SUSTAINABILITY OF PAVEMENT RESEARCH PROGRAMS THROUGH KNOWLEDGE MANAGEMENT, REALISTIC POLICY OBJECTIVES AND QUANTIFIABLE PERFORMANCE INDICATORS

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ABSTRACT

The University of Waterloo's Center for Pavement and Transportation Technology, CPATT, is committed to knowledge management as a cornerstone of it's long term strategic planning and sustainability. Knowledge is considered as an asset; it has value, and thus should be integral to asset management. In CPATT's approach, three basic types of knowledge are used:

- Explicit, which is essentially documented information
- Implicit, or "know how", and
- Tacit, which is related to human creativity or innovative capabilities.

A case example research initiative incorporates the following strategic elements:

- Identifying the activities of CPATT within explicit, implicit and tacit types of knowledge
- Considering knowledge management (KM) and succession planning as synonymous
- Establishing the rationale for KM, identifying the key components and establishing the cost-effectiveness
- Ongoing program of training and skills development
- Developing realistic policy objectives, measurable, key performance indicators, and implementation targets
- Establishing a comprehensive governance structure.

INTRODUCTION

The Center for Pavement and Transportation Technology (CPATT) at the University of Waterloo represents a partnership for innovation. Formed in 2002, and made possible by an unprecedented funding package from the Canada Foundation for Innovation, the Ontario Innovation Trust, the Ontario Research and Development Challenge Fund and various private and public sector partners, CPATT has focused on a state-of-the-art research infrastructure for tackling specific problems, developing new technologies, training and increasing the talent pool of skilled people, carrying out technology transfer and establishing sustained partnerships.

The research infrastructure includes new central and field laboratories as well as instrumented central and satellite field test sites. On the people side it includes faculty, staff and a cohort of graduate and undergraduate students. Financial and technical support from CPATT's partners has been a key ingredient of success for the initiative.

Another key ingredient to success for CPATT has been an explicit and ongoing commitment to strategic planning. Since the "business" of CPATT is essentially that of creating new knowledge and improving existing knowledge as well as knowledge transfer, a guiding requirement for sustainability is knowledge management. This includes the research program itself, succession planning for people, information and technology and the development of measurable, key performance indicators. It also includes the development of a governance structure for the Center and conduct of its research program.

The overall purpose of this paper is to address the foregoing considerations of knowledge management, within the broader context of asset management, to describe CPATT's approach to managing knowledge assets including the initial development of key performance indicators, and the implementation of a governance structure.

KNOWLEDGE AND ASSET MANAGEMENT

Knowledge can have different meaning, contexts, applications, degrees of sustainability and usefulness. Certainly knowledge can be a valuable asset, particularly in the context of asset management systems.

Asset management has focused almost exclusively on physical assets. However, knowledge and human resource assets are also vital to good asset management. Thus, knowledge management should be an integral component of asset management and in turn the principles of asset management are equally applicable.

The process of asset management in a comprehensive sense incorporates three distinct functional levels [1]:
- Strategic level where various social, political, economic and environmental factors are considered, stakeholder(s) input occurs, long range financial forecasts are carried out and desired or specified levels of service (LOS) and safety, or key performance indicators (KPI) for the system or network as a whole are defined as well as cost estimates to meet the LOS and safety or KPI targets. Current and future needs should be established and asset values should be determined.
- Network or system wide level where alternative programs are considered, performance estimates are made and life cycle cost analysis (LCCA) are used to determine an optimal program for given budget(s) or funding. As well, future asset values should be estimated.
- Project level where LCCA and other relevant factors are used to identify and implement the most economically effective alternative for a project/link/site specific area.

All three levels must fit within the agency's business scope and/or plan to be acceptable, useful, practical and understandable. For example, the City of Edmonton articulated a "Corporate Business Plan" (June 26, 2001, available on their website) and their infrastructure strategy fits within that plan [2].

The interrelationships of these three levels are schematically illustrated in the Figure 1 framework. It is generic in the sense of being applicable to any component system (e.g., bridge management, pavement management, etc.). To effect a proper tie-in or integration between the component systems requires an integration platform, as discussed in more detail in Ref. [3]. This platform would include, as a minimum, a location reference, and if possible asset values, levels of service provided and risk exposure.

Knowledge is explicitly or implicitly embedded in each item or activity at all three levels. For example, the strategic level first identifies "Classes/Types of Assets, Location, Amount or Extent", and these can of course be physical assets, but they can also be in the form of documents representing an accumulation of knowledge in the organization. As another example, again at the strategic level, "Current Asset Values" can be assigned to both physical assets and knowledge assets. Still another example is "Investment Needs", which certainly can be assigned to knowledge assets. In essence, the Fig. 1 framework should be applicable in it's entirety to knowledge management.

TYPES OF KNOWLEDGE AND ORGANIZATIONAL APPROACHES

There are three basic types of knowledge, explicit, implicit and tacit [3]. All three types can be viewed as an organizational and personal resource. Accordingly, it is highly important in today's knowledge-based economy to have a well utilized knowledge management system in place that preserves existing knowledge and promotes the creation of new knowledge. This involves three basic objectives: "leveraging the organization's knowledge; creating new knowledge or promoting innovation; and increasing collaboration and hence enhancing the skill level of employees" [4].

Explicit knowledge is generally defined as documented information. This form of knowledge is stored within information management systems and should be widely accessible. Explicit knowledge is articulated through written language and lends itself to the idea of viewing knowledge as a product.

Implicit knowledge can also be termed 'know how' It is a form of knowledge that can be expressed and articulated. As well, it can be transferred through both documentation and verbal communication.

Tacit knowledge is the most difficult form of knowledge to capture as it is created while humans interact with both those around them and their environment. The majority of tacit knowledge is contained within the human subconscious making it extremely difficult to articulate and transfer.

Explicit knowledge is the most commonly considered aspect of knowledge management. The main difficulties arise from its sheer magnitude and the daunting task of keeping it up to date. A common mistake made when managing explicit knowledge is to treat it as an object rather than an activity [5]. Storage locations for explicit knowledge include computer networks (Internet and intranet), files, libraries, etc.

Implicit knowledge falls between explicit knowledge and tacit knowledge in its level of value. Similar to tacit knowledge, it is embedded in the minds of individuals. However, unlike tacit knowledge, implicit knowledge can be made explicit through verbalization [6]. There are many different approaches to managing this form of knowledge including mentoring programs, communities of practice, and network based user help services.

Arguably, the most valuable, but also most difficult to maintain aspect of knowledge management is tacit knowledge. It is embedded in individuals experience and sense of judgement and includes "insight, hunches, intuition and skills that are highly personal and hard to formalize" [7].

A common misconception in organizational approaches is that knowledge management will build organizational culture. On the contrary, organizational culture needs to exist before hand to obtain success. If a knowledge management system does not prevent reinvention of the wheel by leveraging knowledge assets already in existence it is not doing its job [4].

Attempting to place only a dollar value on knowledge capital is another common mistake. This is due in part to the fact that an organization does not own its human capital like it does with other assets [8].

Another major pitfall is an inadequate strategy for recruiting and retaining individuals. A National Cooperative Highway Research Program Report [9], based on a survey of 24 states and 3 provinces, provides some valuable information and insight. Unfortunately, issues of salary, training programs, incentives, work environment and lack of exit questionnaires are still all too prevalent in the transportation industry [10].
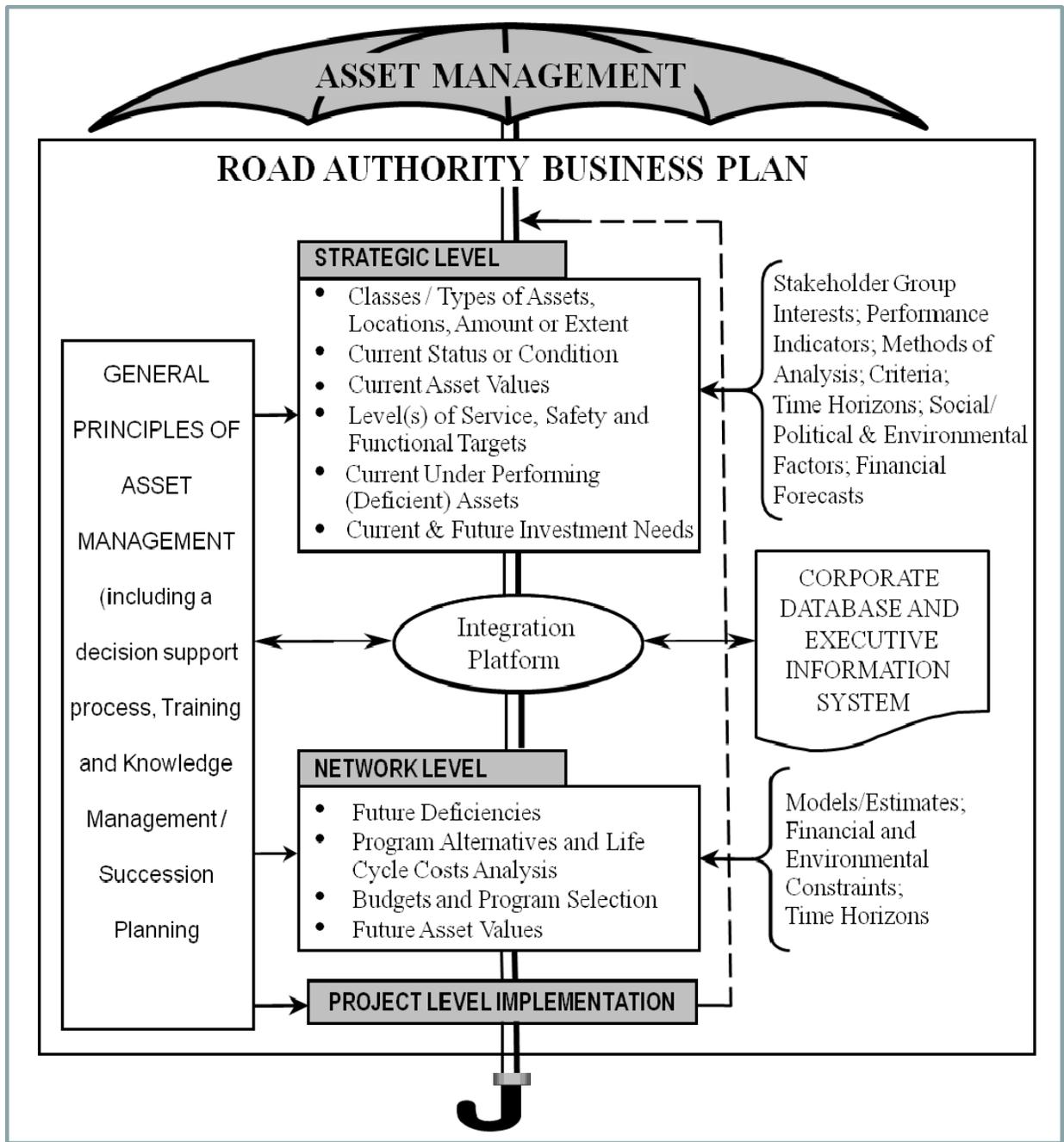
Figure 1 Overall framework for asset management, including knowledge assets

A research organization's long term viability and success is particularly dependent on how well it's strategic planning addresses the management of is its knowledge assets, how well founded are the strategic elements of the plan and how well designed is its governance structure. The following case illustration comes from the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo. While the "business" involved is research and training, the approach used and component activities/elements have generic relevance to private and public sector non-research organizations.

CPATT's approach to knowledge management lies within an umbrella concept for the interrelationships between program areas and the people involved (see Figure 2). The foundation consists of a number of strategic elements, as shown in the lower part of Figure 2.

The umbrella concept incorporates a group of established leaders, emerging researchers, students and staff who work as a team. There is a complementary linked program of activities, priorities and resource allocation in major thrust areas of: (a) materials and geotechnical engineering, (b) structural design, construction and maintenance technologies, (c) field evaluation methods, equipment, instrumentation and data processing, (d) risk and reliability, (e) computational methods and modelling and (f) ITS and safety.

In fact, succession planning and knowledge management were considered as an absolutely essential component of CPATT's planning for long term success and sustainability. As an example, the founding principals of the initiative were two senior, well established researchers and one new, assistant professor. Over the next four years, the originally planned succession strategy was executed. It is notable that one of the primary reasons such an unprecedented amount of funding was provided to the CPATT initiative was the identified commitment to knowledge management through the inclusion of both senior and the junior researchers in the overall plan

STRATEGIC ELEMENTS

The strategic elements shown at the bottom of Figure 2 represent not only the foundation for managing knowledge assets but also the operational realities for successful conduct of a research program. These elements are further described in the following case example.

CPATT's Activities re Knowledge Types

The activities and components of CPATT which are directly related to the three basic types of knowledge include the following:

- Explicit knowledge: documented research results, publications and technology developments, information and data generated, public and professionally associated access to briefings (eg., web site)
- Implicit Knowledge: skills and expertise resident in CPATT's researchers and staff, with the capability of being transferred to others and/or documented
- Tacit Knowledge: creative/innovative capabilities resident in CPATT's researchers and staff

Knowledge Management vis a vis Succession Planning

It has been argued that a key part of knowledge management should be proper succession planning, and in fact the following definition is applicable to or synonymous with both [11]:

"A process for ensuring the orderly planning for renewal, upgrading and continuity of an organization's resources including people, technology and information/data"

Commitment to Mentoring

There is a concerted effort within CPATT to encourage mentoring, both formal and informal. This includes active faculty involvement in the supervision of undergraduate and graduate theses, hiring of intern or co-operative education students, and various initiatives in the promotion of civil engineering. In addition, there is a genuine effort from the senior, more experienced researchers to assist newer researchers in the preparation of proposals and supervision of research. In turn, the younger researchers and students provide assistance with regard to computer packages, assimilation of new technologies, etc. Senior researchers also are actively involved in the outreach of the research.

Essentially, the mentoring within the CPATT organization works at all levels and is cross generational. A cornerstone to the success is a concerted effort to improve communication and to actively engage all members of CPATT to work as a team and provide mentorship as required.

Training and Skills Development

One of the most critical elements of ensuring sustainability in CPATT's approach to knowledge management is a program of training and skills development. The latter is accomplished through normal course work, and hands-on tasks in the laboratories and field sites.

For example, the central research lab has state-of-the-art test equipment for materials characterization input required by the new AASHTO Mechanistic Empirical Pavement Design Guide. As well, the unique test track and other field sites enable students to see pavement field testing equipment and learn many hands-on skills about pavement design and management practices. Overall, this enables students and research staff to become trained in the use of the most advanced equipment available.

Key Aspects of Knowledge Management/ Succession Planning

There is a good rationale for having a system or program for knowledge management/succession planning, including the following: a) cost-effectiveness, (b) organizational cohesiveness, (c) marketplace awareness, (d) preservation of investment, and (e) good business practice.

Several key components are involved in knowledge management/succession planning, including the following: (a) recognizing the need, (b) top level commitment, (c) strategic plan for activities, information resources requirements and allocation of responsibilities, (d) making the necessary investments and keeping the plan dynamic by periodic updating and periodic assessment of its effectiveness, and (e) documenting ongoing activities, accomplishments and the lessons learned.

There can also be obstacles, including the following: (a) high turnover of staff, (b) "we can buy people, technologies and information" philosophy, (c) lack of commitment and lack of training programs, (d) lack of documentation (technology, methods, equipment, procedures, etc.), and (e) lack of balance between outsourced work and "knowledgeable client".

The issue in Economics of Knowledge Management/Succession Planning is really return on investment. There is a direct investment cost associated with explicit knowledge, compared to a less easily quantifiable but quite important investment cost associated with people who have or are being trained for implicit knowledge and tacit knowledge. Returns on the investment can include the development of new
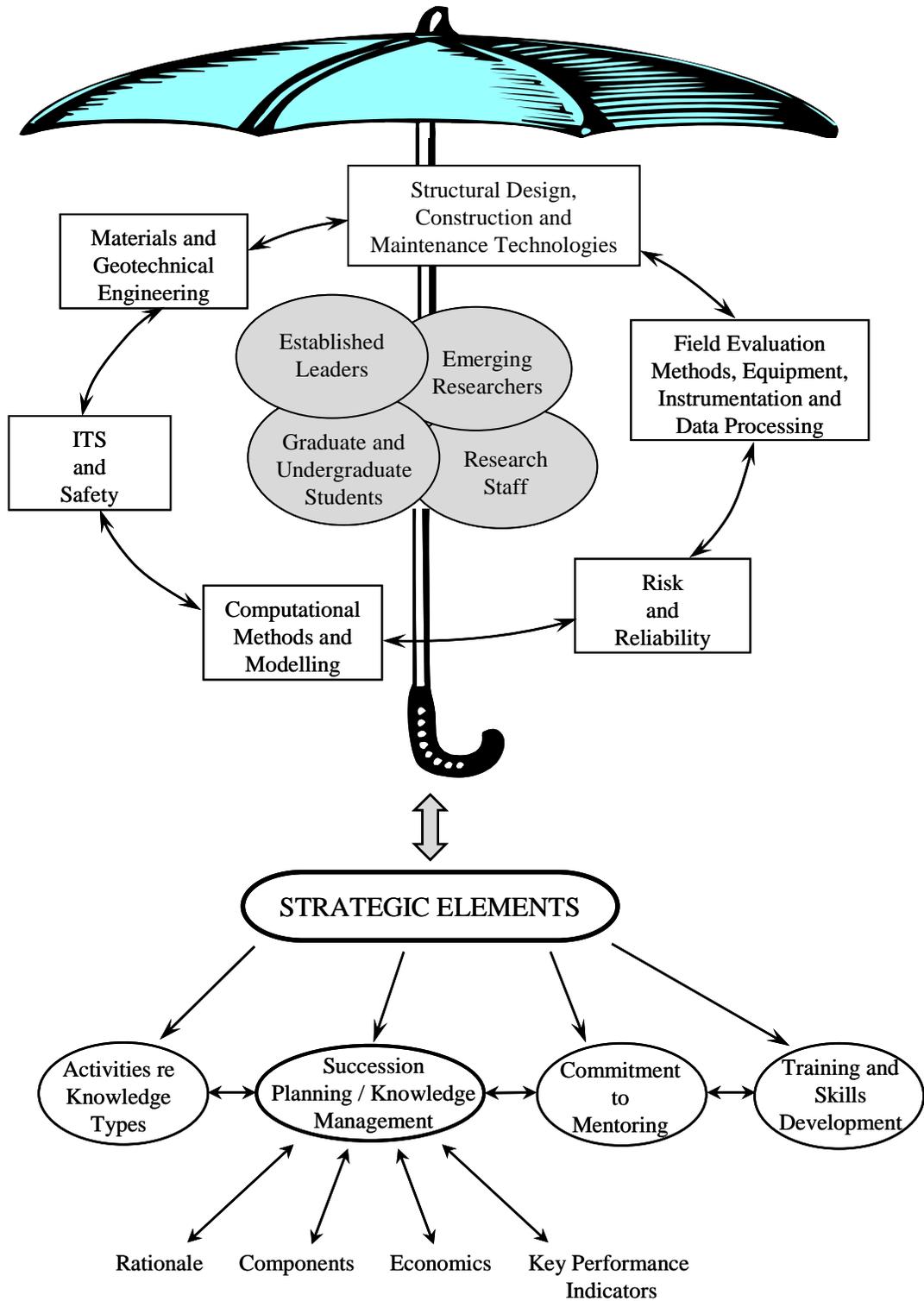
Structural Design, Construction and Maintenance Technologies

Materials and Geotechnical Engineering

Field Evaluation Methods, Equipment, Instrumentation and Data Processing

Established Leaders

Emerging Researchers

ITS and Safety

Graduate and Undergraduate Students

Research Staff

Risk and Reliability

Computational Methods and Modelling

STRATEGIC ELEMENTS

Activities re Knowledge Types

Succession Planning / Knowledge Management

Commitment to Mentoring

Training and Skills Development

Rationale   Components   Economics   Key Performance Indicators

Figure 2 Umbrella Concept for People and Program and Area Interrelationships and the Underlying Strategic Elements for Knowledge Management

and/or better technologies, better more efficient ways of doing things and new ideas for advancing the state-of-practice or technology. As well, cost savings can be viewed as a return on investment.

The development of measurable key performance indicators for knowledge management/succession planning is still in the formative stages for CPATT and similar organizations. However, there is guidance available from the establishment of such indicators for pavements and other road assets [11]. This guidance suggests that key performance indicators, KPI's, should be: a) objectively based, consistent and measurable, b) tied to policy objectives and implementation targets, and c) an integral part of asset management. An example set of policy objectives, KPI's and implementation targets applicable to a research organization such as CPATT, are provided in Table 1. These are very preliminary but the intent is that if knowledge is an asset, then the establishment of related KPI's is warranted in the same way as for other assets.

POLICY OBJECTIVES, KEY PERFORMANCE INDICATORS AND IMPLEMENTATION TARGETS

Key performance indicators should be tied to realistic policy objectives, which in turn should be derived from the organization's vision statement [12]. Regarding the latter, CPATT's vision has been articulated as follows (see www.cpatt.ca):

- Focus on emerging and innovative technologies
- State-of-the-art research infrastructure for tackling specific problems and developing new technologies
- Training students and practitioners and increasing the talent pool of highly qualified personnel (HQP)
- Sustainability in research capabilities, programs and partnerships

Essential to realizing this vision are strong and ongoing commitments to knowledge management and succession planning as related to people as well as continuity in technology and information.

The eight policy objectives in Table 1 are meant as examples, with modifications undoubtedly necessary for adapting to any particular research organization. Nevertheless, any research organization should have some clearly defined set of such objectives, they should have related measurable performance indicators and they should have quantifiable implementation targets if at all possible. It is the latter targets which are perhaps most contentious, but if they do not exist or are treated casually, it can also be argued that the organization is not living up to its mandate or responsibilities.

All eight of the policy objectives in Table 1 may be considered essential not only to sustainability of the research organizations programs but also to its long term survival. The first six of the objectives listed should be self evident requirements, but the latter two may not be common. Regarding sustained partnerships, at least in the case of CPATT, these have been keys to the organization's success and are also considered essential to long term sustainability. The last policy objective, governance structure, is considered important to operational effectiveness, to the sustained partnerships noted, and as an element of the organizations strategic plan. Further elaboration is provided in the next section.

Table 1 Some Example Policy Objectives, Key Performance Indicators and Possible Implementation
Targets Applicable to a Research Organization's Management of Knowledge Assets

Policy Objectives	Key Performance Indicators	Implementation Targets

1. Research productivity, impacts and quality	• Research products
	  a) No. of patents
	  b) No. of major res reports
	  c) No. of journal publications
	  d) No. of conference publications
	  e) No. of invited addresses
	  f) Other (e.g., major awards)
		a) If applicable, at least 1/yr
		b) At least 1/yr/researcher
		c) At least 1/yr/researcher
		d) At least 2/yr/researcher
		
		e) At least 1/yr/researcher
		f) At least 1 major award/yr

2. Preservation of research infrastructure investment (facilities, equipment, etc.)	• Asset value ($)	• Increase (written down replacement cost) annually of 2% or greater
3. Cost recovery	• Revenues ($)	• Annual increase at no less than rate of inflation
4. Organizational productivity and efficiency	• Annual staff turnover (%)	• 5% or less annually through commitment to training, work environment and advancement opportunities

5. Return on investment	• Internal rate- of- return (%)
	  a) Implementation of research products into practice
	  b) Return on internal and external training
	  c) Seminars, workshops, etc.
		a) Greater than 10%
		
		b) Greater than 5%
		
		c) Greater than 5%

6. Provision of education, training and outreach	• Graduate students • Undergraduate interns • Seminars, workshops, etc. • Liason with other res. Organizations and researchers	• At leaset 1 graduated per year per full time faculty • At least 1 term intern per year per full time faculty • At least 1 for each 3 full time faculty per year • A functioning network nationally and internationally
7. Sustained partnerships	• Private and public sector partners	• At least 5 per $1M research funding
8. Governance Structure	• Roles and responsibilities	• Clear defined reporting structure and responsibilities for directors, senior staff, etc.

GOVERNANCE

The concept of governance is widely accepted in the business world. In the academic area, there are policies and procedures which, de facto, represent a governance structure. However, for research centers or institutes, at least in Canada, it is difficult if not impossible to find any kind of comprehensive structure in which the center should function. In the case of CPATT, it was felt that this should be an important and explicit part of its strategic plan.

Accordingly, a set of roles and responsibilities for key players in CPATT (see the Organizational Structure, Figure 3) was developed. It has now been in existence for 3 years of CPATT's mandate (e.g., as approved by the University's Senate), and has proven to be viable and successful.

Basic Approach and Model

The basic approach is to recognize that CPATT is a research unit as opposed to an academic unit, that the roles and responsibilities for the key "officers" of CPATT should be clearly outlined but not be bureaucratic, that communication, coordination and transparency in research and business related activities is essential, that the people involved in CPATT have a responsibility for quality work, ethics and integrity to their sponsors and to the University.

The basic model is that of the operational side of a University Department. In CPATT's case the key "officers" are, respectively, the Director, Associate Director(s) and Research Administrative Officer. As well, CPATT has a Board of Directors and it is appropriate that their role and responsibilities be a key part of the Center's governance structure.
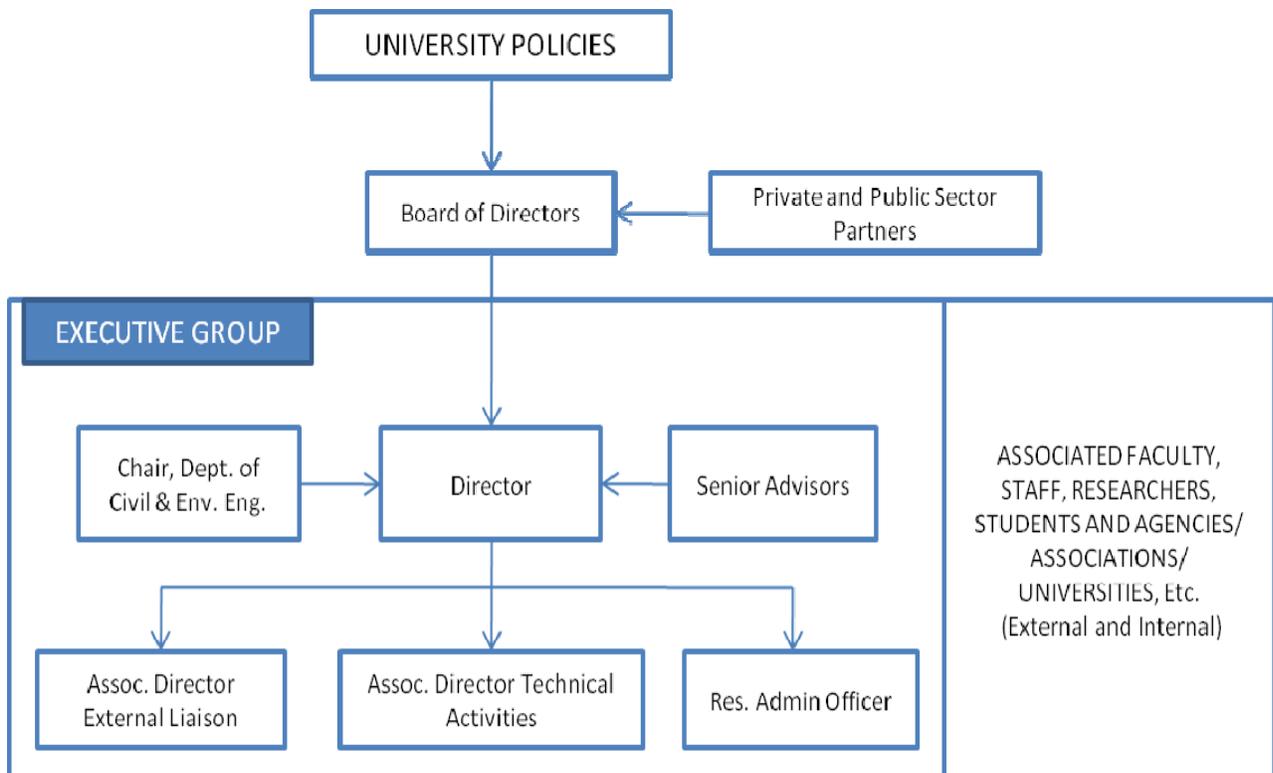

Figure 3 CPATT's Organizational Structure

Board of Directors

The existence of a Board of Directors for CPATT is both a valuable and necessary part of the initiative. It is a unique role, however, in that the "environment" is a University rather than the usual corporate environment. In that sense, CPATT must conform to University policies for fiscal management, reporting, human resource guidelines and various other procedures. Nevertheless, the Board does have a key role and responsibilities, including but not restricted to the following:

- The overall role of the Board is to ensure good stewardship for CPATT in terms of how business is conducted, that ethical standards are maintained and that the interests of CPATT's partners are recognized and protected.
- The Board advises on and generally oversees the strategic direction of CPATT, in conjunction with the University's Strategic Plan and direction.
- The Board concerns itself with the integrity and conduct of the Director and Associate Directors of CPATT in terms of their designated roles and responsibilities.
- The Board ensures that CPATT develops and periodically updates a strategic planning process in terms of short and long term goals, and the planning and timelines for achieving these goals

Director

The Director is generally responsible for CPATT's strategic direction, ensuring good governance and CPATT's financial viability, representing CPATT at the University level, ensuring that CPATT's research program and business activities maintain objectivity, non partisanship and overall credibility in the field and promoting an atmosphere of good communications, collegiality and interpersonal relations within CPATT. More specifically, the Director's responsibilities include but are not restricted to the following:

- Representing CPATT on various internal and external bodies, or designating other individual(s) to do so as appropriate.
- Signing authority for all CPATT accounts, or delegating responsibility, as appropriate.
- Budgets preparation and subsequent monitoring re expenditures and investments
- Staff supervision, or delegating such responsibility as appropriate
- Reviewing financial statements provided by the Office of Research
- Signing off on CPATT research proposals (must also be approved by the Department Chair)
- Ex officio membership on CPATT's Board of Directors
- Preparing CPATT reports for the Board, CPATT publicity (brochures, electronic based information, including a web site, etc.) and the like, and/or designating various individuals to share in these activities
- Liaison with the Department Chair, Dean and other University officials as necessary re space, resources, staff, etc.
- Ensuring that CPATT activities are carried out with adherence to University policies

Since the Director is a faculty member, normal academic procedure applies in terms of where the Centre is "resident"; eg., in this case, the Department of Civil and Environmental Engineering and the Director's immediate reporting for academic matters would be to the Department Chair. Since a centre is approved for a 5-year term, each renewal, including Directorship, must be approved by Senate. Any change in Directorship in intervening years must be approved by the Department Chair, Dean and Vice-President Academic and should also be approved by the Board of Directors. As well, removal or termination of the Director for cause shall be subject to approval by these three office holders.

Associate Director for Technical Activities

The Associate Director is directly responsible for technical programs and research projects, space and laboratory resources, staff, test sites, etc. as identified by the Director. More specifically, the Associate Director's responsibilities include but are not restricted to the following:

- Ensuring that those programs and projects within his/her direct responsibility are carried out to achieve optimum quality and "return on investment" (eg., for the sponsors and students or research staff) as well as adherence to University policies.
- Being an equal partner with the Director and other CPATT members in creating an atmosphere of good communications, collegiality and interpersonal relations.
- Assuming responsibility for those accounts, representations, reporting, etc. as designated by the Director
- Being Acting Director, in the absence of and as designated by the Director.
- Ensuring that any proposals or other initiatives from CPATT, which are initiated by the Associate Director, receive "sign off" by the Director before proceeding to other internal or external levels.

Associate Director for External Liaison

This position was created for the initial 5 – year term of CPATT. It is intended that the Associate Director will have strong links both within the University and externally in the public and private sector as well as with funding agencies. The responsibility is rather flexible but essentially directed to identifying sources of potential funding, working with the CPATT Director, Associate Director for Technical Activities and CPATT researchers to access and develop proposals for these sources, promoting and or showcasing CPATT accomplishments, advising on short and long term research strategies and generally providing a senior mentoring role to CPATT members, particularly those in early stages of their career.

Research Administrative Officer

The Research Administrative Officer is directly responsible for all research administration activities of the Centre for Pavement and Transportation Technology (CPATT). The scope of the position encompasses three main functions: the incumbent manages the research administration of the Centre, supervises the administrative requirements of research staff (including technical staff, visitors, post-doctoral fellows, graduate and undergraduate students) involved with the various projects, and acts as a liaison with granting agencies, industry, Office of Research, Finance, and the Department. The Research Administrative Officer reports to the Director(s) of the Centre.

The Research Administrative Officer is responsible for financial administration and personnel management for all research grants and contracts of the CPATT group. This requires a strong financial background and excellent computer skills including proficiency with the latest word-processing and spreadsheet software. The position also requires knowledge of federal and provincial funding sources and related guidelines. Capabilities of using FORE (Financial Online Reporting Environment) are an additional requirement. The Research Administrative Officer must possess excellent interpersonal, organizational, communication, problem-solving and supervisory skills.

CONCLUSION

A Canadian research initiative, involving the Centre for Pavement and Transportation Technology (CPATT) has adopted a comprehensive knowledge management strategy as a cornerstone of it's long term sustainability. It is based on realistic policy objectives linked to measurable performance indicators.

A well developed governance structure is also a cornerstone of its long term strategic planning and sustainability.

ACKNOWLEDGEMENT

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