Knowledge Systematization in the International IMS Research Program

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ABSTRACT

The international Intelligent Manufacturing Systems (IMS) research program is an attempt to systematize and make operational world-wide knowledge of advanced manufacturing systems as a basis for new paradigms. This paper gives an overview of the IMS objectives, the six test cases to date, and the proposed future research activities. It describes the coordination of the IMS GNOSIS test case, concerned with knowledge systematization to support the full manufacturing life cycle. The systematic acceleration of scientific research was a major objective of the proposed Japanese *Human Frontier* research program. IMS is one of the first attempts to achieve such acceleration on a large-scale, and the paper concludes with a discussion of the need for system-theoretic models for the complex socio-technical systems involved in international collaborative research.

1. INTRODUCTION

The classic model of a research team is of a group of researchers working in close proximity in the same laboratory. If one analyzes such a team from a systemic point of view it is a system of intelligent agents coordinating their different activities, knowledge and skills to achieve common goals. The need for proximity arises from two primary causes: first, to expedite inter-agent coordination; and second, possibly, to expedite access to shared physical resources.

However, the need to create a research team in a common physical location is a major constraint on the effective research, particularly as the pace of research increases and the time to attract and establish a team becomes comparable to, or greater than, the time to undertake the research itself. Kennedy's initiation of a crash-program to get the US into space in the 1960s led to the first attempt to systematically accelerate research by using a 'programmatic' approach [16]. Teams with specified skills and well-defined objectives were put together for relatively short periods, with reallocation of researchers to new teams planned on a continuous basis.

In March 1986, in preparation for the Group of 7 Tokyo summit, the Japanese embassy sent out a press release proposing a *Human Frontier* program for the systematic acceleration of scientific research through international collaboration [2]. It was motivated by the desire to combat US protectionism by demonstrating a Japanese contribution to basic research [11], and, perhaps because of this, it did not gain acceptance by other nations. However, the fundamental notions underlying the proposal, that basic research could be *systematically accelerated* through a programmatic approach based on international collaboration were sound and timely, and have become recurrent themes in strategic initiatives for new research programs [3].

Advances in computer and communication technology have made the environment for programmatic research very different in the 1990s from that in the 1960s. It is no coincidence that DARPA was the driving force behind the formation of what became the Internet in the 1980s. Programmatic research can be carried out more effectively if communications between laboratories are effective enough to support coordination among a distributed research team. The constraint of having to persuade critical team members to relocate to the same physical location one is a severe one. The need to locate physical facilities in the same location is a source of expensive duplication. The growth of wide-area computer networking, teleconferencing and telepresence in the 1990s has made possible a new mode of programmatic research in the 1990s, that of distributed intelligent agents and distributed resources, in which a *virtual research laboratory* can be established very rapidly with no physical relocation of agents or resources.

There are now many examples of effective distributed projects and research collaboration over the Internet [1, 15]. This paper reports on one such example which is particularly interesting because it follows the normative example of the Human Frontier program and has been treated as an experiment in international research collaboration by the nations involved. The Intelligent Manufacturing Systems research program was again an initiative by Japan, commenced test case trials in March 1993, and began a full-scale long-term program in June 1995.

The next section of this paper is drawn from the report of the International Steering Committee for the IMS Test Case phase [10], and gives the background to the formation of the IMS program. The following section is drawn from the final report of one of the test cases, GNOSIS on knowledge systematization for design and manufacturing [9], and recounts the highlights of an international collaborative activity that was heavily dependent on the Internet for its coordination. The final section discusses how such distributed collaborative activities may be modeled, and how these models may themselves become part of the activities, contributing to the systematic acceleration of research.

2. THE IMS PROGRAM

In October, 1989, an international Intelligent Manufacturing Systems collaborative program was proposed by Japan through the Ministry of International Trade and Industry (MITI). Hiroyuki Yoshikawa, now President of the University of Tokyo, headed the effort. This proposal was aimed at maintaining and improving the vitality of manufacturing industry and at contributing to the sound development of the world economy, by undertaking joint international research and development among industrialized nations and orienting manufacturing systems towards the 21st Century.

The Japanese proposal on international collaboration was based on the following fundamental understandings:

- Manufacturing is a key industrial sector and the cornerstone of all economic activities.
- Continuous advance in manufacturing technology is, therefore, vital to realize a sounder and richer world.

Recent changes, however, in the socioeconomic environment have generated a number of problems which are common to the industrialized nations and which may threaten the foundations of their manufacturing industry. These include:

- Changes in human factors, including shortages of skilled labor and the reluctance of young engineers to work in manufacturing industry.
- The appearance of "isolated islands of automation" in the manufacturing field.
- The globalization of corporate activities.
- Insufficient systematization for existing technology.
- Changes in market requirements, including shorter lead time in production and diversified needs.
- The need to preserve natural resources and the environment.

Recognizing the importance of these common problems, an IMS program was designed to promote international collaboration in advanced manufacturing technological areas. Three key research and development objectives were:

- to conduct research in basic and next generation technology;
- to organize and systematize the knowledge so it could be used in developing new technology and facilitating its transfer; and
- to standardize such technology and support the standardization efforts of international organizations.

After the public announcement of a proposed international IMS collaborative program, leading Japanese members visited the USA and Europe to explain the basic concept of this proposal and exchange views. The response was favorable but questions were raised and some people considered the proposals premature. In early spring of 1990, the EC commenced preparation of an alternative proposal and proposed a meeting of representatives from the EC, Japan and the USA to discuss the concept of cooperation and the modalities for implementing an international collaboration in advanced manufacturing. The first meeting took place in Brussels in May 1990. It examined the Japanese IMS proposal and discussed the prospects for international cooperation in the area of advanced manufacturing.

Consensus was reached on the following points.

- A properly structured international collaboration must provide a balanced flow of knowledge. Complementarity would avoid unnecessary duplication of effort.
- Any decision to proceed with such collaboration could only be taken after the three parties agreed on the modalities for implementation, technical content, intellectual property rights provisions and funding arrangements.
- An outline of the basic structure for cooperation had to be jointly prepared as a prerequisite for collaboration.
- To make this possible, each party would conduct extensive consultation with their industry and academic representatives.

A second meeting was held in Tokyo in November 1990 to discuss possible ways and means of international collaboration in advanced manufacturing technology research. Delegates from Australia, Canada and the European Free Trade Association (EFTA) countries attended the meeting as observers. In this meeting, the delegations exchanged views on such issues as modalities, technical content, funding arrangements, and intellectual property rights relative to a possible international collaborative program. It was agreed unanimously to study international cooperation in advanced manufacturing by conducting a feasibility study which would cover several research and development areas as test cases.

The meeting also reached consensus on a number of general principles regarding the importance of manufacturing and the basic structure for international cooperation. These included:

- Manufacturing is a primary generator of wealth and critical to establishing a sound economic basis for an ever improving standard of living.
- Collaboration should be truly international.
- Contributions and benefits should be equitable and balanced.
- Collaborative projects should have industrial relevance.
- Consortia should be interregional, geographically distributed and decentralized.
- Projects under government sponsorship or utilizing government resources should involve pre-competitive research and development.

These general principles were carried over to the development of Terms of Reference for a feasibility study. The feasibility study aimed at developing and testing a framework for international collaboration and, more importantly, at proving whether a collaborative program in this area could be created and structured equitably and beneficially. It was expected that the results and experiences gained in the feasibility study would enable a decision on whether to establish a long-term program.

The feasibility study was planned to consist of two parts. The first was aimed at developing a structure for the program, including such issues as modalities of international collaboration, funding arrangements and provisions on intellectual property rights for international collaboration, technical themes for the program and criteria for approving projects. The second involved conduct of test cases to establish procedures for a future program. This covered cooperation methods, contribution and funding, technical themes, and provisions on intellectual property rights.

Terms of Reference were adopted in September 1991. In December 1991 a meeting of the secretariats was held to plan the implementation of the IMS feasibility study. The main proposal was that a feasibility study should be undertaken by the six Participants: Australia, Canada, the EC, five EFTA countries (Austria, Finland, Norway, Switzerland and Sweden), Japan, and the USA. The Terms proposed that the study should be carried out through three committees: the International Steering Committee (ISC), the Intellectual Property Rights Committee (IPRC) and the International Technical Committee (ITC). In addition, the Terms of Reference identified government agencies in each region which would act as regional secretariats.

The ISC held its initial meeting in Toronto in February 1992. This meeting agreed to proceed with the feasibility study and approved workplans for all three International Committees from that date through to January 1994. The study began in 1992. The Terms of Reference emphasized that all contributions to, and benefits from, cooperation would be equitable and balanced. The study consisted of two distinct parts, first the development and evaluation of a framework and modalities for international cooperation, and second the execution of five test case projects and one study project aimed at gaining practical experience of collaboration. All projects which served as test cases had at least three Participant regions represented, and all projects were industry-led with guidelines for proper intellectual property rights protection.

Technical topics included:

- enterprise integration and global manufacturing;
- systematization of manufacturing knowledge (GNOSIS);
- the control of distributed intelligent systems;
- techniques for rapid prototyping;
- "clean" manufacturing in the process industries.

The feasibility study demonstrated that guiding principles embodied in the Terms of Reference were workable and necessary, and that the IMS framework enhanced global manufacturing cooperation. It facilitated the establishment of relationships amongst large companies, small companies, academic and research institutions, and public authorities on a world-wide scale. It provided a structure for sharing of intellectual property in international consortia, and allowed this structure to be thoroughly tested. In addition, it facilitated international discussions and assessment of what should be the priorities for global cooperation in advanced manufacturing. Several symposia reported the results.

The experience gained by the 140 partners involved in the test case projects was invaluable. Cultural, language and technical barriers were overcome. International collaboration provided added value which outweighed the overheads incurred through collaboration on this scale. High overheads were incurred in the initial study but should be lower in a full program particularly through the use of electronic communications. Important products of the feasibility study were sound recommendations for the subsequent full-scale IMS program, particularly recommendations for terms of reference for a full-scale program and detailed intellectual property rights provisions.

3. THE GNOSIS TEST CASE

The GNOSIS consortium was formed to develop a long-term IMS research program concerned with the systematization of knowledge for design and manufacturing. It made heavy use of digital communication technologies to support the research activities of a highly distributed team, using the Internet for communications and CD-ROMs for reporting. The GNOSIS test case consortium comprised 31 organizations in 14 countries (Figure 1), and involved over 100 researchers. This section gives an overview of the operation of the GNOSIS test case.

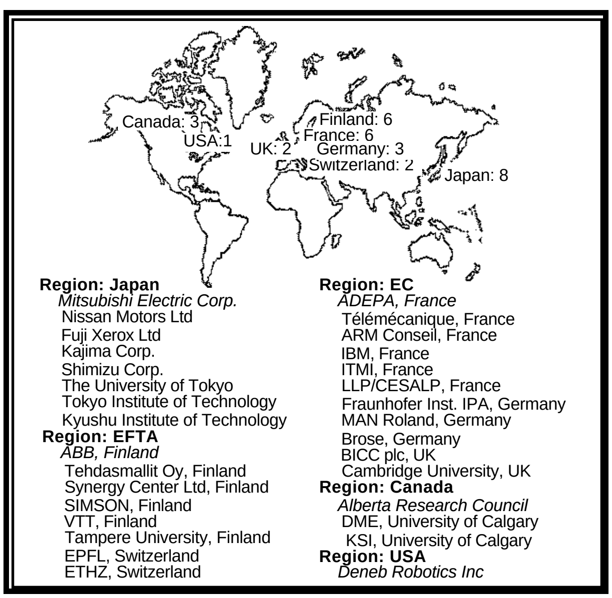


Figure 1 The GNOSIS Consortium

GNOSIS Objectives

The long term objective of the GNOSIS research program is to develop a new manufacturing paradigm which recognizes problems of the present manufacturing environment—growing scarcity of natural resources; problems of environmental destruction; and issues arising out of regional trade imbalances. The new *post mass production paradigm* is based on *systematization of design and manufacturing knowledge* to acquire and organize knowledge in a form that supports the design and manufacturing of *soft machinery*, i.e., products and factories which achieve reduced resource utilization and waste elimination throughout the whole life cycle from design to reuse or disposal. Soft products and factories are characterized by properties such as reusability, reconfigurability, and flexibility.

The short-term objectives of the GNOSIS test case have been to develop concepts, methodologies, technologies, and tools to implement the new paradigm, and provide a global infrastructure capable of supporting it. Major technologies investigated include *configuration management systems* supporting the reuse of engineering and manufacturing knowledge in routine design and *configurable production systems* achieving dynamic product-specific manufacturing in flexible production systems. The major characteristics, critical drivers, and obstacles to the post mass production paradigm were identified to illuminate a path to the new paradigm. Industrial companies are already obtaining benefits from the work during the test case.

GNOSIS Research Streams

These objectives were addressed through 5 technical work streams related in content and membership as shown in figure 2:

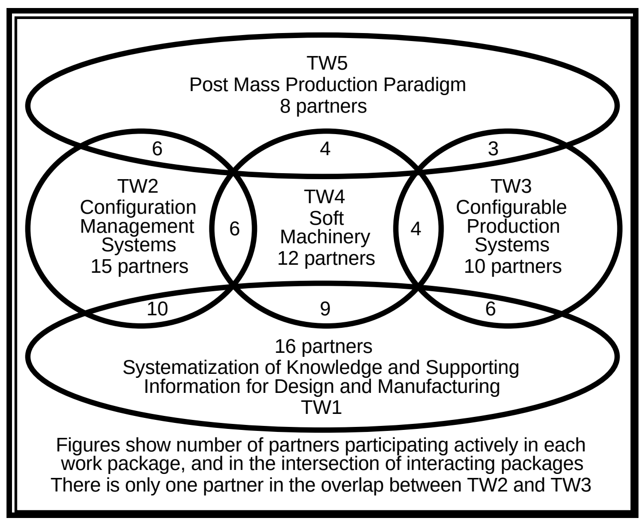


Figure 2 GNOSIS test case relations between work streams

Systematization of knowledge and supporting information for design and manufacturing: Knowledge systematization methods and tools were investigated and demonstrated to support the activities of the other streams.

Configuration management systems: The focus of the work was the formalization of manufacturing problems and constraints in a distributed environment based on the sharing and reuse of product and manufacturing knowledge.

Configurable production systems: Research investigated configurable production systems, production control, and factory design principles, with the longer-term goal of enabling soft factories and reuse of production process knowledge.

Soft machinery: Research utilized the results of the other streams to develop conceptual prototypes of next-generation soft artifacts.

Post mass production paradigm: Research concentrated on the characterization of the post mass production paradigm and its development strategies.

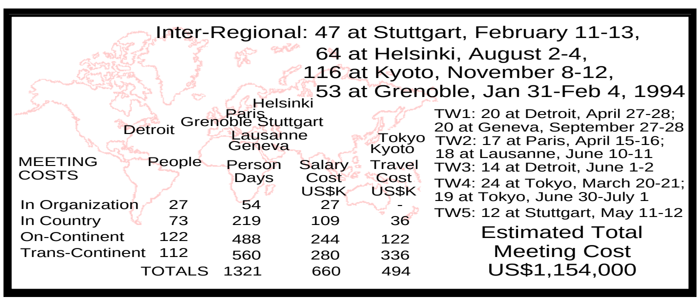
4. GNOSIS RESEARCH COORDINATION

The high overheads of international collaboration noted in the ISC report cited in Section 2 were immediately apparent in the development of the GNOSIS program which involved in-depth negotiation and coordination across three continents. Because the participants were largely new to one another and came from differing cultures many face-to-face meetings were necessary both before and during the test case. As the overheads of such meetings might be a significant impediment to a successful long-term program, they were monitored carefully. As the GNOSIS research involved systematization of knowledge requiring major computing and communication facilities, it was also an appropriate test case in which to investigate such systematization and technologies to coordinate the project itself and to attempt to reduce the overheads of collaboration.

This section reports on the overheads and the use of information technologies to reduce them.

GNOSIS Meetings and their Costs

Each technical work stream involved researchers in many organizations in many countries. Coordination took place through fax, email and meetings. Figure 3 shows the major meetings together with their estimated costs. The total costs of the meetings were some $1.15M which is some 20% of the overall GNOSIS test case budget of $5M.



MEETING COSTS	People	Person Days	Salary Cost US$K	Travel Cost US$K
In Organization	27	54	27	-
In Country	73	219	109	36
On-Continent	122	488	244	122
Trans-Continent	112	560	280	336
TOTALS	1321		660	494

Figure 3 GNOSIS test case major meetings and costs

In financial terms this overhead is substantial, but not unreasonably so for a research program based on international collaboration. However, what is rather more difficult to quantify is how effective were the meetings in coordinating the research. For example, to what extent did discussion at the meetings become concrete in terms of documented objectives, detailed schedules, contingency plans, and so on, and were these effective in actually managing the research?

It was clear from the outset that discussion that did not lead to effective coordination had little value, and hence the emphasis in technical support was upon the capture and systematization of the outcome of the meetings. Maximizing the value derived from the meetings was at least as important as minimizing their cost. The following sections describe some of the uses of computer and communication technology to support these objectives.

GNOSIS Use of the Internet for Project Coordination

The main forms of communication between partners in the test case are shown in Figure 4. The interregional and technical work package meetings allowed partners to come to know one another, to exchange accounts of experience, research capabilities and needs, and to develop plans and agree responsibilities. Fax and telephone communication were used extensively to coordinate ongoing activities.

Face-to-face communication 4 inter-regional plus 8 separate technical work package meetings.
Fax Agreed legal basis of information.
Telephone Used extensively for coordination.
Researcher Exchange Technical collaboration.
Electronic mail Primary basis of technical coordination. Mailing list servers for entire project and each work package. 8 out of 31 partners no email requiring parallel use of fax.
Documents Minutes of meetings and technical reports.
Electronic Documents TW4 Tokyo, electronic document by OCR of papers and slides, plus digital movies of demonstrations — available on CD-ROM and in printed form.

Figure 4 Main forms of communication in GNOSIS test case

Electronic mail was already in use by 23 of the 31 partner organizations, and mail list servers were set up at partner sites in Tokyo and Stuttgart that supported work package and administrative coordination. An electronic document archive with FTP and WWW access was established in Calgary. These Internet facilities played a very important role in facilitating the GNOSIS test case coordination, and continue to operate as the major means of ongoing collaboration between partners. Figure 5 illustrates the operation of the servers. Partners anywhere in the world sent electronic mail to mailing lists on machines in Tokyo or Stuttgart. These machines then re-distributed it to all the other partners who had registered with the mailing list. The Stuttgart machine also faxed the mail to the few partners who did not have email facilities. Figure 6 shows the usage of the lists during the April-October 1993 period.

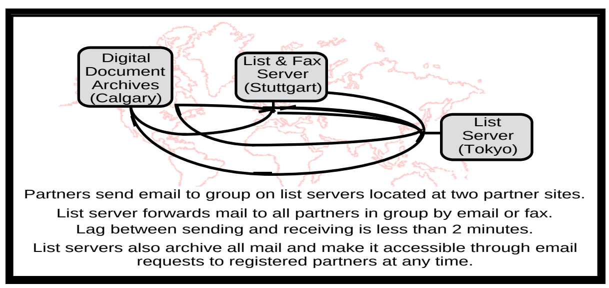
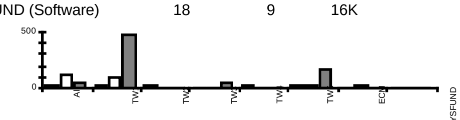


Figure 5 Electronic mailing list server operation

List Server	Subscribers	Messages	Volume
All (general)	35	123	446K
TW1	35	104	4,665K
TW2	29	15	50K
TW3	14	17	501K
TW4	22	8	113K
TW5	28	40	1,640K
ECM (Exec Ctee)	14	20	57K
SYSFUND (Software)	18	9	16K

High volumes per message onTW1, TW3 & TW5 because they were used to exchange technical reports.



Bars are subscribers, messages and volume (in 10K) respectively

Figure 6 Electronic mailing list server usage

GNOSIS Use of Digital Document Capture

To ensure knowledge capture and systematization at meetings, minutes were written immediately after the meeting, circulated by email and archived for access over the Internet. Experiments were also undertaken on the use of digital document technology to capture the technical contents of the meetings.

For example, a camcorder was used to capture software demonstrations and presentations at a 3-day TW4 workshop in Tokyo in March 1993 involving some 30 participants. The slides presented were collected together with the handouts circulated, largely technical papers from conference proceedings and internal reports. On return to Calgary, the papers were optically recognized using Xerox *AccuText* with an accuracy of some 98%, remarkably high considering that some of the papers were late generation copies of double-column conference material in 9pt type. The slides were digitized and the movies converted to QuickTime and edited in Adobe *Premiere*.

The resultant material was put into a uniform style in Microsoft *Word*, resulting in a 300-page workshop proceedings [8] containing 30 articles and 8 QuickTime movies. Figure 7 shows a page from the proceedings with the heading, comments, and movies of computer software demonstrations preceding a technical paper. The production time to OCR the source material, edit it into a uniform format, digitize the slides and movies, and issue the proceedings in print and CD-ROM was 1 week. The effort required was some 40 person-hours. Thus, a high-quality workshop proceedings was produced *after* the event without any additional effort on the part of the participants. The total cost of producing the proceedings was about $3,000, about the same as the air fare to travel to Tokyo.

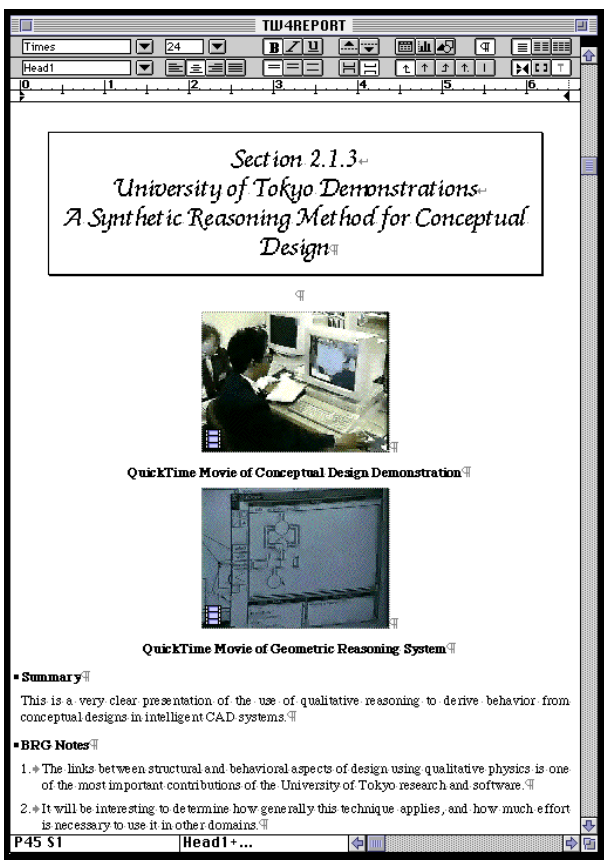


Figure 7 Workshop proceedings with embedded demonstrations

GNOSIS Use of CD-ROM for Reporting

At the end of the GNOSIS test case, the project reports, slide sequences, photographs, movies, and so on, were issued on a CD-ROM. To enable widespread access to the reports, a hybrid format was used that could be read on Macintosh, Windows and UNIX platforms, and all the reports were issued in Microsoft *Word*, Farallon *Replica* and Adobe *PostScript* formats. The total volume of material on the CD-ROM was: 57 reports totaling 1590 pages, each in 3 formats; 11 movies totaling 70 minutes; plus software and maps of the material. 3 test masters were made of the CD-ROM using a Philips *CDD521* recorder and OMI *QuickTOPiX* software. The third one was sent to a CD pressing company that produced 500 copies in 10 days at a cost of $1500.

For the GNOSIS archives, it was appropriate to use as an indexing tool *Mediator* [5, 6], a system that had been developed to support collaborative activities across the network as part of the GNOSIS research program. The *Mediator* implementation is based on groupware concept-mapping tools that were already in use for indexing multi-media materials [7]. Figure 8 shows the GNOSIS project archives being accessed through layered concepts maps. The map in the window at the upper left is a top level "Server Agent" that manages a particular collection of material. In the example shown a local user is accessing material directly through this agent. Remote users connect to the server agent over the network using client agents that give them the same functionality through calls to the server.

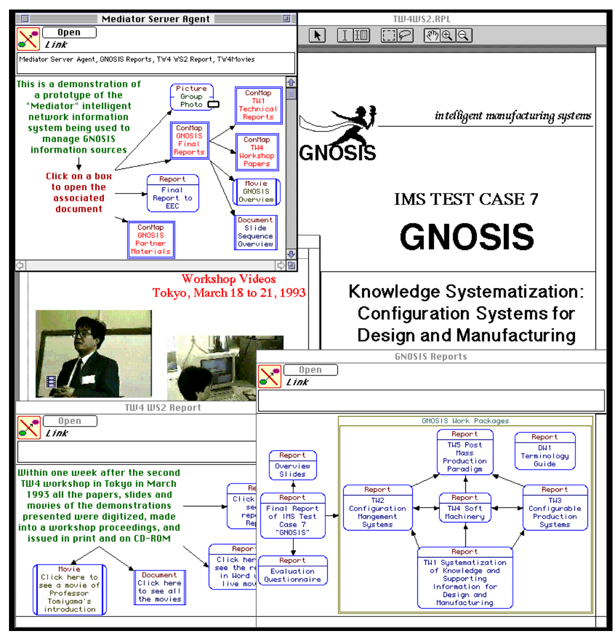


Figure 8 GNOSIS archives indexed by Mediator

The concept map at the top left is currently write-disabled, and the cursor has changed to a button as the user mouses over the "Group Photo" node. Clicking at this point will display the photograph in a separate window. The user has already clicked on the node "GNOSIS Final Reports" to open the concept map shown at the lower right. This has a node for each report, and clicking on one will open the appropriate report, in this application using Farallon's *Replica*. The node at the top left gives access to a series of slides on the project displayed using *Replica*. A similar node in the original concept map at the top left gives access to a movie on the GNOSIS project that will be opened in Apple's *MoviePlayer.*

5. CONCLUSIONS—RESEARCH AS A SYSTEM

The GNOSIS project is concerned with the use of advanced information technology for knowledge systematization to support the complex intellectual and managerial processes involved in the manufacturing life cycle. It has developed technologies such as Mediator to do so, and these technologies have proved useful in supporting the complex intellectual and managerial processes involved in distributed collaborative research. In the manufacturing environment we take it for granted that it is possible to develop a detailed technical model of the system to be operated. What is the equivalent for the research environment? Can we build a model of the system of researchers and resources, their processes and coordination, and make this overt to support the research itself?

These questions were not part of the mandate of the GNOSIS project, but they arise naturally out of the logic of the test cases, which was to investigate the cost-effectiveness of large-scale international collaboration in research. Kim's use of insights from manufacturing to develop a formal model of creative decision making [12], the AAAI92 workshop on the role of AI in communicating scientific and technical knowledge [17], Rosenschein and Zlotkin's formalization of human negotiation conventions to apply to computational agents [14], and other such studies that treat human and computer agents within a common framework, indicate that the questions posed are timely and appropriate to the current stage of information technology.

There are models of human society that treat it as a layered system of compound entities in which individuals, groups, and organizations are functional agents, each recursive sub-divisions of humanity itself conceptualized as an intelligent agent [4, 13, 18]. From such a *collective stance*, the GNOSIS project may be seen as an intelligent compound entity consisting of distributed agents coordinated through the communication systems described in the previous section (Figure 9).

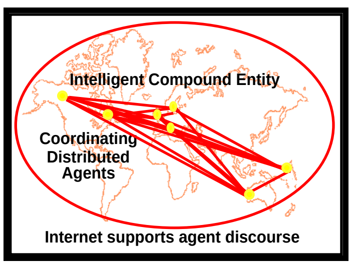


Figure 9 GNOSIS as an intelligent compound entity

The essence of all these models is to take a systemic view which abstracts both the human and technical components to form a society of agents. The problem is make the models operational and effective to enable the design of research support systems that facilitate the systematic acceleration of scientific research.

In conclusion, we see it as a challenge for the systems community to develop operational models of knowledge creation that can be used to design support systems for international collaborative research. The basic computer and communication technology is already in place, the need to collaborate is recognized at the highest levels of government, and the will to succeed exists in individual researchers and their organizations. The formal foundations do not exist as yet, and without them we are undertaking major enterprises on a trial-and-error basis that will be counter-productive in the long run. The *IEEE Systems, Man and Cybernetics Society* is a very appropriate forum for the research issues that need to be addressed.

ACKNOWLEDGMENTS

This work was funded by Industry Canada and by the Natural Sciences and Engineering Research Council of Canada. Much of the material in this paper has been developed from reports written by colleagues in the overall IMS program and the GNOSIS test case, and we are grateful for their cooperation.

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