



NRC-CMRC

Innovative Technologies for

Canada's Civil Infrastructure Systems

Preserving our community lifelines
Time for innovation

Town Hall Meetings – September 9 & 10, 2002

BACKGROUND MATERIAL

FOREWARD

By Reg Andres

Chair of the CIS - TRM Expert Group Panel and Vice-President of R.V. Anderson & Associates Ltd.

The following document is an attempt to summarize the current domestic and international challenges facing the industry with regard to the much needed renewal and enhancement of our civil infrastructure system. All four members of the National Steering Committee (CSCE, CCPE, CWPA, NRC) recognized the importance of investigating what other groups have compiled on the subject prior to engaging in such an important exercise as creating a technology road map.

To achieve this goal, we have retained the scientific services of Dr. Ian D. Moore, Ph.D., P. Eng., Professor and Canada Research Chair in Infrastructure Engineering at Queen's University in Kingston, who compiled this study for us. We would also like to acknowledge the valuable assistance from doctoral students M. Law and M. Nkemitag.

If you wish to validate this information, please review the attached document entitled Phase I – Bibliography.

It is our sincere wish that as this Town Hall Meeting progresses, our views and opinions converge in the identification of a key consensus on the needs and gaps in terms of the technology innovation instrumental to improving our country's civil infrastructure systems.

As the industry works hand in hand with the academic sector and decision-makers to identify this consensus, it is our position that we can build a lasting vision.

As we recognize how infrastructure systems can have an impact on the well-being of our community and its current state of decadence, we have no choice but to impress upon to the decision-makers the need to act with urgency. It is the responsibility of our profession to identify this critical stage and inform the public of the severe degradation of our community lifelines.

It is also our duty to face these challenges and re-engineer design, techniques, and material in order for Canadians to preserve their community lifeline.

By acting together and sharing our vision, we can remind decision-makers that this technology road map is about a realistic and exhaustive analysis of the situation and about the commitment of our industry and profession to preserve what the average citizen perhaps takes for granted.

On behalf of the Expert Panel Group Members, we truly appreciate your contribution and we invite you to monitor the evolution of this process by visiting our TRM-CIS web site at www.csce.ca. Please, do not hesitate to provide us with your comments and suggestions online.

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INTRODUCTION

Every Canadian business and community depends on the nation's civil infrastructure systems (CIS), both its Transportation Structures (roads, bridges, sidewalks, airports) and Environmental Structures (drinking water, storm and wastewater, solid waste recycling and disposal facilities). Infrastructure fundamentally influences corporate access to markets, costs of doing business, and workforce productivity. From the public perspective, infrastructure influences our access to employment and recreation, personal health and safety, and how we function as a society. The consequences of our aging infrastructure are well documented. Design and construction exceeds 10% of Canadian GDP, and transportation consumes 16%. CIS repair and renewal costs are already huge, and unless we accelerate the pace of innovative infrastructure renewal, we will be shackled with the high costs of an ineffective, decayed, inadequate and obsolete infrastructure, and our communities will suffer increased congestion, unreliable services, escalating costs, and a deteriorated physical environment.

This document is based on a review of forty-five documents speaking to the challenges faced as we work to renew and extend our civil infrastructure systems. A vision is presented, indicating directions we should consider over the next ten years. Gaps in technology development and application are identified, and a draft list of research needs is prepared to guide the development of new products and services, categorized as short (5 year) and long term (10 year) investment objectives. This review is intended to promote discussion, then development of a Technology Road Map for management of our Civil Infrastructure Systems.

CHALLENGES

Canada faces a huge infrastructure deficit, since investments to maintain and modernize infrastructure have fallen far behind needs. Infrastructure engineering problems range from specific projects of obvious priority (e.g. decay of critical transportation links like suspension bridges) to degradation affecting a multitude of medium and low cost bridge structures, and thousands of kilometers of water supply, storm-water and sanitary sewer pipes.

Civil infrastructure is unique in our society in that it is generally decentralized, and publicly owned by a myriad of "custodians". This has led to singular challenges. Maintenance is rarely funded considering infrastructure as a capital investment affecting the economic health of our society, and research and development expenditures are small compared to those invested in other engineering endeavours (substantially less than 1% of capital costs, much less than the average of 3.5% spent on other mature North American industries). Tolerance to human risk in these systems is low. Therefore, professional practice is often very conservative, and there is little incentive for innovation, both by municipal and consulting engineers. Fears concerning litigation are exacerbating this; more than 75% of US consultants now report that this motivates them to avoid innovative technologies.

Of the approximately 10% of GDP directed towards Civil Engineering construction, almost half corresponds to investments in CIS. Of that, more than 80% is invested in repair, rehabilitation, and renewal, a challenge since our educational programs are

essentially devoid of references to infrastructure management and repair. Civil Infrastructure Engineering is a multi-disciplinary endeavour, with a variety of technical and social issues affecting decision-making. Our largest cities are home to an increasing share of our population and business activities, heightening challenges associated with supply of water, removal of wastewater, and management of solid waste. Difficulties with rights of way are increasing (an important hidden cost of subsurface utility engineering), as are public pressures stimulated by past environmental indiscretions. Much of our infrastructure operates at far beyond its original design capacity, so services are increasingly vulnerable to disruption. Improvements in efficiency often correspond to reduced redundancy and greater interdependence, rendering infrastructure systems more vulnerable to catastrophic failure.

Coupled with those challenges, the 1990's saw a move of many of the most talented young engineers into the mechanical, electrical, computing and software engineering disciplines. An unfortunate coalescence of career starts in the 60's and 70's has recently resulted in the retirement of many of our most experienced experts in industry and academia. That has coupled with downsizing in provincial government engineering departments to create a substantial shortage of expert infrastructure engineers. Further difficulties have resulted because funding agencies like NSERC perceive Civil Engineering as "striving to reinvent itself" but without "energetic vision", and have directed R&D funds elsewhere.

OPPORTUNITIES

However, changes are occurring, with a number of major developments coming in recent years:

- A. New construction technologies are being developed, like those for pavement repair, pipe installation and repair, and bridge rehabilitation;
- B. New design philosophies focus on performance criteria rather than simple design recipes. This greatly enhances the potential for innovative new materials, products and methods.
- C. New structural materials are being implemented, such as fibre reinforced polymers having the potential to solve a variety of durability and rehabilitation issues, polymer pipes having the potential to provide improved economy and durability, and high strength concrete offering construction efficiencies as a result of rapid strength gain.
- D. New products and techniques have been developed to control environmental issues associated with water resources, construction and waste management.
- E. New federally funded research collaborations ISIS and the Canadian Water Network are building research networks tackling CIS issues identified as of national importance
- F. New NSERC and Canada Research Chairs have been appointed in research areas relating to Civil Infrastructure. This implicitly identifies a group of internationally recognized scholars who can lead infrastructure R&D efforts.
- G. Major research infrastructure investments are being made through the Canada Foundation for Innovation, providing specialized research facilities at campuses across Canada

- H. New collaborations are developing practical guidance for the industry (e.g. NGSMI)
- I. Recent events in Canada and the US have lead to greater government and public awareness of the critical importance of Civil Infrastructure Systems

VISION FOR THE FUTURE

These developments prompt us to formulate a new vision for the future, translating into significant changes in our approach to our work. We need to be a community that:

1. Leads the definition and articulation of the way forward, engaging public and private interests in a partnership to tackle our infrastructure problems, setting not responding to others agendas.
2. Moves further towards solving CIS problems by integrating the technical engineering issues with considerations of engineering science, finance, computer technology, and social and policy issues.
3. Recognizes and promotes investment decisions based on consideration of infrastructure as a capital asset, considering total cost, not just initial investment.
4. Is proactive rather than reactive in responding to infrastructure degradation (making timely interventions instead of larger investments in reaction to failure)
5. Employs sustainable development concepts in CIS development and management, minimizing use of nonrenewable resources, and optimizing use of energy and renewable resources.
6. Implements strategies to encourage adoption of state of the art methods, while working to create an environment enhancing the development of further innovative new technologies.
7. Where appropriate, uses improved materials and structures to extend the design life of current infrastructure, while engineering new structures to avoid another cycle of massive decay.
8. Increases efficiency by integrating provision of services where possible (roads, buried utilities, and so on), while striving to engineer these services to minimize vulnerability.
9. Is adaptive, applying new knowledge to existing infrastructure (whose lifetime generally exceeds knowledge half-life).
10. Learns from mistakes and passes on knowledge within and between generations, so we do not need to relearn by making the same mistakes.
11. Adjusts professional education to further strengthen interdisciplinary training and to provide a substantial new focus on infrastructure renewal and rehabilitation.

12. Enhances investments in research and development to support development, proof and implementation of new construction methods and products, collaborating on the most costly research projects, like field trials and deployments.
13. Attracts the best and the brightest, by renewing its reputation as a leading engineering discipline, using innovative technologies and other creative means to solve pressing societal problems

NEW PRODUCTS AND SERVICES REQUIRED BY THE MARKET

New products and services are required to address shortcomings in the state of practice relating to civil infrastructure systems (five categories listed below are denoted P-I to P-V):

P-I Data Collection and Interpretation

Data collection tools and protocols are needed. Data leads to information, which can lead to knowledge, understanding, and best practices. In particular:

- Instruments are needed for reliable detection of buried utilities (metal, ceramic, & polymer pipes).
- Instruments are needed to effectively assess extent of structural deterioration
- New real-time monitoring techniques are needed to assess water quality.
- Standardized data collection protocols are needed for both visual and numeric data. Interpretation can then be optimized to undertake on-going LRFD calibrations and other load and performance assessments (e.g. traffic/vehicle loads, infrastructure decay rates, structural performance)
- Flexible calibration procedures could also be developed to accommodate multiple data sources
- Standard test methods are needed for all new materials and products, these providing engineering properties or index measurements for use in quality control and assurance during manufacture or construction. Most will employ laboratory tests on samples or components, assessing durability of new materials like fibre reinforced polymers, geosynthetics for landfill barriers, polymer pipes, asphalt binders and pavement mixes. Field evaluation is needed following construction (e.g. for surface coatings, structural repairs).

P-II Decision support systems

Data alone is of little use, and the implementation of novel data collection strategies will not be embraced until decision support systems are available to enable infrastructure managers to plan investments in data collection, evaluation, and then repair or replacement. Software tools capable of interpreting measurements are needed, designed to provide practical guidance. These tools can incorporate reliability theory, considering effect of data quality and modeling on the reliability of infrastructure performance. Decision support systems will incorporate direct and indirect cost components, and is needed by both small-scale and large-scale infrastructure owners.

Design and management decisions should also consider the implications of natural and unnatural disasters on infrastructure performance. Cost estimates for infrastructure projects should include business losses associated with disruption from construction or natural disaster, and might also consider risk arising from infrastructure interdependence. Decision support systems and practice guides should include actions to mitigate, prepare, respond and recover from disasters.

Multi-disciplinary decision-making should link experts in materials and deterioration science, construction and field assessment, disaster prevention and recovery, economics, legal liability, and QA/QC systems. A systems-based approach could be used to consider infrastructure interdependence, including catastrophic interaction producing cascade effects (where interference to recovery operations results from various infrastructure).

P-III Novel materials and construction methods, for new and rehabilitated structures

New materials and construction techniques are needed:

- To repair water sumps and manholes, bridge joints, pipe joints (controlling root intrusion, exfiltration/soil contamination and infiltration), pavement joints, and concrete pavement restoration
- To restore runoff properties following application of impermeable surface layers
- To reduce traffic disruptions: installing or replacing buried pipes with minimal excavation; using prefabricated structures; using automation for steel erection; undertaking paving with zero-clearance equipment to minimize lane closures; using rapid curing concretes so pavements and pavement repairs can support truck traffic within a few hours of placement
- To control workplace safety problems (e.g. using robotic systems to replace lead paints)
- To slow corrosion or deterioration of new or existing structures (coatings for metals, durable polymers, durable asphalt overlays, runway repairs using jet-fuel resistant sealants)

P-IV New design and other procedures to optimize resource utilization

Optimal use of energy, renewable and nonrenewable resources is needed, including efforts:

- To lower energy usage in all aspects of CIS design and management: energy associated with basic transport, low energy waste treatment methods, energy reduction in materials production and construction, energy for heating of water and sewer systems in cold regions
- To reduce total project requirements for investment of non-renewable and renewable resources, including water
- To reduce maintenance requirements

P-V New documentation and other information sources to facilitate implementation

The fragmented, multi-party nature of our infrastructure owners makes communication of the state of the art, including innovative technologies, a considerable challenge. Some possible methods of managing this include:

- Further development of internet repositories to provide ready access to guidance, including information on new market-ready technologies
- Collaborative development of practical tools with industry associations and learned societies, to accelerate application of these techniques by municipal engineers and consultants
- Development of standard data records (to facilitate data integration, comparison, and analysis)
- Development of standard methods of defining material and product characteristics (for Geotextiles and Geomembranes, for example)
- Development of codes for design and materials, and “best practice” guides (e.g. NGSMI)

ENABLING TECHNOLOGIES TO CREATE THESE PRODUCTS AND SERVICES

Five technology groups are identified below (T-I to T-V) to support the five product and service areas.

T-I Data collection systems (to enable P-I products)

- Non-destructive testing equipment (e.g. radar, sonar, seismic, resistivity, magnetic current technologies) for assessing characteristics of both structures (pipelines, hinges, reinforcing and prestressing steel) and their individual material components, for locating buried infrastructure, pavement monitoring, soil cavity detection (scour and erosion voids), post-quake or vehicle impact forensic evaluation, water quality assessment.
- Structural integration of fibre-optic and other sensing systems
- Energy monitoring and control systems

T-II Laboratory tests (to enable P-I products)

- Accelerated testing facilities are needed to conduct laboratory simulations of field performance: (large CFI funded facilities under development include pavement systems at Laval and Waterloo, advanced structural testing facilities at a number of institutions, cold regions testing facilities at Alberta, and large scale buried infrastructure and geosynthetics laboratories at Queen’s)
- Standard laboratory tests to assess short term and long term material properties, and for quality assurance and quality control of manufactured construction products and ‘as built’ characteristics

T-III Decision Support Software (to enable P-II products)

Software is needed to enable interpretation of material and structural assessments from the new NDT procedures. These will be designed to coordinate directly with specific

NDT measurement systems, and will provide guidance about current level of structural stability, timing of future inspections, likely times for repair or replacement. Other software can guide the design of construction operations, indicating productivity rates, equipment needs, and material quantities. Integration with Geographical Information Systems has the potential to locate old and record new infrastructure, and provide input for design, maintenance and construction software.

T-IV Computer analysis software (to enable P-II and P-IV products)

Use of finite element analysis in design permits mechanistic rather than empirical design. This facilitates rational treatment of site-specific and material-specific design constraints, rational comparisons of design alternatives, rational assessment of existing structures, and incorporation of stochastic modeling permits consideration of uncertainty. Generic finite element applications are complex and expensive, so specialization for specific applications can simplify use in routine design (e.g. for buried pipe and flexible pavement design), extending use in high-cost projects.

T-V New Construction techniques, structural products and materials (P-III and P-IV products)

Promising techniques, products and materials include:

- Joint sealants (for pipes, pavements, runways), and coatings (for pavements, water sumps, manholes, metal and concrete structures)
- Stormwater detention and groundwater recharge products to restore runoff characteristics
- Precast FRP or other structures, cast-in-place FRP; carbon fibre reinforcing
- Zero-clearance equipment to minimize lane closures and rapid curing concretes for pavements
- Robotic systems to remove and replace lead paints, and perhaps for steel erection
- Trenchless technologies (e.g. pipe bursting, horizontal directional drilling, pipe lining systems, microtunneling)

HOW TO ADDRESS TECHNOLOGY NEEDS THROUGH R&D

Research is needed to address gaps preventing the implementation of new technologies. Work is also warranted to develop other innovative products and services. R&D objectives are classified as deserving attention in the short- and long-term (say 5 and 10 year time periods respectively).

S.1¹ Work to facilitate implementation of state of the art methods. Reluctance to employ new techniques and products often results from insufficient confidence. Research on products and processes is often undertaken by the corporations owning or marketing the technology. Lack of independent evaluation, credible field trials and objective design methods weakens confidence. R&D work should include: 1. Independent work to

¹ S: Short term objectives (for the next five years)

develop rational design methods (codified or computer based procedures); 2. Field demonstrations and technology trials (covering a credible range of techniques & site conditions); 3. Development of QA/QC procedures (to permit facility owners to assess implementation quality); and 4. Development of management guides (to facilitate decision-making and optimum implementation). Targets are most specific technologies outlined in T-I to T-V.

S.2 Work to develop data collection systems (e.g. nondestructive testing). Non-destructive inspection of lifelines and transportation components is of variable maturity. Video inspection of pipelines is now commonplace, and the use of 'smart pigs' to assess metal gas, oil and water supply pipelines is also increasing. For technologies in use, the short-term research objective should be to undertake structural assessments that relate the data collected to measurements of structural capacity and lifespan; further work should include stochastic considerations, and accelerate preliminary studies on new techniques.

S.3 Work to examine material and product longevity. Laboratory testing should examine durability and long term performance of new products, including crack repair materials, pavement sealants, polymer pipes, geosynthetics, fibre reinforced polymers (including fire resistance studies). Investigations should examine the implications of ambient environment and construction effects (temperature, curing success, moisture, significant chemical and biological factors, and static and cyclic stress or strain). Further work should examine the long-term performance of infrastructure repair and other life-extension techniques, research should establish fundamental physical principles, not just empirical data.

S.4 Decision support software. Combining knowledge of the critical performance criteria and the available data types, decision support software should be developed to support rational, stochastically based design, construction and maintenance decisions. Inclusion of indirect costs should be considered (e.g. service disruption), and the environmental consequences of design and maintenance choices.

S.5 More comprehensive reviews of R&D needs. Documents considered here provide little information regarding research and development needs for sidewalks, airports, drinking water, storm and wastewater, solid waste recycling and disposal facilities. New surveys are therefore needed to further clarify research needs.

L.² Work to develop new coatings. Since infrastructure decay often takes the form of surface damage, continued work towards the development of improved surface coatings is warranted. Success will depend on knowledge of physical, chemical or biological degradation mechanics.

L.2 Work to develop new inspection and diagnosis tools. Innovative new physical testing procedures should also be assessed. Firstly, the objective is to examine whether they have the potential to provide successful product and material evaluations. Some concepts will be judged to have the potential to provide meaningful physical

² L: Long term objectives (for the next ten years)

characteristics of the product or structure. Those should be selected for more extensive research, so that additional nondestructive test methods can be implemented.

L.3 Codification of new products and processes. Once products are available, and have been proved credible in the laboratory and the field, it may be justified to seek formal codification of the product specification and/or construction procedure (through CSA, ASTM etc).

L.4 Infrastructure designs considering natural and unnatural catastrophes. Work should examine catastrophic events, including fire, extreme weather, and earthquakes.

HOW TO ADDRESS TECHNOLOGY NEEDS THROUGH ENGINEERING EDUCATION

A small number of important changes to Civil Engineering curricula should be considered. Given our infrastructure assessment, repair, and replacement problems, curricula should:

- Work to educate professionals able to manage technically complex water and other systems
- Further incorporate environmental & social issues including sustainable engineering practices
- Consider inclusion of training in systems engineering (where such expertise is available)
- Include assessment of existing structures, and design of repair and rehabilitation schemes
- Include more instruction on novel materials (e.g. reinforced and unreinforced polymers)
- Include references to novel construction methods (such as trenchless technology)
- Strive to emphasis innovation and creativity, and work to attract a larger proportion of the most talented engineering students

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