GNOSIS

Knowledge Systematisation: Configuration Systems for Design and Manufacturing

Final Report

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1 EXECUTIVE SUMMARY

The Gnosis project was carried out as part of the Intelligent Manufacturing Systems (IMS) program, with research partners from Japan, the EU, the EFTA and Canada. The success of the initial feasibility study test case, 1993-94, led to the establishment of the full scale research project which ran from February 1996 until March 2000.

The research undertaken within Gnosis has established the framework for a new manufacturing paradigm through the application of knowledge-intensive strategies to all product lifecycle stages. This new paradigm, termed the Post Mass-Production Paradigm, enables new forms of highly competitive manufactured products and processes which are environment-conscious, society-conscious and human-oriented.

The Gnosis research platform consisted of five work packages:

- *Knowledge Systematisation*: the organisation, representation and effective application of knowledge which provides the foundation for the other themes
- *Enabling Technologies and Integration:* support for the knowledge deployment and application-oriented work
- *Knowledge Deployment - Soft Artefacts:* the tools, methods and application domains for the realisation of products for the new paradigm
- *Knowledge Deployment - Virtual Manufacturing*: highly flexible intelligent manufacturing and production systems necessary to realise soft artefacts
- *Post-Mass-Production Paradigm*: setting out the boundaries of the new paradigm and proposed evaluation methods.

The Virtual Manufacturing research was expanded into application-oriented Virtual Factory concepts and pilot schemes. Partners in the EU region are continuing work in this area after the international Gnosis project concludes.

Results from the project are already being implemented by Gnosis partner companies and academic institutions. Pilot schemes in knowledge systematisation have enabled a new Knowledge Intensive Engineering Framework in which prototype cellular warehouse demonstrations have been built. The construction industry partners are deploying results in the design of next generation apartments and environmentally conscious factories. Electrical appliance partners have applied the softness themes to ecological design support systems which are being utilised for new product design. Other partners have applied the Virtual Factory concepts to improve logistics and speed up the design-to-market flow, as well as improving the configuration process for customised products and production. Partners producing software-tools have utilised the project framework to test new tools and application areas, thus expanding their potential market.

This report gives a synopsis of the main research themes of Gnosis and the achievements of the project. The results are also available for viewing on the Gnosis Web site:

http://www.modularisation.com/../gnosis/gnosis.htm

Further results are expected from the continuing work on the Virtual Factory.

2 INTRODUCTION

Due to environmental, societal and economic limitations, the existing mass-production and mass-consumption-based paradigm in the industrial world is unsustainable in the medium and long term. Modern engineering can only produce the most circumscribed solutions to the destruction of the global environment, and manufacturing engineering has traditionally lacked an awareness of global inter-disciplinary issues. As a solution, the Gnosis consortium has proposed an alternative manufacturing paradigm permitting ecological and economic sustainability. This paradigm is called the *Post* Mass Production Paradigm. It involves a new approach to manufacturing, recognising resource limitations and the balance of nature in order to achieve a sustainable manufacturing environment. The new paradigm is based on the manufacture of soft products with their associated production systems and industrial enterprises. Softness here refers to adaptability, robustness, and growth potential together with congeniality to the natural environment and human society through re-usability or recyclability. The Gnosis research posits that the lack of such softness in conventional manufactured products is due largely to the uncoordinated use of knowledge.

The key points of the new paradigm include the following:

- the expansion of current domain boundaries in manufacturing and production to encompass a holistic, lifecycle-oriented view
- the recognition that knowledge has become the most important resource in manufacturing and production; companies are selling not only physical products, but also knowledge and information
- the need for company restructuring in order to cope with shorter delivery times, increased customisation and JIT (just-in-time) philosophies, in addition to environmental pressures and international trade issues

In order to change the current production paradigm, effectively systematised knowledge is needed to achieve new, innovative technologies which will support design for complete product life-cycle and the realisation of new *soft* artefacts and factories. Gnosis is distinguished from other projects by its emphasis on the need for a paradigm shift, and for revolutionary new soft products and production systems. The Gnosis Vision covers not only the needs of manufacturers but also the natural environment and human society, and it can be summarised as follows:

> Gnosis proposes the establishment of a framework for a new manufacturing paradigm -- the PMPP (Post Mass Production Paradigm) -- through the utilisation of knowledge intensive strategies covering all stages of product life-cycle, with the objective of realising new forms of highly competitive manufactured products and processes which are environment-conscious and human-oriented. Knowledge is systematised through a Knowledge Intensive Engineering Framework (KIEF) which supports the necessary enabling technologies to realise new Soft Artefacts, Soft Machinery and Virtual Manufacturing.

The specific objectives of the project cover the following:

<u>Environmental Objectives</u>: One of the major objectives is the realisation of soft products -- products which are easily maintained, upgradeable, and designed for recycling.

<u>Consumer-Oriented Objectives</u>: The project aims not only to make products human-friendly but also to make them customisable and user-adaptable or dynamically re-configurable. The realisation of such systems involves the implementation of virtual factory concepts and intelligent network implementations.

<u>Manufacturer-Oriented Objectives</u>: Staying at the competitive edge in the manufacturing domain requires that new technologies and research ideas be implemented at the earliest possible stage. Adaptable, upgradeable products, machines and manufacturing systems can respond effectively to this pressure.

The research is based on knowledge systematisation which covers the classification, structuring and organisation of knowledge within a systematic framework, giving consideration to the dynamic aspects of knowledge, and the creation of shared ontologies. It is used to provide enabling technologies for the effective deployment of knowledge in soft artefacts and virtual manufacturing. Thus it can be seen that soft manufacturing involves more than being environmentally friendly. It also implies manufacturing which is sufficiently adaptable to respond to human needs for variety, customisation, performance and price.

In summary, the Gnosis research proposes a shift from mass material use in production to mass knowledge application, from quantitative to qualitative satisfaction, and the widening of the scope of manufacturing to include the whole product life-cycle.

3 RESULTS

The research output of Gnosis has included:

- The development of enabling tools and technologies for the design and manufacture of new soft artefacts.
- The development of re-configurable tools for management of decentralisation and customisation. The results are used by industry for re-configuration and control of shop floor activities to promptly and efficiently meet individual customer demands and thus improve competitivity.
- The definition of a new style of engineering called "knowledge intensive engineering". Here, engineering refers not only to design and manufacturing, but also to other kinds of activities in the product life cycle, such as marketing, operation, maintenance, and recycling. Knowledge intensive engineering puts emphasis on improved ways of using engineering knowledge to arrive at soft artefacts and effective manufacturing enterprises through which the post mass production paradigm can be achieved.
- The drawing-up of a blue-print for the transition to the new paradigm, using the knowledge systematisation research to form the basis of a "manufacturing knowledge highway".
- The establishment of technologies for supporting distributed product design and manufacturing through exploitation of computer networking, multimedia communication and intelligent agent technologies. Prototype demonstrations were set up using real industrial problems specified by the industrial partners of the consortium, and these are being upgraded into exploitable industrial tools.

4 SCOPE AND INTERNATIONAL DIMENSIONS

The scope of the project covers all aspects of manufacturing: products, production and the enterprise; the human user or consumer; and the natural environment. The focus of the project is concentrated on the attainment of new competitive, environmentally friendly products and production, using knowledge technologies as a foundation.

The rationale for carrying out the proposed research at an international level, involving partners from the major industrial economies of the world was as follows:

- The environmental aspects of manufacturing and consumption cannot be tackled on a local or regional scale, since the environmental consequences of manufacturing and mass consumption are global in scale and necessitate a global approach toward resolving them. Without a world-wide consorted strategy, a sustainable balance between manufacturing and the environment cannot be achieved.
- The effective use of knowledge as a foundation for tackling world-wide problems requires access to all available knowledge sources. Manufacturing knowledge, environmental knowledge and global market knowledge are not concentrated in any particular region or country but are distributed throughout the world. Thus a research program which utilises such knowledge must have access to it wherever it is located, and therefore must involve all concerned regions and countries.
- Manufacturing is no longer a national or regional concern. The gradual opening of national markets and the international pressure to open up closed markets, the strengthening of world trade bodies, and the consumer desire for the free flow of products and services, require that a global scope be adopted for any research and development of new products and production technologies.
- The recent advances in communication technologies, as evidenced by advanced electronic networks, multi-media transfer of information and knowledge, and the internationalisation of research, make global-level collaborative research feasible for the first time. Such an opportunity should be utilised to advance the living standards and knowledge level of human society.

5 PROJECT OVERVIEW

5.1 Technical Themes

The themes of Gnosis can be summarised as the development and integration of key enabling technologies for the improvement of products and production. This was achieved through the deployment and capitalisation of systematised knowledge in order to move towards a future post mass production paradigm. The project was structured in five inter-related work packages, corresponding to the technical themes. The relationships between the themes are shown in Figure 1:

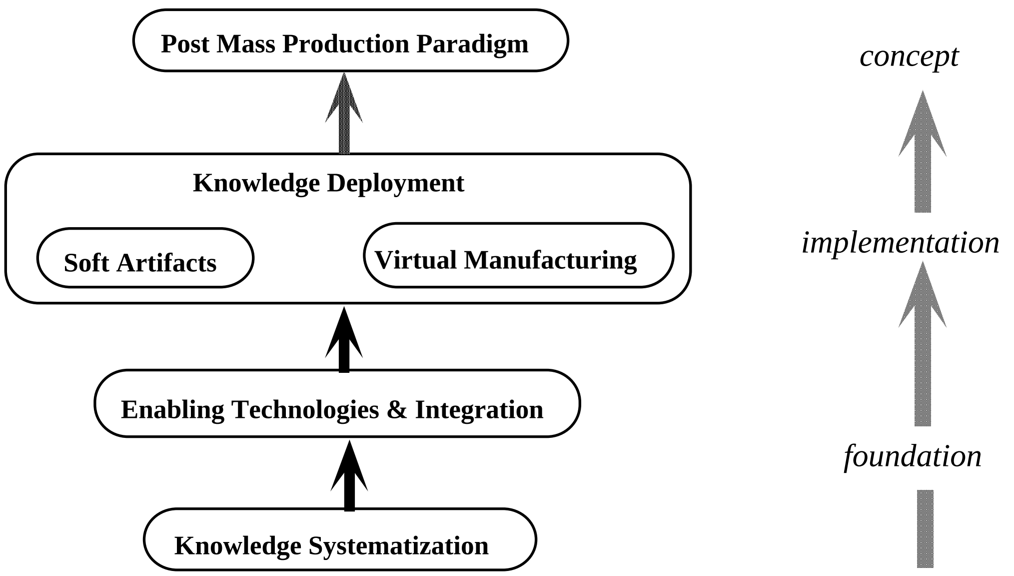


Figure 1: Principal Themes of Gnosis

5.2 Consortium Strategy

Electronic communication media were exploited in order to minimise travel overheads, while ensuring mutual understanding and effective co-ordination on the research themes. Electronic networks were set up as a basic distribution mechanism, and a document repository enabled the sharing of information and data among all partners. Collaboration among partners involved the sharing of methodologies and tools. However, the problems with different ratification methods and different funding time-scales in the different regions – particularly Japan and the EU – resulted in some restrictions to inter-regional collaboration. As a result, cross-region research and joint experiments were mainly limited to the early years of the project – in particular, during the Test Case – and to the final two years when the main regions were funded and active.

The consortium approach towards realising the goals of the project was to have a project structure consisting of linked work packages, each composed of several tasks. Each task had a sharp technical and industrial focus and limited scope. Some of the tasks consisted of developing tools, introducing softness methodologies and knowledge-oriented strategies, and providing enabling technologies. Others address the concepts and models that are needed in order to implement the envisioned shift in production paradigm.

6 WORK PACKAGE OUTPUT AND PROJECT ACHIEVEMENTS

6.1 The Post Mass Production Paradigm (Work Package WP1)

6.1.1 Scope and Objectives

The goal of this work package was to set out the foundation for the Post Mass Production Paradigm, to define its basic concepts, to set up strategies for its implementation and to formulate evaluation methods. This work package governs all the other work packages by providing them with their basic framework in which their enabling strategies, methods and tools are developed and integrated. It facilitates the development of knowledge systematisation and the realisation of products with soft attributes such as modularity, re-configurability and self-maintainability.

6.1.2 Methods, Strategies and Tools

Models and Methods developed include the following:

- PMPP Definition List: definitions of issues and concepts relevant to production from the view of the Post Mass Production Paradigm -- such as Mass Production, Waste, Recycling, Production System, Service, Softness, Extension of Production System, Production Environment. It provides the glossary which expresses the ideas behind the Post Mass Production Paradigm.

- PMPP Index Model: the model by which the degree of conformity to the PMPP concept is evaluated. The parameters include measures of the effective use of material and energy, the efficiency of services, and the rate of flow of financial resources.

- PMPP Evaluation Software: JAVA-based evaluation software which produces PMPP scores for an organisation and for manufacturing products.

6.1.3 Deployment of Methods, Strategies and Tools

In the development and deployment of a generic model for the PMPP, a macroscopic view of the whole production system was considered, where a vast amount of artefacts circulate in a system that incorporates a recycling mechanism. Artefacts continuously flow within the industry nexus system, transform themselves into one another in different forms and functions with various values at their different life stages. These are categorised as material value, service value and economic value. The mechanism is formulated for the model through which identified default values for mass production can be improved upon.

To create new orders in the "closed loop of industry nexuses", it is necessary that new energy flow into the system and that created entropy flow out of the system. The basic objective for this part of the research was concerned with how this can be achieved with minimum energy and material.

Several evaluation methods for the PMPP were developed and applied to manufacturing products such as the camera, building, automobile, phone, etc. As a part of the manufacturing process, the "fractal company" concept developed by the IAF Magdeburg Institute was incorporated into the model and its associated evaluation method was developed. The evaluation was carried out in several European based companies.

6.1.4 List of Partners involved.

Mitsubishi Electric, Shimizu, Kajima, Yamatake, University of Tokyo, Tokyo Metropolitan University, IAF Magdeburg, VTT, Schroff.

6.2 Enabling Technology and System Integration (WP2) and Knowledge Systematisation (WP3)

6.2.1 Scope and Objectives

The purpose of these work packages was to develop methodologies and tools for the realisation of soft artefacts and processes. WP2 mainly deals with providing tools, and is complemented by WP3 which focuses on developing methodologies. Due to the symbiosis involved, the two work packages are summarised together.

6.2.2 Methods, Strategies and Tools

The main methodology adopted for the systematisation of knowledge is that of ontology-application. As a prototype for knowledge systematisation, methods for the "connection of objects" were systematised. Through this trial, knowledge of methods and dependencies on usage contexts or viewpoints were investigated by focussing on product domains and product life cycle phases. Based on the results, a prototype ontology system was developed, i.e., a system of vocabularies and syntax for a particular technical domain. Other work covered in this work package included the development of tools to assist the capture and maintenance of knowledge for configuration process plans.

6.2.2.1 Designer's Amplifier/Knowtebook:

This tool supports retrieval of knowledge with ontologies. DA/Knowtebook not only supports retrieval of knowledge but also accumulation and re-use of knowledge. The tool has two features: use of ontology, and the accumulation and re-use of queries with comments. A user can add comments to queries, and such queries with comments are regarded as knowledge available to other users. This mechanism facilitates transfer of experts' know-how to novice designers.

The idea of the design document management system comes from the recognition that information produced in a design process can be considered an accumulation of the designer's knowledge, and this information is useful not only for the designers working on the product, but also for other designers as well. The design document management system permits sharing and reusing this information. The system supports design activities by the following methods.

- It supports the preparation of design documents during the design process.
- It supports the preparation of design documents by recording the designer's operations during the design process.
- It stores and retrieves design documents by using the design context information.

This document management system was implemented as an interface to the KIEF (Knowledge Intensive Engineering Framework) system developed within Gnosis. Since the document management system can record results of all operations for the KIEF system, it can support the preparation of design documents. In addition, since these created documents are associated with the design object model in the KIEF system, the document management system can use this information as design context information.

6.2.2.2 PROConfig Process Configuration Framework

The PROConfig process configuration framework uses configuration principles for designing multiple-variant production processes. The Plan Skeleton Editor tool was developed to capture and represent process plan structures and process plan generation knowledge by using generic plan skeletons. A graph-based description model was also developed and adapted to the sheet and coil production domain. Different methods for representing generic process plans, valid for all variants of a process family, were tried, including graphical, textual and decision table methods. The selected method using the graph-based model tool was deployed during development to ensure its applicability.

6.2.3 Summary of Results

The knowledge systematisation tools discussed above have been applied to some simple manufacturing cases, and have been shown to be effective in accumulating, systematising, transferring and applying knowledge. The work is considered to offer good prospects for application to knowledge systematisation. The process configuration tool has been highly evaluated for its ease-of-use and effectiveness.

6.2.4 List of Partners involved.

- WP2: Nara Institute of Science and Technology, Kajima, Shimizu, Yamatake, IAF Magdeburg, IPA Fraunhofer, ILOG, Lulea University of Technology, EMA, EPF Lausanne, ETH Zurich, Alusuisse , University of Calgary
- WP3: Kajima, Shimizu, Sumitomo Electric, Yamatake, Osaka University, University of Tokyo, Nara Institute of Science and Technology, ILOG, Tamper University of Technology, Lulea University of Technology.

6.3 Knowledge Deployment: Design of Soft Artefacts (Work Package WP4)

6.3.1 Scope and Objectives

The goal of this work package was to provide tools and strategies for the realisation of soft artefacts which will form the basis of the Post Mass Production Paradigm. Strategies and methods proposed by the Enabling Technologies and System Integration and by the Knowledge Systematisation work packages, WP2 and WP3, were utilised to facilitate the realisation of products with soft attributes, such as modularity, autonomy, re-configurability and self-maintainability. Multiple-variant products, lifecycle assessment and design, and environmental impact were covered.

6.3.2 Methods, Strategies and Tools

Tools developed include the following:

- A design-for-environment support system (D4N) to assist designers of domestic electrical appliances to realise environmentally friendly products.
- A design support tool, Emerald, for the construction industry to enable the design of modular, eco-friendly buildings.
- A configuration tool, PROConfig to enable the design of multiple-variant production processes.

In these tools, some or all of the criteria studied in WP1 – re-use, recycling, reconfiguration, flexibility, low eco-impact, etc. – are incorporated, thus providing one practicable method of moving towards the Post Mass Production Paradigm.

Strategies and methodologies have included the following:

- Methods for realising “cellular machines” with autonomous distributed control to facilitate re-manufacturing, reconfiguration and other properties essential for soft artefacts.
- Proposals for recycling and reuse of discarded products, including up-cycling, down-cycling and ETN (“equivalent to new”) products.

Deployment of Methods, Strategies and Tools

A cellular machine with a decentralised system consisting of many distributed autonomous units (called “cells”) has been developed and tested. This prototype is a “cellular re-manufacturing system” which realises functions of transportation, assembly and disassembly, material processing, and inspection. Experiments verified that the system facilitates re-manufacturing, including material processing and reuse of old components.

The design-for-environment support system (D4N) has been applied to various electrical products, including air-conditioners, television sets, gas and oil heaters, washing machines. Evaluation results have indicated where improvements should be made, and guidelines incorporated into the tool have shown how improvements can be achieved. The D4N system has already been used for training purposes within one of the partner companies and is expected to be used for new product design from 2000.

The construction design tool, Emerald, has been applied to factory design, proposing re-configurable materials using a standardised “kit-of-parts”. Such parts facilitate assembly and disassembly, as well as later adjustments in constructed factories, and lead to the possibility of sustainable, long-life “soft” factory design.

The Process Configuration tool, PROConfig, has been applied to aluminium sheet production, integrating knowledge and data on the complete production process to improve efficiency and flexibility. This tool defines a generic constraint-based configuration model for process configuration.

A prototype of the re-manufacturing system in the form of a cellular warehouse has been built and tested, and the results indicate the potential of the ideas for several areas including manufacturing, disassembly, distributed control, etc.

6.3.3 Summary of Results

The cellular machine enabled functions, such as disassembly and cleaning, to be added after the basic machine was built, thus proving its high functional reconfigurability. This characteristic is a result of the distributed autonomy in the system and is essential in soft machinery. In remanufacturing, the fluctuations in quantity and quality, and in the types of disused products -- which are input to the remanufacturing processes -- are much higher than in the traditional manufacturing processes. The results have shown that the cellular machine architecture with its high flexibility, is the most suitable one for the remanufacturing processes.

The realisation of the necessity for eco-design support tools, such as D4N, has resulted in considerable interest by different company departments, from design sections to eco-auditing to public relations. On-going development is leading towards regular use by designers within one of the partner companies.

The Emerald and XEmerald tools have been applied to building design, to facilitate the creation of building frames using eco-parts. PMPP factors such as distance to site, lead time in selecting supplier, etc. are considered.

PROConfig is still under development but has been tested for applicability by one of the industrial partners and is expected to be deployed this year, improving the efficiency of the production process and replacing conventional planning methods.

6.3.4 List of Partners involved

Mitsubishi Electric, ASTEM, Chiyoda, Kajima, University of Tokyo, Tokyo Metropolitan University, ETH Zurich, EPF Lausanne, Alusuisse, IPA Fraunhofer.

6.4 Knowledge Deployment: Virtual Manufacturing (Work Package WP5)

6.4.1 Scope and Objectives

The goal of this work package was to utilise the results of the knowledge systematisation and the enabling technologies and system integration and provide the production strategy and tools necessary for the realisation of soft artefacts.

6.4.2 Methods, Strategies and Tools

Methods and strategies developed include the following:

Extraction of Meta-Knowledge from the Design Process
Product design is based on function, aesthetics and manufacturing constraints in addition to environmental considerations such as recycling. A methodology was proposed to represent the relationship between these constraints and the product design, and by analysing the design thought process, to extract design process meta-knowledge.

Soft Crane
With the objective of developing a crane capable of adapting flexibly to the constraints of a construction site, the following results were obtained:

- A control device has been developed which can estimate the requirements for moving a load to a destination inside a building site. The estimate is done using sensors and the movement is carried out using suspension wires which can be of any number.

- Control of the load requires consideration of the suspension wire tension and inertia, and the ability to cater for shaking caused by outside effects. A genetic algorithm is used to control the load position. A prototype machine has been developed and tested using virtual values for the position and load sensors. Work is continuing on load control, the avoidance of interfering objects, and co-operation with other transportation mechanisms which can compensate for weak points.

6.4.3 List of Partners involved

Shimizu, Chiyoda, ASTEM, ILOG, ABB, TDM, EMA, DemoCenter, ADEPA

6.5 Virtual Factory

Gnosis has been developing a new generation of highly configurable manufacturing systems, known as the Virtual Factories. The Virtual Factory provides reactivity and efficiency by the optimal use of distributed manufacturing resources. These resources are connected to form virtual manufacturing processes which can be configured and operated as work cells based on product, process or production line principles according to changing demands from the market. The core idea is communicable models which provide both planning and co-ordination functionality throughout the virtual factory. The work is backed by an Industrial Reference Group through which the industrial partners are using the results in their own factories.

6.5.1 Virtual Factory Demonstrator

This demonstrator is being developed at one of ABB's Control Low-voltage Switch Gear Systems factories. The application takes into account the distributed, de-centralised nature of the production system within the switch gear factory to enable efficient planning and scheduling using the limited resources available. The system can respond quickly to production disturbances and changes in customer demand and can solve the ensuing scheduling problems within a single factory. This decreases the down time of production and of through-put time of products. Utilisation of resources in production stays constant. Sophisticated documentation of the model factories and supply chains can be utilised when starting up new or modifying existing manufacturing sites.

7 ACHIEVEMENTS SUMMARY

7.1 Exploitation

Project results are now being deployed and exploited in various ways:

- Partners are using project output to improve their competitivity in design and manufacturing, to implement prototypes of next-generation products, and to establish new business methods compatible with both the ecological environment and the growing knowledge-based economy. In addition, products, methods and tools are being marketed in accordance with IPR (Intellectual Property Rights) conditions specified in the consortium agreement. Within the consortium, research results are available for all partners.

- Partners from the construction industry are proposing changes in the relationship between design and production, and also between contractor and subcontractors. They are improving building construction systems using soft-artefact concepts, production systems using shared resources and virtual factory concepts, and electrical product design protocols so that they conform to the ideas of the PMPP.
- Partners who are software/hardware vendors and system integrators are promoting new software packages developed in Gnosis, either as additions to existing software or as self-contained packages.
- Configuration management and simulation tools, which avoid the rigidity of current CIM approaches, are being applied to products and production systems. These tools facilitate the management of the complex relationships between marketing, design, engineering, production, sales, maintenance and disposal or recycling.

7.2 Industrial and Economic Benefits

The benefits from the Gnosis research include the following:

- Through the Gnosis initiative regarding the PMPP and soft machinery, the first step in next generation product design and production systems has been taken, giving partners an economic advantage over companies still based on existing paradigms.
- The virtual factory, with its emphasis on reconfiguration, has shown how costs may be reduced and access to larger markets attained. The virtual factory approach uses models of the individual elements provided by the machine supplier, with systems developed by linking component models.
- The Gnosis research has shown that manufacturing strategies should be based on continuous improvement, whether to match changing market needs or to improve manufacturing efficiency.
- The flexible organisation structure proposed in Gnosis makes the workforce more efficient particularly in the areas requiring multiple skills and IT awareness. Teams can deal with a wide variety of tasks and collaborate with other teams to ensure that all the objectives in the overall plan are met.

7.3 Environmental Impact

The environmental impact of the Gnosis research includes the following:

- An increased awareness, both among partners and external organisations, of the importance of the ideas proposed by Gnosis, particularly regarding the Post Mass Production Paradigm and the Soft Machinery. Among partner companies this awareness has resulted in new software tools for facilitating the design of soft products and soft production systems.
- Research into the Virtual Factory has shown how full life-cycle design of products and production facilities can be implemented. Reconfigurable production systems support customisation of systems and allow industries to take into account the environmental issues and exploitation of natural resources. The Virtual Factory concept offers also new possibilities in logistics planning of manufacturing systems whereby it becomes possible to configure not only production but manufacturing life-cycle logistics in an environmentally friendly way.

8 PROJECT HISTORY

8.1 The Intelligent Manufacturing Systems Program

In 1989 the Intelligent Manufacturing Systems Program was proposed by Professor Hiroyuki Yoshikawa of Tokyo University as a framework for encouraging collaborative research among the principal manufacturing regions of the world. The rationale behind the proposal included the trend towards co-operation not only in basic science but also in strategic research and the development of new technologies. It was also realised that no country is self-sufficient in technology, and the costs and risks involved in bringing to fruition large scale new ideas deter even large companies from going it alone. International collaboration assists globalisation efforts and the potential for marketing new products on a world scale rather than a national or regional one. In addition, the smaller and less wealthy countries are sometimes left out of new markets and technologies. International joint research program would provide a mechanism for them to catch up and stay abreast of the latest developments. Finally, globalisation of technology and research ideas requires that progress be made in international intellectual property rights (IPR). The IMS program would provide a testing ground for IPR mechanisms and protocols.

8.2 The Gnosis Test Case (February 1993 – February 1994)

Soon after the initial proposal in 1989 for an industry-led, international research & development program in manufacturing – the IMS – information exchanges took place among some of the Gnosis partners in the Japanese region. By the time the IMS Feasibility Study began in 1993, the Japanese partners had incorporated their proposals for soft machinery and the post mass production paradigm with the configuration management ideas and the virtual manufacturing systems outlined by the European partners to produce the Gnosis Test Case Research Proposal. A total of 31 partners from Japan, the European Union (EU), the European Free Trade Association (EFTA), Canada and the US took part in the Test Case which ran for one year from February 1993. Within the relatively short time allowed for research, several demonstrations, research papers and prototype systems, including a Joint Demonstration involving partners from three different regions, were realised and reported in the final Test Case report.

8.3 Main results of the Test case:

Exchange of tools: The Sysfund functional design tool of Tokyo University was distributed as IMS background technology. It was utilised by thirteen partners in three different regions for different application domains and formed the basis of a joint demonstration involving the Finnish and Japanese partners. Manuals, on-site training, and software support were provided and the reports included evaluations of the tool for use in conceptual and functional design.

The Quest factory simulation tool of Deneb Robotics was provided on a variety of different bases as an example of industrial production support software and utilised by six partners in three regions.

The XDEP designer spread sheet tool from Kyushu Institute of Technology was applied to elevator configuration, which is an established benchmark for configuration problems, and was also tested on real construction layout problems by Shimizu, viz., temporary platform design and structural design of long-life foundations

8.3.1 Shared Data Sets

Telemecanique provided manufacturing data for a family of contactors which were used for configuration management research. Calgary University provided a STEP data set for a mechanical part which was used as an application for knowledge systemisation as well as configurable manufacturing.

8.3.2 Demonstrations

A joint demonstration was implemented by the University of Tokyo and Helsinki University of Technology. The demonstration integrated conceptual design to part family description using the Sysfund tool for functional design. Another demonstration involved the flow from part design to manufacturing preparation and was implemented by the Fraunhofer IPA and Helsinki University of Technology, with the Canadian partners providing the part data. Deneb, TDM and VTT developed a virtual manufacturing environment for industrial production lines and tested it with product models and data from ABB. The same partners worked with Shimizu to specify a virtual construction environment. IBM France provided data sets on the evolution of hardware and software products which were evaluated and tested by EPF Lausanne.

8.4 Transition Period (March 1994 – February 1996)

The Gnosis Test Case and the other five IMS Test Cases showed that there was a real demand for international technical co-operation and that the IPR rules were acceptable to the companies and institutes involved. The success of the Test Case led Gnosis partners to propose a longer full scale project. Initial plans were to start work on the full scale project within months of the conclusion of the Test Case, but delays and uncertainty in funding together with problems due to the different ratification mechanisms in the different regions prevented an early start. Research activity continued, however, in some of the regions, particularly where government funding was available. Finally, a full scale proposal was completed and ratified, and the main Gnosis project began in 1996.

8.5 The Full Scale Gnosis Project (February 1996 – March 2000)

When the full scale project was launched considerable work had already been done and the results of the Test Case and transition period were carried forward. However, the problems with funding and regional differences in ratification continued, and most of the activity was limited to the Japanese region until 1997 when first the EFTA and then the EU regained momentum after satisfying their local funding authorities. While the Japanese partners continued to cover all the main themes of the project -- the Post Mass Production Paradigm, Knowledge Systematisation, Enabling Technologies and Soft Artefacts and Manufacturing -- the EU partners focused on the deployment of the ideas into Virtual Manufacturing and the EFTA partners developed and applied tools for the realisation of next generation configurable production processes. Although the full scale project will end in March 2000, work will continue on the Virtual Factory in the EU region until April, 2001, and on the process configuration in the EFTA (Swiss) region until July 2000.

9 PROJECT ADMINISTRATION

9.1 Project Management Structure

Due to the scope and duration of the project, as well as the large number of partners, a number of conflicting factors had to be taken into account:

- Funding and generally all contractual matters were handled on a regional basis, whereas the drive for the project was technical and inter-regional. Funding and ratification procedures were region-based, making the co-ordination of the research difficult.
- Various tasks in the different work packages had be carried out separately, since they varied widely in kind, goals and focus. On the other hand, strong links were required between the tasks in order to ensure that the project continuously converged towards its overall goals.
- The management structure had to be stable enough to guarantee the continuity of the project and flexible enough to accommodate its evolution (tasks ending, new tasks starting, new partners joining).

At the beginning of the project, the consortium adopted a quality plan that detailed:

- the means to be applied to meet the project’s technical and quality requirements,
- the administrative and management aspects of the project (procedures, rules and application methods),

- the administrative and management aspects specifically related to the project's evolution over time (modification in the management following changes in the consortium, the technical tasks, etc.),
- the information to be used by the quality control authorities to organise quality assurance (including transfer of information, verification measures, internal review procedures etc.).

9.2 Summary of Management Structure

The management structure consisted of two parts:

- General administration, which is sub-divided into project management and regional co-ordination.
- Technical administration, which is divided into technical management and work package co-ordination.

The above two administration streams are now described in more detail.

9.3 General Administration

Project Management: This consisted of an Executive Committee, under the direction of the Gnosis Project Manager, with the running of the project carried out mainly by the Executive Committee. This Executive Committee consisted of one representative from each participating region, as nominated by the partners of each region, together with representatives from partners with the largest contribution to the project, based on the results of the Test Case and the projected contribution to the project.

Executive Committee: The responsibilities of the Executive Committee included communication with the IMS authorities, project reports and technical structure, Intellectual Property Rights (IPR) issues, dissemination of research results and exploitation policy, entry of new partners and legacy of partners that left the consortium.

Regional Co-ordination: This consisted of a Regional Co-ordinator appointed by the partners in each region, who was concerned with funding issues, regional reports, regional meetings, in addition to acting as an interface between individual partners and the Executive Committee. Each Regional Co-ordinator nominated one person to the Executive Committee.

9.4 Technical Administration

9.4.1 Technical Management

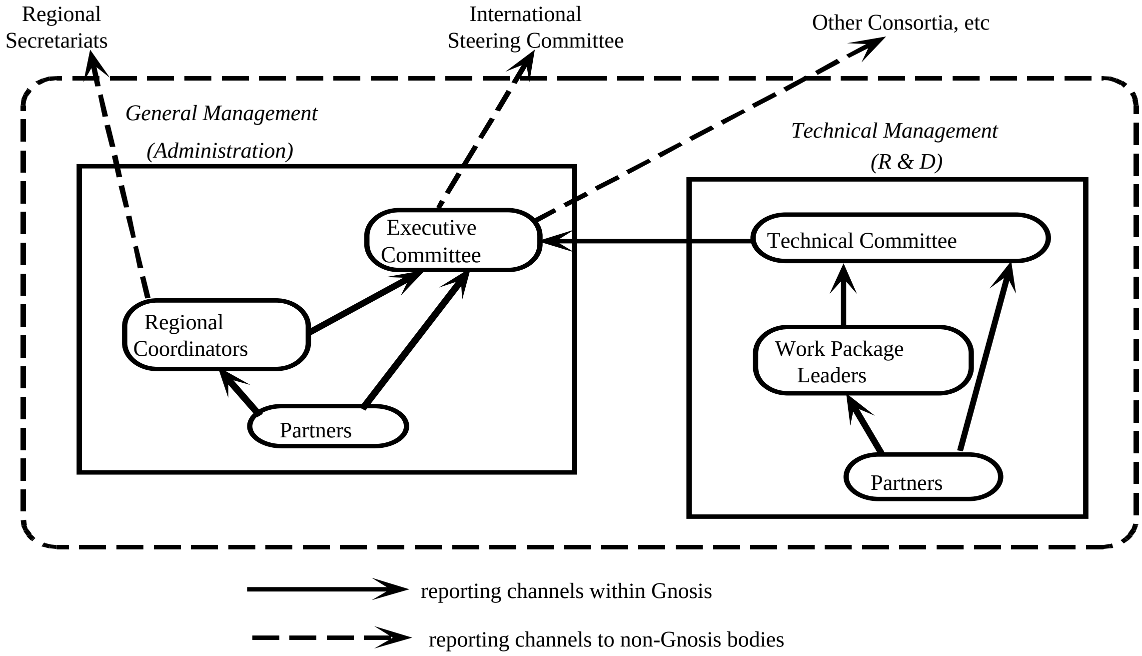
The responsibility for all technical activities was held by a Technical Committee composed of the work package leaders and the Project Manager, and which reported to the Executive Committee. One of the work package leaders was designated as overall technical manager, who, next to the Project Manager, was the final reference for technical issues in the project. The Technical Committee monitored and accepted task plans, results and reports. It was responsible for technical progress of the project, the organisation of exchanges between the work packages and tasks, and the structure and content of the work packages and their constituent tasks. The Technical Committee was the quality assurance reference for the project.

Work Package Co-ordination

Each work package had a designated leader responsible for co-ordinating the tasks within the work package, and was the representative of the work package in the Technical Committee. The WP leader was responsible for recommending new tasks, altering the schedule of existing tasks, appointing task leaders for each task, and for communicating Technical Committee decisions to the members of the various tasks within the work package.

Co-ordination Between General and Technical Administration

The two administration streams were co-ordinated by links between the project management (Executive Committee) and the technical management (Technical Committee). These links consisted of the Joint Committees who referred to the combined project and technical management, i.e., the Executive and Technical Committees.



Executive Committee: composed of Project Manager, Regional Coordinators, selected industrial partners

Technical Committee: composed of Technical Manager, Work Package Leaders

Figure 2: Consortium Administrative and Technical Management

10 CONSORTIUM COLLABORATION AGREEMENT (CCA)

The Consortium Collaboration Agreement drawn up for the Feasibility Study Test Case 1993-94 formed the basis of the agreement for the Full Scale project. This document was based on the IMS Terms of Reference but was adjusted to reflect regional concerns and the views of legal experts from some of the partners. It outlined protocols for joining or leaving the consortium, responsibilities and required contributions, and treatment of results and intellectual property generated during the project.

10.1 Amendments to CCA

With the withdrawal of some partners and the addition of new partners, problems occurred regarding the original document – in particular, the list of partners who had rights to the research results. While this list was accurate at the start of the project, it was not possible to change it to reflect partners leaving and new partners joining, without requiring all partners to re-sign the agreement. Ultimately, the solution agreed to consisted of an amendment which was implemented as follows:

Each regional co-ordinator drew up an active partner list, including new candidates. This list, together with Letters of Intent (LOI) from the new candidates were forwarded to the Executive Committee who finalised the updated partner list and requested the International Co-ordinating Partner to update the CCA partner list. The ICP sent the list to all the current partners requesting approval or disapproval of the new list. Where no objections were raised the list was updated.

One other change made to the CCA was that the reference to the "the beginning date" of the project was changed to "the commenced date" referring to the date when a partner began work in the project. This clarified the period for which partners had responsibilities and rights within the consortium.

No other changes were required to the CCA and no disputes arose during the project.

11 TECHNOLOGY TRANSFER AND DISSEMINATION

Internal technology transfer has taken place at various levels:

- Technical exchanges: tools and technical information were regularly transferred among partners, e.g., industrial product data was made available to tool developers, who in turn provided software and other tools for free testing and evaluation.
- Personnel exchanges: researchers were exchanged for short and medium length stays in order to provide support for tool implementation
- Use of electronic media: Electronic media were utilised to improve information exchange, through mailing lists, web pages for document listings and storage, and through common document storage space accessed through the web. Security was controlled through password and name lists.
- Public Dissemination: Dissemination events open to the public were held during the feasibility study in Japan, and at the conclusion of the study in Germany, France, Finland and Spain. Presentations of the results were made in the US and Japan. At the conclusion of the full scale international project, an Open Day event was held in Japan in March, 2000, and events are planned for the EFTA region with a conference in Zurich in June, 2000.
- Journals, conferences: Publication of results was made through academic and technical journals, at international and national conferences and through specialist newspapers and magazines. A list of the major publications is given in Appendix.

11.1 Involvement of SME’s

Small and medium enterprises benefited from their participation in Gnosis in various ways: through having access to state-of-the-art research and development; by establishing contacts and research liaisons in order to promote their own business and research; by gaining a better understanding of overseas markets and business practices.

SME’s include the following partners: ADEPA, ILOG, Tehdasmallit Oy (TDM)

12 CONSORTIUM COMPOSITION

Regions Involved: Japan, EU, Canada, EFTA

International Co-ordinating Partner

Mitsubishi Electric Corporation (Japan)

Regional Co-ordinating Partners

Japan: Mitsubishi Electric Corporation

European Union (EU) Region: ILOG, ADEPA

Canada Region: University of Calgary

EFTA Region: ETH Zurich

12.1 Consortium Partners

Japan Region

<u>Industrial Partners:</u>

- Mitsubishi Electric
- Shimizu
- Kajima
- Sumitomo Electric

- Yamatake
- Chiyoda

Academic Partners:

- University of Tokyo
- Tokyo Metropolitan University
- Nara Institute of Science and Technology
- Osaka University
- NACSIS – National Center for Science Information Systems
- ASTEM RI

European Union (EU) Region

Industrial Partners:

- ADEPA - Agence de la Productique
- ILOG
- ABB
- Tehdasmallit Oy
- Schroff

Academic Partners:

- Tampere University of Technology,
- Ecole des Mines, d'Ales (EMA)
- Otto-von-Guericke-University of Magdeburg (IAF)
- Lulea University of Technology

National Research Institutes:

- DemoCenter
- Fraunhofer Institute IPA
- Technical Research Centre of Finland VTT

EFTA Region

Industrial Partner:

- Alusuisse

Academic Partners:

- Swiss Federal Institute of Technology EPFL
- Swiss Federal Institute of Technology ETHZ

Canada Region

Academic Partners

DME University of Calgary

APPENDIX

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