SURVEY PAPER ON MANUFACTURING PLANT CONTROL CHALLENGES AND ISSUES

Morel Gérard, Valckenaers Paul, Faure Jean-Marc, Pereira Carlos, Diedrich Christian

gerard.morel@cran.uhp-nancy.fr, paul.valckenaers@mech.kuleuven.ac.be
jean-marc.faure@lurpa.ens-cachan.fr, cpereira@eletro.ufrgs.br
christian.diedrich@ifak-md.de

Abstract: Enterprise-control system integration between business systems, manufacturing execution systems and shop-floor process-control systems remains a key issue for facilitating the deployment of plant-wide information-control systems for practical e-Business-to-Manufacturing industry-led issues. This achievement of the Integration-in-Manufacturing paradigm based on centralized/distributed hardware/software automation architectures is shifting by the Intelligence-in-Manufacturing paradigm addressed by the IMS industry-led R&D initiative in order to define and to experiment the next generation of manufacturing systems capable to cope with the high degree of complexity of meeting agility over flexibility and reactivity in customized manufacturing. This survey paper of the TC 5.1 summarizes these key problems, trends and accomplishments for manufacturing plant control before to emphasize for practical purposes some rationales and forecasts in deploying automation over networks, HMS and its related agent-based technology, as well as in applying formal methods to ensure dependable manufacturing.

Keywords: Manufacturing Plant Control, Automation over Networks, Intelligent Manufacturing Systems, Dependable Manufacturing Systems, Education

1. MANUFACTURING PLANT AUTOMATION CONTEXT

The manufacturing enterprise is intensively deploying a host of hardware/software automation/information technologies (Ollero, *et al.*, 2003) in order to face the changing societal environment pulled by the increasing customization of both goods and services as desired by customers.

Legacy models and standards[1][2] enable manufacturing enterprise-control system integration (table 1) from the business level to the process level in order to meet industry-led B2M (Business-to-Manufacturing) issues (Morel *et al.*, 2003).

Table 1: Enterprise-Control System Integration in Manufacturing

	B2M Systems Integration
CRM	Customer relationship management
SSM	Sales services management
APS	Advanced planning system
SCM	Supply chain management
ERP	Enterprise resources planning
MES	Manufacturing execution system
SFC	Shop floor controls
MECHS	Mechatronic systems
MEMS	Micro mechanical systems
AUTO-ID	Automatic identification

The resulting automation model (fig. 1) is a wide network of automata which is challenging researches and developments in order to achieve synchronic integration (in time) of shop-floor process-controls in large (robotics, assembly, machining, …) into plant-wide information-control systems and diachronic integration (through time) of products life-cycle over

[1] www.mesa.org; www.omg.org/mda ;

[2] IEC62264, 61499, 61131 ; www.opcfoundation.org ; www.mimosa.org ; www.isa.org

the manufacturing chain, as addressed by the IiM (Integration in Manufacturing) paradigm.

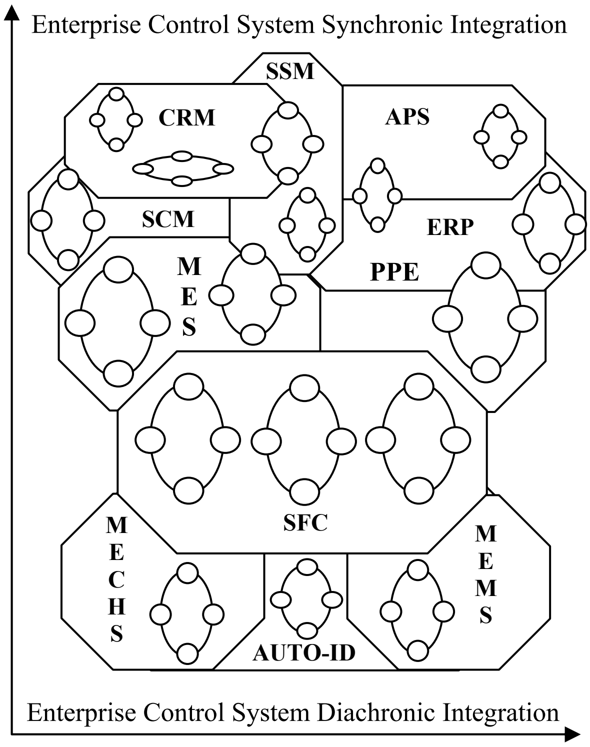

Fig. 1: IiM plant-wide automation context

Despite web-enabled technologies are strengthening distributed automation in manufacturing (Banaszak and Zaremba, 2003), only a form of technical intelligence that goes beyond simple data through information to knowledge and is embedded into manufacturing systems components and within the products themselves will playing a prominent role as the pivotal technology that makes it possible to meet agility in manufacturing over flexibility and reactivity.

This complexity of efficiently deploying interoperability and autonomy for manufacturing plant control and production management issues is challenging the industry-led international IMS[3] initiative in order to define and to develop the next generation of open, modular, reconfigurable, maintainable, and dependable manufacturing systems.

Among many rationales, trends and experiments addressed by this shifting IiM (Intelligence in Manufacturing) paradigm (Morel and Grabot, 2003), a general consensus exists that HMS (Holonic Manufacturing System) should be the unifying technology as well as PPE (Product-Process Engineering) approach for all product-driven control and management issues required by the customized manufacturing era.

The IFAC TC 5.1. is contributing to raise up theses challenges through sponsoring 2 workshops on Intelligent Manufacturing Systems (Monostori *et al.*, 2003) and Intelligent Assembly & Disassembly (Borangiu, 2003) and a Symposium on Information Control Problems in Manufacturing (Pereira *et al.*, 2004) as well as by a continuing collaboration with the IFIP WG 5.7, the European IMS Network of Excellence and the Brazilian MANET Network of Research.

Next section deals with a synthesis of the current key problems/applications and the recent major accomplishments/trends addressed during INCOM'04 for manufacturing plant control.

Following sections describes the field of interest and the roadmap of the 3 TCs' working groups on *Networked Controlled Manufacturing Systems*, *Intelligent Manufacturing Systems* and *Dependable Manufacturing Systems*.

Conclusion state with main research and development forecasts in the field of advanced manufacturing automation.

2. MANUFACTURING PLANT CONTROL ISSUES

The main purpose of INCOM'04 has been to point up international researches and developments dealing with all the applications of automation, information and communication technologies in order to control and to manage the manufacturing plant within the e-enterprise. This general scope involves all methodological and technological aspects to digitally control with more agility the entire manufacturing chain, from supply and design through manufacturing, to maintenance and service, over the whole product and processes life cycle. INCOM'04 has been attended by about 160 scientists and mainly organized around 6 technical tracks introduced by 7 keynote speeches under track chairs ensuring the scientific relevance of 6 Manufacturing Plant Control areas. Research networks presentation, poster sessions and panel discussions have completed this core technical programme reviewed by a panel of 170 relevant scientists and industrialists. Major key issues and trends pointed up at INCOM'04 are presented below and strengthened by relevant works in the area of manufacturing plant control.

2.1. Production & Logistics over Manufacturing Networking

Nof, from CC5 chair and Purdue University (USA), addressed *the state of the art and challenges of collaborative e-work and e-manufacturing for production and logistics managers*. This plenary keynote and sessions on *Cooperative Manufacturing and Design* and *Manufacturing Modelling Issues* emphasized that e-manufacturing is highly dependent (fig. 2) on the efficiency of collaborative man-man and Human-machine e-work.

Even if e-work and e-manufacturing enable new applications for intelligent control techniques, invited session on *Modelling and Benchmarking Issue for B2M Systems Interoperability,* jointly organized with the IFAC TC 5.3, the IFIP WG 5.7 and Re-

[3] www.ims.org

search Networks on IMS, UEML and INTEROP[4], strengthened the closed-loop between engineering and manufacturing (Lhote *et al.*, 1999) and the two-dimensions integration of manufacturing automation (Galara and Hennebicq, 1999).

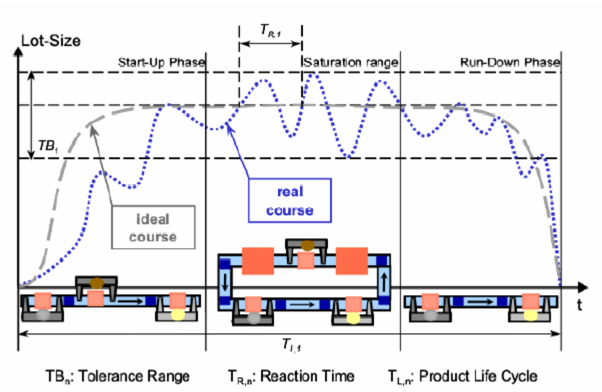

Fig. 2: Customizing effect on the product life cycle (Lepratti and Berger, in Pereira *et al.*, 2004).

Interoperability deals with reference models for both vertical (synchronic) integration through IEC/ISO 62264 standard for B2M applications and through IEC 61499 standard for SFC applications as well as with horizontal (diachronic) integration through e-manufacturing de facto standards for SCM and CRM applications. Interoperability deals also with ubiquitous computing technologies to enable unique product identification in order to ensure the coherence between the physical flows of goods and the related information flows of services throughout the products life-cycle.

Benchmarking techniques deal with R&D project-driven engineering in order to capitalize knowledge and experience to cope with the performance evaluation of these large-scale integrated-distributed manufacturing and logistics systems.

All these approaches emphasized the increasing scalability of manufacturing plant control issues and the need of specializing UML as a unifying modelling framework for all e-work and e-manufacturing purposes.

2.2. E-Manufacturing Technologies and Facilities

Lee, from the NSF industry/university cooperative research centre on Intelligent Maintenance Systems (USA)[5], addressed *infotronics technologies and predictive tools for the next generation of maintenance systems* in order to move from traditional 'fail and fix' to 'predict and prevent' practices. Among many rationales to assess and to predict the performance degradation (Leger and Morel, 2001) of a process, a machine or a service is to merge on-site and remote infotronics components in closed Device-to-Business (D2B) loop (fig. 3).

Embedded accurate algorithms improve the precision of customized information in order to enable the prognostic of when the performance is becoming unacceptable, the diagnostic of why the performance is degrading and the decision of what maintenance action to perform as well as the performance benchmarking coming from similar operating *Watchdog Agents*™.

This plenary keynote and sessions on *Methods and Technologies towards E_Maintenance* and *Remote Experiments for e-learning (Virtual Laboratories)* strengthened web-technology as enabler of D2B integration for applications ranging from preventive condition-based maintenance (CBM) through collaborative product life-cycle management (CPLM) to cooperative learning.

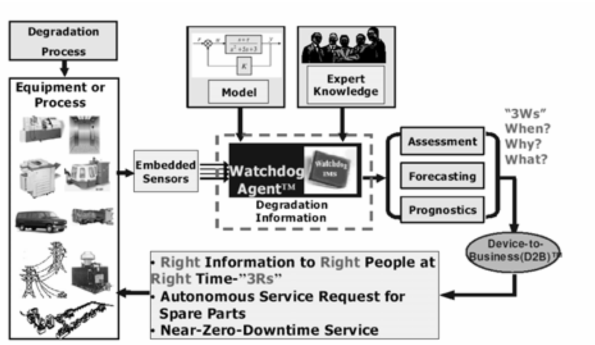

Fig. 3. : Intelligent Maintenance Systems (Lee, in Pereira *et al.*, 2004)

However, the efficient use of these promising mechatronics and infotronics technologies is highly dependent of dealing with the complexity to intelligently combine a host of existing techniques for a global performance rather than a local one, as outlined by Lee to launch a Science of Maintenance over traditional monitoring, diagnosis and prognosis disciplines.

2.3. Hybrid/Discrete Event Systems in Manufacturing Automation

Zaytoon, from TC 1.3 and Reims University (FR), addressed *the state of the art of analysis of hybrid system* to emphasize that manufacturing systems are hybrid systems by nature because their modelling and control requires the combination of both continuous and discrete event-based models. The development of systematic methods dealing with issues related to modelling, specification, analysis, verification, control synthesis, and implementation., is of high interest to engineer manufacturing systems as hybrid systems in industry but represents still a challenge for both computer and automation scientists.

Sessions on *Design and control synthesis of DES* and *Petri nets based approaches* emphasized applications rather reduced to Shop Floor Controls, although some works applied formal approaches to deal with Hybrid/DES modelling throughout time as required at the MES level.

Others promising works are addressing the interest of formal techniques for e-MES issues (Qiu *et al.*,

4 www.ims-noe.org; www.ueml.org ; www.interop-noe.org
5 www.imscenter.net

2004) in order to formally incorporate shop floor controls into plant-wide information-control systems for enabling 'on the fly' rescheduling of product routes as well as manufacturing processes reconfigurability (Tang and Qiu, 2004).

This trend should be strengthened to cope with the lack of DES modelling approach to formally implement auto-ID technology (fig. 4) as an issue for life-cycle product-instance tracability addressed by manufacturing legacy rules evolution.

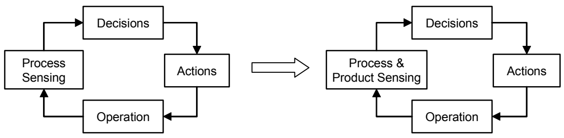

Fig. 4. Moving from process-driven control to product-driven control (Mc Farlane, in Morel and Grabot, 2003)

2.4. Education and Training

Collaborative e-work is addressing in industry the need for agile workforce in competitive organizations and in university the difficulties high-level students when learning about complex systems phenomena.

As any engineer is first a student or a trainee, there is a critical educational and training need for teachers to help these learners to accept and to understand IiM paradigms complexity in order to cope with the increasing complication of automation/information-intensive technologies.

Erbe, from TC 4.4 and TU Berlin (DE), emphasized learning environments in an invited session on *Remote Experiments for e-learning (Virtual Laboratories)* where on-site and remote components merge into a cooperative learning process in order to bridge reality and virtuality (fig. 5.).

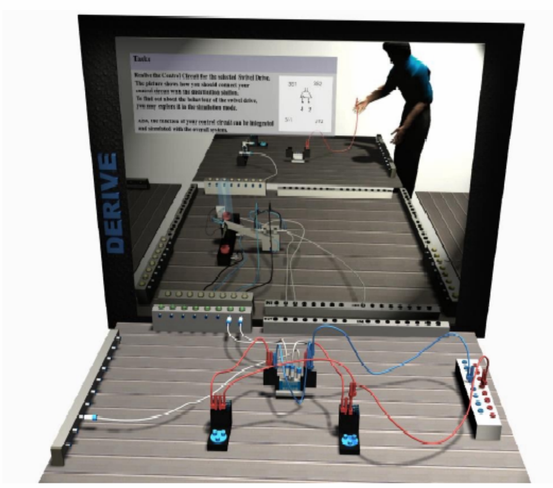

Fig. 5 : Real and virtual environment for training in electro-pneumatics to control a Robot-Arm (Bruns and Erbe, in Pereira *et al*., 2004)

This e-learning low-cost evolution of previous CIM[6]-training concept enables to put trainers and trainees in a mixed situation over idealized computer-simulation to get the stepwise abstraction and concretization of technical system complexity.

3. MANUFACTURING AUTOMATION OVER NETWORKS

Fogliazza, from MCM S.p.A. (IT), addressed *how information technology enables the potential flexibility and reconfigurability of highly automated manu facturing plants.* This plenary keynote emphasized the value-adding of the strong collaborative integration between mechanical, automation and software engineering in order to encapsulate practical skills into mechatronic components. This software/hardware value creation chain in industrial automation systems has been strengthened by Vyatkin in order to address standardised object-oriented automation engineering (fig. 6).

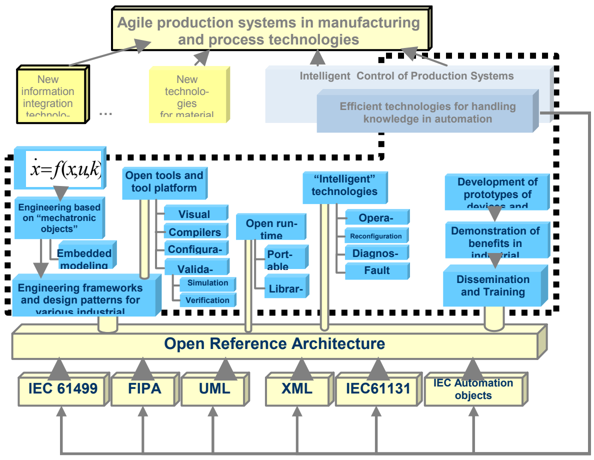

Fig. 6: IMS-OOONEIDA[7] R&D framework (Vyatkin, in Pereira *et al*., 2004)

As complementary, Neumann, from IFAK (DE), addressed *what is going on communication in industrial automation.* This plenary keynote an invited session on *real-time distributed embedded systems* and a regular session on *networked controlled systems* emphasized the increasing impact of networking on manufacturing automation but strengthened also that networks could be its Achille's heels if not well controlled.

3.1. Current key problems

Embedding a distributed technical intelligence (data/information processing, storage and communication) into field automation has been largely experimented in order to enable actuation and measurement systems interoperability as well as to ensure control, maintenance and technical management system integration (Iung et al., 2001). This requires field device meta-models to integrate the devices in the entire engineering life cycle of the automation systems. Vertical communication in the control level

[6] www.aip-primeca.net
[7] www.oooneida.info

and horizontal communication between the factory hierarchy has to be managed additionally. Another major technological challenge of the development of distributed embedded systems is to guarantee both the reliability and the temporal predictability of the underlying software and hardware infrastructures, which must be flexible enough in order to easily accommodate the requirements imposed by new applications and services.

These R&D confirm the limits of the traditional centralized-architecture hierarchical-model control-approaches (Table 2, level 2, 3) to meet distribution in automation and the interest of a standardized object-automation oriented approach to design distributed automation architectures. UML, the de-facto industrial Unified Modelling Language, has all means which have to be limited to meet the automation needs. There are several so called UML profiles on the road which specialize UML for real time, safety/dependability. Special profiles are provided by the OMG which have to be evaluated carefully, such as:

- Profile for Scheduling Schedulability, Performance, and Time Specification.[8]
- Profile for Modelling Quality of Service and Fault Tolerance Characteristics and Mechanism.[9]

3.2. Recent major accomplishments & trends

Networked Controlled Systems should integrate all new technologies such as wireless networks, embedded systems, nomad components and electronics tags in order to enable to meet new requirements such as mobility, modularity, control and diagnosis decentralisation and/or distribution, autonomy, redundancy, quick and easy maintenance.

As a major industrial communication challenge of the related multilevel communication architectures is to unify plant networking with Ethernet, the resulting automation challenge is to guarantee the same deterministic features that those of more specific field buses currently involved in shop floor manufacturing.

That opens a new field of applications for intelligent control techniques in order to model, evaluate and optimise the communication system behaviour within distributed automation architectures.

As example, applying FDI/FTC techniques to networked controlled systems should improve safe control and monitoring of such automation complex systems as well as their global reliability, dependability and availability by dynamically accommodating the network performance, reconfigurating the networks components and adapting the application to the delivered quality of service (fig. 7).

The hugh investment in ethernet based industrial communication of the main indusrial players (e.g. PROFInet by Siemens, Industrial IP by Rockwell, Modbus IP by Schneider, ...) are a challenge for the research because large distributed systems with new characteristics and new opportunities are built. These systems have to be configured, parameterised, operated and maintained with real time, safety and security constraints.

3.3. Forecasts

INCOM'O4 revealed the importance of launching a new Working Group in Networked Controlled Manufacturing Systems in order to gather automation and communication communities to face this new field of interest for automatic control. In detail real time constraints, safety and security are the main requirements for the new architectures and technology combinations.

In future times specific industrial communication means and other commercial communication systems such as telecommunication for maintenance and remote access or private networks can become components of the systems. These systems crossing intranet borders or crossing WANs are virtual automation networks (VANs) with new quality of services and new management tasks.

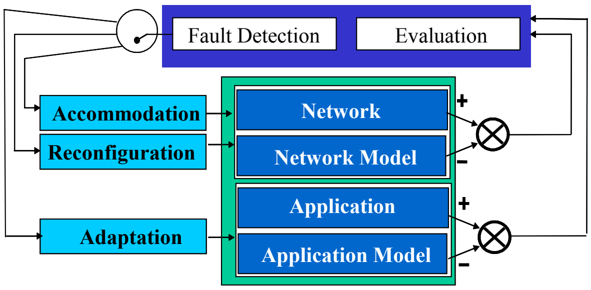

Fig. 7 : Quality Of Service (QoS) of a Networked Controlled System Tolerant to Faults (Divoux, in Pereira *et al*., 2004)

4. IMS MODELING AND EXPERIMENTS

Marik, from Rockwell Automation and the Czech Technical University (CZ), addressed the state of *industrial applications of the agent-based technology*. This plenary keynote emphasized that traditional and centralized approaches are not adequate to cope with the high degree of complexity and practical requirements for robustness, generality and reconfigurability in manufacturing control as well as in production management, planning and scheduling.

Sessions on *IMS engineering trends and issues* and on *B2M performance issues* emphasized that MAS paradigm coming from Distributed Artificial Intelligence and HMS paradigm coming from the IMS community are promising approaches but strengthened that only very few real-life industrial experiments are in use despite laboratory experiments (Cheng *et al*., 2004)

[8] http://www.omg.org/docs/formal/03-09-01.pdf
[9] http://neptune.irit.fr/Biblio/02-01-02.pdf

4.1. Current key problems

Today, the key problem is of the lack of tools and/or platforms to test and validate IMS developments on realistic problems, both in terms of size of the manufacturing system itself and the thoroughness of the evaluation campaign itself. Concerning advanced manufacturing control, conceptual designs exist that address the major research issues at least in principle, for instance (Valckenaers, in Morel and Grabot 2003). The complexity of these system designs makes formal proof of their performance and capabilities infeasible and definitely unpractical.

Therefore, an environment is required in which the research community can provide and retrieve (emulated) test cases of realistic size and complexity; in other words, research developments need to be tested on real-world factories (in emulation). Moreover, the evaluation campaign must answer industrial requirements, which typically implies that test runs must cover several months of production. Evidently, the IMS designs need to be properly designed to allow drawing hard conclusions from test runs; for instance, a manufacturing control system design must randomize parameters and decisions as a default.

The IMS Network of Excellence[10] has started to make such an environment available for advanced manufacturing control and supply network coordination. (Valckenaers in Pereira *et al.* 2004) describes the development status and roadmap for this research effort.

Such testing and evaluation platforms (fig. 8) will enable researchers to generate solid proof-of-concepts for their research results with normal levels of development efforts and resources. Today, toy test cases and token evaluation campaigns are the norm; this needs to be remedied.

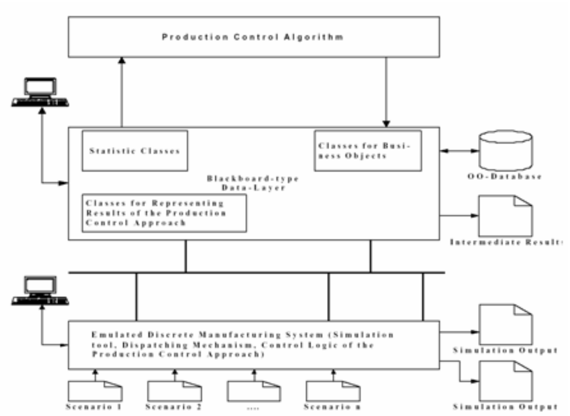

Fig. 8 : Factory and IMS emulation for proof-of-concepts (Mönch, in Pereira *et al*., 2004)

Secondly, there is a need for better and deeper understanding of scale-ability and robustness, typically only achievable through designs that use emergence and self-organization. These designs give up the ability to explicitly prescribe how the system will behave in return for a significant increase in operating range.

The analogy in human organizations is to replace explicitly prescribed procedures (cooking book rules) by empowerment of the people performing the work. It is well known that empowerment produces superior results, given adequately skilled personnel. This shift toward empowered element in an IMS system need further research, producing deeper insight on how this shift can be executed and what benefits can be expected. In other words, better understanding of the concepts of emergence and self-organization are needed, especially from the perspective of designing such systems (synthesis of IMS artefacts).

Finally, research needs to address information handling in sophisticated IMS designs, with trace-ability as a primary concern. Manufacturing control systems already provide the potential to address this issue, but this need to be brought to the surface, and the needs for additional support that transpire must be answered.

4.2. Recent major accomplishments & trends

Recently, research on applying multi-agent systems in manufacturing has produced many valuable results. However, various obstacles for deployment in industry remain. Often, these obstacles require multi-disciplinary solutions, in which for instance the manufacturing system design and the manufacturing control both are conceived to offer flexibility, robustness, scale-ability and cost-effectiveness.

Likewise, advanced designs for multi-agent manufacturing control have emerged, promising to address many issues. However, a definitive proof-of-concept requires the developments described above. Initial steps to provide such missing link have been taken already and key elements of the solution already exist (e.g. suitable emulation technology).

These advanced designs give up functional decomposition in favour of an object-oriented design approach in which a reflection of the world of interest in the software of the control system plays a prominent early role, much like maps are key elements in solving navigation problems. The PROSA architecture (fig. 4) is an illustration of this trend (Van Brussel *et al*., 1998). The object-oriented approach is extended in a multi-agent approach (active objects reflect active entities in the manufacturing system) and by novel coordination mechanisms inspired by insect societies. Through an emergent and self-organizing design, such systems promise robustness and scale-ability. In contrast to older research based on market-mechanisms, it is not necessary to reduce the dimensions of the information in the system, and many tuning problems are avoided. The novel designs postpone the introduction of the decision-making software components until the end. Therefore, the re-usability and operating range of the system increases significantly.

10 www.ims-noe.org

4.3. Forecasts

The area of intelligent systems has generated a considerable amount of interest - occasionally verging on controversy - as well within the research community as in the industrial sector. Intelligence-in-Manufacturing is perceived in various ways ranging from intelligent control and information/communication techniques through Human intelligence in the operating/engineering loop to agents self-organisation. Actions for an annual multi-conference have been initiated to get a smaller number of events from IFAC, IFIP and the IMS community but with more critical mass in order to scientifically found this sound IiM paradigm for the next generation of manufacturing systems.

5. DEPENDABLE MANUFACTURING SYSTEMS CONTROL

Johnson, from GE Global Research, addressed *what role of formal methods for improving automation software dependability*. This plenary keynote, an invited session on *applications of formal methods on industrial controllers software dependability* and a regular session on *design and implementation of dependable systems* emphasized several new trends in industrial manufacturing systems control acting directly upon availability, safety and security. Safety for human beings and for industrial investments become key factors because of international accepted rules. The request for safety certified products has increased by app.30 % in Germany over the last 3 year.

5.1. Current key problems

First the fast pace development of computer-based controllers impacts strongly manufacturing systems dependability. Johnson outlined that the threat now could be that software dependability may limit further automation progress at the enterprise level in spite of very high dependability at the unit operation level (fig. 9).

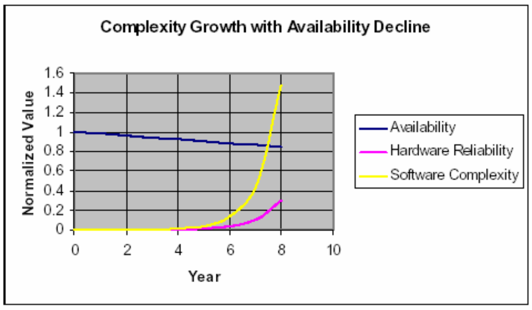

Fig. 9: Scenario of Software Complexity Growth and System Availability Decline (Johnson, in Pereira *et al.*, 2004)

In a similar way, the increasing use of networked control systems within factories and enterprises can increase or decrease systems dependability depending on the fashion in which networks have been designed and set-up. Ethernet TCP/IP based networked control systems, for instance, ease the access to process data and hence enable new monitoring, diagnosis and maintenance functionalities. However a question arises immediately: is the traffic increase coming from these new functionalities compliant with the reactivity constraints required for the application ? If it is not the case, how to route this new traffic? Moreover that kind of networked control systems impacts security for providing potential means to disturb or to damage the systems.

Another current trend is the growing importance of safety/dependability-related standards when designing industrial controllers. These standards may be domain dependant (specific standards for railway transport, power plants, …) or may cover a wider scope, like the IEC 61508 standard (Functional safety of E/E/PE safety/related systems) that introduces a safety life-cycle model and the concept of SIL (Safety Integrity Level).

At last, dependability becomes a major concern even for managers, because current economical constraints ask for increasing availability whilst the demand on the part of society to better control technological risks requires accurate safety analysis. As managers focus continuously to cost control and claim often that dependability improvement leads to too expensive systems, development of new design processes that address both cost and dependability concerns is therefore a challenging issue. The work presented in (Papadopoulos and Grante, in Pereira *et al.*, 2004) that combines semi-automatic safety and reliability analysis with multi-criteria optimization techniques to assist the gradual development of designs that can meet reliability and safety requirements within pragmatic cost and profit constraints is a good example of such a process.

5.2. Recent major accomplishments & trends

To face these new problems, a WG named Dependable Manufacturing Systems Control (DMSC) has been set-up within TC 5.1 after a panel session at B'02. This WG gathers academic and industrial researchers that aim at developing sound methods, models and tools enabling to improve systems dependability.

The main concerns of this WG are the following:

- *Dependability analysis must be carried out with a system engineering view*. This amounts to say that we are not focusing only on process safety or on control software dependability, but that our works are structured by the automation paradigm (Fusuoka, 1983) as stressed for performance-oriented system automation (fig. 10)
- *Dependability must be taken into account as from requirements expression and all along the system life-cycle.* This can be achieved by using semi-formal models that are provide by UML. Starting with the requirements down to the implementation with integrated verification and test steps along the software driven V model can be applied (Diedrich in Pereira et al, 2004). This im-

plies also to bridge the gap between conventional dependability analysis methods (fault-tree analysis, FMECA, ….) and emerging formal methods for Proof-based System Engineering (Morel *et al.*, in Zaremba *et al.*, 2004) as well as between industrial practices for dependability assessment and/or improvement (simulation techniques, test, …) and these formal methods.

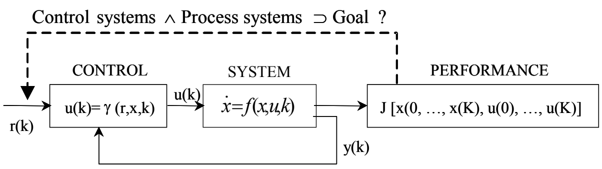

Fig. 10: A closed-loop system modelling with system performance optimization rather than control performance optimization (Morel, in Erbe, 2003)

First panel discussions pointed out some key issues:

- Use of formal or semi-formal analysis and synthesis methods for design, implementation and validation of system components and communication systems,
- Use of formal or semi-formal analysis and synthesis methods on industrial size examples,
- Impact of networked control systems on manufacturing systems dependability,
- Improvement of faults forecasting methods thanks to formal temporal analysis (introduction of temporal logic in faults forecasting methods),
- Improvement of design methods for fault-tolerant systems thanks to formal methods,
- Reconfigurable systems design; mode management,
- Definition of metrics for dependability, safety and security.

5.3. Forecasts

The high scientific quality of the audience attending this INCOM'04 area strengthened that a core community should be gathered and it seems quite realistic to enlarge the audience of the works.

It is the reason why the DMS WG is organizing at IFAC WC'05 sessions dealing with *Dependable manufacturing systems control* and *Recovery and control adaptation for DES*. At last, the DMS WG intends to organize an IFAC Workshop dealing with the WG issues in 2007. The program committee of this workshop will gather both TC 5.1 members involved in this WG, members of IFAC TC 1.3 (Discrete event and hybrid systems) and 6.4 (SAFEPROCESS) concerned by the WG issues as well as high quality researchers who are currently developing research works closely related to the WG topics of interest.

6. FORECASTS IN MANUFACTURING PLANT AUTOMATION

One main rationale issue is to put into question the hierarchical/Integrated vision of the Enterprise-wide control for a more Interoperable/Intelligent one by postulating the customized product as the 'controller' of the manufacturing enterprise resources (fig. 11).

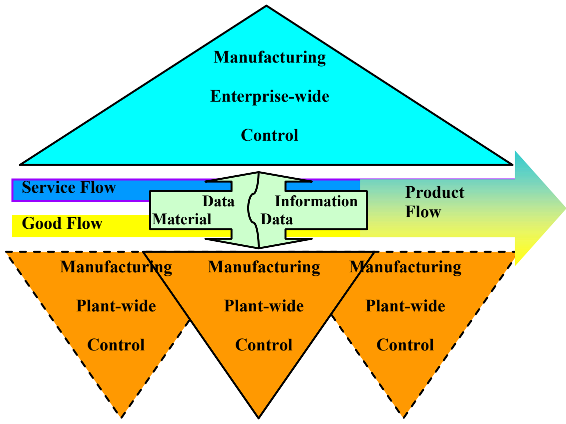

Fig. 11: Product-driven Manufacturing Enterprise-wide Control

Another rationale issue should be to better control Information and its related Communication Technology which is rushing about all directions in Manufacturing Plant-wide Automation in order to prevent dependability concerns in the near future.

Among many others rationale issues which should be debated, learning complexity of such automation-wide systems should challenge with more holism the Education & Training community.

6.1 e-Manufacturing Execution Systems

One main area in which significant development is to be expected in the foreseeable future is the domain of the *e-Manufacturing Execution System.* The reason behind this is an explosion of enabling information technologies among which wireless technology like RFID is a prominent example.

Manufacturing execution is a complex task because of the non-linear nature of the underlying production system, the uncertainties stemming from the production processes and the environment, and the combinatorial growth of the decision space. Schedules and plans, originating from higher levels in a manufacturing organization, are known to become ineffectual within minutes on a factory floor. Manufacturing is a very dynamic environment and handling changes and disturbances is high on its list of research challenges. Moreover, the range of existing manufacturing system types and the performance issues therein as well as the different kinds of equipment and processes is very wide. This heterogeneity is challenging as well.

To cope with these challenges, future manufacturing execution system designs need to apply the most fundamental and recent insights in self-organising systems, a topic that is intensely investigated by the multi-agent systems community today (Di Marzo *et al.*, 2004).

To design such self-organising systems (Table 2, level 5), it is also essential to apply insights from fundamental research (Waldrop, 1992; Valckenaers, in Morel and Grabot, 2003) and to define the related modelling framework in order to meet the required system features (Table 2).

Important progress in the domain, which can be expected, is the emergence of manufacturing execution systems that are able to emergently forecast the state of the underlying manufacturing system while preserving the level of decoupling that has made older multi-agent manufacturing execution systems robust and configurable (Valckenaers *et al*., 2004).

These recent and ongoing developments finally promise to deliver the best of both worlds: the planning ahead in time of centralised older solutions and the ability to cope with real-factory dynamics of the self-organising multi-agent systems.
In addition, enabling technologies bring the above research results closer to actual deployment. Tracking technologies such as RFID provide the eyes for the manufacturing execution system. Omnipresent networking and web technologies provide communication and actuation. Modern PLC and industrial PC designs support the deployment of multi-agent systems developed in higher-level programming languages. Moreover, customer requirements impose demands that render products with a trace of their production history worthless.

Open research issues remain however. First, the cooperation amongst high-level planners and schedulers and the manufacturing executions systems is virtually unexplored. Secondly, scaling the MES technology to multi-site manufacturing coordination and control only is in the initial stages of research.

Furthermore, the development of a comprehensive methodology and theory for the design, implementation and deployment is in its infancy. Overall, the future holds a multitude of challenging research activities in this domain.

Table 2: Capability Profile between system architecture feature and the related theoretical and technical modeling framework (Morel et al., 2003)

System Architecture Feature	Theoretical & Modelling Paradigms
5. Intelligent	Kenetics & MAS & HMS
4. Interoperable	Cognitics & Ontology & Object-Oriented
3. Integrated	Systemics & Systems Engineering
2. Hierarchical	System Theory & Automatic Control
1. Isolated	Empiricism & Ad hoc approach

6.2 Dependability improvement thanks to formal methods

Manufacturing systems dependability is a more and more crucial concern for companies' managers, who focus mainly on systems availability assessment and increase and on compliance to safety-related standards, as well as for the society in general that demand always safer systems. Hence, dependability improvement, that implies to take into account these significant, though often antagonist concerns, becomes a challenging issue.

Despite of the numerous methods (FMECA (Failure Modes, Effects and Criticity Analysis), FTA (Fault Tree Analysis), …) that have been developed to improve systems dependability since the 60's, the increasing complexity of to-day manufacturing systems, that embed lots of processors, different kinds of networks, and that are strongly constrained by production objectives, leads to look for more formal methods enabling automatic dependability analysis and facilitating dependability improvement.
Formal methods based on DES (Discrete Event Systems) theory seem able of bringing solutions to this problem. During the last ten years indeed, research works on DES verification, on supervisory control synthesis, on DES identification and diagnosis have delivered promising results that look useful for dependability improvement. As mentioned in (Faure and Lesage, in Kopacek *et al.*, 2001), these methods may be ranked into two categories: off-line dependability and on-line dependability, with a life-cycle criterion.

The purpose of the *Off-line dependability* methods is to minimize the fault risk during design and implementation, i.e. before the system is used. Properties proof using model-checking techniques (Berard *et al*., 1999), dependable controllers design thanks to supervisory control theory (Ramadge and Wonham, 1987) are examples of such methods.

On the other hand, the objective of the *On-line dependability* methods is to ensure that an already implemented and running system is dependable. DES fault detection and diagnosis, reconfiguration techniques and fault tolerant control are means to reach this objective.

Nevertheless current results of these research works are mainly theoretical and have been generally tested on small-sized case studies (toy problems). Moreover none of these approaches is able of providing a global solution and very few works have attempted to look for potential links between these methods and existing industrial practices.

There is therefore a need for new research works aiming at making available for automation engineers these results on formal methods for DES.
The list below sketches some prospects for such works:

First of all, scalability of formal methods must be tested on industrial size examples. It is quite impossible to claim that a given method provides a solution for improving dependability without taking into account technological features of manufacturing systems components as well as industrial constraints when applying this method. The works presented in (Flordal *et al.*, in Pereira *et al*., 2004), that uses the Ramadge-Wonham supervisory control theory to design the controller of robots cells in the form of PLC code, and in (Roussel et al., 2004), that develops a specific algebraic synthesis method for industrial controllers design, are good examples of industry-oriented researches.

- Another interesting prospect is coupling several formal methods so as to build toolboxes for dependable systems design and implementation. Using in a convenient way formal verification and formal synthesis techniques for instance would surely increase the potentialities of both approaches. In a similar way, diachronic integration between fault forecasting, providing some formal models of faults are built during this step and diagnosis could be a challenging issue.

- There is a huge need for bridging the gap between industrial practices and formal methods (Morel *et al*, 2004). Acceptance of industrial users will be obtained indeed only if these last ones are integrated within a computer-aided framework for dependability that should embed and automate existing industrial techniques, such as FTA and FMECA.

- At last, focus shall be put on researches dealing with probabilistic modelling of DES. Probabilistic model checking, a formal verification method for the analysis of systems that exhibit a stochastic behaviour (Kwiatkowska *et al.*, in Pereira *et al.*, 2004) is for instance a promising technique for assessing and for improving systems dependability.

6.3 e-Education & Training

Any operational system emerges in real-life from an ad hoc combination of formal, informal and intuitive issues by combining top-down approaches with bottom-up ones.

Systems Engineering (SE)[11], as the normative document-driven process for Engineering a System, is emphasizing the industrial needs to bridge the interdisciplinary context of a real SE project with the disciplinary context of an academic programme.

This is challenging the University community in order to promote holistic issues based on Model Driven System Definition, Development and Deployment approaches and on collaborative e-work environments (Table 2, levels 3 & 4).

Another challenge, addressed by the Agile Manufacturing Enterprise, should be to adapt XP-like approach currently applied in agile software development (fig. 12) in order to facilitate face-to-face learner-to-learner teacher-to-learner collaborative e-work reproducing complex engineering situations with lower means (Table 2, levels 4 & 5).

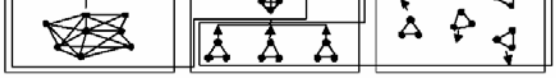

Fig. 12 : Large-Scale Project Engineering approaches (Rumpe and Scholz, 2002)

11 www.incose.org ; EIA 632

REFERENCES

Banaszak Z., Zaremba M. (Eds.) (2003). Special issue on Internet-Based Distributed Intelligent Manufacturing Systems. *Journal of Intelligent Manufacturing*. **14/1**.

Berard B., Bidoit M., Finkel A., Laroussinie F., Petit A., Petrucci L., Schnoebelen P. (1999). *Systems and Software Verification: Model-Checking techniques and tools,* Heidelberg, Springer-Verlag Editions, ISBN : 3-540-41523-8.

Borangiu T., (2003). (Ed.) Intelligent Assembly and Disassembly. *Proceedings of the 3rd IFAC IAD'03 Symposium*. Bucarest, Romania, October 11-13.

Cheng F-T., Chang C-F., Wu S-L. (2004). Development of Holonic Manufacturing Execution Systems. *Journal of Intelligent Manufacturing*. **15/2**, 253-267.

Diedrich Ch., Wollschlaeger M., Riedl M., Simon R. (2001) Three Component Model for field device integration in control systems. *Proceedings of IFAC FET'01Conference on Fieldbus Systems and Their Applications,* Nancy, France.

Di Marzo Serugendo G., Karageorgos A., Rana O.F., Zambonelli F. (2004) (Eds.) Engineering Self-Organising Systems, Nature-Inspired Approaches to Software Engineering. *Lecture Notes in Computer Science and Artificial Intelligence*, **2977**, ISBN: 3-540-21201-9

Fusaoka A., Seki H., Takahashi K., (1983). A description and reasoning of plant controllers in temporal logic. *Proceedings of the 8th International Joint Conference on Artificial Intelligence,* 405-408, Karlsruhe, Germany.

Erbe H.H., (2003). Technologies for Cost Effective Automation in Manufacturing, *IFAC Professional Briefs*, 1-32.

Galara D., Hennebicq J.P. (1999). Process control engineering trends, *Annual Reviews in Control*, **23/1**, 1-11

lung, B., E. Neunreuther, G. Morel (2001). Engineering process of integrated-distributed shop floor architecture based on interoperable field components. *Journal of Computer Integrated Manufacturing,* **14/3**, 246-262

Kopacek P., Morel G., Zaremba M.B. (Eds.) (2001). Information Control Problems in Manufacturing. *Proceedings of the 10th IFAC INCOM'01 Symposium*. Vienna, Austria, September 20-22.

Leger J.B., Morel G. (2001). Integration of maintenance in the enterprise towards an enterprise modelling-based framework compliant with proactive maintenance strategy. *Product Planning & Control*, **12/2**, 176-187

Lhote F., Chazelet Ph. and Dulmet M., (1999). The extension of principles of cybernetics towards engineering and manufacturing. *Annual Reviews in Control* , **23/1**, 139–148

Monostori L., Kadar B., Morel G. (Eds.) (2003). Intelligent Manufacturing Systems. *Proceedings of the 7th IFAC IMS'03 Workshop*. Budapest, Hungary, April 6-8.

Morel G., Panetto H., Zaremba M., Mayer F., (2003). Manufacturing enterprise control and management system engineering: rationales and open issues. *Annual reviews in Control*, **27**, 199-209

Morel G., Grabot B., (Eds.), (2003). Intelligent Manufacturing. *Special issue of Engineering Applications of Artificial Intelligence,* **vol. 16 (4)**.

Morel G., Méry D., Léger J.B., Lecomte T. (2004). Proof-Oriented Fault-Tolerant Systems Engineering : rationales, experiments and open issues. *Proceedings of the 7th IFAC Symposium on Cost Oriented Automation*; Gatineau (Québec), Canada, 6-9 June 2004

Ollero A., Morel G., Bernus P., Nof S., Sasiadek J., Boverie S., Erbe H. and Goodall R. (2003). Milestone report of the Manufacturing and Instrumentation coordinating Committee: From MEMS to Enterprise Systems. *IFAC Annual Reviews in Control*, **26**, 151-162.

Pereira C.E., Morel G., Kopacek P. (Eds.) (2004) Information Control Problems in Manufacturing. *Proceedings of the 11th IFAC INCOM'04 Symposium*. Salvador da Bahia, Brazil, April 5 - 7.

Qiu R., Russel D. (2004). A formal model for incorporating shop floor controls into plant information systems. *Journal of Advanced Manufacturing TechnologyProduction Research,* **23,** 47-57.

Ramadge P.J., Wonham W.M. (1987). Supervisory control of a class of discrete event processes. *SIAM Journal on Control and optimisation*, **25, n°1**, 206-230.

Roussel J.-M., Faure J.M., Lesage J.-J., Medina A. (2004). *Algebraic approach for dependable logic control systems design.* International Journal of Production Research, 42, n°14, 2859-2876.

Rumpe B., Scholz P. (2002). A manager's view on large scale XP projects. *Proceedings of the 3rd International XP'02 Conference on eXtreme Programming and Agile Processes in Software Engineering*, Alghero, Sardinia, Italy, 26-29

Tang Y., Qiu G. (2004) Integrated design approach for virtual production line-based reconfigurable manufacturing systems. *Journal of Production Research*, **42/18**, 3803-3822

Yoshikawa H. (1995). Manufacturing and the 21st Century – Intelligent Manufacturing Systems and the Renaissance of the Manufacturing Industry. *Technological Forecasting and Social Change*. **49**, 195-213

Valckenaers P., Saint Germain B., Verstraete P., Hadeli, Zamfirescu C., Van Brussel H. (2004) Ant Colony Engineering in coordination and control: how to engineer a short-term forecasting system. *Proceedings IWES'04*, 125 - 132

Van Brussel H., Wyns J., Valckenaers P., Bongaerts L., Peeters P. (1998). Reference architecture for holonic manufacturing systems: PROSA. *Computers In Industry* **37**, 255-274.

Waldrop M.M. (1992), Complexity - The Emerging Science at the Edge of Order and Chaos; *Penguin Books*.

Zaremba M., Sasiadek J., Erbe H.H., (2004)(Eds.) Cost-Oriented Automation. *Proceedings of the 7th IFAC COA'04 Symposium*. Hull/Ottawa, Canada, June 21-23.