Int. J. Engng Ed. Vol. 13, No. 4, p. 275–284, 1997
Printed in Great Britain.

0949-149X/91 $3.00+0.00

IOMCS Project—A University/Industry/Government R&D Partnership Program*

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This paper discusses a joint research project called an Intelligent On-line Monitoring and Control System (IOMCS) for pulp and paper processes. One university, two government agencies, two pulp and paper companies, one technology supplier and one consulting company are co-operating in the project. The research is industrial problem-driven. It also incorporates the interests and concerns of all parties involved in the project. This type of co-operation project has great advantages, such as improving the understanding and relationship between different parties, making the project more cost-effective and being able to access expertise from different disciplines.

INTRODUCTION

IN THE past decade, the pulp and paper processing industry has been faced with high competition. It is challenged by technology advancement. The challenge arises from the following facts:

1. Pulp and paper is a resource and energy-intensive industry.
2. The rewards associated with the application of high technology in the pulp and paper processes are extremely significant.
3. Pulp and paper production consists of a complex and long sequence of operations, starting from wood chipping and ending with finished paper.
4. There is much scope for new technology to greatly improve production, profits and the process operations.
5. Public interest has shifted to environmental protection in the last few years and has forced governments to legislate more stringent pollution regulations for the industry: they are usually dependent on high technology and are extremely costly.

The growing complexity of industrial processes, the need for higher efficiency, greater flexibility, better product quality, lower cost and environmental protection have changed the face of industrial practice. Now the competition of industry is the competition of technology. New technology can help a company stay competitive in the world market. The challenge in technology also brings opportunity. The industry does not have any other choice but to accept the challenge and take the opportunity. As pointed out by Joseph Wright, the head of the Pulp and Paper Research Institute of Canada (Paprican), 'We must keep the Canadian pulp and paper industry world class in all aspects' [1].

Research and development is crucial to the above purposes. Without good research and development, it is impossible for the industry to stay competitive in the worldwide market. There are several prerequisites to stay competitive. The most important ones include:

1. Latest technology to make the industry technically competitive. In particular as a first user, the industry can take great advantage of and benefit from new technology.
2. Educated and qualified people to keep the industry competitive. The industry needs qualified personnel to operate the mill efficiently. Moreover, the primary factor in the success of any new technologies in production processes is the ability of mill personnel to use and maintain the technology.
3. Good relationship with government to positively influence many aspects of the business. Government and industry should act like 'intelligent stewards' rather than adversaries [2].

How can a research project be made to address all of the above prerequisites? How can we deal with the problem of inadequate research funding? What kind of approach should be used and which direction should it go? Traditionally, research can be classified into two categories: basic and applied research. Basic research is carried out to generate fundamental scientific knowledge. Applied research always has a firm engineering background and a clear commercial goal [1]. In this paper, we will focus on applied research since it is the major goal of university, industry and government co-operative projects. The above problems are addressed using a consortium type approach to one project conducted in the Intelligence Engineering Laboratory (IEL) at the University of Alberta. Several parties from university, government and industry participate in

* Accepted 20 August 1997.

the project. It is shown that the collaborative project is cost-effective and can produce feasible results.

CONSORTIUM RESEARCH PROJECT

New technologies evolve from research and development. However, a research project may not necessarily produce technology useful for industry without a clear definition of the problem to be solved. Successful research must be integrated with a business opportunity in the pulp and paper companies. The research that can help our industry to become competitive is that which is industry-driven or problem-driven. The only goal of such research is to solve problems that really exists in the companies' production activities. That is, let the engineering needs determine the direction of the research.

To define a research project that has commercial value, the participation of the industry is a must. People from industry understand best what real problems exist in the production process and what the company needs. They can propose problems worth solving. Applied research always requires real-time operating data, process models and technical support for technology development. This type of support can only come from commercial operations. The final objective of applied research is to implement new technology to generate economic benefits. The pulp and paper companies can provide test and implementation sites for new research results.

With the participation of pulp and paper companies, the project has access to the most experienced scientists and experts and the advanced special testing facilities that are otherwise very expensive. The mill operating staff can offer valuable suggestions and ideas during the research project and help to ensure that the project is heading in the right direction.

As mentioned above, the relationship between government and industry has an impact on industry's business activities. Government affects industry by providing incentives regulations, and enforcement. Most of the time, this relationship is positive. Government helps industry to be competitive since the national and provincial economy is driven by the employment and profits of industry [2]. In certain situations, unfortunately, this relationship seems to be adversarial. A good example is pollution prevention. Historically, the public's interest has been directed towards employment and standard of living, but lately it has been shifting to clean air and water, and the forest preservation. The government has to develop appropriate regulations for environmental protection to accommodate the public's interest. However, it may be extremely costly for industry to meet these regulations. This places industry in a dilemma: to be competitive in the world market, industry must make a low-cost product; however, to meet the government's regulations, the cost may increase significantly.

In order to resolve such a conflict, a better understanding is required between government and the industry. The industry should realize the importance of environmental protection to society and try its best to reduce pollution. Government should understand the impact of non-production expenses on a company's business activities and understand the expense and difficulty of eliminating or reducing pollution using available technology. In developing the environmental regulations, government should make a compromise between the public's interest and the company's competitive position, and give industry enough time so that it has the capacity to absorb the cost of the following regulations.

The co-operation of government and industry in collaborative research can improve understanding of each other. During this research project, the government will gain a better understanding of a companies' business and technology situation, and assist industry to do research and development which can decrease the cost of compliance for industry. In this way, the government and industry become mutually beneficial stewards.

The importance of government participation in collaborative research is not limited to the above. Special government departments and agencies have a better global vision about what the industry needs and how to improve the economy. They control the direction of research and development through directing the funding and thus make the research projects more significant in improving the economy. Usually, the results of research projects involving the government are easier to transfer among companies.

The pulp and paper industry wants to see government involved in these research projects because it is difficult for the companies to support research on their own. They expect government to share some responsibility and devote some resources to research. Without government participation, the industry may either refuse to suggest projects or reduce their scope.

Also, government likes to see industry involved in these research projects since this is an indication of industry's interest in the research.

Inadequate resources is a barrier to the success of pulp and paper research projects. Therefore, making full use of all the available resources is a top priority. One advantage of collaborative research is that the resources from all parties involved in the project can be better utilized. As we know, universities have tremendous human and material resources [1], such as well educated personnel, laboratory equipment, computers, library and other facilities required for carrying out research projects. Some universities have already obtained very good research results on pulp and paper. They are waiting for the chance to transfer these results to industry. Therefore, having universities participate in projects is an effective way to reduce project costs and train students for jobs in the pulp and paper industry.

The participation of universities in collaborative research may also change the face of academic research. Collaborative research projects can force university research to be more in tune with the national economy and industrial business activities.

The most important reason for universities to be involved in collaborative projects may be the training. As mentioned above, the competence of mill personnel is crucial to keep our pulp and paper industry competitive. However, some surveys indicate that the pulp and paper industry lacks high quality educated people. The percentage of post-secondary educated employees in pulp and paper industry is lower than that in other industries. University education is an important way to produce educated and qualified personnel for mill management and operation. The products of universities include new technology and educated people to maintain such technology. Unfortunately, most academic research projects do not provide the opportunity to have their students directly involved in an operating plant. Excellent research always trains outstanding students. Lacking practical knowledge, the students need to be trained for a long time before they become qualified mill engineers and operators. With collaborative projects, the students can work with the real production processes and acquire practical knowledge about industrial production.

The participation of universities in collaborative projects has another mission: educating people and improving the public's image of the pulp and paper industry. The pulp and paper industry used to have a poor public image due to remote location, low technology, environmental pollution, and clear-cutting practices. This misleading image has been producing negative effects for a long time. Students miss opportunities to develop successful careers with pulp and paper companies, and the industry cannot recruit the best graduates. In order to dispel this misconception one needs to focus on continued public education. The modern pulp and paper industry is a huge user of high-tech processes, equipment and systems. Most pulp and paper companies have implemented distributed computer systems (DCS) and management information system (MIS). The process operations are highly automated and computer assisted. The environmental pollution has been reduced to a minimum level. With the participation of universities in collaborative projects, the public will realize the importance of the pulp and paper industry in the economy and their private lives, and develop a proper image of the industry.

Suppliers are another important partner in collaborative projects. Implementing new technology in an industrial process inevitably faces the problem of how to use the existing equipment, systems and technology in the mill. New technology is not intended to replace existing system and technology in the mill, but to upgrade them to satisfy the ever-increasing requirement for high quality production. With the participation of the suppliers of the technology and systems implemented in the mills, we can easily interface the new system to the existing systems and build a bridge between the existing facility and the new technology.

The above discussions suggest that the optimum collaborative project should have university, government, industry and supplier working work together. With the participation of several parties, the project can benefit from a large range of expertise and is thus more cost-effective. The collaborative project can improve the relationships between government and industry, government and university, industry and university, and industry and its suppliers. It is beneficial to all the parties.

IOMCS—A MODEL OF A COLLABORATIVE PROJECT

The Intelligent On-Line Monitoring and Control System (IOMCS) for pulp and paper processes is a university/industry/government collaborative project.

Project members

The parties involved in the IOMCS project include:

- one university—the Intelligence Engineering Lab (IEL) at the University of Alberta;
- one Federal and Provincial governmental agency—Canada-Alberta Partnership Agreement in Forestry (CAPAF);
- two pulp and paper companies—Slave Lake Pulp Corporation (SLPC) and Daishowa-Marubeni International Ltd. (DMI) Peace River Pulp Division;
- one technology supplier—MoDo Chemetics;
- one consulting company—Perde Enterprises (PE).

The Intelligence Engineering Laboratory (IEL) at the University of Alberta is a research laboratory on the application of artificial intelligence and process control to industrial processes. In the past several years, IEL has completed significant research on integrated distributed intelligent system technology. An object-oriented intelligent system shell has been developed. IEL has also developed a real-time intelligent multimedia system. A few applications for the pulp and paper and petroleum industries have been completed.

The Canada-Alberta Partnership Agreement in Forestry (CAPAF) is a government research program that has supported several university groups in forestry and forest products (including pulp and paper). The program provides one-to-one matching funds for the research; that is, for every dollar from industry, the program matches another dollar. CAPAF is an excellent research partnership program. In the past few years, it has supported numerous research projects and generated valuable results.

Slave Lake Pulp Corporation (SLPC) is an Aspen-based bleached CTMP mill. It produces high quality pulp for printing, writing and copying paper. Daishowa-Marubeni International Ltd. (DMI) Peace River Pulp Division is a Kraft pulp mill. These two companies have successfully implemented distributed computer systems (DCS) and management information systems (MIS). The DCS implemented in SLPC is Fisher Provox 2000, and in DMI it is TDC-3000. The MIS in both companies is MOPS.

MoDo Chemetics is the supplier of the management information system (MIS), MOPS. MOPS provides such functions as display handling, trend handling, material tracking, statistical process control and cost reports. It has been proven to be very successful in pulp and paper production.

SLPC is a client of Perde Enterprise (PE) which has worked with SLPC since SLPC was in the construction stage. The four-stage peroxide bleaching technology used at SLPC was patented and provided by PE. Now PE is providing technical support to SLPC on production and marketing.

The determination of the project

The determination of the topic of research is a complex procedure. As emphasized before, research projects should be industrial problem-oriented. We need to transform industry's needs to technical functions, industry's business goals to technical objectives and industry's strategic plans to research directions.

Before defining the research project, we had already conducted extensive discussions with SLPC and DMI. They told us what they needed and we showed them what we could do. SLPC and DMI have both successfully implemented DCS and MIS, and this has brought great benefits. However, mill operation still relies on operators' experience and operating decisions are still inconsistent. These inconsistencies made the companies realize that they needed to use new operation support and automation systems. Operation support is a knowledge-intensive task. Traditional control technologies may not be amenable to solve such problems. Artificial intelligence technology is a promising alternative solution.

After further discussions with SLPC and DMI, an agreement was reached to develop an intelligent system, namely Intelligent On-line Monitoring and Control System (IOMCS), that provides on-line operation support functions. This system intends to enhance the pulp and paper operations from information management to decision automation stage. It aims at improving product quality and production profits through more consistent and effective operations. The main functions of the intelligent system are:

(a) monitoring process variables to detect undesirable situations;
(b) advising the operators of evasive or corrective actions to undesirable situations;
(c) optimizing process operating conditions;
(d) training new operators.

The intelligent system is linked with DCS through MOPS. A survey of Canada's Pulp and Paper industry indicated that IOMCS-type systems are demanded by most modern pulp and paper companies. We thus completed the definition of the research project.

PE was one of the initiators of the project. Later on, the project was proposed to CAPAF, and MoDo joined the project soon after.

Requirements from different parties

The design of IOMCS has to satisfy the requirements of all parties in the project. Different organizations has different interests and emphases on the project.

SLPC and DMI emphasize functionality, reliability and maintenance of the system. They require that the system has the following features:

- standardization of operators' changes;
- more timely and knowledgeable decisions;
- identification of complex process situations that have the potential of causing process upsets;
- automatic learning of optimal operation conditions for different product grades;
- having an open structure to implement the local systems independently and then integrate them into a mill-wide system.

Through a multimedia operator interface, operators are able to:

- view and acknowledge situations and advisories;
- view 'how and why' information and access further process information if required;
- scroll through old messages and sort by process area;
- provide an interface for process engineers to program the knowledge base.

Their other requirement is the integration of the IOMCS system with the existing DCS and MOPS. In the past few years, the companies have invested a great deal in DCS and MOPS. These systems have been proven very useful in the process operations. The development of IOMCS does not intend to replace the existing systems, but to make full use of the available computer facilities and systems in the mills. By adding 'intelligence' to the existing systems, IOMCS upgrades pulp production from information management to decision automation.

Last but not least is the requirement that the system must be easy to use. The users need not have too much computer and artificial intelligence knowledge in order to run IOMCS and program the knowledge base.

As an important consulting company for SLPC, PE represents the interests of SLPC. Therefore, its requirements are basically the same as those of the pulp and paper companies.

The reason for CAPAF to support this type of research project is to derive benefits for provincial and national economy. Therefore, CAPAF requires IOMCS to be instrumental in improving pulp and paper production and product quality, minimizing environment impact, producing economic benefits and helping the industry to be more competitive. In this aspect, its requirements are similar to those of pulp and paper production companies. However, CAPAF has other requirements:

- *Portable system and technology:* after they are implemented in the participating companies and proven to be successful, IOMCS and the related technologies should be moved to other pulp and paper companies in the province and country. The system and technologies must be transferable.
- *Employment:* the project should create employment opportunities.
- *Human resources:* as a result of working on the research of the project, a number of people will be trained to be qualified mill personnel or researchers. Therefore, CAPAF prefers graduate students to be involved in the project.

As mentioned above, SLPC and DMI require IOMCS to be integrated with MOPS. Therefore, the funding and technical support from MoDo for developing interfaces is crucial to the success of the project. MoDo's objective focuses on how IOMCS can enhance the competitiveness of MOPS in the management information system market. The requirements include that:

- the functionality of IOMCS is different from that of MOPS, that is, there is no functional overlapping between IOMCS and MOPS;
- the functions of IOMCS are required by industry;
- IOMCS and MOPS can be integrated as a package for the end users;
- the development of IOMCS can upgrade MOPS; however, it will not affect the normal functions of MOPS.

The university needs to combine the industrial requirements with academic research objectives. A university is a special 'production line' that produces both new technologies and educated personnel. Most of the research personnel in a university are graduate students, which is one of the reasons for the government to support university research. The university has requirements for graduate students' thesis research. These requirements may be in conflict with companies' interests. The simpler the better (as long as it can solve the problem) is the criterion for a company to select a technology. However, the successful implementation of a practical technology is not enough for a Ph.D. dissertation or a M.Sc. thesis. Original ideas, creativeness and training are required. This arises a universal problem in collaborative research projects: how to resolve the conflict between university science requirements and industrial needs?

To resolve or minimize the conflict, it was made very clear in project definition that the research aims at solving universal problems existing in process industries. The research direction is extracted from the specific problems and requirements of the member companies. However, these problems are generalized and enhanced to a level of scientific significance. The algorithms and methods generated from the research are generic and applicable to all process industries. For example, in IOMCS project, the member companies' requirements are converted into the science requirements of a new reasoning method that is efficient, able to utilize various levels and types of available knowledge, and consistent with human operator's natural problem solving. These requirements lead to the research on dynamic case-based reasoning, a reasoning method that extends conventional case-based reasoning methods to dynamic problems and enhances their problem solving power.

However, with such research philosophy there may arise a drawback that is common in the collaborative research projects: the prolonged project completion time. University has certain program years for graduate students. The development of universal solutions usually takes longer than the development of direct solutions to specific problems. To accelerate project progress, IEL assigns different research personnel performing different roles in the project: one Ph.D. student and several M.Sc. students as well as research fellows to the project. The Ph.D. student researches the general configuration of IOMCS: theory, development and implementation. Each Master student develops one of the key technologies for IOMCS. Research fellows concentrate on key technology implementation. Some implementations are relied on technology suppliers, and pulp and paper companies.

To incorporate the interests of the different parties in the project, IOMCS is designed as outlined in the following section.

DESIGN OF IOMCS

IOMCS is a mill-wide real-time intelligent system that integrates production information of all areas and from all resources, especially from MOPS. It manipulates the information and various types of knowledge to provide decision support to operators. It assists operations in two different ways [3, 4]:

1. generating and directly implementing new operating conditions or corrective actions on control action devices, e.g., DCS;
2. making feasible operation recommendations to

operators who make final decision and take actions.

The objectives of IOMCS are to help operators maximize production, improve product quality, reduce production costs and minimize environmental impacts through more consistent and timely operations.

Functional requirements

IOMCS intends to provide operation supports for the situations in which human operators feel it difficult to contribute a timely and effective solution. Human operators perform well for routine operations, but not as good for nonroutine operations. IOMCS is designed to provide decision support for the following nonroutine operations:

- *Product/grade transition:* modern pulp and paper companies tend to produce products of multiple grades in small ordering volume to cope with ever increasing competition in pulp market. A new target pulp grade requires a new set of optimal operating conditions, such as temperature, chemical charging rate and refining energy. IOMCS can make plant more responsive to multiple grades, rates and products production by automatically generating optimal operation conditions.
- *Production optimization/disturbance compensation:* DCS and advanced control systems maintain process variables at constant levels. Most of small process disturbances can be compensated by DCS control loops. However, DCS is not efficient enough for some significant disturbances. In face of significant process disturbances and drifts, IOMCS fulfills production optimization to obtain a set of new optimal conditions.
- *Fault correction:* process faults are defined as any undesired situations or incidents that could lead to off-specification products. There are two types of process faults: device failure and operation fault. IOMCS helps operators to identify the fault, evaluate the severity and recoverability, and decide the redeem actions.

Main features of IOMCS

The following features are considered critical for IOMCS, and new methods are applied in system design to achieve the features:

- *Information/knowledge integrated environment:* integration with existing mill facilities, especially DCS and MOPS, is an essential requirement. A standalone intelligent system cannot function efficiently. IOMCS is a computer software system implementation based on the existing MOPS system. It acquires data from MOPS CVD (current value data base) and HDB (historical data base) and uses the value-added data for automatic decision making. The companies need to invest very little in hardware to install IOMCS. IOMCS is not only an intelligent system for on-line monitoring and control of pulp and paper production, it also provides an intelligent system-building tool embedded in MOPS.
- *Timely decision:* process operation is a time critical situation. As a real-time application, IOMCS must provide timely and knowledgeable decision whenever a complex situation occurs. Reasoning efficiency is important to the system. IOMCS applies hybrid reasoning technique that can alternatively select an efficient reasoning method, such as case-based reasoning, rule-based reasoning and model-based reasoning, for a certain situation [5]. Task and process decomposition is applied to further improve the reasoning efficiency.
- *Process generality:* process generality is necessary to make IOMCS portable and enable easy accommodation of process configuration changes. It is also important to make users easy to maintain and upgrade the system. IOMCS separates the general knowledge (problem-solving knowledge) from process-dependent knowledge (process knowledge). The multilayer modularity system architecture is also proposed for this purpose.
- *Full use of operation knowledge:* knowledge acquisition has long been identified as the bottleneck in developing intelligent systems. Knowledge in pulp production exists in various levels and types. To overcome the difficulty, IOMCS make use of knowledge of all levels and types by employing rich knowledge representations and hybrid reasoning technique.
- *Learning capability:* because of the complexity of pulp process and operation, it is impossible to make the knowledge base complete. IOMCS fulfills real-time learning in the hybrid reasoning environment by automatic updating the case memory.
- *Operator acceptability:* operators are end user of IOMCS. Good acceptance by operators is a must for the system to succeed. Besides functionality, easy to understand reasoning process and results display are important to encourage operators to use and maintain the system. IOMCS applies an underlying reasoning scheme that is coincident with human expert's problem solving [6], and uses user-familiar MOPS consoles to display most decision making results.

Multilayer modularity design

IOMCS is configured to achieve the functional requirements and desired features outlined. According to the design objectives, IOMCS is an intelligent system aiming at solving a range of automation problems for a specific kind of process industry. It is designed in a multilayer modularity architecture as illustrated by Fig. 1.

The following main facts about the IOMCS are obvious from Fig. 1. IOMCS is programmed in C^{++} under ALPHA machine in open VMS System 1.5. Above the high level language C^{++}, there are three layers: object-oriented intelligent system tool,

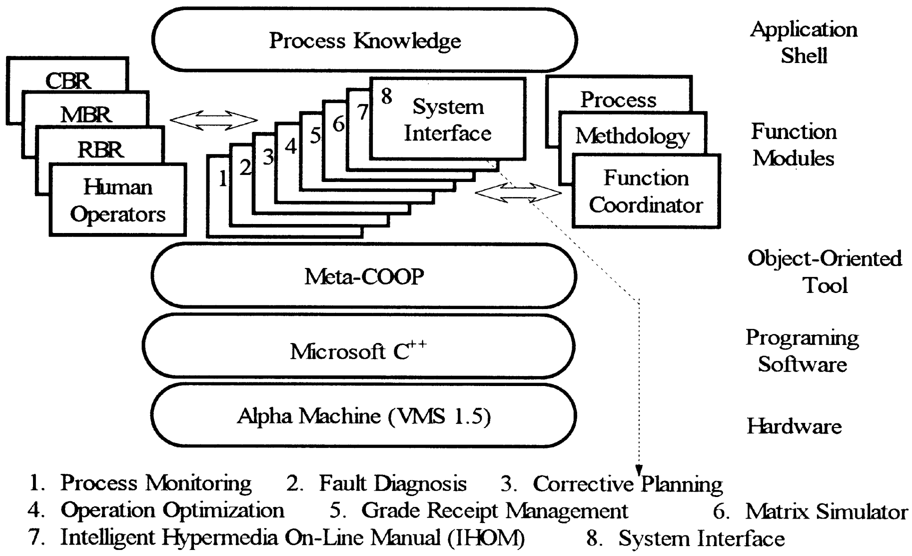

Fig. 1. Multilayer architecture of IOMCS.

operation support function modules, and IOMCS application shell.

The first layer, Meta-COOP, is an object-oriented intelligent system tool coded in C^{++} [7]. Meta-COOP adopts the object-oriented programming technique and frame-based knowledge representation to implement the organization, management, maintenance and applications of complex knowledge base systems. In Meta-COOP, the organization structure of the knowledge-bases can be divided into several components. It provides such distinct characteristics as the integration of various knowledge representations and inference methods.

The second layer is the function modules based on the generic problem-solving task modeling. With the distinct characteristics of Meta-COOP, the programming of these function modules is much easier than directly from high level AI language. These function modules, based on their roles in problem solving, can be classified into three groups:

- *Operation support function modules:* these modules, depicted in the middle of the layer, are the generic operation support functionality. Examples of these modules are process monitoring, fault diagnosis, matrix simulator [8] and IHOM.
- *Reasoning paradigm modules:* these modules, depicted on the left side of the layer, fulfill various reasoning paradigms, including CBR, MBR, and RBR. It should be noticed that IOMCS treats human operators as an integrated external reasoning agent of the system. When none of reasoning paradigms can be applied, IOMCS will communicate to human operators for help.
- *Co-ordination modules:* the modules on the right side of the layer include process co-ordinator, methodology co-ordinator and function co-ordinator. The process co-ordinator integrates the local IOMCS systems to a mill-wide system. Methodology co-ordinator fulfills the co-ordination among CBR, MBR, and RBR. The function co-ordinator combines and queries the problem solving function modules to solve complex engineering problems.

The third layer is an application shell for customizing a specific IOMCS application. Process-dependent knowledge is implemented in this layer. Unique process-dependent knowledge makes a unique IOMCS system.

It is obvious that the desired system features, such as process generality, rich knowledge representation and user acceptability are achieved with this architecture.

RESEARCH TEAM ORGANIZATION

The IOMCS project has an excellent research team. However, to assure the success of the project, good co-operation among the members of the team is still required.

Financial support

All the parties provide expertise, funding and technical support to the project. The main cash contribution comes from CAPAF, SLPC and DMI. In-kind support is mainly from SLPC, DMI and MoDo.

Responsibility and intellectual property

In every collaborative project, there must be incentives and reasons to continue to work together. The primary motivation for every party is benefits. In this project, the responsibility and intellectual property of each party were clearly defined and the agreement was signed before the project was actually started. Every party is playing an important and irreplaceable role in the project.

IEL is doing the major research for the

project, including technology development, system design, software development and implementation. It provides intelligent system shells and technology for the project as well as training for mill personnel to use the system.

IEL has the right to apply IOMCS and the related technologies to other users.

CAPAF supervises the progress of the project. It controls the direction of the research by adjusting the budget. CAPAF also helps IEL to establish contact with more pulp and paper companies. With the participation of CAPAF, the application of IOMCS to other companies will be more successful.

CAPAF has the right to decide which pulp and paper companies to be the first users.

SLPC and DMI each have two process engineers on the project. These engineers provide the technical support, such as functionality definition, feasibility evaluation and implementation, in every stage of the project. They also provide all the process information required for the project, such as process operating data and process knowledge. Besides, SLPC and DMI provide aid for necessary on-site tests.

SLPC and DMI have the right to apply IOMCS and the related technologies to any process within their companies.

Research results from the university may not be the perfect solutions. Some companies do not like to be the first user, which makes the development and implementation of new technologies difficult. SLPC and DMI provided financial support for the project and volunteered to be the first users, which is a great contribution to the project.

MoDo is responsible for MOPS training and for the technical help in developing the interface between IOMCS and MOPS. Since the pulp and paper companies prefer to have a professional company to provide maintenance service, MoDo will also take over the maintenance for IOMCS after it is completed and finalized.

MoDo has the right to commercialize IOMCS together with MOPS (as a package). This deal is also beneficial to the project itself. MoDo has been a successful commercial software vendor for a few years. It is easier to commercialize IOMCS together with MOPS. MoDo is the access to the best computer technologists and marketing experts for the project.

PE provides technical support for the project. With the participation of PE, the project has access to the best scientists in pulp and paper technology.

Organizational aspects of research project

With the help of CAPAF, SLPC, DMI, MoDo and PE, IEL can perform efficient research work.

IEL has direct access to the mill computers from the research laboratory through telephone modems. Updated process data can be obtained with this access instead of traveling to the mills. In this way, traveling expenses can be greatly reduced.

Fidelity and accountability, which are assured by good communication, are important in maintaining a partnership [2]. We organize regular project report meetings to improve communication between different parties in the project. There is a weekly internal meeting in IEL to discuss the progress of each individual and exchange the research results. A monthly project report meeting is organized for all the parties to participate. In the meeting, the research results are reviewed and evaluated, necessary modifications are proposed and further research is planned. A meeting agenda is sent to all parties before the meeting. Minutes of the meeting are prepared and circulated after the meeting. IEL submits a progress report to CAPAF every half year.

The IOMCS is moved to different sites for evaluation, stage by stage. The IEL research staff travel to mill sites to transfer the research results and discuss with mill engineers and operators regarding knowledge acquisition and system refining.

Any new technology has various barriers to acceptance by operators. Fear of advanced technology is a major one [9]. Although artificial intelligence has been proposed in academic research for many years, it is still new to the pulp and paper industry. Great strides have been made to solve this problem:

1. Technology transfer with 'both feet': there are two different ways for technology transfer. One is to develop and implement a technology or system in a company with little involvement of the mill personnel. Any modification or new application has to be done by the original developer. We call it technology transfer on one foot. The other one is to do research with the active involvement of the mill personnel. After the project is completed, the company is able to continue development and application. We call it technology transfer with both feet. It is the best way to transfer technology. With this approach, the outcome of the project is not only basic technology but also enabling technology. Because the mill personnel have extensive knowledge about the system, the problem caused by the fear of new technology can be eliminated. Graduate students joining the companies after graduation is another way to achieve technology transfer with both feet.
2. Providing solutions in a format familiar to operators: the intelligent system should provide a solution which is consistent with the operator's natural way of reasoning and problem solving. Otherwise, the system will not be accepted by the operators. In the research project, we extensively talk with the operators to obtain their response and try to make the system satisfy their requirements. For example, using the case base reasoning method is one of the results of this effort [5, 6]. The operator interface is developed as easily and directly as

possible. Since operators have been quite familiar with MOPS, we design the interface of IOMCS as consistently as possible with that of the MOPS system.

These approaches have greatly improved the understanding of mill personnel of artificial intelligence technology and IOMCS. The acceptability of IOMCS has improved. Most of the difficulties in the implementation of the intelligent system have been resolved.

OUTCOME OF THE PROJECT

The IOMCS project consists of an excellent multidisciplinary team from industry development, business planning, university education, academic research and technology suppliers to the pulp and paper industry. The experts in this research project are teamed to solve complex engineering problems and ensure that the project produces the best solutions.

So far, the IOMCS research project has made significant achievements. The key technologies for IOMCS have been developed, including dynamic case-based reasoning strategy, hybrid reasoning strategy, fault diagnosis, Matrix Simulator, quality prediction and operation optimization for real-time process operations. The integration of IOMCS to MOPS has been satisfactorily solved. A hybrid object-oriented intelligent system is developed as the core of IOMCS. An intelligent multimedia tool is developed for implementing an on-line manual and as an enhanced operator interface. The mill know-how knowledge is acquired and accumulated. The IOMCS systems for bleach plants have been developed and implemented in the mill site, and are playing important roles in process operations. Further improvement and extension to other applications are ongoing.

The experts in the research project have given a few seminars in the Department of Chemical Engineering at the University of Alberta. For example, the manager of the MOPS group from MoDo gave a seminar about the development and implementation of MOPS. A process engineer from SLPC introduced TMP pulp process and DCS to his company. A superintendent from DMI presented the Kraft pulp process. Some of the results generated from the project have been introduced in graduate courses. These seminars showed students the latest technologies applied in pulp and paper industry, improved their knowledge about pulp and paper production, and increased their interests to work for pulp and paper companies. On the other hand, university professors gave seminars at the site mill. They introduced the newest developments in science and technology to the industry.

Through the research project, graduate students in IEL have worked directly with real-world pulp and paper processes. Three graduate students have produced their M.Sc. theses based on research from the project. Another graduate student is completing his Ph.D. dissertation from the project. Having been well trained, these students need not to have special training in order to work in the industry. For example, the Ph.D. student has been hired by a highly respected control company. One M.Sc. student has been hired by SLPC before graduation and promoted to be a division manager. Another M.Sc. student had begun to work as a consultant during his M.Sc. program. We can conclude that such projects are important to develop science and technology infrastructure and to train qualified personnel.

SLPC and DMI are small to medium sized companies. However, the scope of the IOMCS project is relatively large. This project provides a good example for small companies to initiate big projects. SLPC employs a BCTMP process and DMI, a Kraft process; those are the two major types of pulp production processes. The example of the IOMCS project and the developed system and technologies can be applied to these companies.

CONCLUSIONS

Nowadays competition is in the form of competition of people and technology. In order to be competitive in the worldwide market, the industry needs leading technologies and qualified personnel. How to organize a research project to achieve this purpose is a crucial problem. This paper presented a multidisciplinary and multiparty collaborative research project, IOMCS. The project was defined by translating industry's needs into a technical research direction. With the participation of university, pulp and paper industry, government and technology suppliers, the project has the access to the specialists in different areas and makes full use of the available resources from different parties. It was shown that such a project can produce practical research results and is more cost-effective. Through this research project, graduate students had an opportunity to work in the real-world production processes and thus became qualified employees of the pulp companies. It was concluded that these types of projects are important to develop the science and technology infrastructure in Canada. The example of the IOMCS project can be extensively applied.

Acknowledgments—This project is financially supported by the Canada-Alberta Partnership Agreement in Forestry, Slave Lake Pulp Corporation, Daishowa-Marubeni International Ltd., Peace River Pulp Division, MoDo Chemetics, and Perde Enterprises Ltd. The authors are especially grateful to Mr. Brian Karaim for his significant technical and organizational contributions to the project.

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