Knowledge organisation and govern- for-flexibility in manufacturing

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Abstract

In this paper, we investigate co-operative knowledge processing as an opportunity for increasing the capabilities of computer-integrated manufacturing in the presence of varying product-mixes. We achieve this goal by exploiting the flexible capacity of robot-assisted production facilities, developing design innovations iteratively, and using fabrication according to the requirements of market-driven manufacture - all according to the simultaneous engineering rules.

Keywords

CIM, intelligent manufacturing, flexibility, knowledge processing, co-operation

1 INTRODUCTION

Co-operative knowledge processing to be applied to increase CIM capabilities is the main issue of this paper. This opportunity is critical for guaranteeing the effectiveness of 'factory flexible automation' which simultaneously affects products and processes. The locution 'flexible automation', even if entered into practice, is a bit misleading. The term 'automation' is based on the distinction between the execution and governing levels, with separation of the decisional manifold in such a way that feedback is *automatically* enabled by current state; the attribute 'flexible' weakens the closure of the information loop, assuming that some heuristics could modify the actually enabled feedback. The in-process exploitation of knowledge-based systems assures coherence to the proposed innovation.

Intelligent manufacturing, in such a context, could result in an effective combination of factory automation and flexible specialisation. Originally, flexible specialisation existed as a typical attribute of craftsmanship where the craftsman's apprenticeship provided the required specialisation skills. Later, the advent of mass-production manufacturing brought a reduction in emphasis on specialisation. Now, with the objective of factory automation aiming at enterprise profitability based on consumers'-oriented manufacturing (rather than mass-production), there needs to be a renewed emphasis on specialisation.

This new form of specialisation provides a means to respond to market-driven demands for varying product-mixes by requiring changes in work-organisation and execution. These changes can only be accomplished by using the emerging technologies of co-operative knowledge processing to support the synergistic interplay of multiple issues (and design/manufacturing perspectives) grounded in a *web of shared understanding*. In particular, it provides platforms and implementation policies for enabling adaptive flexibility by exploiting knowledge contexts in order to base *patterns of actions* on *patterns of structures*.

The contexts established by situational data, with relate declarative descriptions of conditions to their associated procedural frames, carry the signature of the underlying process from which they were derived and serve as *cached patterns of action*. In order to provide flexibility as a system level attribute, consistent updating to this structure will be embedded within the web of shared understanding in the form of additional situational references together with (potentially) new procedural frames. In our approach to intelligent manufacturing, these cached patterns of action will typically contain the pertinent time horizons, namely: - recovery horizon, for the operational flexibility span; - tactical horizon, for the co-ordination flexibility span; - strategic horizon, for the organisation flexibility span.

1.1 Scope

In this paper, we offer a motivation, in terms of current appropriateness, for developing technologies, tools, theories and models, that might respond to the challenge of supporting co-operative knowledge processing for engineering problem-solving. In addition, we present case-based examples, pertaining to the areas of *intelligent manufacturing*, that exploit flexible automation to deal with diversified product mixes, and reach efficiency by using economy-of-scope rules.

According to the following addresses:

GOVERN-FOR-FLEXIBILITY KNOWLEDGE ARCHITECTURE. Section 2 discusses how to build up shared understanding, which is necessary but not sufficient to assure co-operative knowledge processing. Section 3 illustrates the decision life-cycle, needed in flexible manufacturing aiming at the piece-wise product/process quality upgrading, as aid for enhancing the return from investment. It emphasises paradigms of simultaneous engineering by enabling, among consistent options, the one assuring the highest net production with the given resources.

INTEGRATED CONTROL-AND-MANAGEMENT GOVERNORS. The distributed knowledge processing organisation can serve as an aid for moving back on-process the decisional manifold consistent with flexible manufacturing (e.g. “pulling downstream constraints upstream”). The issues of co-ordinated control-and-management of shop-floor operations are identified in section 4, for upgrading the manufacturing efficiency through govern-for-flexibility strategies, fully enabling embedded technological versatility with required account of leanness.

1.2 The reference frames

Referring to the patterns of structure discussed by the introductory chapter as a basic requirement for supporting co-operative knowledge processing, Figure 1, this paper explicitly makes use of multiple cognitive lay-outs, built on a nine cell arrangement: · *three-layers of knowledge circuits* : communication, co-ordination, collaboration; · *three-stages knowledge instantiation* : results, structure, process; · *three-levels of knowledge structure*: problems, tools, theories.

COGNITIVE LAY-OUT			
Knowledge layers	Communications	Co-ordination	Collaboration
Knowledge instances	Results	Structures	Processes
Knowledge manifolds	Problems	Tools	Theories

Figure 1: Patterns of structure for co-operative knowledge processing.

In addition to patterns of knowledge, there are also patterns of actions which are necessary for enabling co-operative knowledge processing (Kovács, 1995). Figure 2 presents the operative lay-out for these patterns of processing actions and introduces them into theories and technologies (with attention to multi-agent configuration systems), while developing concepts at the level of tools and models, to provide a reference method for supporting on-process decisional capabilities.

OPERATIVE LAY-OUT			
Decisional layers	Recovery	Tactical	Strategic
Decisional instances	Setting	Actions	Behaviours
Decisional manifolds	Contexts	Co-ordination	Organisation

Figure 2: Patterns of action for co-operative knowledge processing.

2 KNOWLEDGE SUPPORTS AND LEANNESS IN MANUFACTURING

The production of artefacts is a creative activity of mankind, which has experienced an important evolution from handcrafting to industrial organisations. The technical way of thinking assumes that 'artificial objects' are the outcome of progress, as compared to what wild-nature yields. Craftsmen were the repository of both the art and skill of generating masterpieces and innovation; at this early stage, the separation, for individual items, of design from fabrication would have resulted a useless complication. With the advent of mass-production, which provided low-cost manufactured goods and which emphasised a steady fully-repetitive work-organisation (according to the scientific job-allotment paradigms), the decentralised role of the craftsman was replaced by off-process centralised decision making and a strict hierarchy of competency. Taylor's methods and Ford's flow-shop vertical manufacturing have been the reference models that, from the USA, inspired the oligopolistic trends toward the effectiveness of such enterprises.

The market saturation of goods now calls for consumer oriented artefacts, in order to win new customers, offering diversified-quality objects which satisfy new personalised needs. For efficiency, industrial business organisations still need to discriminate design (Ettlie, Dreher, Kovács, Trygg 1994) (and conceptualisation through patterns of structure), from production (and manufacturing through patterns of actions); within today's factories, furthermore, social demands of trade unions and extended acculturation of workers move (Michelini, 1992) toward anthropocentric organisations (according to intelligent-task assessment paradigms),

with decentralised decision and distributed competencies. This evolution happens to have been understood by Japanese industry first, and Toyota's lean production is acknowledged as updated reference for establishing a winning enterprise.

	TECHNOLOGY- DRIVEN INNOVATIONS	MARKET-DRIVEN INNOVATIONS
Handicraft work organisation	Mass-production work organisation	Lean engineering work organisation
One-of-a-kind production	Company-wide quality control	Co-operation plus redundancy removal
Flexible specialisation manufacturing	Computer-integrated manufacturing	Customers' oriented manufacturing
<i>Evolving, learning and training</i> <i>Design while producing</i> <i>Craftsmen excellence range</i>	<i>Scientific job-allotment</i> <i>Off-line centralised decision</i> <i>Off-process hierarchical competency</i>	<i>Intelligent task- assessment</i> <i>On-line decentralised decision</i> <i>On-process distributed competency</i>

Figure 3: Trends to knowledge-intensive enterprises.

Comparative studies of Japanese and Western manufacturing industries ascribe (Womack, Jones, Roos, 1990) the difference in effectiveness essentially to sets of

factors that typically entail a work-organisation based on knowledge intensive issues, e.g.: · flexible specialisation in manufacturing; · company-wide quality-control; and: · a 'lean engineering' organisation. As shown in Figure 3, these factors cut across the conventional approaches to manufacturing and are strictly related to the interlacing of material and information flows:

- flexible specialisation is an issue shared with craft works of old, granting the capability to adapt the properties of products to individual taste and fancy within a manufacturing context;
- total quality can be sought as a company-driven goal in mass-production, based on the continuous monitoring of every process-conditioning factor;
- lean-production is appearing as a market-driven opportunity, based on the removal of material and information options that do not improve the enterprise activity.

2.1 Knowledge intensive adaptive work-organisation

Intelligent manufacturing presents as option that might exploit technology-driven innovations, and could reach market-driven effectiveness provided that the limits of lean production arrangements are strictly achieved. A challenging aspect of intelligent manufacturing is that the flexible plants are used not as they are, but only after setup and upgrading. The setup process is concerned with adjusting components, facility configuration and determining control settings (**CFC** structural frames); the development upgrades to the system is an everlasting activity involving improvements to: the selection of the components, the facility configuration, and the control structures in order to provide identification for current (and new) product-and-process arrangements -- all along the operational life of a manufacturing enterprise.

The upgrading of efficiency is concerned with the options of **monitoring** (descriptive but not predictive), **decision-manifold** (contours formed by competing alternatives in the space of possible decisions), and **management (MDM** behavioural frames). A variety of data is required for improving the manufacturing efficiency for the life-long economical exploitation of an industrial enterprise. Collection of this data requires the continuous reference to the descriptive results of monitoring, exploration of the shape of the decision-manifold, reviewing the content of the management frames, and the incremental monitoring of the plant's operational situations and functional trends.

The decision logic for setup and the upgrading needs to be assessed and evaluated based on the measurement of actual performances and the comparison of current figures against the expected levels of performance. Effective utilisation of this type of decision support requires computer simulation, providing virtual reality display of the actual behaviour of (consistent) competitive production plans. Indeed, without quantitative measures of outcome effects which can be evaluated, it is not possible to control and manage flexibility as a local requirement; neither is it

possible to use pre-set local policies and implement flexibility as enterprise policy without quantitative evaluation measures.

	Components	Facility configuration	Control
STRUCTURAL FRAMES	Inventory and capacity presetting	Shop-floor and fabrication agendas optimisation	Decentralised multi-agent synchronisation
	Monitoring	Decision - manifold	Management
BEHAVIOURAL FRAMES	Inventory and capacity measurement	Govern of recovery and strategic flexibility	Supervisory hierarchical co-ordination

Figure 4: The adaptive framework of intelligent manufacturing.

The company-wide characteristics should be assessed from the beginning, when the **CFC** structural frames are initially specified, and needs to be continuously adapted, as the **MDM** behavioural frames are improved. The convenient decisional manifold defines a shape in the space of decisions where the quality of each point can be assessed by the quantitative measures. An understanding of the general shape of this decision manifold is a necessary complement for enabling intelligent manufacturing (Michelini, Acaccia, Callegari, Molfino, 1994), with efficiency based on the govern-for-flexibility issues (Figure 4). The related knowledge lay-out needs can be described as combining results, structure and process, in order to generate distributed decisional manifolds according to the computer-aids arrangements summarised in the third section.

2.2 Flexible specialisation and economy of scope

The manufacturing business, according to the oligopolistic trends interpretation, has been exploiting work organisations with typical deterministic presettings (for product and process) in order to reach economies of scale. Fixed automation, aiming at steady production plans with optimal schedules, therefore, could develop over time, consistently based on the specialisation of jobs, functions, men and machine-tools through relative long product lifetimes.

Flexible manufacturing presents as the answer to the market saturation in demands for mass produced items; now, market demands for flexibility in

manufactured products lead to requirements for a heterogeneous spectrum of options, such as:

- producing different work-piece types;
- manufacturing in several production orders;
- recovering from break-down situations;
- extending product and process easily, due to facilities modularity;
- matching product-and-process, by common control of material and information flow.

Flexible specialisation is by now acknowledged to be a market-driven request; the connection with technology-driven innovation leads to economical effective results, if the 'lean engineering' approach is followed. The underlying assumptions of this new approach are:

- set-apart physical resources are a waste, the continuity of the principal process can be assured by the technological versatility of the manufacturing facilities rather than an inventory of parts;
- redundant logical resources, like excess parts inventories, are a nuisance and contradict leanness by the addition of actually unused functions and capabilities.

The goal of lean engineering requires balanced and integrated control-and-management of fabrication processes; the manufacturing progression must be continuously monitored, and the visibility of every relevant conditioning feature can be exploited, according to the simultaneous engineering rules, for enabling paradigmatic instances of co-operative knowledge processing situations.

Flexibility in industrial businesses, indeed, does not lead, by itself, to economical upgrading. The financial implications of economies of scope (capability of obtaining high product diversity, quality and innovation with higher utilisation of direct personnel and fixed investments) are much more conditioned by engineering-based knowledge, than the earlier financial implications of economies of scale. Enterprise rewarding is a mix of market-driven and technology-driven factors, and the assessment of returns from investments requires a carefully constructed foundation of the enabling technologies (such as co-operative knowledge processing) in relation to fully exploiting flexibility while preserving leanness, in order to maximise the return on investment.

Summarising, enterprise rewarding and flexibility are linked by the required availability of decision support, based on the visibility of the process-pertinent figures (i.e. quantitative measures). In the next two sections, we briefly describe two components of this problem: · in the next section, the off-process decision architecture used as a consultation aid for the effective setup of flexible facilities; · in the subsequent section, the on-line decision architecture used for the best use of the facilities through integrated control-and-management.

2.3 Quality engineering trends and customers' orientation

Important improvements will be gained by the emerging computer technologies, which provide the necessary support for acquisition, sorting, processing and archiving information flows, concurrently and in parallel with the procuring, dispatching, transforming and storage for material flows. The common visibility of every relevant process variable assures the transparent emergence of the required product quality parameters. Computer-integration, therefore, is not a goal in and of itself; rather, it is an opportunity to provide several by-products that need to be conveniently exploited; the related financial implications ought be quantitatively assessed and justified by measuring the actual improvements in company-wide efficiency. With these limits in mind, two facts need be considered:

a) re-organisation (not 'simple addition' of new technologies) is the critical factor, and the return from investments is heavily related to effective practice of quality systems. The creation of knowledge intensive environments, for their own sake, could be misleading; redundancy, by itself wasted or "spoiled" effort, and each individual material and information resource needs to be justified by the fact of being actually useful for some portion of the product life-cycle (with value higher than its cost of acquisition and retention).

b) assessing the actual performance figures of flexible manufacturing is the validation factor, similarly related to the transparency of quality systems. The benefits of adaptability, quality surveillance and efficiency tracking can be combined if and only if the information system supports the monitoring of the current situations in order to make decisions based on well defined features (i.e. quantitatively).

Company-wide quality-control has been defended as a means for reducing costs; the goal requires efficiency in data acquisition, sorting, processing and archival, and it encompasses, for total quality, the product's quality assurance subsystem with every related conditioning subsystem (namely: the objectives and values for the product quality subsystems, and the enterprise management and human resources quality subsystems).

2.4 Lean engineering objectives and re-organisation rules

The main elements of re-organisation aiming at *lean engineering* can be grouped into the following formalised sets of objectives:

- a· integration of the overall business organisational processes: purchasing, design, production, sales, etc.; the integration needs to cover suppliers and dealers in order to avoid unnecessary duplication of functions;
- promotion of team activity for solving current problems with multi-disciplinary and multi-skilled members, instead of functional departments with fixed specialisation and hierarchical tasks allocation;

- build-up of co-operative interpersonal relations, in order to accumulate insights on the enterprise organisation as team culture, and to make difficult, and not desirable, the switching of the worker to a new company;
- b**· distribution of staff and support functions into the primary processes; the size of the staff and support functions is continuously monitored on their ability to add value, with careful attention on preservation of effectiveness;
- enabling the quick visibility of problems, with solving responsibility decentralisation at the point of occurrence, to enhance piecewise continuous improvements, tied to the distribution of the various tasks and responsibilities;
- expansion of enterprise-information systems, supporting knowledge (in addition to data) processing capabilities, to provide transparency to the decisional contexts and to undertake continuous the costs monitoring;
- c**· removal of over-protection and over-production by suppressing functions not strictly necessary, by reducing idle resources, by avoiding the piling-up of stock, etc., through the appropriate use of recovery flexibility;
- activation of just-in-time logistic control with balancing of the distributed capacities to grant a stable production volume with variable products mix output, according to the on-line exploitation of tactical flexibility;
- assessment of the condition-monitoring maintenance standards, to steadily ensure customer oriented quality figures, with zero-defect production, with due regard to the strategic flexibility of enterprise policy.

Group **a** of the objectives deals with organisational perspectives; group **b**, with co-ordination opportunities; group **c**, with execution possibilities. The lists show sample options ranging at different levels. Benefits can come from a successful adoption of the lean engineering paradigms at all three levels.

3 GOVERN-FOR-FLEXIBILITY: OFF-PROCESS OPPORTUNITIES

For enabling intelligent work-organisation efficiency, the ability to exploit flexibility is a critical requirement in order to maintain/reduce manufacturing costs, support/improve products quality, and preserve/extend market share, etc., by the integrated processing of the pertinent information flows, while the principal material flows are performed.

The upgrading is grounded on a multilevel decisional logic, concerning, e.g.: · strategic fabrication policies (inventory decision); · task's tactical pre-setting (planning decisions); · capacity allocation updating (re-scheduling decisions); · shop-floor logistics (dispatching decisions). The optimal management of manufacturing processes is fixed by selecting inventory and planning on the organisational horizon, with due attention on the variety of product mixes according to the enterprise objectives; the optimal control can be reported, on the tactical horizon, by preserving the programmed-mode scheduling and dispatching,

and on the execution horizon, by assuring (at discontinuities or at emergencies) the consistency of recovery-mode operations.

The knowledge lay-out supporting these operations needs be conveniently integrated for embedding the interlaced patterns of structure and patterns of action, in order that the inherent adaptivity of flexible automation with computer-integrated manufacturing could be defined on the pertinent *functional ranges* (operation, co-ordination or organisation) and *time horizons* (recovery, tactical or strategic), enabling the decision life-cycles, required for generating the design and fabrication processes aiming at custom-oriented and quality-driven products. Indeed, this duality of patterns of structure and patterns of actions may be fundamental to all aspects of support for concurrent knowledge processing.

3.1 Decisional architecture aiming at govern-for-flexibility

Computer-integrated manufacturing increases the utilisation figures of resources by exploiting extended product-mix variability, and enhances shop efficiency by managing flexible capacity of versatile production facilities while minimising inventory. The issues are enabled by a knowledge architecture aiming at govern-for-flexibility, provided by the backward introduction in the manufacturing contexts of appropriate decisional manifolds.

The decision supports, conveniently, develop through the iteration of three phases of upgrade cycles: (Michelini, 1991) intelligence and design; (Womack, Jones, Roos, 1990) testing and feedback; (Michelini, Acaccia, Callegari, Molfino, 1994) choice and redesign. The overall decisional process is a typical issue of knowledge intensive organisations, and its characterising steps present as follows (Figure 5):

1. The *intelligence* phase is the process of identifying consistent alternatives; the *design* phase is the evaluation of alternatives and comparison of each. This initial step, when associated with knowledge organisation and computer-aids, requires meta-processing abilities and corresponds to the highest conceptualisation layer.
2. The *testing* phase assesses actual performances; the *feedback* is the review process of the outcome of decision and is used to influence the acknowledging of alternatives. The step needs understanding assessments and can extensively profit of computer supports, that normally split over a (relational, generative and information) multi-layer structure.
3. The *choice* phase is the selection and implementation of a decision alternative; *redesign* is the piecewise process of improving the selected alternative. This last step profits from co-operative knowledge processing and exploits such computer aids as virtual reality, references to enhance monitoring restitution, and acknowledging consultation.

The decision life-cycle illustrates the interactive nature of decision-making; the way in which the choice of one alternative will influence and the alternatives affected are identified for the next loop.

3.2 Structure-conditioned patterns of action

The application of the decision life cycle model to intelligent manufacturing is basically concerned with the issues of governing flexibility, so that varying market-driven requests are satisfied whenever they emerge, expanding consumers' satisfaction and continuously winning new customers. The control and management of flexibility is made up of several decision options for capacity allocation, e.g.: - shop-floor logistic; - operation-cycles schedules; - production agendas planning; - and capacity requirement setting. Each option offers several alternatives for how the manufacturing capacity can be allocated to meet the production requirements, according to the simultaneous engineering practice of mutually adapting products and processes.

Simultaneous engineering methods offer conceptual supports for the upgrading tasks, providing consistent reference information at the levels of: - design of product/process systems (approach and terminology); - representation and modelling codes (for unified virtual collocation); - knowledge architecture and decision life-cycle modes (repository, distribution and control of declarative/procedural data); - concurrent problem solving abilities, with multi-way computer communication; - information exchange and sharing, for co-operative team aid; - knowledge-based simulation/emulation (and related human-and-data interfaces); - decision steps logic (requirements on the structural/behavioural frameworks) -- in short all of the properties identified for a *web of shared understanding*.

The mutual adaptation of products and processes is a complex engineering problem that was traditionally broken down into sub-problems, solved recurrently, transferring constraints and interactions for obtaining the coherent balancing of the requirements. The approach is possibly correct for quite high-technology manufacturing (of the aero-space, nuclear, military, etc. industry), with technical specifications explicitly the object of agreements between buyers and sellers. The expansion of the one-of-a-kind products to consumer areas generically ruled by quality certification standards requires a new approach aiming at economy of scope. For efficiency, the efforts of manufacturer's personnel need be co-ordinated; the pertinent information should be shared and the collaboration ought to progress with the simultaneous involvement of the (human and machine) expertise, within co-operative frameworks that start solving in parallel, all the sub-problems. Simultaneous engineering could actually expand to this higher level, on the condition that co-operative knowledge processing for solving engineering problems might really support team work activity.

3.3 Efficiency assessment and decision life-cycle method

The continuous monitoring of the plant effectiveness and the shared understanding of the effects of flexibility are options of the information technology

resources that need to be exploited for correctly setting, both, the **CFC** and the **MDM** frames.

For upgrading, the decision life-cycle begins with the issues of managing flexibility, over the selected horizon (strategic, tactical, operational), according to the enabling logic: inventory decision, planning decision, schedule decision, dispatching decision. The assessment of the flexibility-dependent performances, thus, is strictly related to actually obtained results. Results, structures and processes cannot be acknowledged separately.

Using a flexible-manufacturing decision-model, the first step is concerned only with establishing and comparing consistent alternatives.

The feedback in the capacity allocation decision life-cycle, is built on the direct monitoring of flexibility (of the real plant or of the equivalent virtual reality model); it provides the necessary reference data describing the over-all procedure. This second step measures the effectiveness of the competing options, most of the times (for reasons discussed in the following), by means of a manufacturing “functions integration model”, through the use of appropriate simulation work sessions. The results provide a uniform basis to compare (for each **CFC** framework) the economic benefits enabled (and acknowledged) by means of the pertinent **MDM** framework.

The locally most efficient alternative is fixed by the third step in the decision life cycle. Each choice represents an optimised configuration of the flexible capacity allocation and provides the time-varying management policy for adapting the production program through convenient selection criteria, such as: - adjust the routing table; - adjust the products schedule; - modify the production process plan; - modify the inventory policy.

3.4 Integration of knowledge structure/action patterns

The practical exploitation of the decision life-cycle approach, referring to real plants directly, would disregard most of the govern-for-flexibility alternatives. The approach will, instead, be more fully effective by referring to appropriate computer aids.

Figure 5: Decision life-cycle for enabling flexibility effectiveness.

Making use of virtual reality simulation and fully duplicating on-process decision logic, it becomes possible to refer to *a posteriori* figures (e.g. resources utilisation ratios) and to make use of net production monitoring as performance index; then, following the simultaneous engineering approach, the three step procedure for implementing the decision life-cycle structure can be used, fully enabling intelligent manufacturing.

The integration of patterns of structure with patterns of action typically profits from expert simulation (Acaccia, Michelini, Molfino 1987). This computer aid requires specialised software, based on the interconnection of programming instruments, aiming at knowledge processing (rather than simple data processing). The simulation provides details on the evolution of the physical resources making use of algorithmic blocks; the governing logic is generated in parallel by heuristic blocks, suitable for emulating the decisional processes. The overall architecture, Figure 6, actually deals with multi-agent *structure/action* patterns: - with knowledge interfacing for *communication • sharing • co-operation* patterns; - requiring structured references for enabling *operation • co-ordination • organisation*; - assuring programming progression for *activation • scheduling • planning* patterns; while: - covering the flexibility *recovery • tactical • strategic* horizons.

The expert simulation is a powerful consultation instrument for supporting the options, actually enabled through flexibility, by directly experimenting with practical applications, with instantiation stages for the reference structures (*databases • models • behaviours*) and for the conditioning modes (*results • contexts • reasonings*). The assessment ranges, needed for co-operative knowledge processing, could accordingly climb *problems • tools • theories*, referring to individual application *cases*, by enabling suitable *procedures (algorithms or heuristics)*, as defined by the selected *methodologies*.

4 CO-ORDINATED CONTROL-AND-MANAGEMENT

Expert-simulation exploiting virtual-reality capabilities supplies the basic support for measuring the benefits of flexibility. Expert-simulation packages are becoming a necessary consultation instrument for production engineers in order to correct the setup of given flexible manufacturing facility, according to the three-phase decision life-cycle model previously discussed. These packages are actually a combination of modules reproducing the time behaviour of the physical processes, and modules performing the governing operations by emulating the decisional capabilities to be recovered on-process in order to exploit flexibility. The closure of the decisional loops for control and management of plant operations make extensive use of heuristics, and the effectiveness of a particular policy is finally assessed by measuring the results really reached. Computer-simulation, therefore, is the only economical way for gathering sufficient experimental evidence.

KNOWLEDGE STRUCTURE / PATTERNS			
ACTION			
Data-bases	Models	Behaviours	<i>REFERENCE STRUCTURES</i>
Results	Contexts	Reasoning	<i>CONDITIONING MODES</i>
Cases	Procedures	Methodologies	<i>ASSESSMENT TOOLS</i>
Communication	Sharing	Co-operation	<i>INFORMATION CIRCUITS</i>
Activation	Scheduling	Planning	<i>PROGRAMMED ACTIONS</i>
Execution	Synchronisation	Collaboration	<i>FUNCTIONAL SITUATIONS</i>
Operation	Co-ordination	Organisation	<i>FLEXIBILITY RANGES</i>
Recovery	Tactical	Strategic	<i>TIME HORIZONS</i>

Figure 6: Co-operative knowledge processing framework of intelligent manufacturing.

These off-process investigations, moreover, introduce to the necessary prerequisites of factory automation, demonstrating the feasibility of on-process implementations.

The closure of the governing actions could be performed, thereafter, on the real manufacturing processes. The implementation follows, with decision modules capable of on-line operativeness. This requires suitable distributed-knowledge govern ability, with the option of functional re-configurability in order to enable (Acaccia, Michelini, Molfino 1989):

- decentralised control efficiency, for keeping steady running conditions under (tactically) optimal schedules;
- hierarchical management flexibility, for presetting the adaptive strategic programmes or for superintending to the recovery operation sequences.

The governing logic, emulating the decisional processes with heuristic blocks, might directly be interconnected to the information system of the real plant, assuring flexible automation. The on-process knowledge architecture, assuring in real time the full exploitation of the available technological versatility, aims at the integration of control and management functions.

4.1 Knowledge organisation for on-line operations

The production of manufactured items requires complex sets of functions, that could suitably be modelled with the closed loop scheme of Figure 7 . The knowledge processing for governing a manufacturing facility accordingly distinguishes three paradigmatic logics:

- thesis (white-box approach, model-based reasoning): the self-sufficiency of system-hypotheses is assumed for setting the processes (through, e.g., feature-based design providing patterns of structure fully pre-setting off-process the decision schemes), with interpretation models that provide homomorphic representations of the singled-out objects.
- antithesis (black-box approach, experience-driven learning): the process observation provides self-consistent acknowledgements (with, e.g., heterarchical decision support generated by patterns of action and educated training), focusing on distributed artificial intelligence tools for shaping the current data and for diagnostics.
- synthesis (grey-box approach, case-based reconfiguration): a mix of process monitoring and conditioning hypotheses is used for adapting process and govern (exploiting, e.g., multi-agent configurations, ruled by patterns of action based on patterns of structure), with constraints-and-conflicts harmonisation aiming at local efficiency.

The schematic in Figure 7 shows that, for flexibility, patterns of structure, embedding changeover features, face patterns of action exploiting expandable decision manifolds, and this can lead to a virtuous upgrading loop on the condition that the synthesis is operated within a properly organised knowledge environment. The closed loop scheme of Figure 7 is becoming a winning opportunity for exploiting adaptive intelligent manufacturing, consciously preserving leanness.

Figure 7: Schematics of the paradigmatic logic for governing manufacturing processes with patterns of structure, patterns of action or combined decision supports.

4.2 The co-ordination of control and management

Scientific job-allocation paradigms and (traditional) fixed automation typically take a white-box approach, and presume that each organisation, co-ordination and execution request is fulfilled by coherent model-based reasoning over the pertinent strategic, tactical or recovery horizons. In these conditions, optimal return from investments means steady mass-production; the decisional architecture is completely frozen and every contrivance should be enabled so that emergencies could not take place.

Earlier handicraft skills and arts and (possibly) future artificial intelligence concerns make use of a black-box approach, and might develop with experience-driven learning for the build-up of congruent understanding of products-and-processes characteristics, based on extensive experimentation. An economical planning, in these conditions, is not possible (but free creativeness is allowed). Intelligent task-assessment paradigms and flexible automation move with a grey-box approach, and assume that consistent case-based reconfigurations could be operated on-process and on-line, differently, at the strategic, tactical or recovery horizons, and with due account of the peculiarities of each organisation, co-ordination or execution level requirements. Leanness and economy of scope are the basic factors of the enterprise reproductivity.

The possibilities of co-ordination, on-process and in real time (while the concurrent manufacturing material and information flows evolve), between control and management have great relevance in view of technologically prospective partial innovations, such as the previously discussed knowledge-intensive issues: - flexible specialisation manufacturing; - company-wide quality-control; - and 'lean engineering' organisation.

4.3 The on-process exploitation of flexibility

The on-process exploitation of flexibility is a far reaching topic even when limited to case-based implementations (Michelini, Acaccia, Callegari, Molfino, 1990); hereafter the discussion is limited to the distributed knowledge architecture to be realised with the engineering concern of improving 'productivity'. Co-operative-knowledge processing with a grey-box approach ranges at an intermediate level of abstraction as compared to problem-embedded knowledge-architectures (e.g. white-box features structured) or result-driven learning-architectures (e.g. black-box, with heterarchical decomposition). The analysis (principles of reduction) should accept a range of non-dissociable constraints; the complexity is faced by shared understanding with cross-links among parallel experts and sequential conditioning along historical experiences, exploiting an *intelligent advisor* that supports co-operative-knowledge processing, by machine-learning, for enabling efficient decentralised control during steady running conditions (tactical flexibility) and feasible supervisory control at emergencies (recovery flexibility).

On these premises, the consistency of automation with flexibility is acknowledged with the setting of the structural frames, i.e.: components, facility-configuration and control (CFC). For the efficiency of intelligent manufacturing through full exploitation of flexibility, one should, further, consider the opportunities granted by on-process and on-line integration of the pertinent knowledge on product-and-production. The efficiency upgrade will, thus, be based on the behavioural frames, i.e.: **m**onitoring, **d**ecision-**m**anifold and **m**anagement (MDM).

The decision life-cycle approach allows a previous setting of both **CFC** and **MDM** frames, using the decision supports based on (off-process) virtual reality simulation. The continuous adaptation of every available technological resources to the enterprise customers' oriented marketing policy is, thereafter, possible if on-line governors operate with integrated control and management.

4.4 Adaptive governors based on on-process data

The mixed-mode simulation/emulation environments, supporting development and efficient implementation of a flexible manufacturing system, through the decision life-cycle approach, conveniently exploit: - model-based reasoning, along with the testing/feedback phases; - case-based reasoning, during the choice/redesign phases. At the second step, the causal inference provides the assessment of the real plant performances by means of categorical features (patterns of actions); the heuristics is called for to implement govern-for-flexibility real-time procedures. At the third step, the statistical inference can be used for the build up of framed databases to be back exploited as consultation aid, for orienting the choices and for redesigning the plant, by patterns of structure.

The benefits in productivity are related to combined settings of improvements, such as: strong customer orientation, intensive involvement of direct personnel, less

indirect personnel, shorter time-to-market, larger product diversity, intensive use of fixed investments, reduction of work-in-progress and inventory, and so on. These upgrades are strictly related to the efficiency in problem solving ability and to the innovations of the work-organisation setting.

The adaptive governors, suitable to operate on-process, present multiple-layer build-ups, with vertical connections between relational, generative and information layers. The relational layer exploits patterns of structure, and the expert governor expands on pre-processing modules for fixing the **CFC** and the **MDM** frames, with interfaces for the structural model selection and for the behavioural mode setting (Figure 8). The generative layer exploits patterns of actions, and propagates causal responses with algorithmic modules while acknowledging consistent suppositions through heuristic modules. The decision supports achieve the efficient exploitation of flexibility by the incorporation of on-process data from the information layer; this monitors the performance evaluation figures and provides the diagnosis of facts for preserving leanness.

5 CONCLUSIONS

Computer-integrated manufacturing-and-engineering, CIME, is a technology-driven innovation; it assures the technological consistency of factory automation and flexible specialisation; it, further, reaches profitability provided that the leanness objectives are preserved. Customers' oriented products up to one-of-a-kind production are made available into industrially organised contexts, that exploit economy of scope for the amortisation of the plant fixed costs by manufacturing diversified product mixes. The innovation is being discussed referring to the underlying requirements of knowledge intensive architectures and decision supports. Co-operative knowledge processing applies as effective option for enabling the perspectives of simultaneous engineering, while assuring transparent shared understanding of the on-going processes and, there through, providing the tests for leanness.

The topic 'co-operative knowledge processing' is by now, perhaps, more related to research projects than to engineers' concerns. In the practice, however, production engineering resulted these past years to be a quite stimulating application field for many developments of artificial intelligence. The basic motivation is related to the ability of referring to information objects encoding 'knowledge', rather than simply 'data'. 'Knowledge' is information with attached relational context, it can be interpreted once the procedural conditions are duly instantiated by the pertinent declarative data.

Figure 8: Schematics of the knowledge flow for expert computer-aids, supporting intelligent manufacturing implementations.

With knowledge-based architectures, a twofold advantage arises:

- the implementation of heuristic modules is straightforward, and the emulation of human-like decisional platforms provides the software instruments for enabling the factory automation with govern-for-flexibility features;
- the goal: 'flexible automation' is coherently obtained by merging patterns of action and patterns of structure, provided that structures carry the signature of the originating changes, and actions grant the consistency of the generated configurations.

The recalled opportunities are two views of the same building. On one side, we look after the possibility of adaptive governors that transform the control actions according to current (up-dated) process data, on condition that the process structure consistency is preserved; the resulting issues lead to the integrated control-and-management expert governors, based on real-time decisional manifolds, directly operating within the actual manufacturing processes. On the other side, we face reconfigurable build-ups combining the patterns of the **CFC** structural frames with the **MDM** behavioural frames; the related opportunities provide the knowledge support for closing the decision life-cycles used for setting the lay-outs and for improving the performances of intelligent manufacturing facilities using off-process virtual reality simulation.

The inclusion of expert-governors directly operating on-line, in real manufacturing plants, is a relevant issue assuring the consistency of flexibility and automation. The final setting of an effective implementation requires shared understanding of process and results, grounded on broad-band experimentation of consistent fabrication plans. This supporting stage needs be previously covered by

computer-simulation, and the knowledge organisation will require the recurrent closure of learning loops, for performing case-based reconfiguration of process structures and govern actions. The interlaced nature of on-process and off-process computer-aids needs be explicitly considered.

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8 BIOGRAPHIES

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