Application of Expert Systems to Transportation: A Strategy for Safety and Productivity Gains

R. T. LEWIS AND W. F. JOHNSON

The purpose of this paper is to outline what Transport Canada has done and intends to do to achieve applications of expert systems in support of its own and broader sectoral objectives. Expert systems represent one of the first areas of commercial development of new computer hardware and software derived from artificial intelligence research programs. The case for innovation in transportation and the objectives and role of Transport Canada in innovation are briefly reviewed. Within this context, the department's understanding of expert systems technologies and their relationship to the transport sector in general and the department in particular is discussed. Areas of application for expert systems are outlined; criteria for development of expert systems research and development (R&D) programs are discussed; and Transport Canada's expert system R&D strategy and current R&D activities are described. The department's current and medium-term R&D activities in this field are outlined. There are two aspects to this work: first, to stimulate awareness of and seek agreement on applications of expert systems to transportation and, second, to develop limited applications in a number of selected areas and, in so doing, both realize benefits from the applications and lay the base for further work in this field. These first applications require a limited number of rules, are amenable to application with the existing base of skills, and are based on available technology.

In the future, the evolution of transportation systems in Canada will correspond closely to market demands on both the freight and the passenger service sectors. As these demands change, the system will have to cope with needs to expand traditional services or provide new ones and phase out uneconomic service at an acceptable social cost. The economic problems of meeting such challenges are compounded by Canada's geography and climate and by continuing uncertainty about the future direction of the economy. Aggregate forecasts, for example, of a 3.5 percent annual growth in demand for rail freight services, mask the uncertainty of the markets for Canada's raw material exports. Economic deregulation will pose challenges to carriers as they adapt to new competitive forces. Compounding these is the need to replace or rebuild equipment and infrastructure as these approach the end of their economic and technological lives.

In developing an approach to these diverse challenges, two common themes, increased productivity and improved safety, have been defined. The productivity theme reflects the fact that, almost uniformly across all modes, transportation operating and maintenance (O&M) costs are rising. This both reduces the funds available for new capital investment and, through its impact on rates or fares, limits the competitiveness of Canadian exporters and fuels domestic inflation. Solutions to the productivity issue must recognize that capital markets are tight and will continue to be tight for the next 20 years and that the ability of the transport sector to finance large investments will be constrained by competition for funds from other sectors. In some measure, investment in new technologies can be expected to reduce the investment that could otherwise be required in conventional technology. However, O&M costs must also be reduced through investment in innovation. Strategies must be put in place to provide job enrichment opportunities for the transport labor force and to overcome readjustment problems as new technologies are introduced.

The safety theme reflects the fact that a new product or system developed to increase productivity must also meet regulatory requirements for safety or, where possible, enhance safety. In this context, safety is defined as protection of individuals and physical assets and prevention of damage to the environment. Justification for levels of effort and objectives in support of productivity increases will also have a complementary safety thrust.

The development of artificial intelligence, which began some 30 years ago, represents an evolution distinct in nature and power from previous generations of computer development. It is the object of multibillion dollar research programs, for example, Japan's Fifth Generation Computer program, the British Alvey program, the European Strategic Program for Research and Development in Information Technology (ESPRIT), and elements of the U.S. Defense Advanced Research Projects Agency (DARPA) program. The resulting development of expert systems or knowledge-based systems provides an immediate tool to resolve some of the pressing needs for productivity and safety enhancement in the transport sector.

The Research and Development Directorate of Transport Canada has recognized the potential of expert systems and is engaged in a long-term strategy to establish the full scope of their potential and to identify and develop specific applications with short-term benefits. The progress that has been made to date is described here. However, the context within which Transport Canada's R&D strategies are evolved is complex and directly affects the form of the strategy. This context is briefly described in the next section.

Tower C, Place de Ville, Ottawa, Ontario K1A 0N5, Canada.

ROLES IN AND RESPONSIBILITIES FOR INNOVATION

The National Transportation Act of 1967 and the federal government's new "Freedom to Move" policy proposals emphasize that, with some exceptions, market forces will be sufficiently strong to meet the transportation expectations of Canadian users. Government roles include safety and economic regulation, provision of subsidies to pay for uneconomic but socially necessary services, and provision of major segments of infrastructure for ports, airports, roads, and urban transportation.

The federal government also acts as a facilitator to bring together the many members of the transport sector whose concerted action is required to meet the challenges of innovation.

There are a number of federal mechanisms that can be used to stimulate Canadian innovation generally. These include tax incentives, directed R&D support programs administered by federal departments, and the programs of the National Research Council and the Natural Sciences and Engineering Research Council.

Transport Canada views transportation innovation activities in the context of

- Research for policy development: This includes socioeconomic and technical assessments to support policy decision making and as required for policy implementation. Examples include research on alternative fuels and tax incentives for innovation.
- Regulatory innovation: This pertains to the assessment of socioeconomic and technical needs of regulation. Examples include studies to determine the technological specifications required for framing dangerous goods regulations, fuel conservation standards, and regulations to govern operations in arctic marine environments.
- Innovation in transport services operated by the federal government: The products are improved systems, equipment, and operating methods for federally provided services. Examples include the development of equipment for the Canadian Airspace Systems Plan, icebreaker design and propulsion technologies, and marine radars and other navigation aids.
- Support for transport sector innovation: This covers innovation for enhanced transportation safety, efficiency, and productivity. Examples are federal-industry R&D programs for aerospace and rail freight. Other goals of this work reflect energy needs, industrial and regional development needs, and technologies for transport of the handicapped.

This definition of the purposes of innovation provides a yardstick for establishing institutional roles and responsibilities that can be and are related to the program mandates of federal departments and agencies and to their strategic and operational objectives. Definition of these, in turn, permits establishment of specific innovation strategies, operational R&D plans, and R&D programs. This is a complex process but one that becomes relatively easy to implement when agreement has been reached on what needs to be done.

The R&D efforts of transportation carriers vary by mode. In dollar terms, the Canadian railways are the largest performers with their efforts apparently concentrated on short- and medium-term R&D programs. The Canadian marine industry also mounts significant research programs. Highway transportation carriers and the airlines, although they seek to upgrade their performance through innovation, usually do so through acquisition of foreign technology. All modes are now exploring opportunities to meet requirements for improvements to management systems.

The Canadian equipment manufacturing industry is strongest in aerospace equipment, in urban transit technology, and in serving Canadian railways and marine carriers. There is strength also in some areas of the automobile parts manufacturing industry and in manufacturing buses. In these areas of strength, the benefits obtainable through early dialogue between carriers and manufacturers on future needs is beginning to be recognized, although much remains to be done. Both the department's proposed investments in aeronautics equipment and systems and the railways' proposed investment in advanced train control systems offer potentially large markets for Canadian equipment manufacturers.

Academic involvement in meeting the transportation sector's needs for innovation is presently largely restricted to socioeconomic research and systems analysis. This pattern is changing with, for example, the development of new working relationships with Memorial University related to the Marine Group's Arctic and East Coast Marine R&D programs. In addition, both the federal government and the railways have worked closely with the Canadian Institute for Guided Ground Transportation at Queens University. The department is also currently working with the Natural Sciences and Engineering Research Council to sensitize Canadian universities to the transport sector's need for innovation.

The interdependent roles of government, the private sector, and universities in Canadian transportation affairs as well as resource scarcity have dictated a collective and mutually supportive approach to innovation. This is not to say that a government department or a carrier does not fund R&D independently in support of its own objectives. It does mean that a conscious effort to identify collective R&D objectives and priorities is made, and advantage is taken of opportunities for joint or complementary R&D programs. A variety of formal and informal linkages exists. These include formal mechanisms for interdepartmental cooperation on transportation R&D at the federal level; modal R&D advisory boards and committees that provide for discussion of transportation R&D among all levels of government, the private sector, and universities; and international agreements, for example, the Canadian-U.S. Volpe-Jamieson agreement.

EXPERT SYSTEMS APPLICATION STRATEGY

The previous sections have provided a description of the context within which the department plans and programs R&D and of the department's roles in innovation. In cooperation with other members of the sector, the department continuously and systematically assesses the contribution that innovation can or should make to realizing objectives for increased safety and productivity. The public announcements by Japan, the United States, and members of the European Economic Community of new artificial intelligence programs triggered the development in Transport Canada of its current expert systems strategy.

Broadly speaking, the regulation, operation, and maintenance of modern transportation systems break down into a hierarchy of interdependent but nonetheless discrete functions. Equipment and systems controls are built on a modular basis. Modern hardware and software permit each module to be controlled by its own microprocessor with human intervention required on an exceptional rather than a continuous basis. This permits greater equipment and system productivity and safety; it also permits greater human productivity. This latter impact has been perceived as a threat. On the contrary, it creates time for operators to enrich their working experience. It does mean, however, that for the foreseeable future strategies for the introduction of advanced computer-based technologies must recognize

- The attainment of specific objectives for increased safety and productivity and
- The psychological impediments to introduction of the powerful new technologies and, the other side of the coin, the need to define strategies to enrich the jobs of the users of these technologies.

In this context, and as noted in the introduction, expert systems are one of the first commercially applicable derivatives of some 30 years of research in artificial intelligence (AI). Other emerging product areas include natural language software, computer-aided learning, and voice recognition. There are many aspects to AI research; however, it may be characterized as

- The part of computer science concerned with designing intelligent computer systems (i.e., systems that exhibit characteristics that humans consider intelligent);
- A branch of computer science the objective of which is to endow a machine with reasoning and perceptual capabilities; and
- The area of computer science that deals with problems that are incomplete in nature or that have indefinite solutions.

These definitions of AI reflect the academic nature of the work and mark the tremendous interest, matched by commitment of enormous sums of money, that has arisen in the field. The Japanese plan to develop a fifth-generation computing system with an architecture heavily dependent on a variety of technologies embodying concepts usually termed AI. For both military and civilian purposes the United States and countries in Western Europe have mounted similar projects.

Aside from the long-term military and civilian objectives that are being pursued under these programs, two applications of AI are now in the marketplace. The first is marked by the development and introduction of robots and computer-aided design/computer-aided manufacturing (CAD/CAM) that have revolutionized manufacturing processes, notably in the automobile industry. The second derives from advances in knowledge representation and expert systems that are reflected in the variety of medical and other diagnostic systems that has recently entered the marketplace.

An expert system (ES) is a computer program that uses knowledge and inference procedures to solve problems that are so complex as to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners in the field.

There are three categories of clients for an expert system:

- Clients who require answers to problems. These are the operators who will require answers in time frames dictated by the nature of the problem. They may range from a dispatcher who is controlling a demand-responsive system, to a scheduler, a maintenance mechanic, a maintenance manager, or a planner. Response time may vary from a requirement for a real-time solution to hours for complex problems.
- Clients who are attempting to improve the quality of the system, to increase its knowledge, or to refine and hone their own expertise. A variant of this would be to use the system as a research assistant.
- Clients who are students taking advantage of the system to upgrade their knowledge and skills.

In summary, an expert system may be used as a decision aid, to transfer knowledge or expertise, to improve the efficiency of an expert's use of time, to improve the quality of an expert, or as a training tool.

The definition of objectives, priorities, and strategy for application of expert systems to transportation reflects in part the concepts of user need for innovative response that are applied on a multimodal and modal basis by Transport Canada's R&D managers. However, at an early stage, two other factors were recognized that have influenced Transport Canada's approach. The first, a scarcity of expertise and resources, requires a centralized focus for work until such time as expert systems capability has been built up in all modes. The second reflects the principal characteristics of expert system technology: it is a humanizing rather than a deskilling technology. Strategies for initial applications of expert systems must be oriented toward enhancing human capability and skills.

In recognition of these factors and of the pragmatic need to build awareness and acceptance of the technology through successfully attaining limited objectives, the department has begun to evolve its expert systems R&D strategy in the context of applications in the following areas:

- Vehicle crews,
- Vehicle maintenance,
- External control of vehicles in transit,
- Permanent way control and operation,
- Terminal facility control and operation,,
- Operational planning and regulation, and
- Strategic planning.

Within each of these areas, and in the two functional areas of administration and regulation that parallel each of these areas, there are classes of jobs, each of which requires its own expertise and each of which should or would benefit from an "expert" assistant.

Preliminary assessments have been made of applications of ES and of some of the further work required to achieve these applications. For example, in the area of on-board systems for vehicle crews, the principal functions of the on-board crew are command and control. These require two main supporting functions, navigation and communications. Secondary functions include engineering (diagnosis and repair of vehicle systems) and cargo monitoring and service. Except in military applications, it appears unlikely that ES will replace humans in these functions in the foreseeable future. Even if it were technically feasible, it would likely be psychologically and sociologically unacceptable. Expert systems will therefore be used to perform trouble-shooting and advisory roles in the on-board environment—roles for which they are particularly well suited.

This suggests that any on-board expert system to be used by the primary operator (captain) of a vehicle in transit will require the successful solution of two problems over and above the technical details of the specific application. These are suitable input-output mechanisms to enable the system and its user to communicate with each other and suitable input-output mechanisms by means of which the system can sense and directly control its environment. The human interface typically considers input and output separately and requires

• A simple mechanism by means of which the operator can consult and direct the expert system without being distracted from the principal task of controlling the vehicle. A computer keyboard is clearly unacceptable, although a limited set of specific function keys may be marginally acceptable, especially in vehicles that require the operator to qualify via a full-time course of instruction. If the input mechanism requires some form of graphics (e.g., icon manipulation, a schematic overlay, or a map), some form of pointing mechanism will almost certainly be required. Current candidates range from digitizing tablets and light pens through touch screens to track-balls and mice. Touch screens and track-balls are probably the only present-day devices that could possibly be integrated into a vehicle operator's control environment.

One of the most promising approaches for textual and command input at present is voice input. Systems such as the Votan VPC 2000 already offer continuous speech recognition of a trained repertoire of command words at approximately $3,500 Canadian. Speech is the most effective vehicle for communication, and humans can readily adapt both vocabulary and speech patterns to match the comprehension level of their audience. Satisfactory interface with an expert system can almost certainly be implemented using a carefully tailored natural language subset.

• A simple mechanism by means of which the expert system can communicate with the operator. This involves a number of issues because some output will be textual, some will be nontextual (e.g., graphic, tabular, numeric), and some may be direct connection to other on-board systems. In a military environment the Head-Up Display (HUD) has proved to be the most effective, albeit costly, solution. The HUD projects a mixture of text and graphics on the inside of the prime viewport, allowing the operator to focus on it or look through it. The technology is currently too expensive to be practical in any but the most sophisticated of vehicles.

An alternative approach is to provide a small display screen, which must be integrated into the control panel in such fashion that the operator is not distracted from the principal control operations when assimilating output from the expert system. Voice synthesis is useful only if the information output is essentially textual in nature; this is an area that requires substantial research, especially the synthesis of textual representations of nontextual data.

The development of mechanisms for direct sensing and control of other vehicle systems, be they electronic, electrical, mechanical, or any combination thereof, has until recently remained the province of engineers and has been largely ignored by the computing community. The problem of real-time sensing and control has been the province of military and process control applications, but the manufacturing sector is now also starting to develop the necessary technology. Typical examples from the automotive industry are electronic fuel-injection systems; engine diagnostic systems; antiskid braking systems; and seat-belt, door, and light status monitoring and warning systems. However, there is considerable research and development yet to be done to investigate how best to interface computer systems to vehicle systems for both monitoring (input to the computer system) and control (output from the computer system).

These two problem areas reveal that fundamental research is required. The human interface problem, usually referred to as the man-machine interface (MMI), requires research that must be directed by psychologists. This will almost certainly come out of the university environment. The machine interface problem requires development of both sensors and real-time computer interconnection mechanisms. This is most likely to be driven by the manufacturing sector of industry, with major focus provided by the military and aerospace sectors.

Possible application areas for on-board expert systems include

- Vehicle control,
- Vehicle system diagnostics and trouble-shooting,
- Navigation,
- Communications,
- Cargo monitoring and service,
- Emergency advice and reaction,
- Specialized on-board applications, and
- Procedural and regulatory advice.

The thrust of all of these systems will be to provide the crew with early warning of problems and advice on how to resolve them. The most difficult application area will undoubtedly be the implementation of on-board systems to cope with emergency situations. Primitive systems exist, for example, fuel-low and brake-failure warning devices in automobiles. More complex systems are in the early stages of development, such as those that would give an airline pilot, for example, a diagnosis of the highest priority problem and outline proposed action. Voice output from the expert system will almost certainly be required, as will research in behavioral psychology both to establish human performance under stress and to devise the most appropriate communication mechanisms. A tricky conceptual problem relates to the correctness of the expert system response in comparison with what the operator "knows" is best. Emergencies by definition invalidate rules. Nevertheless, the expert system can provide an invaluable contribution to problem diagnosis and alert the operator to the required procedure or take action in the event of operator incapacity.

The application of on-board expert systems to the provision of procedural or regulatory advice, or both, will be an early target area. Such systems could, for example, provide advice on procedures at border crossings—tariffs, vehicle configuration, and so on. When married to central office dispatching, scheduling, and routing systems, expert systems will provide an immediate boost to productivity, notably for trucking operators and urban logistic and paratransit fleets. Canadian work in the field will build on work pioneered by the Ontario government, for example, the Computerized Goods Transportation Information System.

Systems for on- and off-board vehicle maintenance have similar characteristics in that they are required to both diagnose the problem and identify remedial action. Both on- and off-board systems require an embedded system capability and a capacity to interface either automatically or on demand of the user.

The off-board systems in particular will require presentation of diagrams, many of which will be extremely detailed. This implies a capacity for high-resolution graphic display and gigabyte (109) storage capacity. The General Electric Diesel Electric Locomotive Troubleshooting Adviser (DELTA) uses an optical disk attached to a dedicated microcomputer system with high-resolution color graphic display. Preliminary areas selected on the basis of their different knowledge base requirements include major structure (hull) maintenance, engine and power train maintenance; control, guidance, and communication system maintenance; auxiliary equipment maintenance, and procedural and regulatory advice.

Systems for external control of vehicles in transit can be divided into two categories: remote control of autonomous or semiautonomous vehicles and control, mainly procedural, via communications links of crewed vehicles. Application areas include vehicle routing and scheduling, traffic control, emergency procedures, weather forecasting, and procedural and regulatory advice. Applications of current computer technology are already widespread in these areas; there is a good understanding of the rules and a good data base that should permit fairly fast introduction of expert systems in this field.

The paratransit vehicle dispatch system being demonstrated now in Vancouver provides an example of the benefits of application in this field. Paul Tuan at Stanford Research Institute (SRI) has pioneered a novel expert system approach to solving this problem by developing a powerful scheduler's workstation that is initially installed in an inexpert form (with background knowledge of the geography and vehicle fleet characteristics) and is capable of learning from the user by observation and analysis. As part of its design, the system has a range of optimization algorithms embedded within its basic mechanism. After some 6 months, the workstation will have gained sufficient expertise that it can handle 80 percent or more of the scheduling situations on its own, at which point it can be networked with a human scheduler. Human schedulers are required to handle unusual situations, which the expert system detects and hands on. The advantage of this approach is that the peculiarities and idiosyncrasies of any system can be accommodated and that, when the system has reached an acceptable level of competence, it can be replicated for the price of duplicating the knowledge base.

Because scheduling is such a skilled job, and because it is much more an art than a hard science, it is an excellent candidate for expert system applications.

Application to permanent way control and operation is foreseen in the following categories: scheduling and capacity planning, communications and control, facility diagnosis and maintenance, weather forecasting, usage accounting, emergency procedures, and procedural and regulatory advice. Systems for operational planning and regulation would include traffic forecasting, financial planning and control, vehicle design planning and configuration, transitway planning and configuration, terminal facility design planning and configuration, communication and navigation system design planning and configuration, emergency procedure planning, and statistical regulatory advice. Applications in these latter areas will be based on the transportation simulation modeling techniques and capability already in existence. The track-train dynamics simulation models developed in Canada provide one example. Another is the Bay Area Rapid Transit model developed at SRI by Bjorn Conrad and Tony D'Esopo. This latter model has proven to be capable of supporting both operational decision making and system planning and development. These are algorithmic solutions from which an ES could evolve.

All of these applications have been designed to improve the performance of experts in the exercise of their daily functions. Because of the psychological risks, as well as the need for further refinement of technology, effective applications in the on-board vehicle category will be most difficult to achieve; conversely these are the areas in which public concern for transportation safety requires immediate action. Immediate action means an immediate start. Immediate results mean the development and implementation of an initial family of "toy" but nonetheless worthwhile applications in the next 2 or 3 years. In the concluding sections of the paper will be discussed how Transport Canada intends both to learn by doing and to systematically build up awareness and competence to reach the potential of the applications discussed here.

APPLICATION TO TRANSPORTATION

The results of preliminary assessments of the relevance of the application of ES to transportation were outlined in the previous section. In this section a methodology for evaluating the suitability of an application is discussed. The principal factors that are recognized in Transport Canada's current strategy are awareness, utility, feasibility, and cost.

Awareness

Media coverage of major research initiatives in the AI field has resulted in both a general understanding of the power and capabilities of advanced computer technologies and a more visceral, potentially luddite, concern about their introduction. Clearly both relate to broader public concerns about transportation safety, job security, and the future of Canada's economy and society. Although not precluding research in any area, this means that Transport Canada's selection of fields for application of ES will focus on enhancement of an individual's skills. Another aspect of this is the need to build an understanding within the transport community of the power of these technologies, of the constraints to their application, of the resources that are required, and of the commitments that must be made to achieve application.

Utility

This requires assessment of the marketability of a given application (that is, a user's readiness to adopt ES) and its impact in traditional cost-benefit terms and in terms of the social or cultural impacts of a particular ES.

Feasibility

Some potential applications are more amenable to implementation than others on purely technical grounds. Areas in which ES applications currently enjoy success include medical diagnosis, computer system configuration, resource exploration, and intelligent computer-aided design. These expert systems tend to operate in relatively static fields, in a relatively "safe" environment, with limited or no external control hierarchies, and with relatively long decision-making time frames. To be applicable to transportation, hardware must be "ruggedized." Other advances are also required. Advances in hybrid knowledge representation, distributed artificial intelligence, fault tolerant computing, on-line real-time and embedded AI systems, and knowledge acquisition will be required to permit expert systems to achieve optimum impacts in transportation.

Cost

The relative cheapness and power of modern computers permit the immediate application of expert systems. Depending on the area of application, ES can be built on a variety of computers. These include the PC/AT that costs less than $5,000 Canadian and ranges to some of the specialized hardware developed by Symbolics, Texas Instruments, Xerox, and others costing from $15,000 to $150,000 (U.S.) up to VAXen mainframes and supercomputers costing millions. The smallest practical system will probably involve some 200 to 500 rules, require at least 6 months to develop, and involve 30 min of expert time and 8 hr of knowledge engineering time per rule. It was believed, until recently, that the lack of availability of skilled knowledge engineers might prove an insurmountable barrier to rapid application of the technology (opening knowledge engineers' salaries are on the order of $70,000 U.S.). There is some evidence, however, that the skills of current computer professionals can be upgraded to a degree that will allow the problem to be tackled. Nonetheless, the demand on the Canadian ES industry already overloads its ability to produce and will constrain what can be achieved in the next 5 to 10 years. Of equal relevance is the ability of the client to assess the technology and fully use it. ES strategy must provide for in-house training and development in parallel with building of initial ES applications.

TRANSPORT CANADA'S EXPERT SYSTEMS STRATEGY

Four factors affect how the department has evolved its ES strategy since it first moved into the field some 2 years ago:

- During the past 10 years there has been an evolution in transportation management and planning processes toward systems analysis and integration. As the technical limits of existing vehicles, ways, and terminals were approached, a search was carried out to find means to improve scheduling, communication, control, and maintenance technologies and procedures. This led to the widespread introduction in transport of computer technologies, to recognition of the rules governing efficient and effective transport operations, and to a better understanding of the expertise involved.

- It was readily apparent that this evolution in transportation management and planning philosophy and practice was amenable to application of expert systems. Indeed, adoption in air and railway modes of advanced computers for scheduling and control; built-in sophisticated microprocessors in automobiles, aircraft, and locomotives; and the technologies and concepts involved in the Canadian National Railroad's hump yard improvement program reflect the state of the art of application of third- and fourth-generation computers. They permit assessment of both the benefits and the costs of applying the next step, expert systems.
- There has been an evolution of ES directly applied to or applicable to transportation. These include DELTA and SPILLS. The latter is a generic name for a set of prototype expert systems designed to assist in the location, assessment, and cleanup of hazardous spills and to train personnel who must deal with such matters.
- A specific problem, one representative of many transportation problems, is the need both to make use of the volume of data and information being generated by research, in this case, by the Vehicle Weights and Dimensions program (a multimodal federal–provincial–private sector R&D activity designed to establish technical specifications for trucking in Canada), and to capture the expertise of highway experts in Canada.

It is fair to state that although these four factors collectively motivated the department's first steps in the field, the internal coalescence was reinforced by growing interest throughout the federal government in AI and, of course, by representatives from the private sector and the academic community.

The following factors shaped the department's ES strategy:

- Applications need to be focused on improving individuals' skills.
- Development of applications of ES is proceeding apace around the world. Regardless of any Canadian efforts in this field, the international nature of virtually all transport operations, equipment, and systems requires Transport Canada to understand what is going on and to develop an ability to amend its own operations and regulations accordingly. "Who has legal liability for failure of a smart car?"
- There is acceptance at the technical level of the benefits of ES application, but, in order to convince senior management, some benefits from R&D in the field have to be demonstrated within the first 12 to 18 months of an ES strategy.
- Development of a capability to fully use ES will take 6 months to 5 years for the delivery of a "finished" AI application. Although an individual expert will be trained as the system is built, there are compelling reasons to start small and learn by doing.
- There is a good base of PC/AT expertise in the department and more broadly within the transport community on which the first limited applications of ES can be built.
- In practice, transportation R&D planning and management are done on a consultative and cooperative basis by all levels of government and the private sector. This reflects both joint or complementary interests in the results of R&D and the

scarcity of resources. In addition to developing in-house capability in ES, it is also necessary to carry out a parallel effort to build awareness and, where possible, engage in joint or complementary ES R&D with this broader community.

STRATEGY

The department strategic expert system goal is, by 1990, to achieve a capability to use ES applications effectively in support of the department's program objectives and to stimulate applications of ES more broadly throughout the transport community.

This strategy is to be implemented by

- Further development and refinement of existing analyses of the applicability of ES to transportation and, where appropriate, conduct of R&D projects to fill in gaps in understanding;
- Development of papers and conduct of workshops to create awareness of ES applicability to transportation and as a device to both generate critical assessments of the department's activity and identify opportunities for joint work in the field;
- Development of limited ES applications (200 to 500 rules) in each modal area of transportation and of complementary training and educational activities to promote effective use of these applications; and
- Development of the capability and expertise to develop or contract for the development of more complex expert systems of up to 5,000 rules after 1990.

It should be noted that although this is a Transport Canada strategy, directed primarily at the Canadian transport community, elements of this program are clearly international in scope. Its conceptualization and at least one major project reflect cooperation with SRI in Palo Alto, California. As Canadian-U.S. cooperation on aeronautics R&D increases, joint ES projects with the United States may be developed. The same will be true for ES applications in all modes.

The department is now well embarked on a 2-year program that represents the first phase of the strategy. Activities and their results to date follow.

- Awareness: A 1-day workshop on applications of ES to transportation was held in Montreal in September 1985. The proceedings of this workshop are available and may be obtained by contacting Transport Canada, Tower C, Place de Ville, Ottawa, Ontario K1A 0N5, Canada. Those who attended included government, private-sector, and university members of the transport community and representatives of the Canadian AI community.
- Heavy vehicle configurations: A contract has been let to develop a feasibility study of the applicability of ES to the management of vehicle weights and dimensions data and information. This contract also provides for development of a prototype ES (200 rules).
- Northern airspace system management: A contract has been let to develop an ES for this purpose. In addition, further work is under way to investigate the applicability of ES to assisting air traffic controllers.
- MV Caribou: A contract has been let to determine the feasibility of an ES fuel-monitoring system on this ferry. In addition, further work is under way to assess the feasibility and utility of developing other ESs to provide expert advisor capability for the navigation of this vessel.
- Demand-responsive transportation: As discussed earlier in this paper, an ES has been developed to assist in the scheduling of demand-responsive transport services. It is on display at Expo '86.
- Transportation of dangerous goods: An algorithmic model is being developed to cut down the response time and improve the quality of responses to requests for information telephoned in to Transport Canada's emergency center. This again can be evolved into an expert system.

The resources committed by the department to this work in FY 1985–1986 amounted to some $175,000 and involved commitment, at varying levels of effort, of some 10 professionals. In 1986–1987, the department expects to spend some $500,000 in this area, mostly for contracts with the private sector.

SUMMARY

The challenges that face transportation over the next decades and the innovation activities that are being carried out by the department and other members of the transport community to address these challenges have been discussed.

R&D programs to address these challenges are established in the context of the degree to which innovation (new equipment, new systems, new procedures) can make a contribution to transportation objectives. Transport systems are both "technologically intensive" and "people dependent"; these characteristics heighten the attraction of a technology, expert systems, that can materially increase the skills and capability of the work force.

The department's strategic objective is thus to stimulate application of, and apply, expert systems as aids to increasing on-the-job safety and productivity. As in any new technology, advances will be required. Components will have to be made more rugged, and technical developments will be required before optimum advantage can be realized. Nonetheless, the promise of this family of technologies, and the success of even the preliminary applications, has resulted in a departmental commitment to "get started" and to "learn by doing."

Applications of expert systems are foreseen on board vehicles and in maintenance, external-to-the-vehicle and way-control systems, terminal operations and planning, and regulation. Eventually, applications are expected in virtually every aspect of a transportation operation.

The department's current and medium-term R&D activities in this field have been outlined. There are two aspects to this work: First, to stimulate awareness of and seek agreement on applications of expert systems to transportation. Second, to develop limited applications in a number of selected areas and, in so doing, both realize benefits from the applications and lay the base for further work in this field. These first applications require a limited number of rules, are amenable to application from the existing base of skills, and are based on available technology.

The department's objectives for work in this area beyond 1990 will in large measure depend on the lessons learned from this relatively low-cost venture. The impact of these technologies on human resources, and the dynamism of expert systems technology, precludes establishment of medium- (past 1990) and longer-term objectives in this field. Experience gained during the next 5 years is absolutely necessary before such objectives can be specified meaningfully.

As in other fields of transportation R&D, the department is developing its plans and implementing R&D projects in cooperation with other members of the Canadian transport community. The department's operational and regulatory roles are inextricably linked to other members of the transport community through technology. Scarcity of resources, particularly in this field, also makes cooperation, as reflected in a number of the expert systems projects, absolutely mandatory.

The results of a workshop on the topic, attended by representatives of governments, the private sector, and universities, confirmed the department's assessment of the need to mount a concerted effort to achieve productivity gains and increased safety through application of expert systems.