Application of Intelligent Systems Technologies to Advanced Manufacturing

Final Report

Prepared for:

precarn

Intelligent Systems. Thinking Technology.

Systèmes intelligents. Penser technologie.

By:

Integrated Manufacturing Technologies Institute (IMTI)
National Research Council (NRC)

Application of Intelligent Systems Technologies to Advanced Manufacturing

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Executive Summary

The manufacturing sector has been facing major challenges as it undergoes revolutionary changes fuelled by new and sophisticated demands from customers, global competition, distribution of manufacturing and marketing activities, and technological advances. Intelligent Systems (IS) technologies offer a great promise in coping with the challenges and play many significant roles in advanced industrial automation and manufacturing processes and in the factory of the future. They are receiving increasing attention from industries and are being applied to the entire spectrum of manufacturing activities to gain global manufacturing competitiveness. The value and impact of IS technologies are more profound than the earlier industrial revolutions, contributing to a new era in automation and manufacturing.

This report presents the results of the Precarn funded study on the application of intelligent systems to advanced manufacturing. The objective of the study was to determine future market and technology trends in order to have a better idea of potential areas for further research, development and commercialization of IS technologies in advanced manufacturing.

The report provides a comprehensive state-of-the-art survey on the application of IS technologies in advanced manufacturing, based on the team members' knowledge and expertise, research literature and technology roadmaps reviews. The major sources of the review and analysis include the papers published in the Journal of Intelligent Manufacturing (1995-2004), the projects under the international Intelligent Manufacturing Systems (IMS) program (1995-2004), and the related projects under the European Fourth and Fifth Frameworks (1994-2002).

The future trends presented in this report are primarily based on the statistical analysis of the historical data collected during this study as well as the expertise of the study team members. Other major sources of findings are based on the external scanning and analyses of R&D trends in advanced manufacturing technologies conducted by IMTI in 2004, related technology roadmaps and visionary reports.

Two consultation workshops were organized and attended by 26 experts from Canadian firms, research organizations, universities, provincial and governmental agencies. Additional consultations were conducted through e-mails, phone interviews, as well as a Web based survey. The consultation results have been consolidated into this final report.

The report provides a brief review of the Canada's IS industry capability and Canadian strengths, and discusses the challenges faced by Canadian manufacturers as well as the opportunities of developing and applying IS technologies for Canadian manufacturing industry.

Based on the technology survey and the consultations with experts, the following areas are identified as priorities for the next five years:

- Integration of design, planning, monitoring, control, etc.
- Intelligent systems for mass customization (low volume and high variety)
- Intelligent systems for manufacturing management
- Intelligent agents, collaboration and coordination technologies
- Modeling and simulation for product and process design
- Real time information for automated decision making
- Intelligent systems for inspection, diagnosis and maintenance

The report also discusses the possible social and economic benefits of applying intelligent systems technologies in the manufacturing industry.

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1. Study Background and Methodology

Precarn is a national, industry-led, not-for-profit consortium that supports collaborative research and development in intelligent systems. Precarn's mission is to make Canadian firms more globally competitive by promoting the development and use of intelligent systems technologies and expertise. In support of this mission, Precarn funded six studies on the application of intelligent systems to six priority application areas: health care informatics; robotics and automation for medical applications; monitoring and control systems for environmental applications; public safety and security; advanced manufacturing; communities and their infrastructures. The objective of these studies is to determine future market and technology trends in order to have a better idea of potential areas for further research, development and commercialization of technologies in the these application sectors.

This report presents the results of the study on the application of intelligent systems to advanced manufacturing.

The study team consists of seven IMTI researchers and managers as well as two university professors. A discussion paper was prepared by the study team based on the team members' knowledge and expertise, research literature and technology roadmaps reviews, interviews, as well as the results of external scanning and analysis of R&D trends in advanced manufacturing technologies done by IMTI in 2004.

The major sources of the review and analysis include the papers published in the Journal of Intelligent Manufacturing (1995-2004), the projects under the international Intelligent Manufacturing Systems (IMS) program (1995-2004), and the related projects under the European Fourth and Fifth Frameworks (1994-2002).

Two consultation workshops were organized (one in London, Ontario and the other in Calgary, Alberta) with the administrative assistance of Precarn and were attended by 26 experts from Canadian firms, research organization, universities, provincial and governmental agencies. Additional consultations are conducted through e-mails, phone interviews, as well as a Web based survey. This final report has been prepared by IMTI based on the discussion paper and the consultation results.

The future trends presented in Section 4.1 are primarily based on the statistic analysis of the historical data collected during this study as well as the opinion of the study team members.

IMTI conducted a comprehensive external scanning and analyses of R&D trends in advanced manufacturing technologies during the nine-month period ending in October 2004. The relevant results from this exercise have been incorporated into this final report.

2. Introduction to the Application Sector

The manufacturing sector consists of establishments engaged in "the mechanical, physical, or chemical transformation of materials, substances, or components into new products." The assembling of component parts of manufactured products is considered manufacturing, except in cases where the activity is appropriately classified as construction. Advanced manufacturing can be defined as "the insertion of new technology, improved processes, and management methods to improve the manufacturing of products."

The manufacturing sector has been facing major challenges as it undergoes revolutionary changes fuelled by new and sophisticated demands from customers, global competition, distribution of manufacturing and marketing activities, and technological advances.

Intelligent Systems (IS) technologies offer a great promise in coping with the challenges and play many significant roles in advanced industrial automation and manufacturing processes and in the factory of the future. They are receiving increasing attention from industries and are being applied to the entire spectrum of manufacturing activities to gain global manufacturing competitiveness. The value and impact of IS technologies are more profound than the earlier industrial revolutions, contributing to a new era in automation and manufacturing.

Advanced manufacturing was one of the earliest and is currently one of the most active application sectors for IS technologies, leading to the widely accepted term "Intelligent Manufacturing Systems (IMS)."

This report follows Precarn's definition of Intelligent Systems: "Intelligent Systems are systems that emulate and actively employ some aspect of human intelligence in performing a task." Furthermore, intelligent systems also attempt to enhance the human ability to perceive, reason, make decisions, and act. They enable machines and devices to anticipate requirements and deal with environments that are complex, unknown, and unpredictable.

For the purpose of this study, IS technologies are classified into seven groups:

- **IST1:** Classical AI techniques: including expert systems and knowledge based systems, decision support systems, search and meta-search methods, constraint based methods, heuristics and meta-heuristics, machine learning, data mining and knowledge discovery, case based reasoning and modeling based reasoning, AI planning and scheduling.
- **IST2:** Soft Computing techniques (biologically inspired and evolutional computing techniques): including neural networks, fuzzy logic, and genetic algorithms.
- **IST3:** Intelligent Agents technology.
- **IST4:** Perception techniques: including sensing and vision systems with pattern recognition, speech recognition, and image interpretation.
- **IST5:** Human-Machine Interactions and Virtual Reality: including human-machine interfaces, intelligent user interfaces or intelligent user advisors, haptic devices.
- **IST6:** Modeling and Simulation technologies: including CAD/CAM/CAE, mathematical modeling and symbolic modeling, optimization.
- **IST7:** Collaboration and Coordination technologies: including Internet and Web based technologies, cooperative distributed systems, CSCW and Groupware, collaborative engineering and environments.

Real applications of IS technologies typically require combinations of these techniques / technologies.

The application of IS technologies in advanced manufacturing goes beyond the introduction of computer technology. In fact, computer-integrated manufacturing (CIM) can be considered as an early application of intelligent systems in manufacturing. It is the introduction of human-like decision-making capabilities into the manufacturing system that makes it intelligent. According to Kusiak and Heragu, CIM includes the following domains:

- Part (component) and product design
- Tool and fixture design
- Process planning
- Programming of numerically controlled machines, material handling systems, etc.
- Production planning
- Machining
- Assembly
- Maintenance
- Quality control
- Inspection
- Storage and retrieval

These domains are also applicable for IS technologies in manufacturing. Accordingly this report will use a matrix that maps intelligent systems technologies (ISTs) to application domains in manufacturing (AMTs: Advanced Manufacturing Technologies).

R&D work in advanced manufacturing is usually classified into three areas: (1) Manufacturing Processes, (2) Manufacturing Systems, and (3) Manufacturing Management. Most IS technologies applications in manufacturing are related to Manufacturing Systems and Management. In the area of Manufacturing Processes, IS technologies can be used for design, modeling, simulation, monitoring, and control of manufacturing processes.

Similarly, advanced manufacturing technologies (domains) can be classified into the following groups:

AMT1: Product and Process Design
AMT2: Manufacturing Systems Design and Manufacturing Management (including enterprise resource planning, manufacturing process planning, production planning and scheduling, materials handling)
AMT3: Enterprise Integration and Enterprise Collaboration
AMT4: Monitoring and Control (including control of micro- & nano-fabrication processes)
AMT5: Inspection, Diagnosis, Maintenance (including repair)
AMT6: Product Use and Disposal (including training and environmental issues)

3. State of the Art in the Application Sector

In the context of intelligent manufacturing systems, a number of IS technologies have been used to improve product and process design, to optimize production processes, to improve utilization of materials and resources, and ultimately to develop and produce high quality products faster and cheaper. This section provides a state of the art review of the application of IS technologies in advanced manufacturing.

3.1 Classical AI Techniques

Artificial Intelligence (AI) emerged in the late 1950's with two main goals: (1) a scientific goal in an attempt to understand the human intelligence and reasoning capabilities; and (2) an engineering goal in an attempt to design and build "intelligent" machines.

In the mid of 1960's, a subfield of AI known as expert systems came into being. The approach initially consisted of modeling experts' knowledge as condition-action rules acting on a representation of the external world. The next step forward came when the tasks to be solved happened to be complex and required diverse skills. Thus, in the mid 1970's, the HEARSAY speech understanding system was developed to record data and partial conclusions in a single location and then use several expert systems to work on different aspects of the data simultaneously. The different sets of rules were called *knowledge sources* and the overall architecture a *blackboard*. In fact, the various sources under the blackboard architecture could be considered to be separate experts working on the same problem in a distributed fashion. This is why such blackboard systems are also called multi-expert systems. This amounted to perform parallel distributed problem solving and set the foundation for a new subfield of AI known as distributed artificial intelligence (DAI).

Later on, DAI introduced more formal concepts, leading to the research themes related to intelligent agents and multi-agent systems which will be reviewed in Section 3.3.

Classical AI techniques can be particularly useful for:
- automating repetitive tasks to free the user from the burden,
- leveraging skills of the user through intelligent support,

- dealing with uncertainty,
- managing large amounts of information,
- retrieving facts from a large body of knowledge,
- transforming raw data into useful information,
- aiding in training and educating users.

Over the past decades, classical AI concepts and techniques have been widely applied to diverse aspects of advanced manufacturing, including product and process development, production management, manufacturing process diagnosis and quality control. It is no longer a question of whether classical AI techniques will have an impact on manufacturing but one of better understanding and exploiting the broad deployment of these techniques in industrial settings. Most classical AI techniques and their applications have been studied for several decades, and are not seen as active research areas. Recent active R&D work has been focused on machine learning, data mining, and knowledge discovery, and in particular, applications related to the integration with Internet and Web based technologies for process planning, monitoring, diagnosis, and maintenance. Some achievements have been reported, but significant R&D efforts are still needed before broad application in manufacturing industries.

3.2 Soft Computing Techniques

The principal constituents of soft computing (SC) are fuzzy logic (FL), neural networks (NN), genetic algorithms (GA), with the latter subsuming belief networks, and evolutionary computing including DNA computing. Soft computing differs from conventional (hard) computing in that, unlike hard computing, it is tolerant of imprecision, uncertainty and partial truth. In fact, the role model for soft computing is the human mind. The guiding principle of soft computing is to exploit the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness and low solution cost.

The soft computing research started early in 1960's and various applications of soft computing techniques in manufacturing (including industrial applications) have also been widely reported. These techniques can be applied in almost all domains of advanced manufacturing, but are particularly useful for manufacturing process planning and scheduling, monitoring and control, inspection and diagnostics, product and process design.

Fig. 1 shows various applications of soft computing techniques in advanced manufacturing reported in the Journal of Intelligent Manufacturing (about 800 papers published from 1997 to 2004). The pie chart shows the percentage of various applications (same for Figs. 2-19). Table 1 lists the abbreviations used in Fig. 1 though Fig. 19.

Among 69 IMS projects (see Section 3.8 for details), only two projects are related to the SC techniques applications (at least, soft computing techniques are not taken as key technologies in these projects). Among 230 related projects under the European Fourth and Fifth Frameworks reviewed during this study (see Section 3.8 for details), only a small number of projects are related to the application of soft computing techniques in manufacturing. Fig. 2 shows the application of soft computing techniques in advanced manufacturing by these projects.

Table 1. Abbreviations Used in Figs. 1-19

Abbreviation	Description
CCT	Collaboration and coordination technologies
EC	Enterprise collaboration
EI	Enterprise integration
HMI	Human and machine interactions/interfaces
I&D	Inspection and diagnostics
I&M	Inspection (including diagnostics) and Maintenance (including repair)
IA	Intelligent agents
M&C	Monitoring and Control
M&S	Modeling and simulation
MM	Manufacturing management (including process planning and control)
MSD	Manufacturing systems design
PPD	Product and process design
PPS	Process planning and scheduling
PT	Perception technologies
PUD	Product use and disposal
R&M	Repair and maintenance
SCT	Soft computing techniques
VR	Virtual reality

Fig. 1. Application of Soft Computing Techniques (Publications in JIM: 1997-2004)

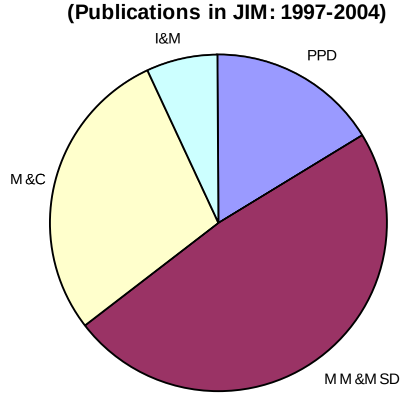
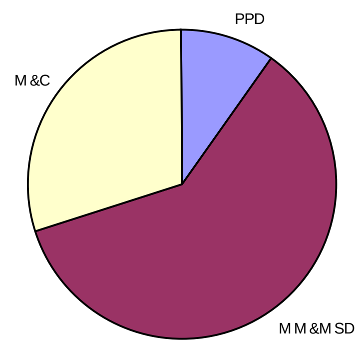


Fig. 2. Application of Soft Computing Techniques (EU FP 4&5 Projects: 1994-2002)



3.3 Intelligent Agent Technology

Within the context of this study, an intelligent agent is defined as a software system that communicates and cooperates with other software systems and humans to solve complex problems that might be beyond of the capability of the individuals.

Agent technology has been used to develop *collaborative product design* systems for more than a decade. In these developed systems, intelligent software agents have mostly been used for supporting cooperation among designers and integrating heterogeneous CAD/CAE tools. Recently, agent technology has been integrated with other emerging technologies, such as Web Services, Semantic Web, Grid Computing, CSCW (Computer Supported Cooperative Work) and Groupware, to develop effective collaborative product design systems. On the other hand, very few projects have been reported on the application of intelligent agents to *process design*.

Within the past two decades, researchers have applied agent technology to resolve the *manufacturing process planning and scheduling* problems. In fact, this represents one of the most active research topics on the application of intelligent agents to advanced manufacturing. Intelligent software agents are used to represent manufacturing resources such as production lines, cells, machines, tools, fixtures, AGVs, as well as products, parts, operations, and operators to facilitate manufacturing process planning, scheduling, and execution control. Recent interesting research work includes agent-based integration of manufacturing process planning and scheduling, combination of agent-based approaches with other optimization techniques such as heuristic search methods, performance matrix, genetic algorithms, neural networks, and simulated annealing.

Application of intelligent agents to manufacturing shop floor control is typically at the high level for coordinating the available manufacturing resources to make the desired numbers and types of products, but also at the low level for controlling individual manufacturing resources to deliver unit-processes expected by the high-level control functions. In most agent-based shop floor control systems, an agent is used to represent a manufacturing device. These agents form a heterogeneous or hybrid architecture to negotiate laterally or vertically (through a mediator or coordinator) using coordination protocols. Most systems apply Contract Net based protocols. Some others use the market-based negotiation. However, some researchers believe that the applicability of agent-based coordination in real time control environments still requires validation and special negotiation protocols that could promote the real-time performance need to be exploited.

Many researchers have been probing into solutions for *enterprise integration* and some have reached the conclusion that agent technology provides a natural way to realize *enterprise integration* effectively. In addition to significant academic research, some projects have attracted active industrial participation and developed industrial applications. In most projects, software agents are used to encapsulate existing legacy software systems using various middleware approaches. In the area of *enterprise collaboration*, intelligent software agents are used to represent negotiation partners, either physical plants or virtual entities, such as master plants, virtual enterprises, or dynamic consortia to facilitate enterprise collaboration.

With the emergence of the Holonic Manufacturing Systems (HMS) concept, agents are used to implement holons. Holon is a word coined by combining 'holos' (the whole) and 'on' (a particle). A holon is defined as “an autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects”. A holon can be part of another holon. Another important concept is the “holarchy” that is defined as “a system of holons which can cooperate to achieve a goal or objective”. A Holonic Manufacturing System (HMS) is “a holarchy which integrates the entire range of manufacturing activities from order booking through design, production and marketing to realize the agile manufacturing enterprise”. An HMS is therefore a manufacturing system where key elements, such as raw materials, machines, products, parts, AGVs, etc., have autonomous and cooperative properties. In an HMS, each holon's activities are determined through cooperation with other holons, as opposed to being determined by a centralized mechanism. Agent technology has been used to implement the HMS concepts. In this type of systems, intelligent agents called 'holons' have a physical part as well as a software part. HMS applications have been at the inter-enterprise level on holonic collaborative enterprises, and mostly at the enterprise and manufacturing system level, and at the MES level.

Figs. 3~5 show the applications of intelligent agents reported in the Journal of Intelligent Manufacturing (1997-2004), in IMS projects (1995-2004), and European FP projects (1994-2002). Note that most research on Product and Process Design is primarily published in other journals like CAD and Computers in Industry, rather than in JIM.

Fig. 3. Application of Intelligent Agents (Publications in JIM: 1997-2004)

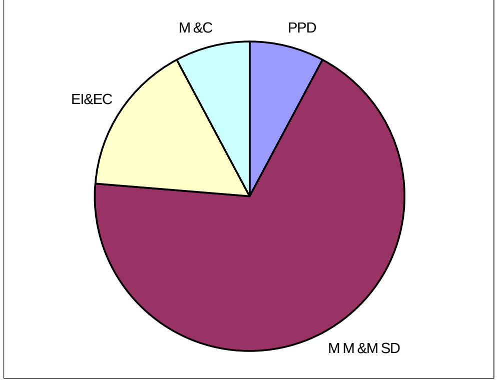


Fig. 4. Application of Intelligent Agents (IMS Projects: 1995-2004)

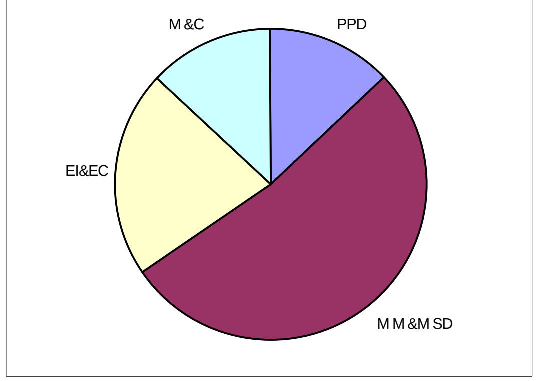
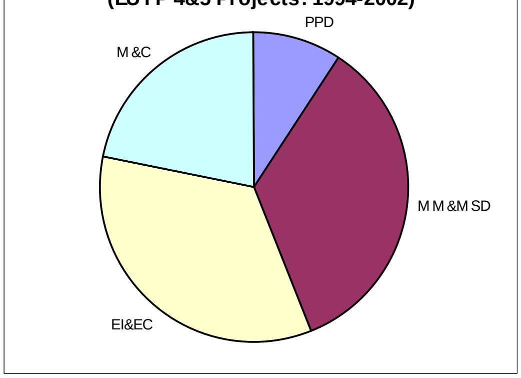


Fig. 5. Application of Intelligent Agents (EU FP 4&5 Projects: 1994-2002)



3.4 Perception Technologies

In the context of this report, perception technologies include sensing and vision systems with pattern recognition, speech recognition, and image interpretation. These technologies have been well presented in the literature (and in previously published Precarn documents). Various sensors (e.g. moisture, pressure, flow, temperature, and image-capture sensor) are widely applied in the manufacturing sector, to both monitor and control processes. Machine-vision systems integrate electronic components with software systems to imitate a variety of human functions. These systems range from image acquisition and analysis, through to higher-level functions including interpretation and decision-making. They have been applied in the manufacturing sector in various ways: to measure part sizes, to detect surface flaws, to verify assembly correctness, and to guide automated vehicles and robots.

Machine vision is by nature intelligent since the interpretation of images requires intelligence. Humans find vision tasks trivial as the brain processes images subconsciously, without any need for deliberate thought. Conversely, interpretation of images is complex for computers but tasks depending on a large amount of known calculations are relatively simple. To date, no system has been developed with the ability to interpret arbitrary images. Rather, they have been built to deal with one specific object in a restricted environment.

Over the recent years, a growing body of research has been aimed at incorporating classical AI techniques and soft computing techniques into machine vision systems to increase their capability.

Figs. 6~8 show the applications of perception technologies reported in the Journal of Intelligent Manufacturing (JIM) (1997-2004), in IMS projects (1995-2004), and European FP projects (1994-2002). Note that JIM is not the primary journal where perception technologies are reported.

Fig. 6. Application of Perception Technologies (Publications in JIM: 1997-2004)

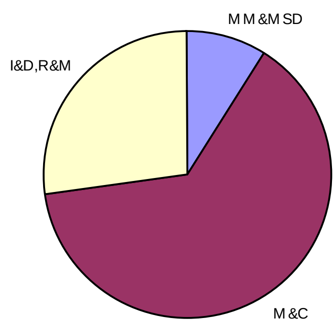


Fig. 7. Application of Perception Technologies (IMS Projects: 1995-2004)

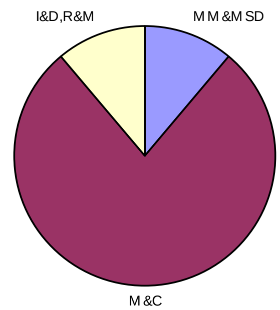
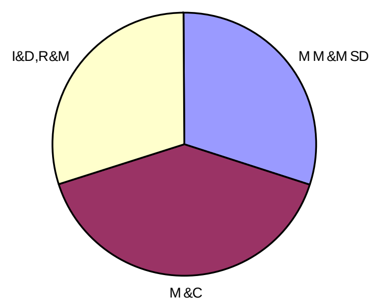


Fig. 8. Application of Perception Technologies (EU FP 4&5 Projects: 1994-2002)

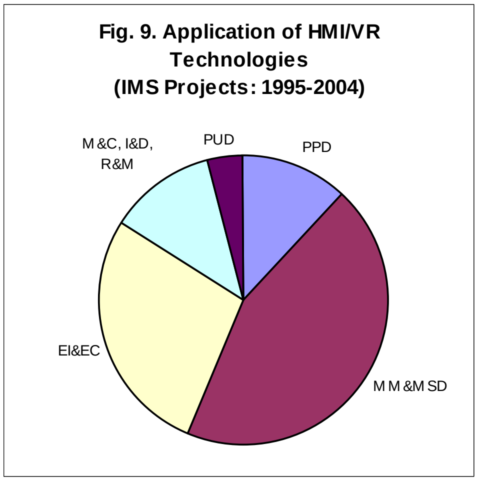


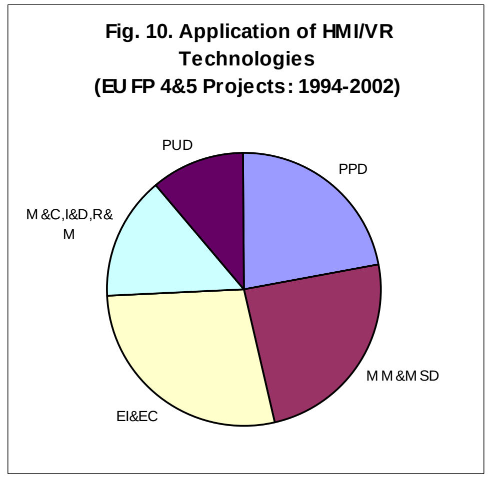
3.5 Human-Machine Interactions and Virtual Reality

Because intelligent systems complement and augment human abilities, rather than replace them, the human-machine interface is an integral component of many of these systems. The interface, which is built around knowledge representation and interactive visualization software, allows operators to interact with intelligent machines by presenting vast quantities of data in formats easily interpreted by humans. In turn, input-output devices, which transmit and receive position, motion and force data, allow operators to give instructions to machines through movement and force.

Virtual Reality (VR) can be considered as one of the HMI technologies. In most applications, 3D graphics and devices such as the data glove are used to allow users to interact with simulations. VR has been widely used to develop various simulators for training machine operators, and aircraft pilots, etc. With recent R&D work on "human-in-the-loop simulation" and "hardware-in-the-loop simulation", there will be more and more applications in manufacturing environments, e.g., for real-time remote monitoring and control, for design and validation of assembly cell / line, involving both machines and human operators.

Figs. 9~10 show the applications of HMI/VR technologies in IMS projects (1995-2004) and European FP projects (1994-2002).





3.6 Modeling and Simulation Technologies

Modeling and simulation technologies enable designers to test whether design specifications are met using virtual rather than physical experiments. The use of virtual prototypes significantly shortens the design cycle and reduces the cost of design. It further provides the designer with immediate feedback on design decisions which, in turn, promises a more comprehensive exploration of design alternatives and a better performing final design. Simulation is particularly important for the design of multi-disciplinary systems in which components in different disciplines (e.g., mechanical, electrical, embedded control, etc.) are tightly coupled to achieve optimal system performance.

One of the most basic requirements for simulations in the context of design is that the modeling language be *sufficiently expressive* to model the non-linear, multi-disciplinary, hybrid continuous-discrete phenomena encountered in the design prototypes. During the past decades, many modeling and simulation languages have been proposed and developed, but only a few of them are well suited for modeling of multi-disciplinary systems. The earliest simulation languages, based on CSSL (Continuous System Simulation Language), were procedural and provided a low-level description of a system in terms of ordinary differential equations. From these languages emerged two important developments: declarative (or equation-based) modeling, and object-oriented modeling. Current research further builds on these developments by moving towards component-based modeling and by providing support for hybrid (mixed continuous-discrete event) systems. Another requirement is that *simulation models are easy to create and reuse*. Creating high-fidelity simulation models is a complex activity that can be quite time-consuming. Object-oriented languages provide clear advantages with respect to model development, maintenance, and reuse. In addition, to take full advantage of simulation in the context of design, it is necessary to develop a modeling paradigm that is integrated with the design environment, and that provides a simple and intuitive interface that requires a minimum of analysis expertise.

Simulation for a single domain such as mechanical or electrical systems is a mature area, with a number of companies offering robust simulation packages. Multi-body dynamics simulation is one of the well-known technologies in this area and has a rich literature. Several commercial software systems, including ADAMS and DADS, provide efficient multi-body analysis capabilities. Some of these analysis systems are integrated with design tools allowing the mechanism data to be transferred to the simulator directly from CAD models. There are also other simulation tools for the simulation of electrical and electronics systems, control systems, hydraulic and thermal systems. Some research work is underway to extend the single-domain integration between design tools and simulation tools to multiple domains.

To coordinate design processes among geographically dispersed and multidisciplinary teams, many global enterprises have taken advantage of computer aided engineering (CAE) technologies that provide sharing, visualization, documentation, and management of product models. However, the aspect of collaborative modeling and simulation is still in its infancy. To support *collaborative modeling*, design teams need common, shared model representations, repositories to manage model components, and model abstraction capabilities to provide different views of models to designers.

Figs. 11~13 show the applications of modeling and simulation technologies reported in the Journal of Intelligent Manufacturing (JIM) (1997-2004), in IMS projects (1995-2004), and European FP projects (1994-2002).

Fig. 11. Application of Modeling & Simulation Technologies (Publications in JIM: 1997-2004)

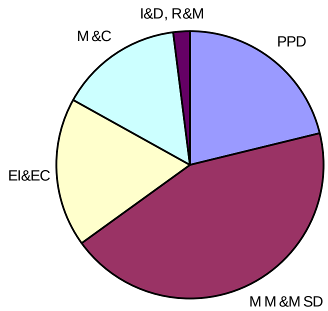


Fig. 12. Application of Modeling & Simulation Technologies (IMS Projects: 1995-2004)

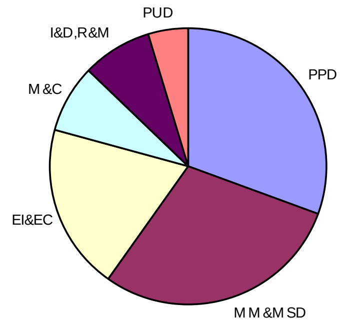
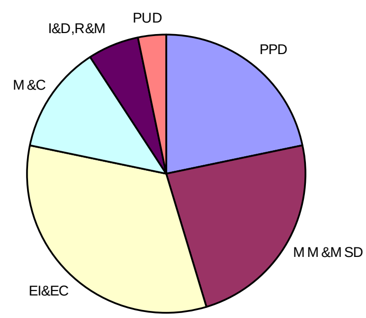


Fig. 13. Application of Modeling & Simulation Technologies (EU FP 4&5 Projects: 1994-2002)



3.7 Collaboration and Coordination Technologies

Collaboration and coordination technologies are the key in collaborative design and manufacturing environments that enable people (including designers, engineers, managers, and customers) to collaborate and interact on the development of a new project/process and monitoring and control of manufacturing processes regardless of their geographic locations and interaction means. Collaborative environments should assist users to participate in different workspaces, discover collaboration opportunities, provide knowledge or services, seek information or assistance, and perform and coordinate their product and process development activities.

During the past few years, the Web-based infrastructure has been widely used in developing collaboration systems for product data sharing and exchange, manufacturing process monitoring and control, and particularly for enterprise (business) integration, enterprise collaboration and supply chain management. Although academic research results have been reported, leading IT vendors are taking the leading role in this area. Some commercial tools have been available.

As mentioned in Section 3.3, intelligent agent technology has also been applied to develop various collaboration systems. However, most of such systems are still used within the academic community.

Figs. 14~15 show the applications of collaboration technologies in IMS projects (1995-2004) and European FP projects (1994-2002). The dominant application area is enterprise integration and collaboration.

Fig. 14. Application of Collaboration & Coordination Technologies (IMS Projects: 1995-2004)

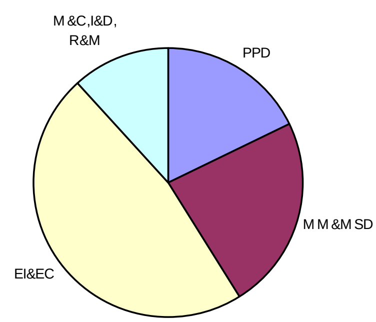
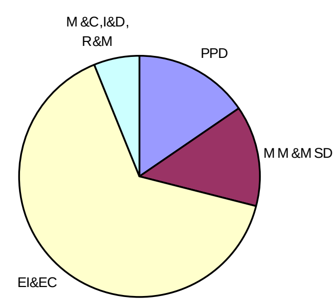


Fig. 15. Application of Collaboration & Coordination Technologies (EU FP 4&5 Projects: 1994-2002)



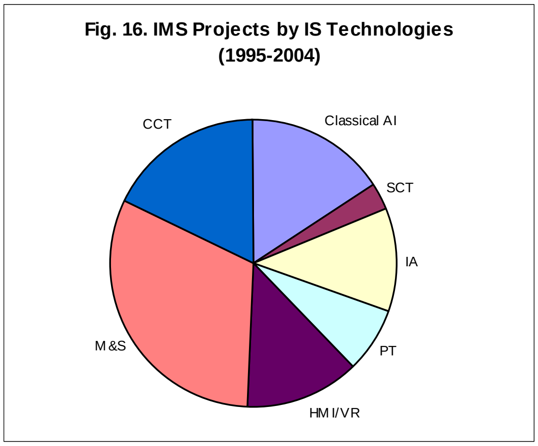
3.8 Related Significant International R&D Programs

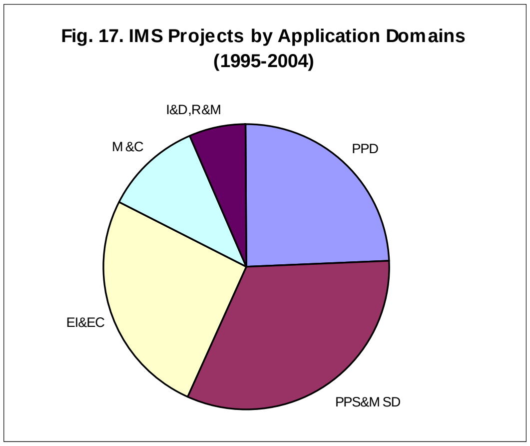
International IMS Program

The international IMS (Intelligent Manufacturing Systems) program launched in 1995 has attracted 300+ companies and 200+ research institutions from Australia, Canada, the European Union and Norway, Japan, Korea, Switzerland, and USA. At the time of preparing this report, 17 projects have been successfully completed; 16 projects are ongoing; 20 projects are being approved; 21 new projects are being proposed. The total budget of all completed and ongoing projects is about 250 millions US dollars. The IMS program will close Phase I and start Phase II on May 1, 2005.

All IMS projects are industry-led, and therefore most of them are on the stage of pre-commercialization research and development. Some projects have resulted in commercialized products and/or internationally recognized specifications or standards.

Figs. 16~17 show the distribution of the projects (69 reviewed) by the IS technologies and the manufacturing domains. The three most active manufacturing domains are (1) process planning, scheduling and manufacturing system design, (2) product and process design, (3) enterprise integration and collaboration. In addition to classic AI techniques, Modeling and Simulation, Collaboration Technologies, Intelligent Agents, Human-Machine Interfaces and Virtual Engineering technologies have been widely adopted. However, Soft Computing is not widely used in these industry-led projects (compared with its dominant position in publications).



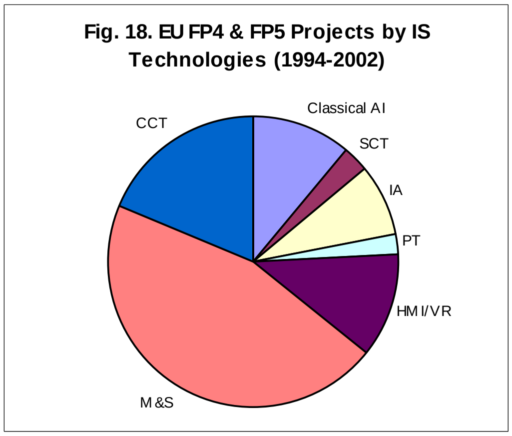


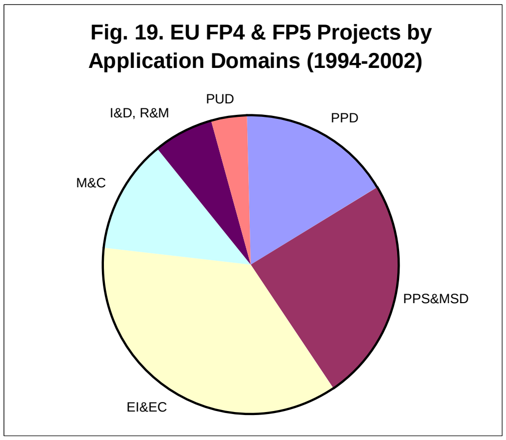
EU FP 4 (Esprit 4) and FP 5 Projects

Esprit 4 projects are EU funded industrial R&D projects, as part of the EU's Fourth Framework Program (FP 4), which ran from 1994 to 1998. About 40% of the organizations participating in Esprit projects are user industry enterprises. In total, 65% of participants are industrial companies. Approximately one-third of participants are SMEs, one-third large companies, and one-third research institutes and universities. About 160 Esprit 4 projects are found to be related to the application of intelligent systems to manufacturing.

EU FP5 projects are part of the EU Fifth Framework Program (FP 5), which ran from 1998 to 2002. Most of the projects related to advanced manufacturing are found under the IST category.

Figs. 18~19 show the distribution of the projects by the IS technologies and the application domains. It can be found that Modeling and Simulation is the dominant technology and the dominant application domains include enterprise integration and collaboration, manufacturing management and manufacturing systems design, product and process design, monitoring and control.





4. Future Trends – Five to Ten years

4.1 Future Trends – Overview

Classical AI Techniques have been applied in various intelligent manufacturing systems, particularly those expert systems or knowledge based systems used in product and process design, machine monitoring and diagnosis, etc. In the next five to ten years, some new AI techniques will be further developed, e.g., machine learning, data mining and knowledge discovery, particularly together with emerging Internet/Web based technologies like Semantic Web and soft computing techniques. Major efforts will be on the development, deployment, and improvement of these systems in manufacturing enterprises and their shop floors.

Knowledge management and knowledge based systems will still be a key R&D topic, particularly for product development. However, knowledge engineering is a time consuming process that heavily relies on the scarce and expensive expertise of computer scientists that is a barrier to its widespread application. Data mining and machine learning techniques have the potential of alleviating the time and expense of traditional knowledge engineering. Developing improved, more systematic methods for knowledge engineering is also a possibility, e.g., the equivalent of Taguchi experiments for knowledge engineering.

Although ***Soft Computing Techniques*** have been proposed and developed for a few decades, further R&D is still needed before they can be widely applied in manufacturing, particularly to be accepted by the industrial communities. The successful applications of soft computing suggest that the impact of soft computing will be increasingly felt in coming years. Soft computing is likely to play an especially important role in science and engineering, but eventually its influence may extend much farther. In many ways, soft computing represents a significant paradigm shift in the aims of computing - a shift which reflects the fact that the human mind, unlike present day computers, possesses a remarkable ability to store and process information which is pervasively imprecise, uncertain and lacking in categoricity . Fig. 20[1] shows the trend of the soft computing techniques application in different application domains.

Fig. 20. Application of Soft Computing Techniques

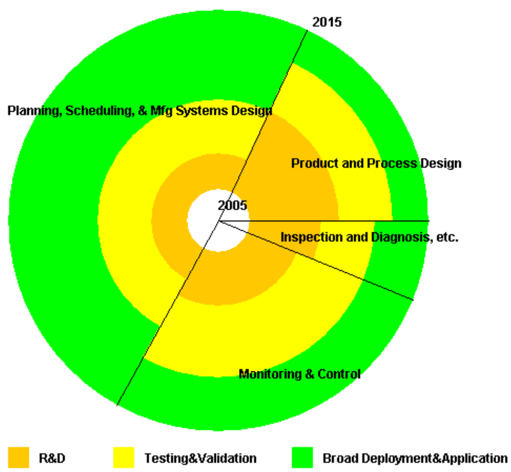
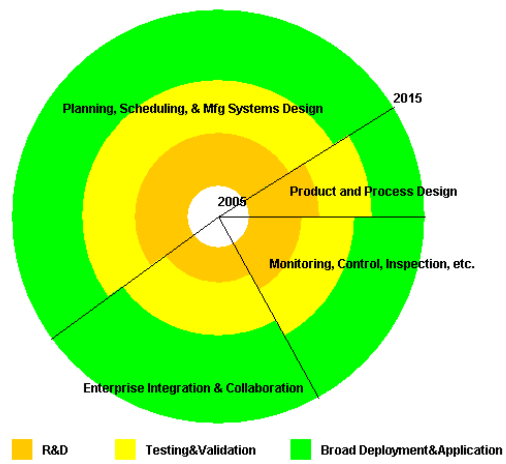


Fig. 21. Application of Intelligent Agents



Intelligent Agent Technology is becoming close to mature for industrial applications. It is particularly promising when being integrated with other emerging technologies including Web Services, Semantic Web and Grid Computing. Major application areas include manufacturing process planning, scheduling, control, monitoring, inspection, diagnosis, maintenance, enterprise integration (particularly systems integration) and collaboration (see Fig. 21).

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[1] **Notes to the Pie Charts (Figs. 20-25):** Percentage of pie portions indicates the distribution of efforts (based on the statistical analysis of all publications and projects reviewed during this study); Radical axis is used to represent the duration (years) required for R&D (orange), testing and validation (yellow), broad deployment and application (green) (based on the results of this study). It should be noted that the three mentioned phases do not happen in a strict sequential order, but they rather partially overlap. Therefore, an R&D period in Figs. 20-25 shall be interpreted as a phase where the main emphasis is on R&D although some testing and validation and even broad deployment of partial results might start in parallel.

However, significant R&D efforts are still needed before agent solutions can be accepted by industries and implemented in real applications. Further R&D work will focus on collaboration and coordination mechanisms, ontology and semantics, security measures, system stability and reliability.

Perception Technologies have been seen wide applications in manufacturing industry, though further R&D work is prospected, particularly on the integration with other technologies including software computing and data mining techniques, for smart and plug-and-play perception devices. These technologies are primarily used for monitoring, control, inspection, diagnosis, and maintenance. Future R&D in this area will be on the development of new sensors and sensing technologies (such as wireless distributed sensing and monitoring), and new vision systems, etc. Major efforts should be put on the broad deployment of these technologies in manufacturing shop floors (Fig. 22).

Human and Machine Interaction (HMI) and Virtual Reality (Engineering) will play more and more important role in manufacturing, particularly on the integration of human with physical machines as well as on the integration with modeling and simulation technologies, e.g., "human in the loop simulation" and "hardware in the loop simulation". This will also be one of the most important technologies required for the skills training of the future manufacturing workforce. Significant R&D efforts will be needed on the application of HMI/VR technologies to the development micro- and nano-scale devices and systems, including medical devices. Fig. 23 shows the trend of the HMI/VR technologies application in different application domains.

Fig. 22. Application of Perception Technologies

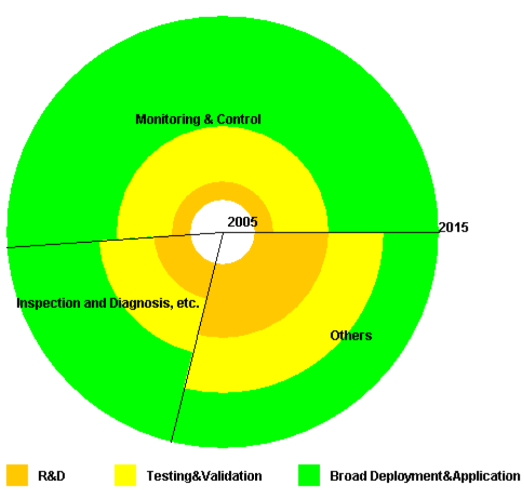
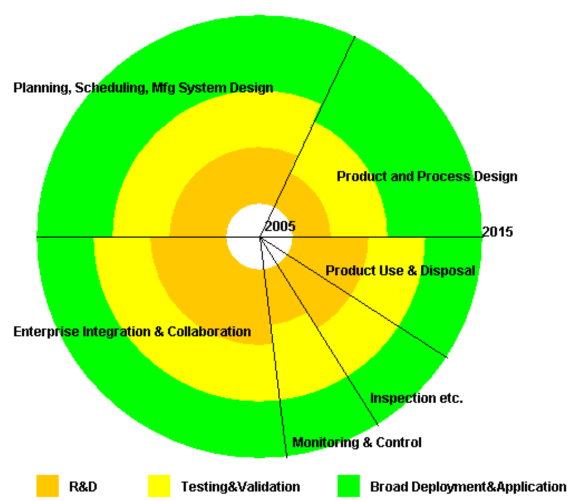


Fig. 23. Application of HMI/VR Technologies

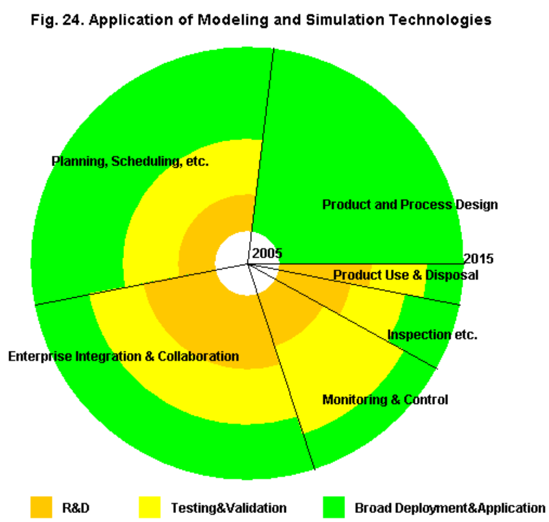


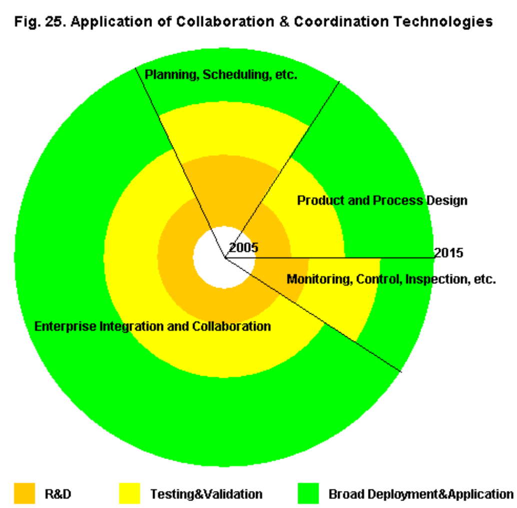
With the emergence of high performance computing (including high performance computers and high speed networking), ***Modeling and Simulation*** will be the most widely used IS technology in manufacturing. In fact, it has been used widely in manufacturing industry for product and process design, modeling and simulation of manufacturing processes including forming, joining, and assembly processes. For example, the automotive industry is looking for new forming processes for future cars – modeling and simulation should make significant contributions in this area. Future R&D should focus on the modeling and simulation of dynamic machining processes (including the dynamics of the machine, tool, and working piece), micro and nanofabrication processes, micro-, nano- and bio-material structures. This may include the development of new design methodologies for intelligent and rapid design of tooling without extensive trial and error as well as innovative methodologies for modeling and simulation of manufacturing processes and material structures at the micro- and nano-scales. Other important R&D directions include distributed collaborative modeling and simulation of complex systems and processes, as well as multidisciplinary design, modeling, simulation, and optimization. Fig. 24 shows an overview of future trends in this area.

Collaboration and Coordination Technologies will be the key technologies for product and process design as well as enterprise integration and collaboration. As jobs and factories are distributed around the globe, real-time information technology will be the most effective means of collaboration. Collaboration and coordination technologies will require models of the dynamics of human interactions that can simulate behaviours, characteristics, and appearances to simulate physical presence. Behavioural and social scientists will be essential members of development teams.

Recently, the Automotive Industry Action Group's Collaborative Conferencing Work Group (AIAG-CCWG) has established data collaboration requirements, reviewed various solutions from about 40 vendors, and concluded that, "while all vendors were able to address some of the requirements, no single vendor was able to meet all of the requirements." In fact, most current collaboration tools and environments provide a set of persistent services to users. However, they often rely on a centralized infrastructure. This makes the tools impossible to use when a specific resource or server is unavailable. Ideally, the collaboration environment should not depend on any specific resource or server; instead, the resources and servers should add value to the system when they are present. In addition, this infrastructure-centric approach makes these tools difficult to set up and scale, particularly when security is involved. A collaboration environment should be structured to support informal, spontaneous collaborations as well as highly structured environments and it should allow for "the secure real-time data collaboration from any software program, used on any automotive industry standard hardware platform, to virtually anywhere in the world." Although AIAG-CCWG has issued a RFP (request for proposals) to all vendors and is expecting a "complete" solution within several months, significant efforts are still required to produce a practical and efficient "complete" solution. Wide deployment and application in SMEs will require additional investments and efforts.

Fig. 25 shows the trends of R&D on the application to collaboration and coordination technologies to advanced manufacturing.





4.2 R&D Trends in Manufacturing Technologies

NRC-IMTI Recent Survey on R&D Trends in Manufacturing Technologies

From January to October 2004, NRC-IMTI conducted a scanning and analysis of R&D trends in manufacturing technologies in Canada, US, and worldwide, including related R&D projects and investments, patenting, publications, and roadmaps. According to an extensive literature search on available roadmaps, surveys, vision and white papers relevant to advanced manufacturing, the top sixteen areas have been recognized as follows:

- Extended Enterprise
- Life cycle and knowledge management
- Intelligent Product and Process Advisors
- Concurrent Engineering
- Modeling and Simulation
- Virtual Manufacturing Engineered Materials
- Production Process Simulation
- Production Monitoring & Supervisory Control
- Micro & Nanofabrication
- Robotics and Intelligent machines
- MEMS Manufacturing
- Reconfigurable & Flexible manufacturing
- Systems Integration and Automation
- Engineering Materials
- Advance Coatings and Surface Modifications
- Reuse and Recycle

All of the above areas are related to the application of intelligent systems technologies.

IMTI's recent survey on manufacturing related conference and journal publications (collected in Compendex within the past 5 years) shows the following interesting results:

- In the "Business Relations" area, only "life cycle and knowledge management" shows relatively large number of publications (about 1000 papers per year), while in other areas there is much less publishing activity.
- Within the "Design and Simulation" area, "modeling and simulation" dominates the publication activity (3000-4000 papers per year).
- In the "Use and Maintenance" area, only "equipment monitoring" shows significant publishing activity (about 2000 papers per year).

Fig. 26 shows the top 15 manufacturing areas by publications in Canada and US.

Fig. 27 gives a snapshot of the patenting activity in advanced manufacturing around the world during the years of 2001 – 2003. The data in the Figure represents 95% of the total patenting activity in advanced manufacturing. Significant patenting activity took place in only seven areas, as listed in the Figure. In general, the patenting activity was steady. Slight increase can be observed in the areas of "Robotics & Intelligent Machines", and "Engineered Materials", while a decrease in the areas of "Joining & Fastening", "Advanced Coatings & Surface Modifications", "Systems Integration & Automation", "Cutting & Tooling Technologies", and "Forming Technologies".

Fig. 28 shows the gross R&D expenditures of different countries in terms of %GDP. Although Canada is in the middle compared with other developed countries, Canada is the second lowest (just behind Belgium) in the government R&D expenditures against Higher Education and Business/Industrial R&D expenditures.

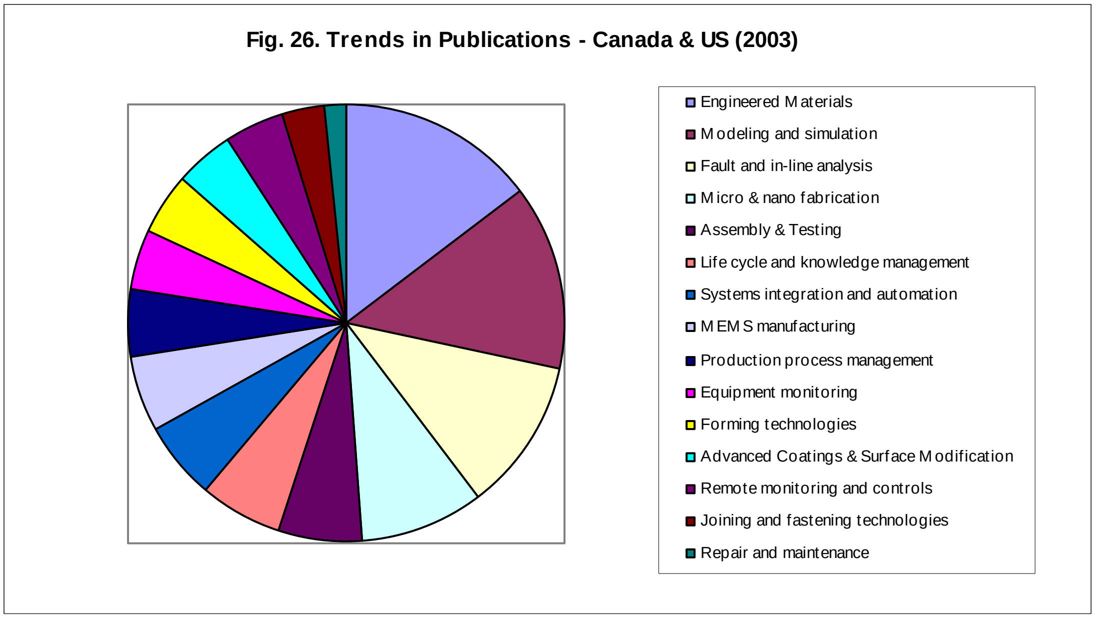


Fig. 26. Trends in Publications - Canada & US (2003)
Engineered Materials
Modeling and simulation
Fault and in-line analysis
Micro & nano fabrication
Assembly & Testing
Life cycle and knowledge management
Systems integration and automation
MEMS manufacturing
Production process management
Equipment monitoring
Forming technologies
Advanced Coatings & Surface Modification
Remote monitoring and controls
Joining and fastening technologies
Repair and maintenance

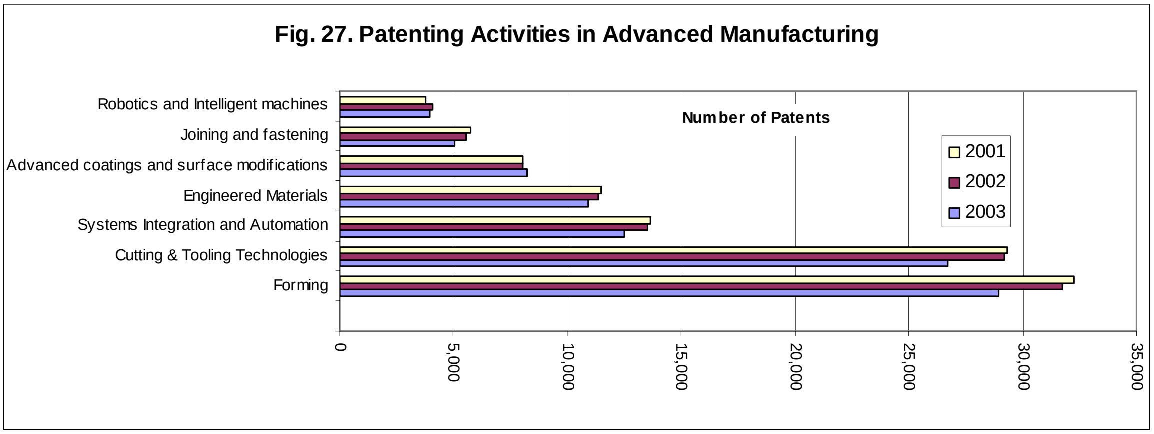


Fig. 27. Patenting Activities in Advanced Manufacturing
Robotics and Intelligent machines
Joining and fastening
Advanced coatings and surface modifications
Engineered Materials
Systems Integration and Automation
Cutting & Tooling Technologies
Forming
Number of Patents
2001
2002
2003
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000

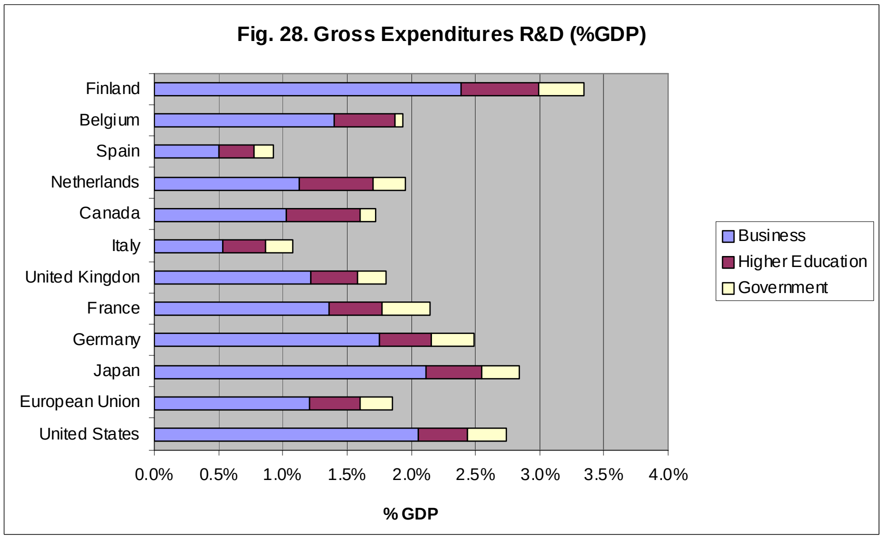


Fig. 28. Gross Expenditures R&D (%GDP)
Finland
Belgium
Spain
Netherlands
Canada
Italy
United Kingdon
France
Germany
Japan
European Union
United States
Business
Higher Education
Government
0.0%
0.5%
1.0%
1.5%
2.0%
2.5%
3.0%
3.5%
4.0%
% GDP

EU Technology Maps - Intelligent Manufacturing Systems

This study was funded by the European Commission through the European IMS secretariat. The objective of this study was to assess the capabilities of manufacturing to cope with the challenges of 2020 and to set the stage in a forward looking manner. The means to achieve this is a technology map with a 15 to 20 year perspective. This technology map is intended to serve as a basis for detailed research road maps and priority areas for manufacturing to be tackled by IMS. According to the IMS Technology Maps, "manufacturing enterprises today are still struggling just to exchange design data. Exchanges of design data have been limited by the lack of interoperable systems-level applications software. … High performance computers may eventually have sufficient computational capacity for comprehensive integrated designs, but the optimization of product and process life cycles is still a distant possibility. The bottleneck is models and simulations that can be expressed and presented adequately."

According to this study, significant advancements will be made possible by designing and processing products at smaller and smaller scales, ultimately at molecular and atomic levels. Revolutionary operations will lead to dramatic new capabilities in the following ways:

- Integration of multiple processes into a single operation will significantly reduce capital investment, inspection time, handling, and processing time.
- Processes that are completely programmable and do not require hard tooling will enable the customisation of products and rapid switching from one product to another.
- Creation of self-directed processes will simplify tooling and programming requirements and provide greater operational flexibility.
- Manipulation at the molecular or atomic level will lead to the creation of new materials, eliminate separate joining and assembly operations, and allow material composition to be varied throughout a single part.

Development of these innovative processes would enable the manufacture of new products, such as bio-computers with molecular-sized components, molecular-sized surgical tools that could operate at the molecular or cellular level, efficient and inexpensive solar energy collectors, and new materials with significantly improved and tailored properties.

For the next five to ten years, major R&D work related to the application of IS technologies in this area should focus on the application of the IS technologies that were developed and successfully used in large scale systems (e.g., application of modelling, and simulation, and virtual reality technologies) to micro and nano-scale products, processes, and systems.

NSF Engineering Design 2030

According to a recent report of the NSF Workshop on Engineering Design in Year 2030, a major challenge of the emerging Micro-, Nano-, Bio- industries is the design of products and processes in these new fields: "very high capability in the science and discipline of design are required to create the new products in these large and rapidly growing research fields."

According to this report, "in 2030, designers will interact in task-appropriate, human terms and language with no particular distinction between communicating with another human team member or online computer design tools. Such environments will amplify human creativity leading towards innovation-guided design. Future design tools and methods will not only support analysis and decision making from a technological point of view, but will also account for psychological, sociological, and anthropological factors based on fundamental understanding of these factors and their interaction." In order to achieve this vision for 2030, significant efforts are needed on the development and application of IS technologies in product and process design. The ED2030 report suggests the following high priority areas (design informatics, collaborative & integrated design environments and smart CAD/CAE tools):

- design Informatics for capture and re-use of design knowledge, and ontologies, search engines to support them;
- integration frameworks and inter-operable, multi-scale, multi-phenomena design and simulation environments that operate at multiple abstraction levels;
- smart synthesis and analysis tools for generative design as well as deep reasoning questions for predictive product realization without trial and error, virtually eliminating the need for physical prototyping.

European Sixth Framework Program

"Past FPs have helped to develop a culture of scientific and technological co-operation between different EU countries and they have been instrumental in achieving good research results. They have not, however, created a lasting impact on greater coherence at European level. FP6 has therefore been re-defined and streamlined with the following objectives:

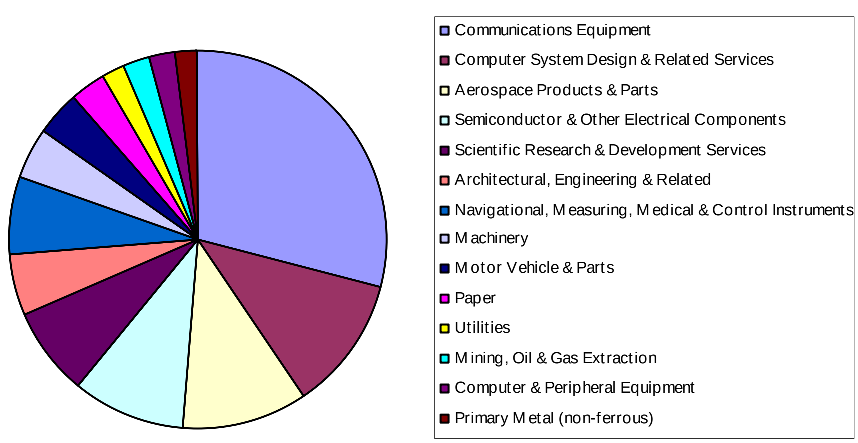
- concentrating European efforts on fewer priorities - in particular on areas where co-operation at European level presents clear added value;
- moving towards progressive integration of activities of all relevant participants working at different levels;
- promoting research activities designed to have a lasting, "structuring" impact;
- supporting activities that will strengthen Europe's general scientific and technological basis;
- using the scientific potential of candidate countries to prepare and assist their accession to the EU for the benefit of European science at large.

Most FP6 projects are usually large or very large projects (with several dozens of participating organizations and 5~10 million euros), though there are also small projects, particularly with the participation of SMEs.

4.3 Manufacturing Related R&D Investments in Canada

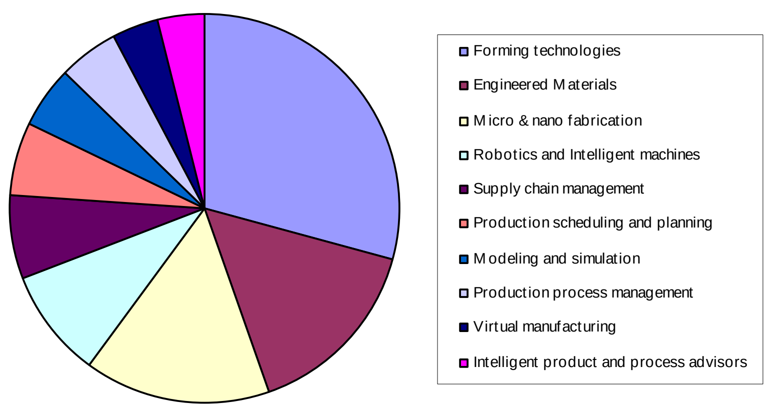
R&D investment is an important indicator of R&D trends in the related areas. The top industrial R&D spending industries in Canada, as shown in Fig. 29, represent about CAD$34 Billion in 2001-2003.

Fig. 29. Canada's Top Industrial R&D Sectors (2001-2003)



Among the top ten manufacturing technologies according to the data on recently funded university researches by NSERC shown in Fig. 30, the investments by NSERC are concentrated in the top 10 areas (84.2%).

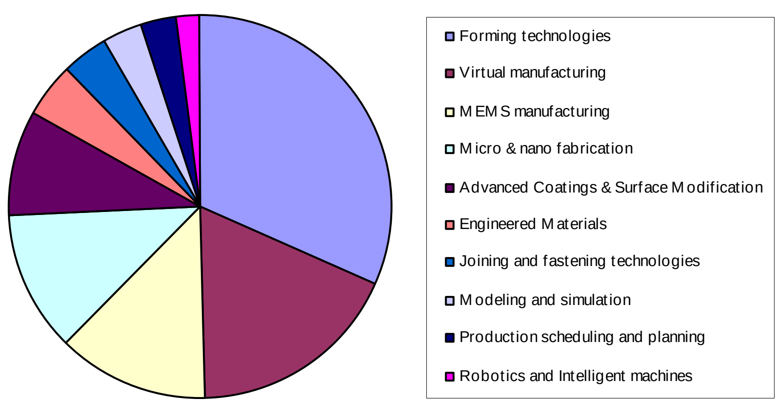
Fig. 30. Top 10 Technologies by Value of NSERC Funded Projects



In Canada, the focus is shifting to modeling, simulation and management. Forming technologies and new materials continue to be a priority, with increased interest in robotics and intelligent machines. While most of NSERC's investments were in people, small amounts also were awarded for equipment and infrastructure.

Over 3000 infrastructure projects have been funded since the establishment of the Canada Foundation for Innovation (CFI). According to the analysis done by IMTI, there were 85 projects to support manufacturing R&D since 1998, representing an investment in R&D infrastructure of over $44 million. The greatest investments have been in forming technologies, virtual manufacturing, MEMS manufacturing, and micro & nanofabrication. The top ten technologies (as shown in Fig. 31) represent 80% of the number of projects or 91% of the total value.

Fig. 31. Top 10 CFI Funded Technologies by Value of Projects



Note that CFI projects are created to set up the infrastructure for other R&D projects and the most of funding is used to purchase equipment, therefore most of these projects are not very related to the application of IS technologies to manufacturing by themselves. However, they create the infrastructure for future R&D projects, and therefore indicate the future R&D trends in Canada, i.e., these investments provide Canadian researchers the infrastructure to carry out significant R&D work in these ten areas.

5. Canadian Strengths and Opportunities

According to the CME (Canadian Manufacturers & Exporters) report on "The Importance of manufacturing in Canada", manufacturing directly accounts for 18% of Canada's Gross Domestic Product and is directly employing over 2.3 million Canadians. Manufacturing makes the largest direct contribution of any economic sector in Canada, representing 22% of total business activity in the country.

According to the CME report on "Manufacturing Challenges in Canada", Canadian manufacturers are at a critical crossroads. They face a number of current market challenges. They will face even greater challenges over the next five to ten years as the business of manufacturing evolves rapidly in response to the development of new technologies and new competitive pressures. Among a dozen of challenges identified by the CME report, some of them could be addressed by applying the intelligent systems technologies, e.g., changing customer requirements; product and process innovations; and global outsourcing.

Consultations with experts indicate that the major challenges facing the manufacturing sector that intelligent systems could address include:

- Real-time monitoring, sensing, and inspection
- Mass customization
- Education / receptor capacity
- Integration and collaboration of corporate knowledge and technologies

This section provides a brief review of the Canada's IS industry capability and Canadian strengths, and discusses the challenges faced by Canadian manufacturers as well as the opportunities of developing and applying IS technologies for Canadian manufacturing industry.

Canada's IS Industry's Capabilities

According to the recent Precarn report on "A Profile of Canada's Intelligent Systems Industry", Canada's IS industry's capabilities cover the range of key IS technologies, with the highest concentration of activity in control systems, modeling and simulation, sensors, expert systems, input-output devices, and interactive visualization software. IS technologies applications cover almost all manufacturing industries, with the concentration in defence, automotive, aerospace, and electronics.

According to the same report, Canada's IS industry has grown rapidly in the part two decades, from estimated 25 companies in 1987, to about 300 in 1998, and about 400 in 2003. Although Canada has a strong and growing IS industry sector, IS technologies application in manufacturing is still very limited. Efforts are required to encourage and support SMEs to develop and deploy IS solutions in their plants.

We believe that the Canada's growing IS industry will not only serve manufacturing industries in Canada, but also rapidly penetrate into global manufacturing industries.

Application of IS Technologies in Canadian Manufacturing Companies

The CME survey has shown some interesting results (some of them may be surprising): in 2002 only 3% of Canadian companies were using classical AI (expert systems), 8% of companies were using automated storage & retrievals systems; 14% of companies were using sensor based inspection and testing systems; … some areas are seeing rapid changes in the current five years (2002-2007), e.g., expert systems from 3% to 17%; AGV systems from 3% to 10%; automated storage & retrievals systems from 8% to 20%; sensor based inspection and testing systems from 14 % to 33%; supervisory control and data acquisition systems from 17% to 43%; inter-company networks from 37% to 75%; CIM systems from 22% to 44%.

Global Leader in Advanced Networking

With the deployment of CA*net4 (developed and operated by CANARIE), Canada has been recognized as the global leader in advanced networking. This provides a significant potential for networked manufacturing, including modeling, simulation, control of manufacturing processes, diagnosis and maintenance of manufacturing equipment, as well as inter- and intra-enterprise collaboration. In fact, this is one of the most important reasons why the inter-company networks have been widely adopted by Canadian companies (37% in 2002) and is growing rapidly (to 75% in 2007) as mentioned above.

Focus on SMEs

More than 95% of IS companies (registered with the Precarn IS Company Directory) are SMEs. The majority of the companies in the manufacturing sector are also SMEs. According to the CME Management Issues Survey 2004-2005, 90% of the companies responded to the survey are SMEs (with 500 or less employees), where 66% of them are in the manufacturing sector. Therefore, R&D investments should focus on the development of IS solutions for SMEs, based on the current needs of Canadian industries, e.g., IS solutions to improve the productivity and profitability including advanced production planning, scheduling, control, and enterprise integration and collaboration. It is imperative to create an efficient IT infrastructure for Canadian SMEs to collaborate in order to compete in a global market. Although Canada has the best network in the world (CA*net 4), it is only connected to universities and research organizations, and these SMEs are not connected yet.

Energy Conservation

With the shortage of the energy (electricity particularly) as well as the pressure on efficiency and cost reduction, energy conservation is becoming an important issue for Canadian manufacturers. A few companies have adopted advance technologies in the machineries to avoid non-value added operations so as to save energy and used see through roof for the optimum utilization of sun light in the day time in shop floors to reduce the consumption of electricity for lights. However, this could be a whole new area for R&D investments and no enough attention has been taken up to date. Intelligent systems technologies should play an important role in this area.

Bio-Tech and Medical Device Manufacturing

Medical device manufacturing is an emerging and growing industry in Canada. Almost all IS technologies can play important roles in this area, but the dominant IS technologies would be modeling and simulation technologies (including micro- and nano-level modeling and simulation as multidisciplinary collaborative modeling and simulation as mentioned in Section 4). HMI/VR and perception technologies will be widely applied.

Other Challenges and Opportunities

According to the CME Management Issues Survey (2002-2003, 2003-2004, 2004-2005), Canadian manufacturers are investing heavily in new technologies, research and development, skills training, as well as in organizational restructuring and process re-engineering. They still face major constraints when it comes to improving their competitive performance – especially in the form of resource constraints, operating costs, a lack of qualified personnel, and organizational cultures that make it difficult to response to changes. … Investments in new information management systems, as well as in new e-business capabilities, have allowed many companies to improve logistics management, network with other businesses, and run internal processes more efficiently. In order to overcome these constrains, Canadian companies are introducing new product and process innovations, … They are considering outsourcing as a means of boosting their productivity and growth potential. Many of them are implementing improvements based on Lean business principals. A large number of companies are also focusing on achieving a higher degree of agility in their business as a response to more stringent and frequently changing customer requirements. It is believed that IS technologies will play very important roles in these areas.

6. Recommended Directions

Based on the technology survey done by the study team and the consultations with experts, following areas are identified as priorities (in order of importance according to the survey and consultations) on intelligent systems application to advanced manufacturing for the next five years:

(1) Integration of design, planning, monitoring, control, etc.
(2) Intelligent systems for mass customization (low volume and high variety)
(3) Intelligent systems for manufacturing management
(4) Intelligent agents, collaboration and coordination technologies
(5) Modeling and simulation for product and process design
(6) Real time information for automated decision making
(7) Intelligent systems for inspection, diagnosis and maintenance

Integration of design, planning, monitoring, and control is not a new R&D topic. Researchers have been working in this area for several decades. Recent R&D efforts and trends include: cooperation and coordination of multidisciplinary design teams (including customers and suppliers) using multiple sophisticated commercial and non-commercial engineering tools such as CAD tools, modeling, simulation and optimization software, engineering databases, and knowledge-based systems; integration of product design and process design; integration of manufacturing process planning, scheduling, monitoring, and control (including ***real time information for automated decision making*** which is to be elaborated further below). Various research prototype software systems have been reported, but a complete solution for industrial use is not available yet. A relatively new concept in this area is Product Lifecycle Management (PLM). A number of vendors have started to provide PLM solutions to manufacturers, but industrial implementations are still rare. Significant R&D efforts are needed to progressively develop and implement solutions for manufacturing enterprises, particularly SMEs. Although the basic solutions can be developed by PLM solutions providers or other software companies, practical solutions and industrial applications must be developed together with the user companies – those adopt and implement the new technologies.

The main challenge that ***mass customization*** has to face, concerns the design of manufacturing systems that are capable of producing customized goods (usually with low volume and high variety) with respect to cost efficiencies as well as quality and time considerations. The development of a mass customization manufacturing system is much more challenging than a mere optimization of an existing manufacturing system. It would not be enough to simply adjust a mass production manufacturing system to lower volume and higher variety. Instead, major changes are necessary, eventually leading to a radical reconfiguration and redesign process within manufacturing. Another important aspect is how to optimally plan and control the production processes in a variant-rich environment. On the other hand, the performance of manufacturing systems for mass customization depends not only on the configuration of the manufacturing system itself, but also on manufacturing related tasks, such as product family design, supply chain management, information system integration, etc. These have also to be addressed in order to fulfill all of the requirements of efficient and effective mass customization manufacturing systems. ***Intelligent systems*** can play a very important role in the implementation of agile manufacturing systems to address the mass customization requirements. Among the intelligent systems technologies described in this report, ***intelligent agents, collaboration and coordination technologies*** are particularly suitable to implement agile manufacturing systems to address the mass customization needs at various levels: from supply chain and inter-enterprise collaboration level, to enterprise integration (***Integration of design, planning, monitoring, and control***, as well as marketing and customer relations, etc.); to the reconfiguration of production lines, work cells, and even individual machines. It is also evident that ***modeling and simulation technologies*** can help provide quick responses to the customers, ensure the product quality, and reduce the product development costs. Presently, no one has claimed to be able to provide a total mass customization solution. The user companies (manufacturers) may need to take the lead on the development and implementation of applications in this area.

Under the context of this report, ***manufacturing management*** is considered to include enterprise resource planning, manufacturing process planning, production planning, scheduling, and materials handling. Almost all intelligent systems technologies can be applied in this area. These systems can be developed by the solutions providers and implemented in various user companies without further developments. However, manufacturing management is very complex, since it also deals with human beings, rather than only machines. An advanced technology/system that has been well proved by many successful applications may still fail if the people using the technology/system do not cooperate. Therefore it is very important to develop new tools for ***training*** the workers using IS technologies such as modeling, simulation, VR, intelligent agents, and Web based technologies. It is also important to ***educate*** industrial people, particularly the managers in manufacturing enterprises and shop floors, on the advantages and benefits of applying intelligent systems technologies in manufacturing environments. A possible approach would be to involve managers and shop floor personnel in the planning, implementation, and evaluation of R&D projects in demonstrating intelligent systems technologies in their operations.

Using ***real time information for automated decision making*** has been studied for a long time, particularly in autonomous robotics and other unmanned devices and systems. Recently, this has been recognized as an important area in the manufacturing industry due to the continuously increasing global competition and the advancements in information and communication technologies. The solutions in this area can be developed by solutions providers, but significant efforts would be needed to test and validate these solutions. The testing and validation of these technologies is another difficult issue since it is highly risky to do the testing with the real production facilities. Similar situations may happen to the development and implementation of ***intelligent systems for inspection, diagnosis, and maintenance*** in manufacturing environments.

7. Possible Social and Economic Benefits

High-Tech Job Creation and Wealth Generation

“Innovation will be our ticket to a vibrant healthy economy with a competitive edge, and the creation of large numbers of high quality jobs.” (US National Academy of Engineering, “The Engineer of 2020: Visions of Engineering in the New Century”, NAE Report, 2004.) Innovation in intelligent systems and applications to advanced manufacturing will bring significant social and economic benefits to Canada, including the creation of high-tech jobs.

According to the survey of the Canadian IS industry done by Precarn recently, the IS industry in Canada represents a total number of more than 400 companies (up from an estimated 300 in 1998) with total revenues of $2.5 billion and employment of 7,300. Most of these companies are small and recently established firms, which shows a very fast growth of the IS industry sector. Therefore, the IS industry has brought and will contribute to bring significant social and economical benefits to Canada, including jobs creation and wealth generation.

Increased Productivity and Profitability

According to a recent report by CANMET Energy Technology Centre, "Heavy industry is enlisting artificial intelligence to automate complex processes and extend the skills of human operators. Well-considered application of the technology can boost productivity, quality and energy efficiency. ... Users report a wide range of benefits from the use of AI, including improved decision making, more responsive control, more efficient material flow, increased labor efficiency, greater consistency in product quality and reduced maintenance costs."

Other Benefits

In addition, successful applications of IS technologies to advanced manufacturing can bring a number of other social and economical benefits:

- Improving manufacturing processes so as to reduce its negative affects on the environment (e.g., various kinds of waste, noise, air emissions, industrial disposals, etc.) and therefore improve the quality of life.
- Replacing human operators with intelligent machines and robots in dangerous, heavy duty, and unreachable working environments.
- Predicting and/or detecting failures in working machines or manufacturing systems to avoid incidents/accidents happening in the shop floor so to save dollars and even lives.

8. Concluding Remarks

It is no longer a question of whether IS technologies will have an impact on advanced manufacturing but one of better understanding and exploiting the broad deployment of these technologies in the manufacturing sector. New manufacturing concepts and philosophies such as lean manufacturing, agile manufacturing, reconfigurable manufacturing, virtual manufacturing, and holonic manufacturing place increasing emphasis on the need for more intelligent manufacturing systems, and there is general consensus that intelligent systems technologies will play a key role in the manufacturing enterprise of the future.