artificial)
4. $\mathcal{M}_{\mathcal{R}}$ = set of resources (financial, capital, work-in-progress)
5. $\mathcal{M}_{\mathcal{K}}$ = set of knowledge
6. $\mathcal{M}_{\mathcal{A}}$ = set of activities (flow-work activites)
7. $\mathcal{G}$ = business goal based on decomposition tree (objectives / activities / tasks)

The extended *e*Cube has, as CIM-OSA, the following dimensions:

1. The first dimension consists of:
   1. e-manufacturing
   2. e-logistics
   3. e-planning / scheduling

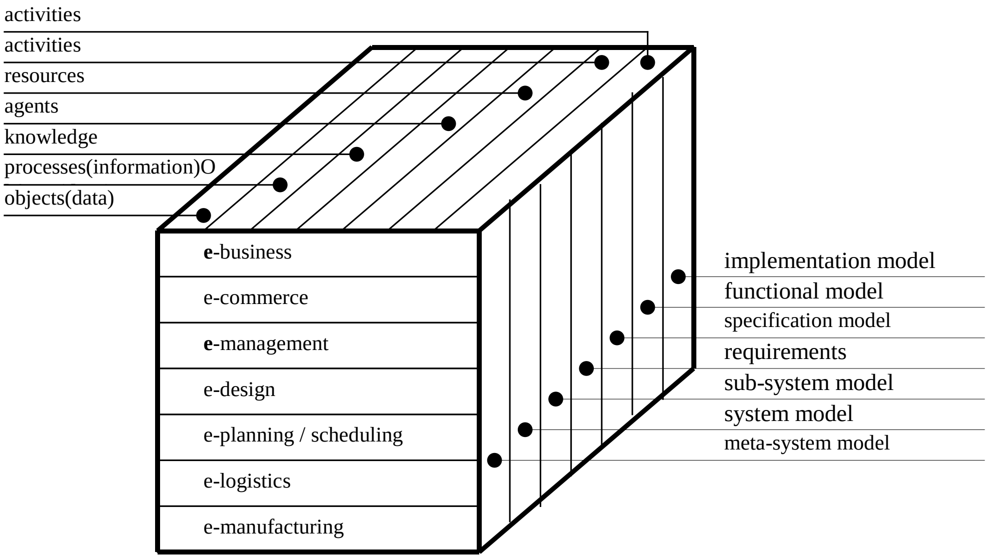

Figure 3. The extended *e*Cube.

4. e-design
5. e-management
6. e-commerce
7. e-business

2. The second dimension consists of:
   1. objects (data)
   2. processes (information)
   3. knowledge
   4. agents
   5. resources
   6. activities
   7. objectives
3. The third dimension consists of:
   1. meta-system model
   2. system model
   3. sub-system model
   4. requirement model
   5. specification model
   6. functional model
   7. implementation model

3. THE FABRICATOR CONCEPT

The Fabricator is an autonomous agent offering products and production services on the business market. It is required to perform all activities to achieve the business goal-structure according to the selected strategy and policies.

The concept of Fabricator involves the following hybrid system integrating three layers architecture (Raulefs 1994), shown in figure 4.

Virtual Factory is the software models and applications system describing, in virtual environment, the dynamic behaviour of the real manufacturing system. It aims:

- to assist strategically/ tactical/ operational decision making process;
- to develop products/ processes/ manufacturing facilities;
- to develop automation control system;
- to develop processes management and resources management.

Automation System is the integration platform-based system that maps the virtual manufacturing processes ordered by a scheduling plan, into a space-temporal activity pattern. It works according to an optimum dynamic task allocation of manufacturing resources.

A business-rules-based scenario, produced within dynamically changing virtual enterprise environment is translated into a virtual manufacturing scenario, based on problem-solving and decision-making functions, to achieve the global goals of a profitable enterprise.

The following basic requirements, but not limited to this list, we are taking into account for advanced control manufacturing system syntheses within Virtual Factory framework:

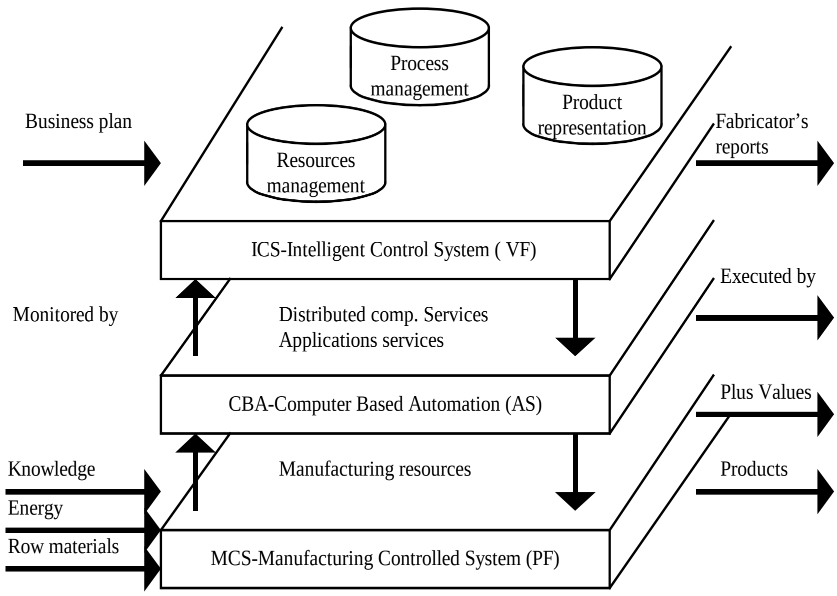

Figure 4. Fabricator.

- **system robustness**: to preserve the structural proprieties of DEVS (e.g. viability, bound ness, reversibility) in the presence of internal disturbances(e.g. equipment break down, delays, etc). The qualitative supervisory theory is, generally speaking, the theoretical background;
- **system adaptivity**: to deal with changes so robustness is supplemented with the ability to freely adapt to external changes. An internal market-base model should undertake the task to fulfil this requirement (Lin 1993);
- **decision-support system autonomy**: to improve the role of co-operative multi-agent systems within a synergetic framework of advanced manufacturing concurrent enterprise (e.g. holonic manufacturing systems) (Brussel 1995).
- **manufacturing representation completeness**: to support the multi-view approach for manufacturing enterprise consisting of heterogeneous resources and a mosaic of activities (Camarinha 1995);
- **multi-modelling system connective ness**: to create a facility able to integrate the underlying models required by necessary for the integrated design complex task.
- **functional modules reusability**: to develop reusable software to adequately respond to the need for frequent changes in manufacturing systems.
- **VF software compliance**: to comply with open system standards and specifications.

The extended concurrent engineering methodology involves the whole life cycle of product development from requirements, engineering to product disposal. The tight correlated conceptual design for product/ process/ production requires a new design framework which has fours system views (Vi, i=1,4) namely:

- new product development (NPD);
- work processes of production (WPD);
- new cross-departmental automated manufacturing system (AMS);
- ICT based intelligent communication system (ICS).

Traditionally design engineers have deployed Product Data management (PDM Systems) to the control access to the documented versions of product design. Many complex software product have been developed during last 10 years (e.g. Catia - V4/V5, Euclid - Software Factory, Optegra etc.). The V1/NPD dimension of FABRICATOR framework is based on both the generic PDM system and the particular commercial software systems. The different groups of designers have access to documents emerging from archive and collaborative stages of new product development (Philpotts 1996). Workflow management systems (Georgakopulos 1995) conversely allow managers to coordinate and schedule the activities of organizations to optimise the

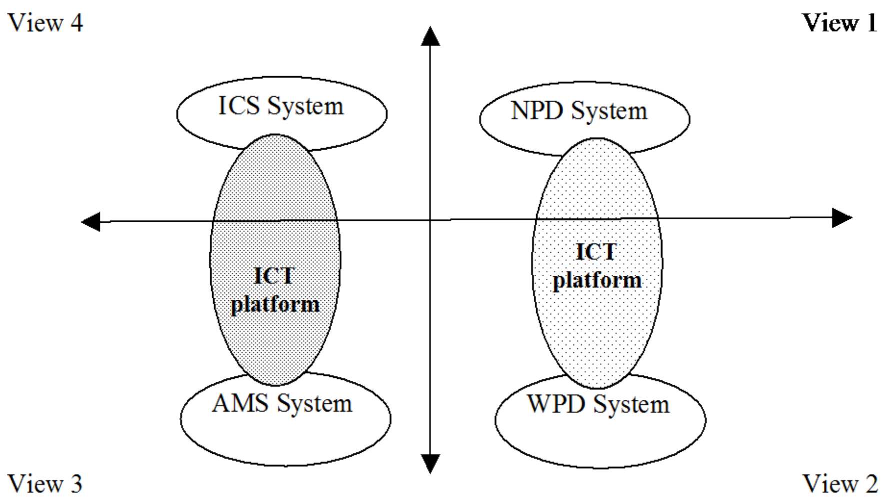

Figure 5. FABRICATOR framework.

flow of information between resources of organisation. Emerging commercial workflow systems (e.g from SAP/R3) seem to be appropriate tools for supporting enactment of defined production operation.

In the actual manufacturing systems, NPD engineers use a PDM system whilst production mangers use production planning and control systems and/or workflow management system. An interesting trend is concerned with integrating the product data and workflow management for more complex products (e.g. aeroplanes, cars, a.s.o.). Some years ago, the integration of product data and workflow "views" has only been proposed for the capture of design documentation in manufacturing (Ramanathan 1996). A challenging research has been noticed in different laboratories but an example as CRISTAL system, developed at CERN Geneva is very representative (Mc Clatchery 1997).

Figure 5 presents the basic FABRICATOR framework as authors have already proposed it.

4. FOUR LOOP SUPERVISORY CONTROL FOR VIRTUAL ENTERPRISE

The reference-input data for every Fabricator's manufacturing control are provided by the supervisory system, MRP (Manufacturing Request Planning), and the control deviation is observed by the process data acquisition mechanism. This is the "A" control loop in figure 6. When it is looking for an optimal manufacturing schedule the starting point is the real time process information database, where there is the whole process history. In order to predict the manufacturing system behaviour under an established control schedule it is necessaries to simulate the process. By simulation can be compared different manufacturing scheduled aiming to choose the optimal schedule. The "A" control loop is supplemented by B control loop, which contain the RTM (Real Time Model) of the manufacturing system. A real time model shall be provided with the characteristics as following, but not limited to:

- incorporate field proven technology system architecture;

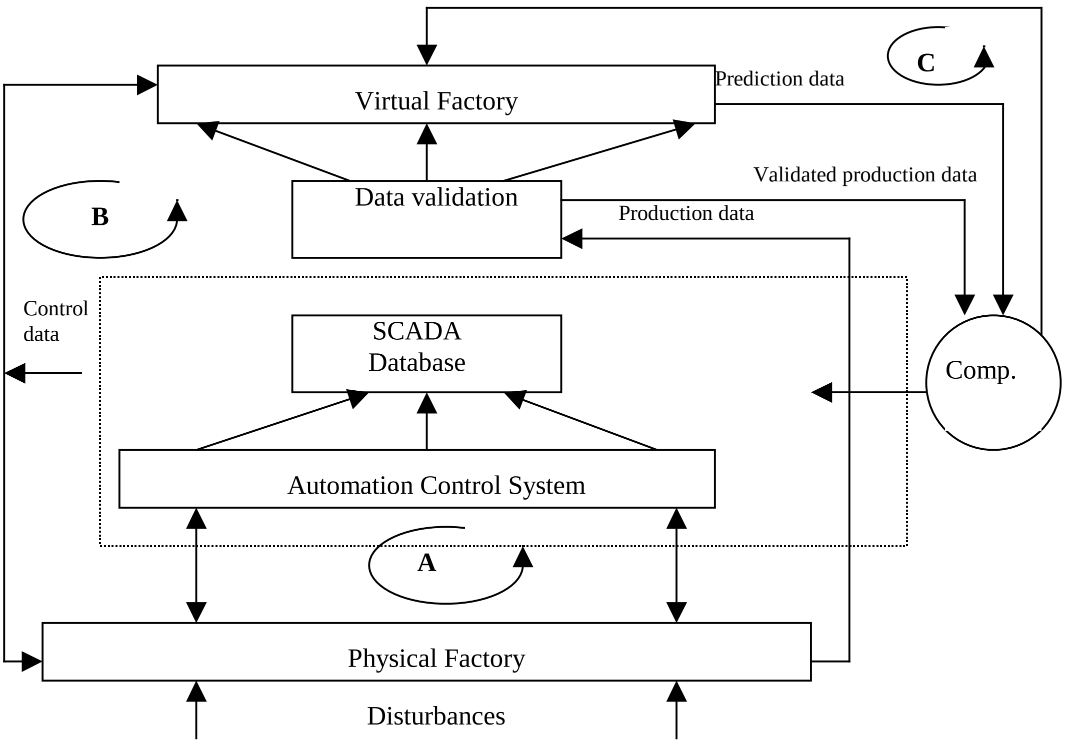

Figure 6. FABRICATOR- Supervisory control system architecture.

- allow for future expansion;
- provide ease of operation and maintenance;
- provide timely and efficient response to both anticipated and unanticipated demand and supply changes;
- provide the capacity to easy recognise and rapidly respond to operational problems and effectively minimise their impact;
- efficiently maintain data describing historical physical factory operations and permits quick retrieval of this information.

Under the normal manufacturing conditions more and more increasing difference will arise between the simulation results and the manufacturing processes. This is due the stochastic influence such as express job orders or machine breakdowns as well as inaccuracies of the manufacturing model (e.g. not exactly known working, loading/unloading, calibration times, etc.). It have to be controlled also the RTM itself and also its initial data. The "C" control loop, an off-line one, is in charge with control of the model (Sauer 1997). The information flow aiming to support the SCADA system is presented in (Curaj 2001).

The planning process in VE asks for a Global Master Production Schedules (GMPS), the Aggregate Production Planning (APP). Due to the uncertainties at the different levels, from Fabricators to the logistic chain network within the VE it was proposed (Frederix 1996) to split the control task into two parts. The first one, the proactive part, is concerned with the optimisation of the plans ahead of time consistent with constraints of orders and Fabricators (seen as production systems). The second one, the reactive part, is in charge to adapt locally the plans issued by the GMPP, according to the actual system status.

Every Fabricator - manufacturing partner in the virtual alliance can use the proposed three-layer SCADA architecture. For planning and controlling the VE it is a strong need to have meta-model of the virtual alliance and this model is used for proactive control. This RTM of the VE has to be also controlled due to the continuing process of configuring-reconfiguring of VE during its lifecycle.

5. THE EXPERIMENTAL SET-UP

There are different other different aspects that we have to take into account when a SCADA is proposed: look-ahead model (LAM), predictive model (PM), deviation analysis module, system training module etc. The experimental set-up is offered by the project in the World Bank funded-research project, FABRICATOR – Virtual Enterprise University pilot project based on intelligent agents, object-oriented techniques and concurrent engineering methodologies. It gives the possibility to implement, test and validate different solutions for an advanced control system for VE.

6. CONCLUSIONS

The actual paper describes conceptual framework for a four loops supervisory control system exploring the basic concepts of the planning and control of the Virtual Enterprise.

Starting with presenting the VE concept continuing with the VE lifecycle and Fabricator definition the paper proposes a SCADA architecture for every partner in VE alliance and a four loop in charge with RTMs both for local control and for proactive control of VE alliance. The further research is focused on two different directions. The first direction is concerning to the formalism for modules based design of virtual enterprises for configuring and reconfiguring alliances based on a global reengineering knowledge network. The second research direction intends to more focus the efforts in establishing a decision support system for VE piloting including RTMs for Proactive Control of the virtual alliance.

REFERENCES

1. SMIRNOV,A. 2001– "*Knowledge Fusion in the Business Information Environment : a Concept and Major technologies*". In: Proceedings of the 7th International Conference on Concurrent

Engineering. Bremen, Germany, 27-29 June, pp.273-276. ISBN 0-85358-098-7.

2. CURAJ,A. 2001- "*Supervisory Control and Data Acquisition for Virtual Enterprise*", International Conference on Production Research - ICPR16 Praga, 29 July-3 August, 2001; ISBN 80-02-01438-3
3. METAKIDES,G. 2001 - Invited Conference in the 9th IFAC/IFORS/IMACS/IFIP Symposium on Large Scale Theory and Applications. Bucharest, Romania, July 18-20.
4. ANTONIAC,P., PULLI,P. 2001– "*MARISIL – Mobile user Interface Framework for Virtual Enterprise*". In: Proceedings of the 7th International Conference on Concurrent Engineering. Bremen, Germany, 27-29 June, pp.171-180. ISBN 0-85358-098-7.
5. PALLOT,M., MAIGRET,J-P, BOSWELL,J., DE JONG,E. 2000 – "*EPICE: Realising the Virtual Project Office*". In: Proceedings of the 6th International Conference on Concurrent Engineering. Toulouse, France 28-30 June, pp. 57-70. ISBN 0-9519759-9-4.
6. CAMARINHA-MATOS,L.M., AFSARMANESH H. 2000 – "*The Virtual Enterprise Concept*". In: Infrastructures for Virtual Enterprises. Networking Industrial Enterprises". Edited by: Luis M. Camarinha-Matos and Hamideh Afsarmanesh. Kluwer Academic Press, pp. 3-14. ISBN 0-7923-8639-6.
7. AFSARMANESH,H., GARITA,C., UGUR,Y., FRENKEL,A., HERTZBERGER,L.O. 2000– „*Federated Information Management Requirements for Virtual Enterprises*". In: Infrastructures for Virtual Enterprises. Networking Industrial Enterprises". Edited by: Luis M. Camarinha-Matos and Hamideh Afsarmanesh. Kluwer Academic Press, pp. 31-48. ISBN 0-7923-8639-6.
8. KATZY,B.R. 2000 – „*The Value System Designer – An Infrastructure for Building the Virtual Enterprise*". In: Infrastructures for Virtual Enterprises. Networking Industrial Enterprises". Edited by: Luis M. Camarinha-Matos and Hamideh Afsarmanesh. Kluwer Academic Press, pp. 409-420. ISBN 0-7923-8639-6.
9. TOLLE,M., VESTERAGER,J., PEDERSEN,J.D. 2000 – „*A Methodology for Virtual Enterprise Management – Results from IMS 95001 / ESPRIT 26509 Globeman21 project*". In: Proceedings of the 6th International Conference on Concurrent Engineering. Toulouse, France, 28-30 June, pp.119-127. ISBN 0-9519759-9-4.
10. STANESCU,A.M, CRISTEA,V, FLOREA,A, CURAJ,A. 2000, "*Cluster Projects to Promote Concurrent Enterprising Paradigm*", Proceedings of the 6th International Conference on Concurrent Enterprising, Toulouse, France, 28-30 June, ISBN 0-9519759-9-4.
11. ARAI,T., AIYAMA,Y., SUGI,M., OTA,J. 1999 – "*Holonic Assembly System with Plug&Produce*". In: Proceedings of the second International Workshop on Intelligent Manufacturing Systems. September 22-24, Leuven, Belgium, pp. 119-126. ISBN 90-73802-69-5.
12. BONGAERTS,L., INDRAYADI,Y., VAN BRUSSEL,H., VALCKENAERS,P. 1999 – "*Predictability of hierarchical, heterarchical and holonic control*". In: Proceedings of the second International Workshop on Intelligent Manufacturing Systems. September 22-24, Leuven, Belgium, pp. 167-176. ISBN 90-73802-69-5.
13. HATONO,I., YOSHIMURA,M., TAMURA,H. 1999– "*Knowledge Acquisition for Distributed Real-time Scheduling Algorithm Using Co-operative Co-evolutionary Genetic Algorithm*". In: Proceedings of the second International Workshop on Intelligent Manufacturing Systems. September 22-24, Leuven, Belgium, pp. 195-201. ISBN 90-73802-69-5.
14. CURAJ,A. 1998, Ph.D. Thesis "*Control of Manufacturing Systems integrated in Virtual Enterprise Framework*" Politehnica University of Bucharest.
15. KOSANKE,K., NEIL,J.C., VERDANAT,F., ZELM,M. 1998 - „*Enterprise Integration – International Consensus (EI-IC) EP 21859*". In: Proceeding of the Conference on Integration in Manufacturing, Göteborg, Sweden, 6-8 October, pp.233-243. ISBN 0926-9622.
16. FABIAN,M., LENNARTSON,B., GULLANDER, P., ANDRÉASSON,S-A, ADLEMO,A. 1998 – "*Chalmers Architecture and Methodology for Flexible Production – CHAMP*". In: Proceeding of the Conference on Integration in Manufacturing, Göteborg, Sweden, 6-8 October, pp. 720-731. ISBN 0926-9622.
17. HUNT,I., CASKEY,K., BROWNE,J., DUARTE, A. 1998 – "*LOGSME and Its Vision for the Food Industry – (Logistic to Support Continuous Improvement for SMEs in the Virtual Enterprise)*". In: Proceeding of the Conference on Integration in Manufacturing, Göteborg, Sweden, 6-8 October, pp. 599-609. ISBN 0926-9622.
18. BISCHOFF,J. 1998 – "*The Fractal Company – Success factors of a High-Performane Organisation*". In: Proceeding of the Conference on Integration in Manufacturing, Göteborg, Sweden, 6-8 October 1998, pp. 257-265. ISBN 0926-9622.
19. ALLA,H., BOBEANU,C., FILIP,F.G. 1997 "*Modelling and Simulation of Complex Production Systems using Petri Nets Based Formal Approach*", Proceedings of the 11th, European Simulation Multi-Conference, Istanbul, pp.831-838.

20. MC CLATCHEY,R. 1997 “*A Distributed Workflow and Product Data Management Application for the Construction of Large Scale Scientific Apparatus*”, NATO ASI Series F: Computer&System Sciences Vol. 164, pp. 18-34.
21. SANTORO,R. 1997 The Virtual Vertical Enterprise approach for SMEs. Proc.of the 4th International Conference on Concurrent Enterprising, Nottingham UK, pag.361-363. ISBN 0-951-9759-6X.
22. STANESCU,A.M. 1997 “*New Approach for Advanced Control in Flexible Manufacturing Systems*” Proceedings of the 11th Control Systems and Computer Science Conference, Bucharest, May.
23. STANESCU,A.M., DUMITRACHE,I., CURAJ, A. 1997 – “*Multi-Mode based System Design within Virtual Factory synergetic Framework*”. In: Proceedings of the 4th International Conference on Concurrent Engineering. Nottingham, UK, 8-10 October, pp. 173-183. ISBN 0-951-9759-6X.
24. PHILPOTTS,M. 1996 – “*An Introduction to the Concepts, Benefits and Terminology of Product Data Management*” in Industrial Management & Data Systems Journal, Vol. 4 pp. 11-17.
25. RAMANATHAN,J. 1996 – “*Process Improvement and Data Management*”, IIE Solutions, 1996 28 12, pp. 24-27.
26. FREDERIX,F. 1996 “*Planning and Scheduling Multi-Site Semiconductor Production Chains*”, IT and Manufacturing Partnership, Browne J. (Eds), IOS Press, pp.107-116.
27. SAUER,A., THONEMANN,H-G. 1996 “*The Global Engineering Network and Virtual/Extended Enterprises*”, IT and Manufacturing Partnership, Browne J. (Eds), IOS Press.
28. GEORGAKOPOULOS,D., HORNICK,M., SHETH,A. 1995 – “*An Overview of Workflow Management from Process Modelling to Infrastructure for Automation*”, Journal of distributed and Parallel Database Systems Vol.3(2) pp. 119-153.
29. VAN BRUSSEL,R., 1995 “*Architectural and system design issues in holonic manufacturing systems*“ IFAC/IFIP/IFORS Workshop in Intelligent Manufacturing Systems, Bucharest, Romania.
30. CAMARINHA-MATOS,I.M., PINHEIRO-PITA, M., RABELA,R., BARATA,J. 1995 “*Towards a taxonomy of CIM activities*” International Journal of Computer Integrated Manufacturing, vol.8, N.3, pp160-176.
31. KIDD,P.T. 1994 “*Agile manufacturing*” Addison-Wesley Publishing Company.
32. RAULEFS,P. 1994 “*The Virtual Factory*” Proceedings of the 13th World Computer Congress, vol. 2, Brunstein K., Raubold E. (Editors) Elsevier Science B.V. pp.18-32.
33. LIN,G.Y. 1993 “*Distributed Production Control for Intelligent Manufacturing Systems*“ Ph.D. Thesis Purdue University, West Lafayette, May.
34. MENGA,G., ELIA,G. 1993 “*Object Oriented Design of Flexible Manufacturing Systems*“, Advanced Researches in Manufacturing, ch.12, pp.315-341, Mc-Graw Hill, New York.
35. LEVIS,A.H., SLUSKY,S.L., 1990 “*Migration of Control in Decision Making Organisations*”, Information Decision Technology, No.15.