ISIS CANADA

Intelligent Sensing for Innovative Structures
A Canadian Network of Centres of Excellence

NCE 2nd Funding Cycle

Progress Report

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1. Network Summary

ISIS Canada was established in 1995 to provide civil engineers with smarter ways to build, repair and monitor structures using high-strength, non-corroding, fibre reinforced polymers (FRPs) and fibre optic sensors (FOSs). It was created by the federal Network of Centres of Excellence (NCE) program and encompasses 12 universities, 30 Project Leaders (principal investigators), 256 researchers, 100 associated organizations, and 36 multidisciplinary demonstration projects. The Administrative Centre for ISIS Canada is at the University of Manitoba.

Governments around the world are grappling with the costly problem of rapidly deteriorating concrete structures reinforced with corroding steel. Using FRPs in place of steel can break this cycle because they are non-corrosive, six times stronger, 80 percent lighter and non-magnetic. The ISIS research program is unique because it is the only one in the world to bring together leading edge research in civil, mechanical, materials, aerospace, photonics and electrical engineering.

The mandate of ISIS Canada is to advance civil engineering to a world leadership position, through the development and application of FRPs and integrated intelligent FOS technologies, for the benefit of Canadians through innovative and intelligent infrastructure.

Major accomplishments and impacts of the ISIS Canada Network have been many and varied. The research is progressing extremely well. All milestones have been met and most exceeded. Over the past three years, the scope and complexity of the research program has expanded to meet the growing needs of the infrastructure sector. At the same time, significant achievements have been made in the four other components of the NCE funding criteria.

The research program has achieved many firsts. A new concept for long-gauge FOSs has been developed that incorporates mirrored optical fibres in place of more conventional Bragg gratings. Associated measurement instruments have been developed which have a light source far more powerful than current technology. At the same time, the first structural strain measurements have been demonstrated using a Brillouin sensor system, resulting in a narrow spatial resolution not achieved before.

Structural health monitoring continues to advance from conventional strain gauges to FOSs to major breakthroughs in wireless remote monitoring. For demonstration purposes, a camera has been installed at one bridge, which is synchronized with a computer that records strain measurements and permanently stores photographs and records overweight trucks. Several years of data are now available on the durability and performance of installed sensor systems.

Innovative structures and components continue to be designed and tested under actual field conditions, ever expanding the envelop of conventional practice. Some of the innovations include FRP/concrete hybrid systems, filament-wound bridge decks and poles, steel-free concrete bridge decks, glass fibre reinforced polymer (GFRP) tubes filled with concrete, FRP/stainless steel hybrid components, and the use of FRPs to rehabilitate masonry structures, which is particularly applicable for historical buildings.

Patents have been filed for innovative ground anchors, as well as for the embedment of FOSs as an integral part of manufacturing FRP reinforcing rods. The rehabilitation of concrete structures with FRP wraps, and wood bridges with FRP rods, has proven to be effective and economical. A nuclear reactor structure is being rehabilitated using FRP wraps designed by ISIS personnel and will be monitored using

the newly invented long-gauge fibre optic and Brillouin sensors. Even the containment of hog wastes and underground chambers for an electrical utility form part of the ISIS research achievements.

Training of highly qualified personnel is a priority for the ISIS Network because, eventually, it will be the graduates who bring about the desired technological changes in the infrastructure sector. New ways of enhancing student education and practical training are continuously pursued. Students are given the opportunity to present their research findings at conferences and workshops, both at home and abroad. Research and demonstration projects are organized so that students are meshed with industry and government counterparts to enhance their work experience. An increasing number of students form part of the ISIS program, and they have no difficulty finding jobs in their chosen field upon graduation. This component of the Network is evolving as a major accomplishment.

Networking and partnerships are an integral part of the ISIS endeavour. This has been enhanced by establishing a policy for each new research proposal to include a minimum 50-50 cost sharing budget between NCE funds and cash and in-kind contributions from other sources. This approach creates new partners and has resulted in 1999/2000 non-NCE funds being 57 percent of the total budget, which is 170 percent greater than the previous year. Networking abounds within the ISIS umbrella, with extensive interaction between an ever-increasing number of ISIS researchers, projects, partners and universities. Probably the best example is Theme 5, where the initial 5 projects have expanded to 16, based at 9 universities under 15 Project Leaders. The ISIS networking program works extremely well because everybody recognizes the benefits involved. This is a significant accomplishment of ISIS Canada.

Knowledge exchange and technology exploitation is one of the major challenges for ISIS Canada. Achievement of our mandate is dependent upon success in this area. For this reason, we are pleased with the increased receptor capacity, evolving partnerships, increased cash and in-kind contributions and the creation of a spin-off company. On several occasions, industry and government have approached ISIS Canada to carry out specific research to fulfil a need in the infrastructure sector. In addition to the distribution of newsletters and annual reports, ISIS personnel are involved in a never-ending series of presentations at conferences, workshops, lecture tours and one-on-one consultations with our Network partners. By far, the greatest accomplishment in this area over the past year has been the production of manuals and design guidelines for the engineering community. This is an essential ingredient for the acceptance and utilization of ISIS technology by infrastructure owners.

Management of the ISIS Network has been provided by a competent administrative team which functions within an organizational structure that meets the needs of the program. Additional Board members, Theme Directors and Project Leaders are readily available when required. ISIS Canada is run like a business. Decisions are made by consensus and on a timely basis, with everyone held accountable for productivity and results. Incorporation of the Network in 1998 went smoothly and no operational difficulties are being encountered. The transition to a new Program Leader and President has been efficient and seamless. Also, appropriate steps were taken to incorporate the enhancements suggested by the NCE expert panel during the mid-term review. Over the past year, management has recognized the need to provide a better balance between the research program and the effort expended on accelerating technology utilization by the user public. This has been addressed in the organization structure for the NCE 2nd Funding Cycle.

The impact of the ISIS Network is reflected in the training of highly qualified personnel, increased receptor capacity, new demonstration opportunities, and international recognition of its solution-oriented research for the global infrastructure crisis.

2. Research Program

2.1 Introduction

The research program has progressed very well over the past three years. Milestones established for the mid-term review will all be achieved by 2002, with most of them completed a year early. Space limitation does not permit inclusion of a comparison of achievements versus the 77 milestones that were established for the 31 projects outlined in six pages of the mid-term strategic plan. However, it is available on request.

Generally, deviations from the last strategic plan consisted of expanding the scope of the research program. Nine new Project Leaders (Principal Investigators) joined the ISIS Network in the past three years and 19 more research projects were added to the program, which are scheduled for completion by the end of the current mandate. Four projects have been completed and their Project Leaders are no longer in the Network. For clarification, Theme 1 was completed prior to the mid-term review and has been excluded herein.

2.2 Theme 2 – Fibre Optic Sensor Technology
Director: Dr. R. C. Tennyson

Achievements and Milestones

A new method of measuring strain profiles along a fibre Bragg grating (FBG) has been successfully developed and published. Also, a new concept for a long-gauge FOS has been developed which incorporates mirrored optical fibres rather than Bragg gratings. In addition, a new automated, computerized long-gauge instrument has been built that is faster and more accurate than the current manual system. It is equipped to handle 16 sensor channels. A 4-channel module of a 32-channel FBG instrument has also been constructed to simultaneously measure static/dynamic strains from a serial/parallel array of FBGs. Its power level far exceeds a conventional light emitting diode source that is typically used in such an application.

For the first time ever, simultaneous measurements of distributed temperature and strain have been carried out on a structure utilizing the Brillouin gain/loss scattering based system. At the same time, the line-width narrowing effect was discovered, which resulted in a world-leading 10-cm spatial resolution. All milestones in Theme 2 will be achieved or exceeded.

Deviations from the last strategic plan occurred in the research program of Dr. Simmons when it was discovered that anticipated results using a split electrode laser light source did not materialize and an alternative methodology had to be developed. At the same time, a superior laser chip became available from industrial sources and was incorporated into a new instrument, which proved to have the desired capabilities. Two new projects were added to the program, with one new Project Leader invited to join the Network for this theme. Project T2.6 was completed and the Project Leader is no longer in the Network.

2.3 Theme 3 – Remote Monitoring and Field Assessments
Director: Dr. A. A. Mufti

Achievements and Milestones

Over the past three years, monitoring of field demonstration projects on bridges and structures has been successfully carried out at seven new sites throughout Canada. The durability and reliability of FOSs have now been demonstrated for four years in some installations. Data collected from several demonstration projects have been used to develop a data archive and retrieval system for use by Network researchers. A web page has been created which facilitates interactive access to data and downloading of this information from the database. A software program is also available for intelligent processing of dynamic data.

A harbour project represents the first application of ISIS technologies in a marine environment. Several firsts were involved, including the use of steel-free concrete deck panels in conjunction with a hybrid pile cap design. Some of the GFRP rods that were used had FBG sensors embedded in them during manufacture. The structure is currently being monitored using three separate gauge systems for comparative purposes.

Refinement continues on the patented pultrusion processing technology for embedment of FOSs in FRP reinforcements during the manufacture of reinforcing rods. This new innovation has been installed in field demonstration projects, including the foregoing harbour project. Also, the cracking pattern of a steel-free concrete bridge deck has been monitored for four years to establish that crack growth becomes stabilized through time.

Major advances have been made in the area of remote monitoring of civil engineering structures. Through innovation and utilization of low cost market-place components, portable and affordable equipment has been developed to facilitate remote monitoring. In the process, a wireless transmission system has been developed and a portable and economical microchip data acquisition system constructed, which will accommodate transmission through radio frequency, Internet or via satellite. A wireless remote monitoring system has been installed on a bridge and two pipelines. This is an important achievement because wireless remote monitoring is emerging as the preferred methodology of the future. All milestones will be achieved or exceeded in Theme 3.

Deviations from the last strategic plan consisted of initiating five additional field assessment projects. They include bridges, underground concrete chambers, timber piles for Arctic housing, and a nuclear reactor containment structure. As the opportunities arose, ISIS expanded the research program to gain more experience in the monitoring of various structures. Three new Project Leaders have been invited to join Theme 3 since the mid-term review. One of them was recruited to satisfy the NCE expert panel suggestion to develop a data archival and retrieval system. Projects T3.2, T3.3.2 and T3.3.4 have been completed and the Project Leaders are no longer in the Network.

2.4 Theme 4 – Innovative Structures with Integrated Sensing
Director: Dr. S. H. Rizkalla

Achievements and Milestones

Development continued on the steel-free concrete bridge deck technology, including adapting it for use as a deck system for marine structures. The inventors were granted the prestigious Nova Award for the innovative steel-free concrete deck concept. GFRP dowels were successfully installed in place of steel in two concrete pavement projects for demonstration purposes. In addition, a bridge deck system is being developed for commercialization. It utilizes a new concept of a GFRP filament winding process with three tube modulars, combined with pultruded top and bottom plates.

A new FRP/concrete hybrid design has been investigated which includes filling GFRP tubes with concrete to produce a composite hybrid system. Increased strength and favourable economics have been achieved. FRP for shear reinforcement has also been investigated. In addition, hybrid FRP/stainless steel reinforcements for bridges have formed part of the research program. A project has been carried out to determine the structural and material performance of FRP reinforcements in concrete structures. For evaluation purposes, a new generation of carbon fibre reinforced polymer (CFRP) bars has been installed for reinforcement in concrete structures.

Experimentation has been completed on masonry diaphragm walls using GFRP for shear reinforcement. Also, newly created FRP ground anchor configurations have been evaluated by researchers in three universities, with a view to commercialization. Two manufacturers in separate provinces are working with ISIS researchers to develop GFRP filament-wound poles for hydro and telephone distribution systems, for commercial purposes.

Following laboratory testing, an innovative technique using GFRP bars was used to rehabilitate a timber bridge to increase the flexural and shear capacity of the structure by 30 percent to accommodate increased traffic demands and truck loads. The cost of repair was 15 percent of replacement. Also, an innovative construction system is being investigated which uses various applications of FRPs for the purpose of storing corrosive hog wastes. The new facilities will be more durable and environmentally safer than those presently used. All milestones will be achieved or exceeded.

Deviations from the last strategic plan consisted of three new projects added to the research program and four new sub-projects undertaken.

2.5 Theme 5 – FRPs and Integrated Sensing for Structural Rehabilitation
Director: Dr. K. W. Neale

Achievements and Milestones

Numerous research projects have been carried out to demonstrate the use of FRP wraps and reinforcements in the rehabilitation of concrete structural components. Integration of FOSs and a monitoring program form part of most of these projects. A life-cycle cost analysis model is being developed for evaluating the economics of FRP repairs. Accelerated experiments have been conducted in four locations to determine the impact of steel rod corrosion in concrete structures that have been rehabilitated with and without FRP wraps and subjected to varying climatic conditions.

An innovative concept of using sprayed FRP-based composites has been demonstrated as an alternative means of rehabilitating structural components. FRP wraps have been successfully applied to brick masonry columns. Testing has been completed to establish the impact of using FRPs as reinforcement for wood under bending conditions. In addition, an evaluation of using FRPs in concrete structural components under seismic loadings has been carried out. Numerous structures have been strengthened using ISIS FRP rehabilitation technologies.

For the first time, a nuclear containment structure will be rehabilitated using an innovative design application provided by ISIS personnel and employing FRP wraps. The field rehabilitation projects carried out in Theme 5 over the past six years have clearly demonstrated that FRP wraps can be used effectively for structural repair at a much lower cost than traditional methods. All Theme 5 milestones will be achieved or exceeded.

Deviations from the last strategic plan involved the addition of six more projects and the inclusion of five new Project Leaders in the Network. Some of these new researchers provided the expertise needed by ISIS to explore the application of FRPs for seismic conditions.

2.6 Theme 6 –Design Aids and User Manuals
Coordinator: Research Management Committee (RMC)

Achievements and Milestones

One of the most important achievements of the ISIS Network since the mid-term review has been the preparation of four design manuals: (1) Installation, Use and Repair of Fibre Optic Sensors; (2) Guidelines for Structural Health Monitoring; (3) Reinforcing Concrete Structures with Fibre Reinforced Polymers; and (4) Strengthening Reinforced Concrete Structures with Externally-Bonded Fibre Reinforced Polymers.

These manuals are important because they form the basis upon which widespread utilization of ISIS technologies can be achieved. They are the forerunner of design codes, yet to be prepared and adopted. These manuals have already established ISIS Canada as a global leader in the application of FRP composites in the design and rehabilitation of civil engineering structures. The milestones for this theme were exceeded when it was decided to advance completion of the manuals by one year to meet demands of the user sector.

2.7 Research Integration Across Major Themes

From the outset, ISIS Canada has been organized and managed to ensure research integration across major themes. Theme 2 deals with research and development of FOS technology, Theme 4 with innovative structures, and Theme 5 with repair and rehabilitation. The outcome of these three themes is being integrated in Theme 3, in which sensor data are being used to monitor the performance of innovative structures, as well as that of repairs on existing structures.

Further evidence of the integration lies in the fact that Theme 2, Fibre Optic Sensor Technology, has four Project Leaders based in three universities who specialize in optical physics, photonics, and the production of laser chips. In addition, the theme employs the disciplines of aeronautical, civil, electrical and mechanical engineering. Theme 3, Remote Monitoring and Field Assessments, currently has 10 Project Leaders, based in 7 universities and working on 10 research projects. Similar integration prevails in Themes 4 and 5. Research integration is one of the criteria for approval of new projects.

2.8 Response to Research Problems

Response to research problems is dealt with by the RMC on an as-required basis as part of its management responsibility. They are viewed as research opportunities. The invitation to new Project Leaders to join the Network is usually in response to a research problem that needs resolution. Opportunities are presented to new researchers and additional projects are launched to provide needed answers for areas in which current knowledge is inadequate. Feedback from the Network keeps the RMC apprised of current and emerging research problems. No difficulties have been encountered resolving ongoing research challenges.

During the mid-term review, the NCE expert panel identified shortcomings in the research program and made suggestions for improvement. Although such a report is available, space limitation does not allow a direct comparison of the panel's detailed suggestions and the subsequent response of ISIS Canada. However, the following highlights cover the main issues.

Monitoring – All suggestions have been achieved, including the major concern to develop a management system and retrieval strategy for the archival of data. This is being addressed by Dr. J. Humar, who was invited to join the Network for this purpose. Collaborations are also underway with Dr. A. E. Aktan at Drexel University to benefit from the achievements of others.

Sensors – All issues have been addressed and accomplished. A major research project to determine the effects of fire on structures using FRPs is planned in joint venture with the National Research Council of Canada.

Corrosion – Commercially-available equipment is being utilized and a superior methodology has been developed to that suggested by the panel.

Materials – As explained to the panel during the interview, ISIS has always had materials engineers in the Network and intends to pursue basic materials engineering considerations during a later phase. This now constitutes a major part of the 2nd Funding Cycle, 2002 to 2009.

Highly Qualified Personnel – ISIS has endeavored to incorporate all of the panel suggestions as it moves forward. However, in the past four years, 67 percent of ISIS Ph.D. graduates have been employed by industry in preference to Masters students. This is contrary to the panel's perception of industrial needs. Also, ISIS Canada has always had a plan to replace key people in the Network, as evidenced by the transition to a new Program Leader. The shortage of technicians in universities is being addressed with increased use of ISIS funds for this purpose.

Transfer of Technology – All of the suggestions are being pursued. For instance, the provision of general information to the infrastructure sector through technology transfer officers has been phased out. From the outset, the focus has been to provide training to the engineering community through workshops. The design guidelines and manuals are forming a basis for the development of short courses across Canada.

International Collaboration – Excellent progress has occurred in this area.

Networking and Partnerships – Opportunities have been explored with other NCEs, as suggested. ISIS is currently networked with Photonics Research Ontario. Also, one of the new Project Leaders in ISIS conducts separate research in another NCE program, the Canadian Institute for Photonics Innovations.

Intellectual Property – The commercialization success of ISIS technologies is accelerating with a spin-off company, Fibre Optic Systems Technology, Inc., and the industrial efforts of Faroex and Canzeal Enterprises Ltd. Management continues to encourage commercialization of ISIS research.

Justification for ISIS Canada to have continued funding to the year 2009 lies partially in the numerous areas where further research and development must be carried out prior to general acceptance of ISIS technologies and the achievements of our long-term mandate. These research needs are outlined in the accompanying Strategic Plan for the 2nd Funding Cycle.

2.9 Keeping Abreast of Advancements in ISIS Technologies

Monitoring emerging research and application of ISIS-related technologies is an ongoing activity of the entire Network. One of the key strategies in this regard is to have ISIS personnel participate in a multitude of international conferences. Often, several ISIS presenters are involved in orchestrating a special session. In addition, individual ISIS Project Leaders are currently in the process of organizing major conferences in Canada over the next three years, at which ISIS will play a leading role. During the past two years, the ISIS Network has published 316 technical papers and made presentations at 102 conferences. Another means of keeping in touch with current research is by way of informal surveys as was carried out to determine the state of sensor technology throughout the world.

Widespread international collaboration has been a priority of ISIS Canada for the past several years. These extensive contacts and the exchange of information have greatly expanded the knowledge base of the ISIS Network. In the process, joint research programs are being formulated and memorandums of understanding consummated. This not only keeps ISIS abreast of emerging technology, but also enhances the exposure of student researchers and provides a potential base for Canadian exports.

3. Highly Qualified Personnel

3.1 Contribution to Development and Retention of Outstanding Researchers

The training and development of 160 highly qualified personnel based in 12 universities is a priority of ISIS Canada. ISIS graduates form the nucleus for widespread usage of the new technologies, so it is important that they be well equipped to take a leadership role over the long term.

To broaden their experience, ISIS researchers are exposed to interdisciplinary teams whenever practicable. They are directly involved with representatives of industry and government on joint research programs and demonstration projects. Women are encouraged to join the ISIS team through two $5,000 scholarships awarded annually to outstanding Women in Engineering. Eighty-nine percent of ISIS graduates find jobs in Canada.

Research students have been encouraged to form a committee and present recommendations to the RMC for Network enhancements. They gain experience in public speaking by participating in the Annual Conference as well as other national and international conferences. Management pays attention to student suggestions and every effort is made to have them see themselves as equal partners in Network deliberations.

3.2 Response to Challenges Faced

One of the challenges facing ISIS is to accommodate the number of students who wish to participate in the program. ISIS has responded by expanding the program to include additional Project Leaders, occasionally in universities outside the original Network. New areas of research have been embraced, with the view of broadening the base of ISIS and presenting opportunities for students.

Early in the program, students had difficulty appreciating the full scope of ISIS activities. With the establishment of the web site and dissemination of information by e-mail, and through the Project Leaders, this has greatly improved. Attendance of students at the Annual Conference has been doubled by subsidizing their travel and hotel accommodations.

Jobs after graduation are foremost in the minds of the students. To facilitate this, ISIS uses every opportunity to have students work with representatives of industry and government in the infrastructure sector. Field experience on relevant projects is a good means of facilitating job offers.

3.3 Contribution of Network Partners to ISIS Training Strategy

ISIS partners recognize the value of the training program to develop highly qualified personnel and cooperate fully to achieve the objective. Our partners view the students as potential employees and, consequently, are receptive to varying work arrangements. These are excellent linkages.

At the ISIS Annual Conference 2000, all of the presentations at the day-long public forum were made jointly by a representative of the user public and the ISIS researcher involved in the subject demonstration project. This constituted a significant contribution by Network partners and is the best endorsement one can get for increased use of ISIS technologies in future infrastructure projects.

3.4 Meshing Value-added Training with User Sector Needs

In addition to what has already been stated on this subject, one emerging issue needs to be mentioned. In order to satisfy a need in the market-place, ISIS has taken on a responsibility that goes beyond the training of research students within its own program. To complement ISIS graduates in the workplace, consulting engineers and contractors need technologists and technicians who are skilled in the use of FRPs and FOSs. Currently, there is a shortage of such skills. Consequently, ISIS has been encouraging the establishment of appropriate courses in technical colleges that teach civil technologies. This will provide added value to the graduates of the ISIS program.

4. Networking and Partnerships

4.1 Value-added Network Approach to Research

Some of the advantages of a network are obvious: no duplication of research, no unnecessary purchases of equipment, no waste of funds and no research carried out in isolation. At the same time, it facilitates the sharing of ideas and research results. For instance, there are five complementary research projects underway in four universities that pertain to the use of FRPs for mitigating corrosion of structural reinforcing steel. The overall benefits being derived could never be achieved without a network approach. Similarly, researchers in one university often call upon expertise at another university in the Network. As part of the project approval process, the RMC is always looking for the best person who has access to the best equipment to carry out a specific research project.

The increased value of a network is most evident at the ISIS Annual Conference. It is a requirement of the RMC that each Project Leader make a presentation of his or her research program and findings at the conference. Each person is held accountable for progress and contribution to the ISIS mandate. Being part of a network, presenters are more receptive to critical peer review than would otherwise be the case. The sharing of ideas and findings that takes place as part of this review process is a valuable exercise for everyone, especially the students. There is no question that the network concept has made a huge contribution to reaping increased benefits from Canadian research.

4.2 Fostering Multidisciplinary and Multisectorial Linkages

As part of its thrust to train highly qualified personnel, ISIS Canada uses every opportunity to create and expand multidisciplinary and multisectorial linkages. It is standard practice to have Project Leaders based in several universities researching components of the same theme. For instance, Theme 4 has 10 Project Leaders based at 7 universities. Theme 5 has 14 and 9, respectively.

Engineering disciplines of civil, mechanical, electrical, aerospace and physics are intertwined on several projects. For instance, in Theme 2, Sensor Technology, engineering physicists specializing in laser chips and photonics are working with aeronautical and mechanical engineers to develop the equipment needed to monitor stresses and strains in civil engineering structures. Wherever practical, research teams are made up of students from different disciplines. This enhances the research program and provides the students with a broader range of experience.

4.3 Fostering Ongoing Relationships with Network Partners

ISIS is fortunate to have many ongoing relationships with industry and government. Several of these have evolved as a result of outsiders approaching ISIS with a research or design problem that needs to be resolved. Some are looking for longer life-cycle structures and lower maintenance. Others want to develop a product for commercialization. One of the strategies that ISIS has pursued to increase partnerships is to be approachable and open to new ideas and opportunities. Another is the policy of requiring 50-50 non-NCE funding from government or industry prior to project approval by the RMC.

There are many ongoing relationships throughout the Network. The most significant are with the Provinces of Québec, Manitoba, Nova Scotia and British Columbia, as well as the Cities of Calgary, Winnipeg and Sherbrooke. Private sector companies have approached ISIS to pursue research and demonstrations of particular interest to them. Receptor capacity for ISIS technologies continues to grow.

Over the past few years, a concerted effort has been made to develop international partnerships. Ongoing relationships continue with organizations in Japan, Sweden, Britain, Switzerland, the United States and France. The objectives in these international endeavours are to avoid research duplication, to learn from the experience of others, and to increase the influence of the ISIS research program.

4.4 Key Achievement in Attracting Non-NCE Funds

The strategy used by ISIS for attracting non-NCE funds is to maintain and enhance relations with traditional sources and use every opportunity to find new sources of outside funds. Seldom is a project funded from one source. In most cases, ISIS Project Leaders use NCE funds to leverage funds from others. This approach works, as evidenced by the ever-increasing non-NCE funds available.

A key achievement of ISIS has been the support of provincial governments, both for cash and in-kind contributions. Manitoba is the leader with $190,000 in cash and $120,000 of in-kind support over the past year. It is followed by Nova Scotia, Québec, Alberta and British Columbia, with the five provinces providing $320,000 in cash, plus $340,000 in-kind. These funds are used for a variety of purposes: supplement graduate student salaries, purchase of materials, technician support, services of specialists, travel for researchers to demonstration sites and conferences, technology transfer, and public awareness programs. It should be recognized that ISIS NCE funds contribute, on average, only 29 percent of the annual salaries of ISIS graduate students. The balance comes from NSERC and non-NCE cash contributions. ISIS could not function effectively without this support.

Another achievement is the growing support from industry, with $89,000 in cash and $1,322,000 of in-kind contributions. The largest industrial in-kind contributor last year was Nortel Networks Corporation with a huge discount on the supply of specialized equipment for sensor technology research, valued at $384,000. The second largest was Canzeal Enterprises Ltd./Fibreglass North, which contributed $369,000 for software equipment and salaries of scientific staff associated with a new filament-winding technology. At first glance, cash contributions from industry appear small. However, one has to consider that infrastructure is owned by governments and the only interest industry has is associated with spin-off ancillary considerations in connection with demonstration projects funded by government. ISIS Canada is pleased with the continuing support of the Network universities, particularly our host, the University of Manitoba.

5. Knowledge Exchange and Technology Exploitation

5.1 Applying Research Results through Collaboration with Public and Private Sectors

Everything that ISIS does is geared to applying its research results to technology advancement, market opportunities, public policy development, and health and social benefits. It does this through consultation and collaboration with partners in the public and private sectors.

The focus of ISIS demonstration projects is technology advancement utilizing FRPs and FOSs. Each of these projects is aimed at convincing the owner of infrastructure that there are advanced ways of rehabilitating structures that result in lower costs and longer life cycles. Collaborative efforts are essential because the projects would not move forward without approval by the user sector. In most cases, cash and in-kind contributions by the owner are substantial. At the same time, Project Leaders are continuously exploring market opportunities for their creative ideas through collaboration with manufacturers, suppliers, contractors and investors.

Changes in public policy follow demonstrated technology advancements. The infrastructure rehabilitation policies of the Provinces of Québec, Manitoba, Nova Scotia and British Columbia are beginning to embrace ISIS technologies as a result of successful joint-venture projects. The Cities of Calgary, Winnipeg and Sherbrooke are doing likewise. In addition, ISIS Canada has made submissions to the Federal Government regarding the anticipated national highways' upgrading program. We are endeavouring to influence public policy by having FRPs incorporated in the rehabilitation program. It takes a long time to change public policy, but receptivity to our proposals has been encouraging.

Other than requiring a safe and efficient infrastructure network to service the needs of its citizens, spin-off benefits related to health and/or social issues are limited within the context of the ISIS research program. However, it is conceivable that ISIS projects which focus on seismic considerations could one day translate into increased public safety with a reduction of catastrophic structural failure during an earthquake. In view of the health hazard presented by contaminated ground water supplies, current research using FRPs to improve the containment of hog wastes could constitute an ISIS contribution in this regard. ISIS Canada believes that there is a need to build structures that will last longer, require less maintenance and eventually cost less. In a national context, the envisaged savings in infrastructure budgets could be directed toward enhanced social benefits.

5.2 Communicating and Transferring Research Results to the Public Domain

One of the reasons that ISIS Canada was created was to utilize the NCE opportunity to transfer benefits of university research to the user public. Consequently, ISIS researchers are encouraged to publicize their results and transform them into practical applications for the benefit of Canadians. From its inception, ISIS Canada recognized that it would have to communicate its work and successes to three distinct audiences: the general public, stakeholders and the scientific and engineering communities.

An effort is made to make the general public and political representatives aware of ISIS activities and the benefit of its research through widespread distribution of an annual corporate report, newsletters, Annual Conference promotions, web site, magazine articles and public presentations.

Stakeholders receive all promotions provided to the general public and, in addition, are invited to workshops and seminars specifically geared to the user sector. Recently, the design guidelines and manuals have been used as a basis for enhancing the capability of design engineers and contractors to utilize FRPs and FOSs. Stakeholders also have access to one-on-one consultations with ISIS personnel as they explore opportunities and formulate research and demonstration projects.

The scientific and engineering communities receive all pertinent public information. In addition, a concerted effort is made by ISIS Project Leaders to present their findings at national and international conferences. Also, specific ISIS workshops have been organized in conjunction with conferences held by others. An ISIS Theme Director conducted a lecture tour on behalf of the Canadian Society for Civil Engineering, making the scientific community and stakeholders aware of the advance of ISIS technologies. Similar lectures were given in Egypt, France, Japan, Sweden and the United States. Using the design manuals as a base, a tool kit is being formulated for engineering educators so that ISIS technology can effectively be taught at the undergraduate level across the country. The dissemination of results from ISIS research and demonstration projects is a never-ending quest of the Network.

5.3 Intellectual Property Considerations

Early in the ISIS mandate, a policy was adopted for all ISIS research whereby the intellectual property associated with the creation of a new invention was owned by the researcher and/or the university in which he or she resides, in accordance with the policies of that university. ISIS Canada makes no claim to a share of the benefits that may flow from such intellectual property. Consequently, there have been no challenges associated with protecting or exploiting intellectual property.

The policy has been reviewed twice by the ISIS Board of Directors. The NCE expert panel also suggested a review. Each time, the RMC recommended, and the Board approved, continuation of current policy because patents are being pursued by ISIS researchers and the policy has strengthened the working relationship and bond among Network participants. Management continues to encourage and facilitate commercialization of ISIS research results.

5.4 Creating and Commercializing New Products for the Benefit of Canada

ISIS researchers have generated several commercial opportunities, some of which are already making a contribution to strengthening Canada's industrial base. This has been achieved in spite of the fact that the user public considers the application of new technology in the infrastructure sector to be in the public domain, which limits the number of patents and market opportunities. To take maximum advantage of the opportunities that do evolve, the responsibility of the Technology Transfer Committee (TTC) is currently being expanded to include commercialization of ISIS intellectual property.

Patents have been filed for FRP anchorages and embedded FOSs in pultruded FRP reinforcement rods. Use of glass fibre dowels in pavement joints instead of steel presents another market opportunity, as does the development of filament-wound GFRP for bridge decks and hydro poles. The patented steel-free concrete deck has been marketed for the past three years. One of the most exciting market opportunities is the creation of a spin-off company, Fibre Optic Systems Technology, Inc., which will ensure that made-in-Canada equipment is available to monitor ISIS structures using FOSs. Other achievements are on the horizon for the benefit of Canadians.

6. Network Management

6.1 Management Structure

The organization chart that is illustrated in Appendix "A" reflects the management structure that has been used since the mid-term review. This structure has served us well but, as the research program moves into the 2nd Funding Cycle, a need has emerged to introduce a new level of management that involves Project Coordinators. Other enhancements are detailed in the accompanying Strategic Plan. The strengths of the ISIS Network management team from the outset have been its openness and willingness to change, and using consensus as the basis for its decision-making process.

6.2 Involvement of User Sector in Planning Research Program

The user sector is foremost in the minds of the ISIS management team throughout its decision-making process. By requiring matching participation from government or industry for each project, there is an assurance that the research is being carried out in response to specific needs of the user sector. The Board of Directors also provides input as part of the project approval process.

For the mid-term review and again for the current 2nd Funding Cycle consideration, an invitation went out to all ISIS partners and participants, soliciting their input regarding the future direction of ISIS Canada. The response was significant and insightful. Prior to finalizing the research program for the current NCE submission, presentations were made to the Board, TTC, Project Leaders, Working Group and 80 student researchers to solicit feedback on the draft proposal. The most direct involvement of the user sector occurs on those numerous occasions when industry and government approach ISIS to carry out specific research and demonstration projects to resolve a sectoral problem. Involvement of the user sector is considered an essential part of fulfilling the ISIS Canada mandate. Commencing in December 2000, the RMC is being expanded to include additional representatives from the user sector to strengthen this aspect of management considerations.

6.3 Response to Management Challenges

ISIS Canada has not been encumbered by management challenges. Since the mid-term review, the administrative component of the ISIS Network has been incorporated as a separate legal entity at the request of our host, the University of Manitoba. The incorporation process went smoothly and the working relationship with our host university continues to be excellent. Recruitment of additional members for the Board and TTC has been readily achieved on an as-required basis.

Recently, our initial Program Leader, Dr. S. Rizkalla, took up a position outside of Canada. On the recommendation of the RMC, the Board immediately appointed Vice-President, Dr. A. A. Mufti, to the position of Program Leader and President of ISIS Canada. At the same time, Dr. Mufti was invited to accept a professorship at the University of Manitoba, which he did, effective September 1, 2000. There was no lapse in leadership. To fill the resulting vacancy on the RMC, Dr. J. J. R. Cheng accepted the directorship of Theme 3. Since the ISIS Network is blessed with talented people who are anxious to keep the operation viable and progressive, the transition unfolded quickly and smoothly. There has been a conscious effort made to include young Project Leaders in the Network to build in longevity and succession in the ISIS program.

6.4 Mechanisms for Internal Communications

In the beginning, ISIS management relied on its newsletter, corporate annual report and three-day Annual Conference to keep the Network informed about the scope of ISIS activities. In addition, Theme Directors met with their Project Leaders and research teams to review progress and expand their knowledge of overall Network activities. In 1998/99, all Project Leaders were visited by the RMC for in-depth evaluation of their progress and focus on the ISIS mandate.

Commencing prior to the mid-term review, increased effort has gone into keeping the Network better informed. The web site has been a tremendous help in this regard, especially since it can be easily updated by our head office web master on receipt of an e-mail from anyone in the Network.

As part of the Annual Conference, a dinner meeting for Project Leaders was initiated to enhance networking and solicit feedback regarding management and research issues. This has proved to be very beneficial. Out of these sessions came the suggestion for the Chief Executive Officer (CEO) to provide Project Leaders with a list of key issues discussed after each meeting of the RMC and Board. This is now a regular communication feature that has proved popular. A student committee has also been formed to further enhance internal communications.

6.5 Publicizing Network Success

Considerable detail on the approach that ISIS management uses in publishing network success and transferring knowledge to the user public has already been provided in article 5.2. Management recognizes that the success of ISIS Canada will be measured by how widely the new technology is utilized by the infrastructure sector. Consequently, ISIS endeavours to promote acceptance of its research findings for the long-term benefit of Canadians.

7. Conclusion

One of the major constraints to rapid acceptance of ISIS technologies is the conservative nature of the civil engineering community and infrastructure owners. Because safety of the public is involved, there is a natural resistance to take risks. Consequently, it will take several more years before the use of FRPs is common practice in the infrastructure sector. Continued funding for ISIS to 2009 is essential to the process.

To address this long-term challenge of user acceptance, the proposal for the 2nd Funding Cycle, 2002 to 2009, places increased emphasis on technology utilization by making it an integral part of each research project. Now that the design manuals of Phase I are nearing completion, the base has been established to accelerate the transfer of technology, both in the infrastructure sector and the engineering education curriculum. The strategy of ISIS Canada as it goes forward is to build on achievements thus far, with increased emphasis on end-user acceptance and widespread utilization of ISIS technologies. Only then will the promised benefits flow to Canadians.