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THE DEVELOPMENT AND IMPLEMENTATION OF FOREST FIRE MANAGEMENT DECISION SUPPORT SYSTEMS IN ONTARIO, CANADA: PERSONAL REFLECTIONS ON PAST PRACTICES AND EMERGING CHALLENGES

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Abstract. Forest fire managers in the province of Ontario, Canada have used computer-based decision support systems (DSSs) and actively supported their development since the late 1970's. I describe four DSS projects in which I was involved and discuss factors that I believe contributed to the success and failure of those initiatives. I then outline some emerging fire management challenges and present some recommendations concerning the development and implementation of forest and wildland fire management DSSs.

Keywords: Multi-objective optimization, integer programming, public good provisions, auctions

1 Introduction

Fire supports many natural forest ecosystem processes but it also poses significant threats to people, property and forest resources. The detrimental impact of fire has featured prominently in the media in recent years largely due to destructive wildland-urban interface (WUI) incidents in parts of North America, Europe and Australia as well as other regions. Climate change is expected to exacerbate fire problems and complicate the lives of fire mangers who are regularly called upon to resolve increasingly complex decision-making problems. It is therefore not surprising that Operational Researchers, Information Technology Specialists and Decision Support System specialists have developed and continue to be asked to develop forest and wildland fire management decision support systems. In this paper I describe some of the fire management DSS projects in which I have been involved and reflect on the extent to which they were successful. I then discuss some emerging needs and challenges and how those in the OR/MS/DSS communities might address them.

My focus is primarily on fire management in the boreal forest region of the province of Ontario, Canada (Fig. 1) in which there are many small widely scattered communities inhabited by residents engaged in industrial forestry, mining and tourism activities and small isolated First Nations communities. Fires are ignited by both people and by lightning and a small fraction (typically less than 3%) of the roughly1,500 fires that are reported each year escape initial attack and a small number of those become large "project fires", some of which can exceed 100,000 ha or more in size.

I have focussed on Ontario not because it is unique but because 1) it is in many respects, representative of the type of forest fire management that takes place across much of the actively managed portion of the boreal forest region of Canada and 2) it is the area in which my students and I have carried out most of our research. There has of course been an extensive amount of DSS-related research and development carried in the United States, Russia, Australia and parts of Europe. Although I learned at conferences and through the scientific literature what my colleagues in those areas have done and achieved (see, for example, Martell (1982), Martell et al. (1998), Martell et al. (1999) and Martell (2007)), I restrict my comments and observations to some of the projects with which I have been involved.

2 What is a DSS?

My use of the term Decision Support System (DSS) is consistent with that of Keen and Scott Morton (1978) for whom decision support implied "the use of computers to:

1. Assist managers in their decision processes in semi-structured tasks.

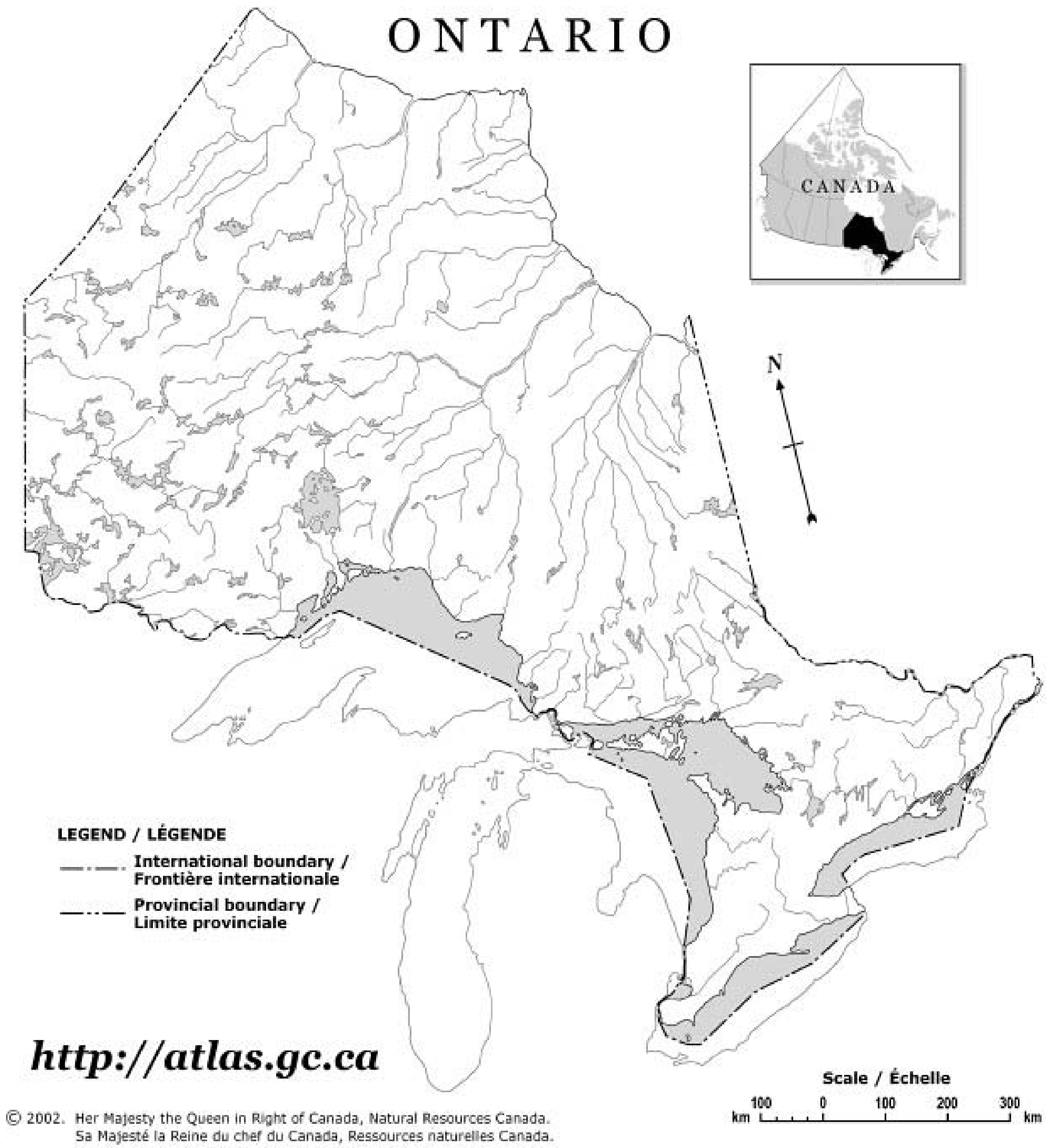

Figure 1: The province of Ontario in central Canada.
Source: http://atlas.nrcan.gc.ca/site/english/maps/reference/outlineprov_terr/ont_outline/referencemap_image_view
Accessed June 15, 2010

2. Support, rather than replace managerial judgment.

3. Improve the effectiveness of decision-making rather than its efficiency.”

My primary interest has been and remains, the use of Operational Research and Management Science (OR/MS) methods to develop forest fire management decision support systems. In this paper I focus on computer-based DSSs that include mathematical models that can be used to predict and sometimes evaluate the consequences of implementing alternative courses of action. I do not cover, for example, traditional computer-based management information systems (e.g. fire danger rating or inventory management systems) or computer-based models that predict fire activity (e.g. fire occurrence and fire spread models) but focus rather, on computer-based optimization and simulation models that fire managers can use to help resolve their strategic, tactical and operational decision-making problems.

2.1 Forest Fire Management in the Province of Ontario The Aviation, Forest Fire and Emergency Services (AFFES) Branch of the Ontario Ministry of Natural Resources (OMNR) is the provincial government agency that is responsible for forest fire management on public forest land in the Fire Region which comprises about 80% of the approximately 1 million km^2 province of Ontario. Organized forest fire management began in Ontario with the 1878 passage of the Fire Act but it did not begin in earnest until the early 1900’s when a number of tragic incidents associated with large fires resulted in the loss of many lives and precipitated increased efforts to minimize the impact of fire on people, property and timber.

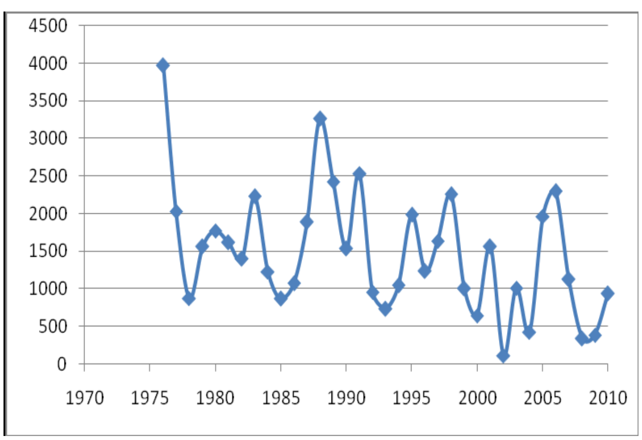

Figure 2: Number of fires per year in the province of Ontario (source of data: Ontario Ministry of Natural Resources)

The number of fires and area burned vary significantly from year to year as depicted in the figures 2 and 3. Roughly 40 % of the fires are caused by lightning and 60 % by people but lightning-caused fires produce 75 % of the area burned.

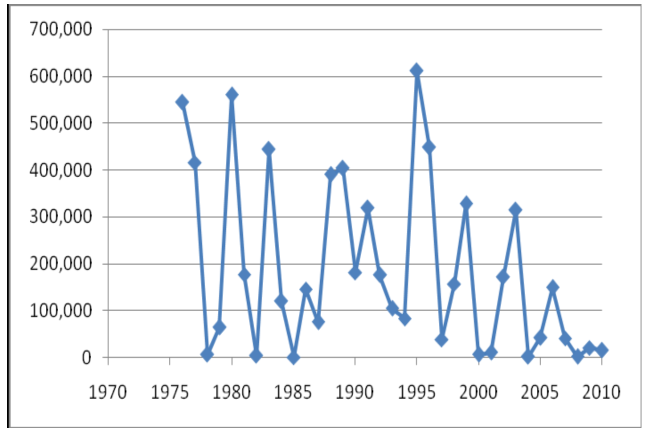

Figure 3: Annual area burned by forest fires in the province of Ontario. (source of data: Ontario Ministry of Natural Resources)

Ontario’s forest fire management policy has, as have those of most North American forest and wildland fire agencies, evolved from administering an essentially fire exclusion policy under which fire was viewed as a destructive force that was to be eliminated from the forest at almost any cost, to delivering a more progressive program that is based on explicit recognition that fire is natural and that it is neither ecologically sound or economically feasible to suppress all fires. The AFFES’s activities are guided by a fire strategy that designates the extent to which different values (e.g. public safety or the ecological benefits of fire) should influence how specific fires are managed. For a description of the strategy see Ontario Ministry of Natural Resources (2004).

During each day of the fire season (which usually begins on or near April 1 and ends on or near October 31), fire managers across Ontario engage in the following suppression-related activities:

1. They predict when and where fires are likely to occur,

2. Decide when and where to route detection patrol aircraft to find fires while they are small,

3. Deploy airtankers, fire fighters, and transport aircraft close to areas where fires are likely to occur to minimize response times,

4. Dispatch initial attack forces to contain fires while they are small, and

5. Deploy incident management teams and other resources to manage escaped fires that pose threats.

Computer-based DSSs and management information systems are used extensively to support such activities.

3 Past Successes and Failures

There have been many attempts to develop and implement forest fire management decision support systems, some of which are documented in the traditional peer-reviewed literature and some of which are described on public web sites. It's reasonable to assume however, that many fire management organizations have developed and/or contracted out the development of DSSs that have not been publicly documented. I will focus on projects in which I have been directly involved on the assumption that I am well positioned to assess, albeit subjectively, the extent to which they were successful.

One of the first DSS projects in which I participated was the development and implementation of the Ontario Initial Attack Model (IAM). I was one of a group of four that was asked to develop a model that the OMNR could use to help evaluate its airtanker needs. It was a simulation model that was used to evaluate how the OMNR's initial attack system would perform with different mixes of airtankers, fire fighters and transport helicopters. The OMNR used the results of our analysis to support its request to the Management Board of Cabinet of the government of Ontario to acquire nine CL-215 airtankers to enhance their initial attack system. The development and implementation of our model is described in Martell et al. (1984). The OMNR later enhanced it to create the LEOPARDS Level of Protection DSS that the OMNR has since been used to support its planning and policy development (see, for example, McAlpine and Hirsch, 1999).

Many factors contribute to the success and/or failure of DSS projects but I think three that contributed to the success of that project were:

1. Senior managers asked us to help them resolve what they considered to be a very important decision-making problem.

2. We met with one of the senior managers on a regular basis to keep him abreast of our progress and most importantly, to obtain his feedback concerning which features of the system he deemed to be most important and merited special attention as we developed and tested our model.

3. Our collective expertise spanned both operational research and forest fire management and we were led by an analyst (G.E. Doan, an OMNR employee) who had studied operational research, had field experience and had experience in preparing proposals for the Management Board of Cabinet.

A graduate student and I developed a mathematical programming model that the OMNR used to help decide where to home base their airtankers, which is described in MacLellan and Martell (1996). They had an airtanker fleet that included nine CL-215 airtankers and five much smaller multi-purpose Twin Otter aircrafts that were used for firefighting when required. Some OMNR staff were concerned that the airtankers were not properly allocated to home bases for the fire season – that some bases had more than they needed while others experienced shortages. The OMNR did not implement the "model solution" but gained insight from our collaboration as we developed and ran the model. I attribute our success to the fact that:

1. We were asked to solve what senior OMNR fire mangers considered to be an important problem.

2. We worked closely with a working group of OMNR staff who were responsible for airtanker management while we formulated, tested and ran our model.

3. We both had OR and initial attack fire fighting expertise.

A third success, which arose somewhat serendipitously after the research had been conducted, ultimately had more impact on forest management of which fire management is but a component. Reed and Errico (1986) published a seminal paper in which they formulated an aspatial timber harvest scheduling model that accounted for fire losses by assuming some constant fraction of the forest burns each year. One of my graduate students, R.G. Davis, who studied the Reed and Errico model, developed a silvicultural decision support system as part of his M.Sc.F. thesis research (see Davis and Martell 1993). He was subsequently hired to play a leadership role in developing the OMNR's Strategic Forest Management Model (SFMM), which has since been used extensively for forest management planning in the province of Ontario. The inclusion of fire in SFMM makes it possible for the OMNR to do what most other Canadian forest management organizations do not – to explicitly incorporate potential but uncertain fire losses in their strategic planning. The success in this case was not mine – I played no role in the development and implementation of SFMM. My role was simply to supervise a graduate student who the OMNR subsequently hired, which in the Canadian research community would be described as a contribution to the training of Highly Qualified Personnel (HQP).

DSS initiatives are not always successful and one of my failures resulted from an attempt to develop and implement a queueing model that the OMNR could use to help resolve their daily airtanker deployment problems. Jim Bookbinder and I published (Bookbinder and Martell 1979) a paper in which we described how a time-dependent queueing model could be coupled with a dynamic programming model to specify optimal deployment strategies for helicopters that transport fire fighters to initial attack fires. Ours was a curiosity driven project that we undertook in part, to illustrate how such models might be used, but we made no attempt to implement our model. Later, an OMNR staff person and I drew on the Bookbinder and Martell (1979) model and developed an airtanker deployment model that could be used to evaluate alternative daily airtanker deployment strategies. An OMNR software specialist developed the software required to run our model and it was run in test mode in the Northwest fire region of Ontario for one fire season. The regional field staff ran the model each day and perused the results but were not asked nor, to my knowledge, did they use them to help resolve their daily deployment decisions. At the end of the fire season they were polite but firm – they characterized the model as being "interesting" but pointed out that it did not account for a very important aspect of airtanker operations in their region – airtanker bases do not operate independently, and they were not at all interested in using the model unless it could account for such behaviour. My failure to appreciate that a complex model that did not account for what managers considered to be an essential feature of their system made it impossible for us to implement our model.

4 Common Factors That Contribute To Success and Failure

The projects described above illustrate several common themes that arise when the topic of implementing OR and DSS technology arise (see, for example, the many columns that Gene Woolsey has published in the journal INTERFACES, some of which have been reprinted in Woolsey and Hewitt (2003)) and one (the need to develop HQP) that is not often addressed in the literature. Success appears to be more likely when:

1. Analysts address what senior managers consider to be important problems.

2. They work closely with the senior managers and technical specialists they designate to work on the project.

3. The analysts have both fire management experience and DSS expertise.

I have also indentified and consider another important contributing factor to be:

1. The training of HQP who ultimately join the organizations with which one is working, to support what has been developed and to contribute to new DSS initiatives within the organization.

5 Some Observations

During the course of developing, testing and assisting with the implementation of forest fire management DSSs in Ontario, I have come to learn and appreciate a number of things that were not at all obvious to me when I first began to work in this area.

5.1 Importance of field trips and participant observation Researchers are accustomed to embarking upon field trips to gather data and, in the case of those that develop DSSs, to speak with decision-makers to further their understanding of the decision-making problems on which they are studying. I believe that both researchers and their clients can benefit from researchers spending time involved in what social scientists describe as participant observation activities. Participant observation calls for researchers to spend extended periods of time in a manager's natural environment so they can further their understanding of how the systems they have been asked to study really function. In my experience, the best way to develop an understanding of how a fire management system really operates is to sit quietly in the corner of a response centre and/or the command post of a large fire incident and watch and listen to what transpires. As things quiet down, one can approach individuals and ask them to explain why they did what they did and what factors influenced their decision-making. I also find that eventually many managers will approach and ask me to explain what I am doing and what I am looking for. The ensuing conversations almost always result in important two-way communication. I learned important lessons and while doing so I was sometimes able to bring useful research results to the attention of the managers involved. One of the most important long-term benefits of participant observation however, is that it cultivates future research initiatives. Managers that have observed and interacted with researchers in the field are much quicker to respond to subsequent requests for information and data. More importantly, some will bring important real problems to the attention of researchers and thereby provide them with a wealth of new challenging problems they can investigate with the knowledge that they will be exceptionally well supported by the managers and their staff.

5.2 A Need for both Basic and Applied Research Research can be classified as being either basic (curiosity driven) or applied (focussed on solving practical problems). I expect many philosophers or sociologists of science would view any forest fire research as applied but I think it is reasonable to classify fire research initiatives on a basic to applied scale. The development of new methodologies for formulating and solving stochastic integer programming models to support the eventual development of spatial harvest plans for flammable forest landscapes or investigating how high intensity fires interact with the atmosphere are examples of basic fire research. The development of simulation models of initial attack systems or the development of fire danger rating systems that can be used to predict fire occurrence and fire behaviour are clearly applied research.

Both basic and applied research are important and complement each other and I believe researchers should work with organizations and institutions that are supportive of both types of research. Agencies cannot expect researchers to provide good solutions to practical problems unless they are able to draw upon applied science that is well grounded on both practical experience and basic research. The development of sound decision support systems calls for a thorough understanding of the systems being managed and in the absence of basic research, such understanding will be sorely lacking. I also share the widespread belief that investment in basic research sometimes leads, serendipitously, to knowledge that can eventually be used to help resolve practical problems. Furthermore, most university-based research is linked with graduate education and that if we simply train rather than educate graduate students we will short-change them and future generations by undermining their ability to develop their own research programs.

5.3 It Takes Time When I first began developing forest fire management decision support systems Peter Kourtz (a research scientist with the Canadian Forestry Service) and I tended to think in terms of five year planning horizons with the expectation that one could develop, implement, test and revise a DSS within a five year period. Although some DSS projects can and indeed must be completed in much less than five years, I have since come to appreciate that it often takes much more time to bring the development of a fire management DSS project to a successful conclusion. The rapid pace with which new information technology appears gives one the impression that information technology is developed and implemented very quickly. In fact, R. Martin, the Dean of the Rotman School of Management at the University of Toronto, writing in a column in the Business section of the Globe and Mail newspaper (Friday, June 11, 2010, page B2), reported on the results of a United States National Research Council study that found “the average time from invention to market exceeded 20 years for communications and computer technologies”. That may come as a shock to young researchers who need to produce publications to meet research granting agency and university and promotion tenure committee expectations, but will be re-assuring to those that find it often takes much longer than expected to complete DSS development projects.

6 Emerging Challenges

Fire management and fire management decision-making has changed dramatically and become far more complicated since the 1960’s when Shephard and Jewell (1961) first proposed that OR be brought to bear on forest and wildland fire management problems. During those “fire exclusion” times fire was viewed as an almost entirely destructive force that posed threats to public safety, property and forest resources. The fire management objective was to exclude fire from forested landscapes at almost any cost and decision-making was relatively simple. Most fire management agencies are no longer driven by fire exclusion policies and there is widespread recognition that fire supports natural ecosystem processes and of the need to both temper wildfire suppression and to use prescribed fire to achieve ecological objectives. Although many fire management agencies still practice what is essentially fire exclusion over large areas where public safety and resource values are at high risk, modern information technology, transportation infrastructure and inter-agency resource sharing agreements now make it possible for them to mobilize and share suppression resources on national, continental and even global scales. One consequence of carrying out fire management in McLuhan’s global village is that agencies can quickly mobilize, deploy and eventually have to pay for much larger suppression forces than their predecessors could ever imagine. Decisions concerning how best to use the available resources in the past have morphed into decisions about how many resources should be marshalled and how they should be deployed.

We have also, in some areas, moved back to the future with respect to forest and wildland fire impacts on people and their property. During the early part of the 20^{th} century, many large wildfires quickly burned across vast tracts of land and wreaked havoc on people living in rural areas and small isolated communities in Canada and the United States. Although few civilian lives have been lost to wildfire incidents in Canada and the United States in recent years, such losses have been experienced in Europe in recent years and Australia suffered enormous losses of both lives and homes in 2009. Such incidents, which many attribute to fuel build-ups and changing land-use patterns, complicate already challenging decision-making problems.

The suppression imperative has also no doubt been bolstered in part, by media coverage that has, induced many fire managers to use costly resources (e.g., airtankers) to demonstrate a willingness to "engage the enemy" even when such efforts are ineffective. Fire managers who were once left to decide how best to contain fires that threatened to destroy mostly forest resources out of the limelight in isolated forested regions must now contend with far more complex incidents under intense media scrutiny and political pressure in areas that are heavily populated by residents with ready access to media resources they can use to publicize their "needs".

7 Recommendations

There is a large and rapidly growing gap between the DSS needs of fire managers and the decision support currently available, ironically, at a time when information technology and its use are expanding at phenomenal rates in other sectors. Operational researchers and many others have studied and developed models and generated valuable insight that, I believe, can contribute to improved fire management decision-making. However, much of that knowledge and experience will be lost and our credibility as potential "problem solvers" will be lost unless the OR/MS/DSS communities quickly respond to the urgent needs of fire managers. I view it as essential that we focus not only on our research but that we also work closely with fire management organizations to develop and support a global community of fire managers and OR/MS/DSS specialists who can work together to develop and implement solutions and that they share their knowledge, expertise, experience and solutions with each other. Some of the measures we should consider adopting to begin to build and support such a community include but are by no means restricted to the following:

1. **Pay attention to what fire managers have done and are doing for themselves:** Computer expertise is no longer the sole domain of computer "experts" and line managers and their staff often possess and draw upon their own expertise to develop their own "desktop" solutions to their DSS needs; the quality of some of these DSSs that I have seen surpass some of the applications described in the scientific literature.

2. **Don't ignore junior staff:** Those engaged in efforts to develop DSSs should pay heed to what is happening within the larger organizations in which they are working and think about the long term maintenance and use of the DSSs they are developing. That calls for listening to and addressing the needs, not only of the primary client, but also of those currently occupying junior positions. The knowledge, insight and support of the manager who has commissioned the development of a DSS is pivotal in the project's success, but junior staff members often possess crucial detailed information about systems and, in many cases, will become responsible for the maintenance and use of a DSS if and when their supervisor moves on.

3. **Share knowledge and experience with other researchers and practitioners:** Academics are rewarded for peer reviewed publications but managers are motivated to improve the performance of their organizations. With the exception of those that choose to publicize innovations to enhance their corporate image, most managers have little or no incentive to document their innovations in the scientific literature; in fact, many innovations are not widely publicized for competitive reasons. Such practices make it difficult to share knowledge and increase returns on research investments. Some forest "science" journals implicitly label applied research as marginal and encourage researchers to submit their "applied" research papers to regional and applied journals which further undermines attempts to transfer knowledge to managers that wish to practice "science-based management". Although some scientific and professional societies now go to great lengths to recognize and reward excellence in applied research (e.g. the Institute for Operations Research and Management Sciences' Edelman competition and the Canadian Operational Research Society's Practice competition), it is not always accorded the status it deserves.

4. **Share solutions:** Fire management is ultimately a public good that is delivered by both large and small organizations, many of which have neither the expertise nor resources to develop DSSs. We should therefore support the development of well documented open source DSS software that can be adopted for use by others.

5. **Recruit graduate students from the ranks of experienced fire fighters:** Gene Woolsey has long been a very vocal and colourful advocate of the need for operational researchers, including graduate students, to spend time on the "factory floor" before they initiate their research (see, for example, Woolsey and Maurer 1995). The ranks of many forest fire management organizations are populated

with seasonally employed college and university students, some of which are enrolled in formal education programs in which they study information technology and are seeking to build fire management careers. Academics should recruit fire fighters with several years of fire experience to enrol in their graduate programs where they could share their practical knowledge and experience with both their professors and their fellow graduate students as they complete their thesis research.

8 Ontarios Decision Analysis Culture

On the preceding pages I have drawn on my personal experience with developing and implementing a small number of fire management decision support systems in Ontario but I am but one of many that carried out research in this area in Ontario. Other researchers (e.g. P. Kourtz of the Canadian Forest Service) played very major roles but even more importantly, the OMNR's fire program leaders recognized very early, that the OMNR could and should develop its own "in house" DSS expertise, and it did so. P.C. Ward, for example, spear-headed the development and implementation of Ontario's Daily Fire Operations Support Systems (DFOSS). J. Caputo has, for a number of years, developed and maintained many of Ontario's fire management DSSs. D. Boychuk, who played a major role in the development and implementation of the original Ontario initial attack model, is now developing a much more powerful strategic fire management planning DSS that will satisfy Ontario's needs in the coming years.

Ontario's forest fire managers use and rely on many computer-based decision support and information systems and they are now very capable of developing and satisfying many of their own DSS needs, but even more importantly, Ontario's fire management program has developed and adopted *an analytical culture that now permeates its fire organization.* Although researchers continue to study forest fire management in Ontario, more often than not, when Ontario fire mangers are confronted with challenging decision-making problems, they either develop their own models or contract software developers to satisfy their decision support needs. Although fire managers always have and will no doubt continue to have to resolve many of their decision-making problems "by the seat of their pants", Ontario's fire managers are now firmly committed to science-based management and the use of computer-based decision support systems to augment their knowledge and experience and thereby enhance the performance of Ontario's fire program.

Acknowledgements

I have collaborated with the Ontario Ministry of Natural Resources (OMNR) and its predecessor, the Ontario Department of Lands and Forest for 40 years and during that time I had many opportunities to work with very many individuals who went out of their way to support my research program in many ways. Space limitations preclude my naming all of the many individuals who have assisted me and my graduate students but special thanks are due G. E. Doan who first hired me as a summer student and introduced me to fire management and R.J. Drysdale, P.C. Ward, A. Tithecott and R.S. McAlpine who provided invaluable assistance in their science and technology development and liaison roles. Ontario's fire managers welcomed me into their response centres and fire planning sessions, let me wander freely throughout their operations and chat with their staff, and answered my many questions. They suggested interesting research topics and always responded positively to my many demanding requests for background information and data. I will forever be grateful to my friend and mentor, B.J. Stocks of the Canadian Forest Service, who took me out into the field, involved me in his fire behaviour field research program and taught me how to interact with fire managers in the field.

Particular thanks are due H. Redding, R. Kincaid, A. Johnson and G. Frenette who had the courage to assign me, then a newly appointed assistant professor, to a fire fighting unit crew in Thunder Bay District for part of the 1975 fire season, and P. Parker who took me under his wing at the Shebandowan base during that period. I also wish to thank A. Tithecott, G. Gordon and D. Manol who continued that tradition by assigning me to one of the OMNR's incident management teams for the 2010 fire season.

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Finally, this paper that was scheduled to be presented[1] at the Workshop on Decision Support Systems in Sustainable Forest Management - Experiences and Perspec-

[1] This paper was not presented at the Workshop because the author was not able to travel to Lisbon as flights from Canada to Europe were cancelled because of the cloud of volcanic ash that covered much of Europe.

tives, Lisbon, Portugal, April 19-21, 2010

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