A PREPAREDNESS PLANNING EVALUATION MODEL

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INTRODUCTION

The pre-positioning of fire suppression resources to deal with potential wildfires is a fundamental problem for forest protection officers. In Western Canada, a number of preparedness planning systems (PPS) have been designed to determine the required manning levels (Gray and Janz 1983; Lanoville and Mawdsley 1990; De Groot 1991; Hirsch 1991). These systems are based upon observed fire weather conditions, which estimate the relative fire danger in the forest. More recently, fire behavior has been directly modelled (Forestry Canada Fire Danger Group 1992) thus allowing computer-aided decision support systems with forest inventory, terrain, and weather databases to add spatial detail, providing a more direct method of coverage assessment (Lee and Anderson 1990). Linear programming (LP) has been applied to coverage assessment to arrive at optimal solutions of required resources and area coverage (Anderson and Lee 1991).

Currently, preparedness planning systems do not directly consider the fire containment problem. To address this, Hirsch (1998) conducted interviews with experienced crew leaders in order to study the problem of initial attack containment by a medium helicopter and initial attack crew (5 to 7 person). Data from these interviews were analysed and through logistic regression, an equation for the probability of containment was derived for fires in the boreal spruce fuel type.

The purpose of this paper is to present a method to measure the effectiveness of a preparedness planning system. This is accomplished through a dispatch simulation. Through the simulation process, preparedness planning systems can be compared, showing which is more efficient and at what cost. This approach has been applied to the province of Saskatchewan with the intent of comparing preparedness planning systems used in the past as well as possible strategies for the future.

METHODOLOGY

The dispatch simulation models the number of escaped fires over a fire season. This consists of defining resource deployment strategies within the preparedness planning system in terms of daily fire weather or fire behaviour conditions. Then, by stepping through the historical weather, daily resource deployments are recreated. Next, using the historical fires database, available resources are dispatched to fires that occurred on that date. Hirsch's probability of containment is calculated for each fire and from this, the probability of escape. Continuing this process for each day and each fire within the fire season, a cumulative count of escaped fires can be made. The percentage of fires contained and the number of helicopter days (a surrogate for cost) can be used as measures of the efficiency of the preparedness planning system.

RESOURCE DEPLOYMENT

Preparedness planning systems provide rules and guidelines to determine the deployment of initial attack resources. These systems typically use fire weather and fire behaviour conditions as the determining factors. By following or approximating these rules and using historical weather, the model recreates deployments of initial attack resources on a daily basis.

Saskatchewan's current preparedness planning system is based upon two components: fire danger and fire risk (Saskatchewan Forest Fire Management Branch 1996). Fire danger is a measure of the potential fire behaviour, which is determined from the daily Initial Spread Index (ISI) and Fire Weather Index (FWI) as calculated from the Canadian Forest Fire Weather Index System (Van Wagner 1987). Fire risk, or the probability of fire starts, is based upon the presence of lightning within the concerned area over the last three days or the knowledge that people-caused fires may be expected.

While Saskatchewan's system provides PPS levels for each weather station, there are no set rules that determine the required number of crews and their deployment. This decision rests with the protection officer, who uses the PPS levels as guides.

Saskatchewan has used their new system for only one fire season, and thus an evaluation of the historical deployment would be limited. To expand the evaluation, five scenarios were constructed. The first three are current or proposed preparedness systems, while the remaining two are extreme cases intended to test the limits of the model.

Scenario 1 (PPS 1996) approximates the system currently used in Saskatchewan. The preparedness levels of 19 initial attack bases were estimated by interpolating the FWI and ISI values to base locations using a weighted moving average scheme (Lee and Anderson 1990). Bases with preparedness levels of 3 or more (FWI $\geq$18 and ISI$\geq$7) were activated. Note that this scenario does not account for risk and is, therefore, a limited approximation of the province's system.

Scenario 2 (PPS 1989) approximates the former preparedness planning system developed by de Groot (1991). Similar to scenario 1, preparedness levels were estimated at 33 initial attack bases from interpolated FWI and ISI values. A base was activated if the interpolated preparedness level matched the preparedness level of the base as defined by de Groot.

Scenario 3 (LP) represents the minimal number of resources require to provide 100% coverage of Saskatchewan's primary zone (Anderson and Lee 1991). The linear programming solution was based on 19 initial attack bases and 519 25x25 km cells. In addition, any cells with a predicted HFI of 10 kW/m or less were removed from the calculations.

Scenario 4 (constant deployment) depicts the extreme case of activating each of 19 initial bases with a single crew every day from May 1 to August 31. This represents the "fire hall" approach, in other words the perpetual state of readiness as exemplified by urban fire fighters. This scenario is useful as a benchmark showing the maximum effectiveness of single crew/single base deployment.

Scenario 5 (perfect knowledge) shows the perfect solution, perfect in the sense that the numbers and locations of each fire were known beforehand and a crew was deployed at the closest base in anticipation of the fire. This scenario represents the best possible solution with all fires actioned and no extra crews.

DISPATCH

Similar to resource deployment, dispatch is a responsibility of the protection officer and there are no specific rules for what crews or resources (if any) are sent to a fire. Thus, for this study the following set of rules are used:

1. One medium helicopter and crew is dispatched to each fire.
2. Fires are actioned in the chronological sequence with no knowledge of future fires.
3. The closest crew is always chosen.
4. Once dispatched, it is assumed the crew is unavailable for the remainder of the day.

According these rules, crews were dispatched from the daily deployment to fires that were reported that day and the probability of containment is calculated.

ESCAPED FIRES

When the system dispatches a crew to a fire, the probability of containment is calculated. As determined by Hirsch, the probability of one medium (5 to 7 person) initial attack crew containing a fire in the boreal spruce fuel type was calculated as

$$P_{Containment} = \frac{e^{U}}{1 + e^{U}},$$

where

$$U = 4.6835 - 0.7043 \times size - 0.00041 \times HFI - 0.000052 \times size \times HFI.$$

The *size* is the size of the fire in hectares at the time the crew arrives and *HFI* is the

The probability of escape is the failure rate for containment, that is,

$$P_{Escape} = 1 - P_{Containment} .$$

The an estimate of the total number of escaped fires for a season is the sum of the probabilities of escape for all fires over a season

$$N_{Escaped\ Fires} \approx \sum_{i=1}^{n} (1 - P_{Containment})_i ,$$

where n represents the number of fires in the season.

It is important for the reader to realize that these values are probabilities. Normally, containing a fire is a dichotomous process, either a fire is contained or not. As the number of fires increases (n), the estimate of the total number of escaped fires will approach the observed number of escapes.

HISTORICAL DATA

Seven years of data (1989-1991 and 1994-1997) were used in this study. Fire weather data was obtained from 48 weather stations for the period of May 1 to August 31. This data consisted of the values of the 6 components of the Canadian Forest Fire Weather Index (FWI) System, which are calculated daily at noon local standard time based on the temperature, relative humidity, wind speed, and 24-hour precipitation (Van Wagner 1987). Data consisting of the location and reported time of each was obtained for a total of 3097 fires that occurred within Saskatchewan's primary protection zone.

RESULTS

A summary of annual results for each scenario are shown in tables 1 and 2.

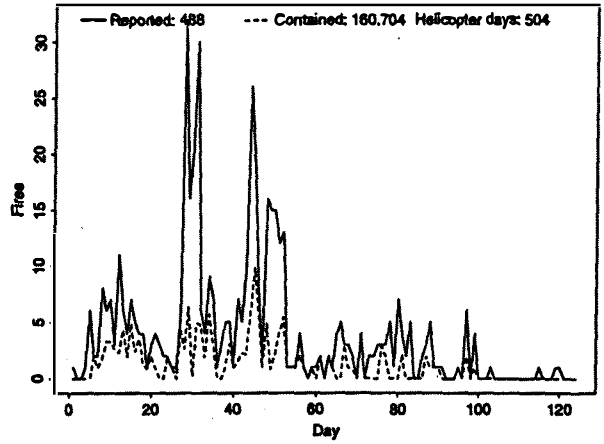
Year	Number of fires	Number of helicopter days				
		PPS96	PPS89	LP	Constant deployment	Perfect knowledge
1989	697	413	694	1281	2299	697
1990	519	253	425	971	1406	519
1991	375	258	404	1013	1824	375
1994	349	328	567	1215	2237	349
1995	490	504	862	1283	2318	490
1996	296	278	473	1053	1938	296
1997	371	413	677	1285	2261	371
Average	442.4	349.6	586.0	1157.3	2054	442.4

Table 1. Annual summary of the number of helicopter-days for the five preparedness planning system scenarios as calculated by the dispatch simulation. PPS96 and PPS89 are the 1996 and 1989 preparedness planning systems respectively; LP is the linear programming solution.

Year	Number of fires	Percentage of fires contained					
		PPS96	PPS89	LP	Constant deployment	Perfect knowledge	Actual
1989	697	25	42	60	64	79	75
1990	519	31	47	79	82	88	78
1991	375	33	55	85	86	90	86
1994	349	34	61	79	83	88	86
1995	490	41	57	63	69	76	71
1996	296	38	55	77	84	92	81
1997	371	39	56	67	69	77	79
Average	442.4	34	53	73	77	84	79

Table 2. Annual summary of the predicted number of contained fires for the five preparedness planning system scenarios as calculated by the dispatch simulation. Values under the actual column indicate the percentages of fires that were reported and contained (i.e., being held) on the same day. PPS96 and PPS89 are the 1996 and 1989 preparedness planning systems respectively; LP is the linear programming solution.

DISCUSSION



The dispatch simulation provides insights into the effectiveness of various preparedness plans. Figure 1 shows a sample of the dispatch simulation with the daily number of reported fires (solid) and contained fires (dashed). Annual summaries are recorded at the top of the graph. It is apparent from the figure that most escaped fires occur on days of multiple ignitions. On these days, initial attack crews are rapidly used up and a large number of fires go unactioned. This may be seen as a strong argument for the development of fire occurrence prediction models to predict these extreme events.

Of the various plans, the PPS96 system used the lowest number of helicopter days (350 per year on average) but was the least effective preparedness system, resulting in an average containment rate of 34%. On average, PPS89 required 82 more helicopter days than PPS96 but resulted in a 19% increase in initial attack containment. This was, in part, due to using 33 in PPS89 rather than the 19 bases used in PPS89. It is important to remember, however, that the simulation was only able to approximate the planning procedure used in the two weather-based approaches and that the risk component in PPS96 was not incorporated.

The LP model was considerably more effective than PPS96 and PPS89, having an average containment rate of 73%, but it required two to three times the number of helicopter days as the other two systems. This improvement is gained from the spatial, fire behaviour based approach as opposed to the fire weather data approach used in PPS96 and PPS89. A shortcoming of the LP model is that it depends on fire danger only and does not consider risk. Both the efficiency and effectiveness of a fire behaviour based system could be improved by deploying multiple crews in areas with high fire occurrence potential, re-emphasizing the importance of fire occurrence prediction. Also, using a system that deploys resources according to probability of containment rather than an arbitrary fire size would further improve preparedness (Hirsch and Anderson 1997). The constant deployment strategy is a highly risk averse approach to preparedness planning that would be appropriate only if there was no information about either fire behavior or fire occurrence potential. However, the constant deployment strategy does provide a benchmark for the best possible level of containment (77% on average) that can be achieved from the 19 primary initial attack bases, assuming a maximum of one initial attack crew per base. Comparing constant deployment to the LP solution, we see that LP is only slightly less effective but uses about about half (approximately 900 fewer) helicopter days per fire season. This considerable cost saving is obtained by optimally deploying resources based on fire behavior information.The perfect knowledge simulation indicates the highest levels of effectiveness (76% to 92%) and efficiency (350-700 helicopter days) that could be obtained given the current 19 initial attack bases. In other words, the model suggests that for Saskatchewan, the best any preparedness system can achieve would be the containment of 80 to 90% of fires by initial attack crews, using an average of 400 to 500 helicopter days per fire season. The fact that the containment rate is not higher illustrates the need for using multiple crews and airtankers on some fires but it also shows that medium initial attack crews are an extremely effective initial attack resource.

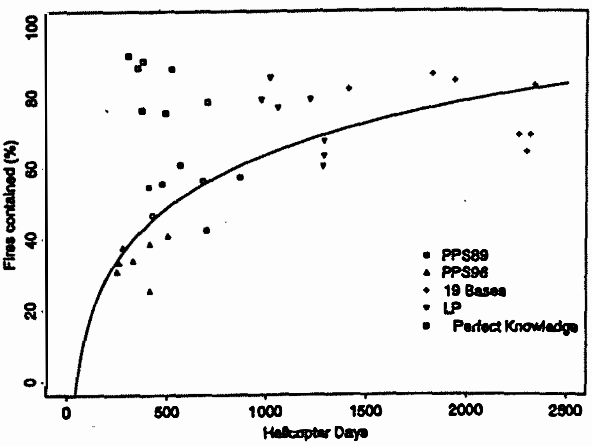


Figure 2 shows the cost effectiveness of each of the plans. The reference curve is a best fit through all the points excluding perfect knowledge. It shows that there are diminishing marginal returns to preparedness planning. Therefore, it is important that managers determine the point where they believe the benefit on adding extra initial attack units no longer exceeds the cost.

In viewing the results, one must remember that this is a simplistic model for both deployment and for dispatch. While the simuation calculates the number of escaped fires, these escapes are based on the limited scope of the dispatch rules and do not capture the full capabilities of a protection agency. Therefore, the actual number of escaped fires will be much lower than the simulated number. There are many factors not incorporated in this model. For example, air tankers have been overlooked, yet they play a large and important role in fire suppression in Western Canada. Also, indirect factors such as terrain, which could stop a fire, have not been examined. The degree to which this may be a factor is difficult to measure and simulate.

CONCLUSIONS

The dispatch simulation presented in this paper allows for the evaluation of the efficiency and effectiveness of preparedness planning systems. Due to the assumptions required to simulate some systems it is not appropriate to state definitively which system is "the best", although results suggest a significant improvement by using a fire behaviour based appoach over one based strictly on fire weather. However, the model does provide a standard mechanism by which it is possible to assess the strengths and weaknesses of each deployment procedure. These key insights can be used by fire managers with other types of information in developing the most appropriate preparedness planning system.

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