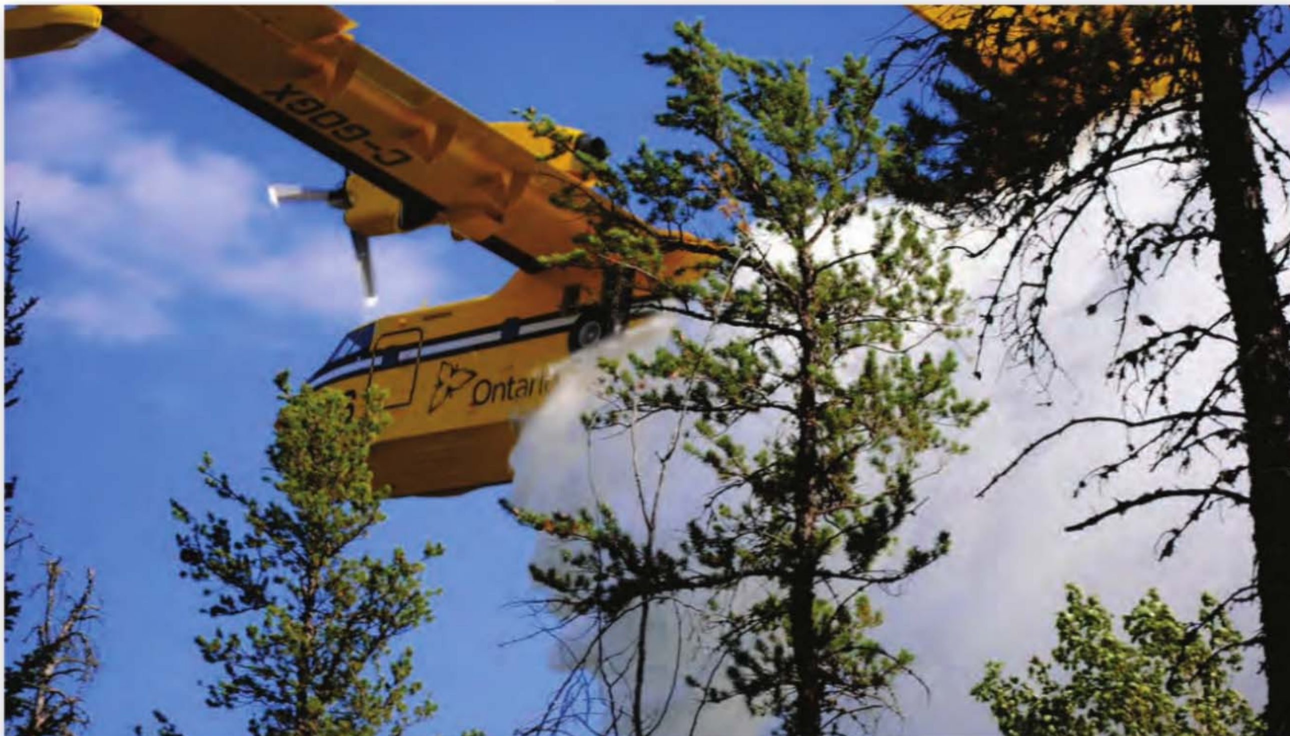

Photo Courtesy the Ontario Ministry of Natural Resources.

OMNR airtanker dropping water on a fire.

# Modeling airtanker operations

## GPS data used to develop queueing models of forest fire initial attack systems.

By Nicholas A. Clark and David L. Martell

**Airtankers are used to help fight forest and wildland fires in many countries,** and initial attack airtanker systems can be viewed as complex spatial queueing systems (see, for example, Martell et al. 1984 and Islam et al. 2009). Unfortunately, forest and wildland fire management agencies manage fire across large areas – in the case of the Ontario Ministry of Natural Resources (OMNR), one of the fire management agencies with which we collaborate, more than 750,000 square kilometers. Such vast expanses pose special challenges to researchers who seek to gather the data required to model airtanker operations.

The authors and our colleagues in the Fire Management Systems Laboratory in the Faculty of Forestry at the University of Toronto have long envied the operations researchers who worked on the New York City Rand Fire Project (see Walker et al. 1979) and were able to acquire data that made it possible for them to model urban fire operations in much more detail than we ever dreamed possible with forest fire operations. More recently, we extended our envy to those modeling ambulance and other urban emergency response services (see for example, Budge et al. 2010), as well as those that study call center operations (e.g., Green et al. 2007) that can use the massive amounts of data compiled by computers that are used to support call center operations.

Photo Courtesy the Ontario Ministry of Natural Resources.

**OMNR airtanker scooping water from a lake.**

However, we recently learned that modern information technology coupled with GPS and satellite technology has, in some respects, shrunk the province of Ontario into a small virtual "fire center" that is, in some ways, no larger than a typical call center. We have used that technology to develop service time models that can be used to develop queueing models of the OMNR's initial attack airtanker system.

### Airtankers: initial attack on forest fires

AIRCRAFT HAVE PLAYED an important role in forest fire management in North America since the early decades of the 20th century. They were first used in the province of Ontario during the 1922 fire season and by 1924, the Ontario Provincial Air Service had acquired a fleet of 13 Curtiss H2SL flying boats that were used to carry out detection patrols, map fires and transport fire fighters and their equipment to and from fires.

The Ontario Ministry of Natural Resources now owns a fleet of nine CL-415 airtankers and five Twin Otters that can be used for transport or water bombing, and seven helicopters that are used primarily to transport fire fighters and their equipment to and from fires. Each summer they augment that fleet with roughly five helicopters, and they also charter roughly 15 fixed-wing aircraft that are used to fly detection patrols. They share their airtankers with other fire management agencies under the terms of mutual aid agreements and charter additional helicopters for short-term use as required.

The OMNR's CL-415 airtankers are amphibious aircraft. Each day they are deployed at airports close to areas where fires are expected to occur with an alert status that includes get-away time targets that vary with the expected number of fires and the anticipated spread rates of any fires that might occur. Ontario's airtankers are sometimes used to support line building on large fires, but their primary role is initial attack on small fires. When they are dispatched on initial attack they are preceded by an air-attack officer in a faster flying bird-dog aircraft who assesses the fire, decides where he or she wants the airtankers to drop their loads, and manages air operations over and near the fire.

The CL-415s are referred to as skimmers or scoopers because they pick up water by flying low just above the surface of a lake near the fire and lowering their hydraulic scoops into the water to quickly fill their tanks with approximately 6,000 liters of water (see photo). Once they arrive on scene they check in with the air-attack officer and identify a nearby "landable" lake from which they can pick up water. They then begin a cycle of scooping water from the lake, flying over to and dropping the water on the fire and returning to the lake to pick up another load. Given the abundance of lakes in Ontario, they can usually complete a drop cycle in less than five minutes.

### Complex spatial queueing systems

THE INITIAL ATTACK airtanker system can, as noted above, be viewed as a complex spatial queueing system with fires as customers and airtankers as mobile servers. The number of servers assigned to each fire is random inasmuch as it can vary from fire to fire depending upon the size and behavior of the fire, when it is reported and the values at risk in its vicinity. The service time includes the time required for the airtanker pilots to scramble and power-up their aircraft, taxi for take-off, take off, fly to the vicinity of the fire, assess the suitability of nearby lakes for picking up water, discuss with the air attack officer where their loads are to be dropped, begin their approach for a drop, drop their load on the fire and then return to the pickup lake to begin another drop cycle. The cycle will be repeated until they are no longer required on that fire, they are assigned to a higher priority fire, or they are required to return to their base to re-fuel and resume their alert status.

It's not surprising, therefore, that simple exponential service time distributions that are commonly used to model queueing systems may not be suitable for modeling airtanker service

Map courtesy the Ontario Ministry of Natural Resources

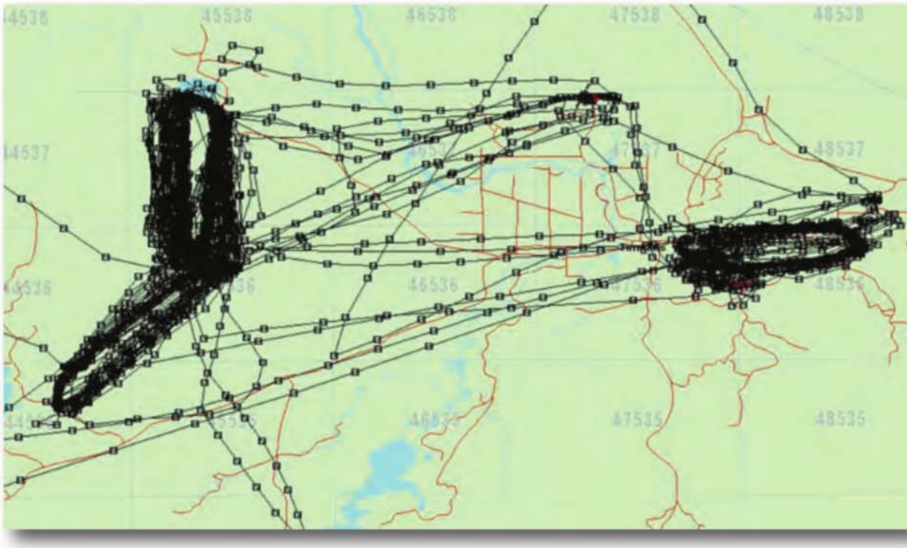


**Figure 1: Map of airtankers dropping on forest fires in Timmins district in Ontario.**

times. Fires are reported or arrive at rates that vary throughout the day, and since fires can grow in size as they wait in the queue, the longer a fire waits the greater the number of drops that may be required to contain it. Initial attack airtanker systems are, therefore, in the parlance of queueing theorists, multiple channel queueing systems with arrival rates that vary over both time and space, with a random number of servers dispatched to each fire, service times that depend on waiting time and priority arrivals that may pre-empt the service of fires currently being served.

### Early attempts to model airtanker operations

IN ORDER TO MODEL airtanker service times one must know many attributes about each fire that is attacked and their corresponding airtanker missions including: 1) what airtankers were dispatched to what fires at what times, 2) the locations of the bases from which the airtankers were dispatched and how long it took them to fly to the vicinity of the fire, 3) the distance from the fire to the nearest landable lake, 4) the number of drops delivered to the fire by each airtanker, and 5) how much time was required to complete each drop cycle. The OMNR compiles detailed fire or incident reports on all the fires they manage and those reports contain more than 90 data fields that describe where each fire was reported, detected, first attacked, contained and controlled, the size of the fire at each stage of control and many other fire attributes. Unfortunately, they do not contain the type of data that would be required to model airtanker service times as described above.

Airtanker pilots maintain flight logs and report how many drops they delivered to each fire they attacked but again, not in sufficient detail to model their service times. One could, in principle, put an observer in the bird-dog aircraft and ask him or her to record the timing of events as they take place, but keep in mind that he or she would seldom see the tanker take off and land at the airtanker base nor would he or she be able to document all pickups at lakes that are not adjacent to the fire. In the past, initial attack airtanker modelers therefore resorted to using manufacturers' published specifications for aircraft speeds, whatever estimates of performance data they could scour from the literature, and estimates of performance measures solicited from fire mangers and others, often in a somewhat ad hoc manner. We envied those that developed queueing models of urban emergency systems but despaired of ever being able to replicate their success. Fortunately, in May 2010, we learned we would no longer have to work with one hand tied behind our backs.

Photo Courtesy the Ontario Ministry of Natural Resources.

**Forest fire in northwestern Ontario.**

### Processing and analyzing the ATS data

ON MAY 21, 2010, one of Ontario's senior fire managers sent one of us (Martell) an e-mail message to which the map depicted in Figure 1 was attached. One of us (Clark) was in the early stages of his Master's program and had yet to decide upon a specific thesis topic. We had one look at the data and quickly agreed that it could be used to model airtanker operations much better than ever before. We requested more data from the OMNR and within days, they provided us with a fully documented Aircraft Tracking System (ATS) dataset that Clark incorporated in his thesis research project.

Source: *Nicholas A. Clark (see reference No. 2)*


**Figure 2: Map of an OMNR airtanker completing one cycle of the drop process on a fire (shown in orange) in northwestern Ontario – generated by imposing ATS data on a digital map of Ontario.**

The ATS data indicates where each airtanker was located every 30 seconds that it was powered up from the start to the end of each year, but it does not indicate what the airtankers were doing at those times. It might, for example, have been warming up its engines, flying from one airport to another, flying to or from a fire, or flying to or from a lake while dropping on a fire.

Our first challenge was to develop an algorithm that could delineate the initial attack missions that were embedded in the very large ATS dataset (that in some cases contained more than 80,000 records for an individual airtanker for a year) for the purpose of determining when and where each mission began and ended. Our next challenge was to pair each initial attack mission with one of the roughly thousand or more fires that occur in Ontario each year. To achieve this we needed to develop a pattern-recognition algorithm that could detect on which missions and at what times during each mission the airtanker dropped water on a fire. That allowed us to determine the amount of time associated with each major segment of each initial attack mission.

Clear evidence that we were able to do so is evident in Figure 2, which illustrates initial attack action on one of the fires that airtankers fought in Ontario in 2010. Having accomplished that task, we then carried out statistical analyses of the processed data to characterize many aspects of initial attack airtanker action in Ontario – including for example, the times required to: 1) warm up the engines, taxi and take off, 2) fly to the vicinity of the fire, 3) complete a drop cycle, 4) return to base or fly to another fire, 5) the number of drops delivered to each fire, as well as 6) the total service time. We then incorporated those estimates in a simple simulation model that was developed to illustrate how it could be used to help answer questions such as: When an airtanker completes a mission should it return to the base at which it was deployed for the day or should it land and await further direction at the closest base?

### Future initiatives

NOW THAT WE CAN characterize initial attack airtanker operations much better than we ever dreamed possible, we plan to use that data to develop more realistic models of the OMNR's initial attack systems. Having cut our teeth on airtanker data, we have since broadened our attention to the use of GPS data to model other fire-related aviation activities. For example, fixed wing aircraft are used extensively for fire detection in Ontario, and deciding when and where to route detection patrol aircraft can be viewed as a complex variant of the vehicle routing problem with multiple vehicles departing from multiple depots to "pick up" random loads (fires). We are now investigating the use of the OMNR's detection aircraft ATS data to model detection system operations and performance. The OMNR also uses helicopters to transport initial attack crews and their equipment to and from fires and to service on-going fires and we plan eventually, to investigate how to use GPS data to better understand and model the use of helicopters for both initial attack and for servicing on-going fires. **ORMS**

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