DISCUSSION ON FUTURE PROSPECTS AND EMERGING GROWTH AREAS IN CIVIL ENGINEERING[1]

PREAMBLE

I would like to clear up a few points before proceeding with this presentation. I do not wish to give any impression that I am in a position to suggest what is good for the future of our profession. I merely wish to provide food for thought and provoke healthy debate. It is important that I do not put off anyone with the issues that I am about to raise as some may perceive suggestions for any change may infer that the current practice is being questioned. We should avoid arguing between old and new civil engineering, rather we should concentrate on the most effective delivery of our services using the latest relevant technology within a sound business framework. Similarities can be drawn to many other traditional businesses (such as banking, insurance, retail, manufacturing, autos etc) who have successfully implemented the new technology to expand their range of services and improve productivity. This neither means the fundamentals have become redundant nor that the core business needs to be changed.

It is my strong contention that we are well poised for growth and with the successful adaptation of the changes we will be in a better position than ever before to offer exciting services and attract top-notch students to our discipline. I really feel that we have an opportunity here to transform ourselves for a more prosperous future and do not see any reason to take a defensive position for our survival.

One final note before I proceed with the specifics is to describe the method I have used to gather and organize the information. First and foremost, I tried to think outside the box; rather than trying to tweak with the currently accepted structure or breakdown of our discipline (e.g., in the form of structures, transportation, enviro, geotech etc), I have taken a more liberal approach of looking at the whole market place by considering an approach that is more consistent with how other businesses manage and offer their services. In this pursuit, I liased with colleagues, examined the initiatives that currently are being considered in the US and Canada to address the future of civil engineering and also studied other traditional businesses that have managed to use technology to their advantage. In the presentation of my findings, I have been rather selective as I could not see a consensus on the changes that should be adopted. My bias has been towards identifying emerging growth areas and the use of modern tools and techniques for delivering services. In this write-up, I have also excluded issues that I believe will be covered by others such as improving enrollment (quality and quantity) by better marketing our profession at the high school level etc.

Disclaimer: While I am somewhat responsible for the style of this presentation, I do not take ownership of the ideas and contents. To ease the narration, I have not adequately cited all the references, however, the omission is not intended to imply I am the originator.

[1] This paper was developed for presentation at the Civil Engineering Workshop in London on June 7, 2000 and the NSERC Civil Engineering Reallocation Program on June 8. I have been appointed the Chair of the latter and was invited by the CSCE Conference organizers to present the same to the Chairs of Civil Engineering Departments in Canada at a special workshop.

QUICK OVERVIEW

Hard Core Civil Engineering

The basic challenges to our society that require civil engineering talent are increasing in number and importance. They include housing an expanding population, addressing decaying urban infrastructure, maintaining our environment, dealing with the effects of natural disasters and climate change, and transporting ever more people and goods in a safe and efficient manner. Addressing these challenges successfully will take a new kind of technology and a new kind of civil engineer.

Emerging Growth Areas

The emerging hot fields of biotechnology, materials, electronic commerce, advanced communications and information technology will have a major impact on civil engineering. While far-fetched, it is conceivable to see that in the near future genetically engineered micro-organisms will be used in the manufacture of high-strength building materials. Biotechnology disposal will eliminate plumbing pipes for waste. Photonics, lasers and fiber optics will replace metallic wiring, and computers will be pervasive throughout the building environment. Wall membranes made of new materials will store and transmit light and heat.

Challenges and Tasks Requiring Immediate Attention

R&D monies are in short supply in our field, because they are pouring into areas like biotechnology, IT and advanced communications. Our response must be to draw from fields that are advancing faster than ours wherever possible, and use that technology as a springboard for our own progress. Other older industries that have incorporated such innovations have truly prospered. We should not be intimidated or threatened by technology, rather we should integrate it seamlessly into all aspects of our profession and thus open up new opportunities for research that potentially can be funded at much higher levels than our traditional areas of research.

As the driving forces behind developments in emerging growth areas come from outside civil engineering we ought to actively seek to understand and use technology developments from other fields to our advantage, and that will call for a new curriculum for our students and a more entrepreneurial mindset for our engineers and businesses. Our profession must attract its share of the best and the brightest. To achieve this goal, our profession must be full of promise and creative potential as well as offering the satisfaction of contributing to the welfare of our society as has always been our central mission.

JUSTIFICATION FOR GROWTH IN CORE AREAS

Worldwide Population Growth: Current world population stands at 6 billion and is expected to grow by another one billion over the next 10 to 15 years. By the turn of the century, world population is expected to exceed 10 billion. While civil engineers play the central role in planning and building the necessary infrastructure for the growing population, it is unlikely that yesterday's technologies will suffice for tomorrow's challenges.

Decaying Infrastructure: One sure bet is that the deterioration of major infrastructures in N. America will continue to provide us with a sustained level of work. The oldest and largest cities face the most serious problems. Examples of infrastructure include underground water pipes which may not only fail mechanically (rupture) but also encourage the growth of bacteria. The EPA estimates that America will need to spend $300 billion over the next 20 years to upgrade its water systems, and because little is being done, it will get worse before it gets better. The same is true of the oil pipelines. Over one trillion dollars is required to repair or upgrade bridges and major buildings.

Waste Management: Population and economical growth are expected to boost the rate of waste production. Considering land shortage and environmental constraints, waste management projects will be around for the foreseeable future.

Shortage of Fresh water Supply: Supplies are being depleted faster than they are renewed. Amongst the major nations (in terms of users and producers of food) such as China, India [2] and the US, water tables are falling and an increasing number of rivers are sucked dry before they ever reach the sea. By the year 2025, 3 billion of the world's population will live in places where fresh water resources have fallen below sustainability levels. There are no easy answers to the challenge of providing an adequate water supply, and we cannot extrapolate on what we have done in the past into the future.

Natural Disasters: Land-use patterns continue to put more people and property at risk for natural disasters. The past several decades have seen a global population migration to marginal land that is at risk for natural hazards. When both the threat of damage to lifeline infrastructure and the speed of commerce are increasing simultaneously, the potential for economic losses from natural disasters expands significantly. In 1998, worldwide damage from storms, floods, drought and fires reached $89 billion, three times what it was in 1997. Natural disasters killed 32,000 people and drove 300,000 from their homes, and much of the suffering and property loss was the result of humans building on high-risk terrain. Global warming, which has been influenced by human activity, has increased the severity and frequency of hurricanes.

Transportation Issues: Projection of the present trend of vehicle usage reveals a rather ugly and unsustainable situation both in terms of traffic congestion and air pollution. For instance, while the U.S. population increased 30 percent over the past 30 years, the number of licensed vehicles increased 87 percent and the number of vehicle miles traveled increased 130 percent. The S. California Council of Governments warns that by 2020, rush hour there will last all day, with a top average speed on the area's expressways of 15 miles per hour. In my opinion, however, the technology is likely to change this trend; more people will be operating from their homes.

Commercial air travel is also growing rapidly; statistics indicate 1.5 billion passengers worldwide in 1998 and this number is expected to double in the next 15 years. All of this does not even count the rapidly increasing air traffic caused by air freight operations, which are being pushed to new levels by e-commerce.

In summary, the effects of population growth, increasing transportation congestion, decaying infrastructure, shrinking waste management options, environmental deterioration, destruction from disasters, and effects of global warming represent a significant problem to mankind which must be mitigated by civil engineers. We have the opportunity to develop solutions to these complex problems using innovative approaches involving the most effective technological and management techniques.

THINK OUTSIDE THE BOX

Be creative and conform to the practices and needs of the new market. Don't try to solve traffic problems by adding additional lanes to freeways. Long term waste problems cannot be solved by opening more landfill sites and incineration of everything that cannot be landfilled. Imagine what the consequences of the internet age would be on how people conduct their business in 10 to 20 years henceforth. What percentage of people in the service sector would be commuting to work as they do today? Will a typical work day be 8 to 4:30 or could it be well spread out throughout the day? Should we be concentrating on solutions to yesterday's problems or become facilitators of tomorrow's growth areas?

The emerging growth areas of today will be the core business of tomorrow. What would the university system of say 2020 compare with today? What percentage of our work will be conducted on line? Will the meetings and conferences in 20 years time be done as they are today? I don't have the answers but I do know that anything that creates redundancies and cost inefficiency will be eliminated. If people can communicate effectively from their place of work, they would question spending time and money to have face-to-face meetings. We should try to provide solutions for this new economy as civil engineers of the late 19th century did by having the forethought to construct underground subways (London and Paris) resulting in significant growth of cities, creation of suburbs and the creation of so many new businesses that still remain with us.

[2] India is now depleting its underground water reserves twice as fast as they are being replenished; in effect, its aquifer depletion could reduce India's grain harvest by a fourth.

We need to become leaders again. We must look to technology for direction and solutions. Note that we do not need to compete with high tech, rather we must be smart enough to see how it will change the priorities and then provide solutions that the new industry will purchase from us. We have the opportunity to sell our services at a much higher rate than we do on traditional problems as solutions to the new problems require high end skills beyond what a typical technologist can offer.

Several examples of emerging growth areas that may be relevant to our future are discussed below. This is not supposed to be exhaustive, rather an illustration of the possibilities.

Pure Tech

The full impact of computers in our profession has not been realized yet. Far more is still to come as computing power and optical and wireless networks continue relentlessly to double in power every two years. Researchers in the field will soon enter computer data by voice and it will be relayed instantly to the lab. Robots have already made testing safer at sites with hazardous materials, and they will help to improve construction productivity and safety.

Innovations in information and telecommunications, such as, satellite global positioning systems (GPS) for precise site measurement and control in real time are reducing the costs of design and construction. Innovative knowledge systems and novel technology applications may be just as important to our industry's performance as technology itself. Computers and communication technology are also at the heart of intelligent transportation systems. A variety of advanced sensing, computing and communications technologies handle tasks that range from collecting tolls to controlling traffic signals, and they are integrated into coordinated systems that manage traffic flow.

The power, lighting, heating, air conditioning, security and fire protection systems of new buildings are already beginning to talk to each other, and they are about to get even smarter. We are entering an era when building security systems will routinely read voices, palm-prints or footprints rather than keys or keycards, and computers will automatically adjust the inside environment based on how many people are there, where they are in the building and what they are doing. Building vibrations will be controlled by responsive systems that can interpret precursors to the actual driving events.

Future trends in computers include changing human intelligence by employing neural implants to intercept and intervene in the signals that pass between the brain and sense organs like eyes, ears, nose and skin. These devices will not only correct some sensory disabilities, they will also enable all humans to enter virtual environments without any other equipment than what is in our heads. The question that we ought to ask ourselves is how such inventions can be used in the delivery of our core services.

Materials Tech

Smart materials have already become commonplace in such areas as shape memory metal alloy (SMA) eyeglasses, piezoceramic copier devices, viscoelastic brake pads, and active polymeric implants. Self-repairing materials may be used to restore a structural component to its original shape, stiffness or orientation, the restoration being a function of the metallic memory selected and incorporated in the alloy during its formation. New materials are making today's bridges longer, stronger and lighter than ever before. They are decked out in slim box girders, lightweight concrete, high-performance steel, epoxy-coated cable strands, and composite prefabricated anchorages. Fiber-reinforced polymer (FRP) composites have led to a new generation of vehicular bridges using modular construction techniques. These bridges are pre-fabricated off site, which strengthens quality control. The modular bridge units may be transported over roads and installed in one eight-hour day.

Advances in high-performance concrete indicate that for many types of designs, most of the downtime for repairs of bridges, tunnel and pavement overlays could be virtually eliminated by using high-performance concrete that gains high compressive strength within an hour of placement. London's Millennium Dome, opened last year, features 90,000 square meters of glass-fiber fabric coated with polytetrafluoroethylene and stretched across a web of 2,600 stressed cables. New materials are stronger, faster-setting and far more durable and compliant.

At the cutting edge of the new materials is optical fibers that contain strings of sensors. Data from the sensors passes along the fibers to an opto-electronic data processing unit. These optical fibers are now being tested in

carbon fiber composites that can be used as building materials. The goal is for the sensors to detect stress or strain and relay it along the fibers to create a picture not only of the present stress being placed on the structure, but also of the cumulative lifetime stress the structure has experienced. It is easy to foresee the dramatic impact such innovations will have in the design and construction of skyscrapers, bridges, pipelines and tunnels.

Construction Tech

Construction considerations for infrastructure renewal include the development and dissemination of integrated sensor, measurement, simulation, and project information systems to increase construction productivity and quality. Automated steel erection methodologies promise to reduce construction time greatly, while steel connections with improved energy absorption capability will be a critical asset in structures built in seismic regions. The industry is using scanning, global positioning and trenchless technologies to locate underground cable without resorting to traditional excavation.

Communications technology represents one facet of a broader change in construction management strategies. Traditional approaches have emphasized a separation between owner, designer, project manager, and contractor. This piecemeal approach is shown as one of the reasons why productivity in the construction industry declined by 0.5% a year from 1964 to 1998, while other industrial productivity increased by 1.7% annually. This old model of construction is too disjointed and cumbersome in the face of the pressing problems that lie ahead, and it also represents a strategy that does not appeal to today's bright young people who have an entrepreneurial mindset and many other options for their career choices.

The present trend toward design-build is a start in the direction of simplifying management of large civil engineering construction projects. It brings together the owner, design team, contractor and project manager around a consensus vision for the project so they work together to build it. Used correctly, design-build can speed project completion and save money.

Biotech

While the medical improvements of the past century doubled the world's average life expectancy, the expected improvements in the 21st century, as a result of biotechnology, are expected to be far greater. New computing technologies are responsible for the most crucial break in the field of biotechnology.

The mapping of the human genome is giving us new insights, and genetic engineers are exploring ways to fix congenital defects and diseases. New hybrid mechanisms use silicon chips to activate biological processes such as neural networks. Artificial implants that the body will embrace and weave into its own structure are undergoing testing, and the engineering of living tissues will enable transplants to be grown in the lab from the recipient's own cells. Researchers have also achieved significant improvements in cell longevity, which they hope to extrapolate to entire organisms. All these advances will increase life expectancy. Demographic changes are so substantive that they can redefine economic and political systems in the developed countries over the next generation. An aging population will call for civil engineers to change their perspectives on how to design housing, transportation and public structures in the coming years. Biotechnology will also help to shape the materials we use to build them. The impact of biotechnology is also being felt in environmental engineering. Bio-remediation to clean up waste was unheard of 40 years ago. Today microbes clean up 80 percent of the world's oil spills. It is the cheapest and most effective approach. Biotechnology also has the potential to change the treatment of wastewater dramatically, and even raises the possibility of treating wastewater at the point of generation, significantly reducing the need for large-scale sewage infrastructures.

Green and Sustainable Tech

The development and acceptance of "green" technologies that conserve energy and utilize renewable or recycled resources will become commonplace, both in construction design and execution. We used to view development as something that of necessity happened at the expense of environmental preservation. As the population grows and our resources dwindle by comparison, we are coming to realize that any approach that is adverse to environmental preservation and resource conservation will be a dead end. Civil engineers must provide leadership in sustainable developments. Sustainability is more than simply slipping in a green material here or there. It mandates a different approach to design and problem solving. It is best to view sustainable technology as a large umbrella that covers

not only the work of civil and environmental engineers, but also of those in manufacturing and production, business management, science, public policy and architecture. The challenge is to use practices that are environmentally friendly while ensuring that business constraints are met with respect to cost and timeframe. Sustainable technology is also the key to forward-looking solutions for some of the pressing infrastructure problems of developing countries.

Modern Business Management

E-commerce has a huge impact on the way the business will be conducted. In the US, business-to-business Internet transactions are expected to reach nearly three trillion dollars by 2003, and this is a rich area of potential for increased productivity in civil engineering and construction. In a recent survey of industrial buyers more than a third said they had already begun purchasing over the Internet. Most of the remaining two-thirds are using the Internet to compare suppliers and find new sources, to learn about delivery options and track orders, and to get technical advice. Of the industrial buyers who have not yet begun to make Internet purchases, more than half expect to start within the next three years. Another e-commerce trend that will change civil engineering is electronic construction management companies that use the Internet to coordinate communications, share design updates, and even hold project meetings in chat rooms.

In general civil engineers do not receive adequate formal training in the area of business management which some believe is partly responsible for our slow adaptation of changes as well as relatively weak entrepreneurial skills and our inability to work effectively in multi-disciplinary projects. These problems are likely to be exacerbated in the future if we do not find effective strategies for identifying and implementing the current and upcoming technologies, such as B-To-B, that impact our field. Today's most agile industries and corporations have adopted techniques that utilize teaming, partnering, entrepreneurial skills and Internet communications. This approach unleashes the creative abilities of technology talent, and it has steered graduate students coming from industry toward studies of technology rather than the classical management track.

Jack Welch, the CEO of GE and one of the most respected business managers of the modern times, describes his success as "moving intellectual capital: taking ideas and moving them around faster and faster and faster." He further says that in today's world, the thriving company must go through three stages: (1) globalization of markets, (2) globalization of sources, and (3) globalization of the intellect of the company. GE can be used as a good model (traditional and engineering-based business) for demonstrating that faster prosperity and growth can be achieved by proper use of the new technology and opportunities that it creates.

CHALLENGES AHEAD

We need to change the perception and create growth, particularly in the previously untapped areas. We need to create break-throughs and that sometimes means breaking tradition. The civil engineering community must help to introduce and broadly commercialize a wide range of technological advances that will fundamentally change the way we do our jobs. It must begin to focus on how to better prepare the current workforce to understand and use emerging technologies, and it must develop curriculum that will prepare our future workforce. These emerging technologies will permit us to stay competitive and dramatically reduce adverse environmental consequences of human development. We must be prepared to recognize the challenges these emerging technologies will pose for curriculum and teacher development. We should be prepared to train technologists to deliver some of our traditional services so that we can be freed up to create new niches that truly require advanced knowledge.

To achieve our objectives expeditiously we need to hone our skills in business, become active users of technology and foster stronger working relationships with the technology developers to form synergies and create new areas of service (the GE model). Most importantly we need to strengthen our creativity skills and become innovators. Innovation is often used interchangeably with "new." However, innovation does not necessarily mean state-of-the-art or cutting-edge technologies *per se.* Innovation often means the process of employing new combinations of existing, demonstrated, and market-ready technologies, processes, and methods to improve the quality of the built environment. Innovation is doing something different-*breaking tradition*-because there is a greater perceived value. In the recent times, our profession (teaching, research and practice) has not actively encouraged innovation and as a result we have become conservative and accordingly lost some of the luster to attract the best and brightest who enjoy the excitement of innovation.

As educators we need to do our utmost to appeal to the young generation and attract the best minds to our profession. The challenges society faces and the remarkable changes occurring in technology lead to the conclusion that the civil engineer of the next generation must be educated differently than in the past. The question is not if we must adapt, but how far and how fast can we move. We must look not only at what should be offered in a formal engineering degree curriculum, but also at what enhancements should supplement this staple both during the collegiate experience and in the context of life-long learning.

The curriculum changes that we have all been actively pursuing over the past decade or so were primarily in response to the suggestions from the industry regarding their needs and desires. As a result we tried to improve our students' ability to communicate, function in teams, solve open-ended design problems, and conduct hands-on laboratory work. But even as we are still implementing the last decade's reforms, we can now see the need for civil engineers to learn about information technology, advanced materials, biotechnology, sustainable technology and entrepreneurial management techniques. The development of these ongoing learning opportunities does not solve the problem of how to make the formal four-year university curriculum more relevant. Achieving a curriculum that prepares our next generation of students for practice will require creative approaches and a willingness to set aside some of what was required in the past. Although the modification of the curriculum will require great effort, the end result can be a more exciting learning experience for both students and faculty, and one that will help attract the talent required to maintain the vitality and adaptability of our profession.

Finally, we need to consider the new trends in delivering education content. Educational material is increasingly being offered over the internet. Some major universities, including UC Berkeley, Stanford, Michigan, Georgia Tech and Columbia have linked up with major information and entertainment providers in the private sector such as Time Warner, Disney Corporation, Microsoft and Cisco. These partnerships will be attacking the global market in higher education. Universities provide most of the academic expertise and the "branding"; commercial partners provide the production, distribution and marketing facilities. Many major corporations are using the distance learning and on-line model of education for their own management and business training. Their objective is to develop a learning culture by providing job-relevant training within their companies. While it is inconceivable that the internet can totally replace the present role of universities, there is no doubt that it will have a major impact on our business. John Chambers, CEO of Cisco Systems, recently stated, "The next big killer application for the Internet is going to be education. Education over the Internet is going to be so big it is going to make e-mail look like rounding error." If this is true, then future educational opportunities for engineers will abound, and traditional universities will have to hustle to keep their market share in the face of competition from non-university sources or the universities who have better positioned themselves for this mode of education delivery.

I close this discussion paper by stating that in my opinion we are well poised to build a solid foundation for our future by using our leverage in the core areas to create growth and excitement. The rapid changes in the last decade have created untapped opportunities for us that we should exploit. We have to work harder and smarter but the potential rewards will definitely make it all worthwhile. We should be able to see tangible benefits within the next five years and see accelerated growth thereafter. I end by stating a well known motto "*The best way to predict the future is to create it"*. We need to tap into our creativity and find rational methods to implement them. The demands are no more than finding a viable solution to practical engineering projects that we deal with routinely. We need to identify the critical areas of work (and objectives), examine our resources, develop partnerships where resources are lacking, and setup a schedule for deliverables. I hope this workshop will help us to identify the problems and the resources that we have to work with. We need to work as a team to deliver the solutions.