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1 CANADIAN FORCES FLYING TRAINING SCHOOL (1 CFFTS) RESOURCE ALLOCATION SIMULATION TOOL

René Séguin

Defence Research and Development Canada
Box 17000 Station Forces
Winnipeg, MB R3J 3Y5, CANADA.

ABSTRACT

1 CFFTS trains Air Combat Systems Officers (ACSO) and Airborne Electronic Sensor Operators (AESOp). The operation of the school is stochastic and dynamic in nature and a resource allocation planning tool has been built to simulate the interactions of its various components. For example, it takes into account weather, aircraft reliability, instructor availability and student failure. This presentation gives an overview of the school's operation, describes how it is simulated with a custom built C++ application and shows how the tool has been used to estimate average course duration, to determine what resources are the most significant bottlenecks and to study the effects of changes to parts of the school's operation. The tool was instrumental in showing that one of the offered courses will take much more time to complete than was anticipated and that a small improvement in the availability of the most constraining resource could produce significant benefits.

1 INTRODUCTION

The school has been experiencing delays with graduation dates and sometimes quite significantly. The underlying problem faced by 1 CFFTS could be described as a combination of resource allocation and school timetabling without really being either. In classical resource allocation (Ibaraki and Katoh 1988), a mixture of resources is required to accomplish an activity and several activities compete for the limited amount of resources available. Usually, a cost is associated to resource usage, a benefit to completion of activities and the objective is to maximize benefits. For the problem at hand, there are no such costs and benefits and very often not enough resources to complete the activities of the day. In this case, the decision is what activities should be performed today and which ones can be postponed, making sure that they eventually get accomplished. In classical school timetabling (Burke and Petrovic 2002), instructors, student and classes have to be scheduled over a period of time (usually a week). The goal is to find a recurrent weekly schedule without conflict. Even though the 1 CFFTS problem looks like a timetabling problem it does not have that regular weekly schedule. The problem is very dynamic and activities to be accomplished change every day. This is due to the dynamic availability of resources and the dynamic nature of the training itself.

The objective here is not to come up with an a priori optimal resource allocation and schedule as the stochastic and dynamic nature of this complex problem makes the task rather impossible. Since unpredictable events happen almost daily, frequent schedule adjustments are required. The goal is thus finding a method to predict how long should each type of course typically last and determine what are the most significant factors that influence course duration and hence graduation dates. The rest of the paper is organized as follows: Section 2 describes the school operation in detail, Section 3 presents the methodology employed for the simulation, Section 4 discusses results obtained and a Conclusion follows.

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2 SCHOOL OPERATION

2.1 Resources

The school uses the following resources: different types of instructors, simulators, aircraft, and flight crews. All resources have a maximum number of hours they can be used each day. However, several of the resources have random availability (for example, aircraft breakdown or instructors get sick) and are not always fully available. Some resources may also be unavailable due to planned events (for example, scheduled maintenance on aircraft (A/C) or instructors' vacation). Furthermore, weather can prevent the completion of an activity, delaying several other activities.

At 1 CFFTS there are three types of instructors: ACSO, AESOp and meteorology (MET) instructors. The instructors' availability depends on several factors. First, as military personnel are posted to other assignments or locations on a regular basis (every three to four years), a portion of the instructors at the school have to be replaced every year as they are posted out and personnel getting transferred in require a certain amount of (re-) training. Second, Air Force personnel are frequently required to attend specialized training courses, perform proficiency and secondary tasks, attend professional development activities, and the like. These activities are of various length and spread over the year; they reduce the instructors' availability for teaching. Third, instructors may occasionally be sick. Fourth, instructors may be on leave (all personnel have a certain amount of leave granted and some personnel may be guaranteed a certain amount of leave in the Summer time). Last, instructors may become unavailable for extended periods of time; for example, maternity leave or prolonged sick leave.

The aircraft are mainly used by 1 CFFTS during daylight hours and, typically, more flights per day are flown during the summer as days are longer. Aircraft breakdowns render the aircraft unavailable for various periods of time. Aircraft may also become unavailable for extended periods of time due to periodic maintenance.

2.2 Teaching Activities

Activities are lessons that students attend; at 1 CFFTS, lessons consist of standard classroom lessons, simulator sessions or flights. Several of the activities require preparation for the instructor. This extra activity is usually done one day before. A complete series of specific activities form a course flow and 1 CFFTS teaches five different courses. An instance of a course is called a serial and usually more than one serial of each course is being taught at the school simultaneously, each being at a different stage of completion.

For each different course, there is a standard curriculum that consists of a series of daily activities to be performed in chronological order. Depending on the activity, the resources' requirements are quite different. For classroom instruction or exams, only instructors are required. Note that in some cases more than one instructor may be required. For simulator sessions, there is usually one simulator per student and one instructor for two students. For a flight mission, a number of instructors, a flight crew and one or more aircraft are required. Depending on the mission, the number of each required resource varies. Furthermore, flight missions have varying weather requirements (see Section 2.3). Usually, only one type of activity is performed daily but on some days classroom instruction may be combined with another type of activity.

For some courses, in the early part of the curriculum, the students leave the school to take part in an off-campus two-week course where no resources from the school are used. In addition, for some courses, once or twice in the course of the curriculum, students take part in a trip that is part of the training. The whole class leaves for a few days with a group of instructors using the school's aircraft. On the longer trips, the aircraft may not have to stay with the class for the whole trip and can be flown back to be used for other school activities.

Some activities where students' progress is evaluated have a failure rate. If a student fails an activity, remedial actions have to be completed. This implies that special activities are dynamically added to the scheduled curriculum. Note that the whole class is delayed as students have to progress as a whole rather than individually. Students can also get sick and, again, the class has to wait for the return of the sick student.

If students are in the practical part of their course, they are allowed a refresher activity in the simulator if they have not been in it or if they have not been flying for more than 10 calendar days. This usually happens after student summer leave and Christmas or when resources become limited and cause long delays. In this case a simulator activity is dynamically added to the course flow for the whole class.

For each course there is a general attrition rate: for example, 25% of the students fail the course or have to drop out for some reason. Historically, students attrite from courses at different sections of the curriculum with varying probabilities. For example, a large percentage of the attrition may happen at the first set of check rides (“marked” flight missions) of a course flow.

2.3 Weather

Depending on the specific mission, different weather requirements will be defined. For any flight, takeoff (TO) conditions are mandatory, then a combination of instrument flight rules (IFR) and/or visual flight rules (VFR) requirements is also defined. The different weather conditions are defined using various values for elements such as temperature, visibility, ceiling, etc.

As each specific mission does not have to be flown in a precise location but rather in a general area and due to the extent of the area covered by the school’s flight missions, the weather must be examined at multiple locations to determine if the mission can be flown.

2.4 School stand-downs

There is no instructional activity at the school for two weeks at Christmas time, during sports days in the summer or when there is a graduation ceremony. There is not necessarily a graduation ceremony every time a serial is completed; if another one finishes just a couple of weeks later, the first one will wait and they will both have their graduation ceremony the same day. As the school loses a day of teaching when there is a graduation ceremony, combining ceremonies is beneficial. Certain long serials are also granted leave for two weeks during the summer.

3 METHODOLOGY

As explained earlier, the objective of this study is not to come up with an a priori optimal resource allocation and schedule but rather finding a method to predict how long should each type of course typically last and to determine what are the most significant factors that influence course duration and thus graduation dates. Due to the stochastic and dynamic nature of the underlying resource allocation and scheduling problems, a simulation approach has been adopted. A custom built C++ simulation software tool with a Visual Basic GUI has been developed. Similar work has been done previously for the NATO Flight Training in Canada program (Caron 2005). However, the two training programs are so different that new algorithms and a new simulation tool had to be built.

The tool simulates the activity of the school every day for several years. It simulates weather, aircraft breakdowns, instructor sickness, leave and posting, student sickness, student failures as well as take into account planned resource shortages or surges. Each day, decisions are made as to which serials get scheduled and which ones get delayed. To ensure that each activity eventually gets scheduled, a priority is assigned to each serial and, as delays are incurred, priority increases. A list of serials, sorted by priority is thus kept, and resources are allocated to each serial in a greedy manner: each day, the serial with the highest priority takes as many resources as it needs until it is either satisfied or a resource runs out. If a serial is satisfied then the serial with the next highest priority does the same. If a serial cannot be satisfied, all resources it took are released and it waits idly until the next day (its priority increasing). Then, the next serial in the priority list tries to take resources. This goes on until all active serials for the day have been either scheduled or wait idly. Then, the process is repeated the next day and so on.

3.1 Algorithm

From a high level perspective, the model uses the algorithm shown in pseudo code in Figure 1 to solve this specific version of the resource allocation problem. First, sort the serials by dates, the earliest start date first. Then, for each day, make all resource changes necessary (posting, planned shortages, illness, etc) and, for each active serial (that has no sick students) in succession, and in priority order, try to claim all resources required and verify the weather requirements if the serial involves flying. If the daily activities of the serial can be at least partially satisfied (see Section 3.2.3), put the serial on the schedule for today. If any student fails an activity on that serial, add the appropriate remedial activities to the serial course flow. If the serial could not be scheduled today, release all resources that it claimed and make this serial wait idly until tomorrow. If there are sufficient resources available to do the preparation work for the serial's next activities, claim the resources. Otherwise, delay the serial preparation and complete it the next day.

```
sort all serials by date
for each run:
    apply any planned resource losses that started before the period of interest
    calculate student attrition
    for each working day in the period of interest:
        apply posting if required
        apply any planned resource losses that start today
        determine how many instructors are available:
            end yesterday's instructor random losses (sick, away)
            calculate how many are away (leave, training, professional
                development, secondary duties)
        apply student illness
        apply daylight hours for A/C if required
        apply random resource losses (instructors' illness and A/C breakdown)
        sort all serials by priority
        for each serial s:
            if (s is active and has no sick students):
                s claims resources until s is satisfied or there are no more
                    resources available to claim
            if (s involves flying):
                verify weather
            if (s is at least partially satisfied):
                schedule s for its current mission
                if (any student failed)
                    add remedial activities in the course flow
            else:
                s releases all resources it took
                s waits idly until the next day
            try to do the preparation work for next day
            graduate serials when complete
        release resources
        apply student attrition
        end any planned resource losses that end today
    end any planned resource losses that could still be in effect
    reset resources
    sort all serials by date
```

Figure 1: Resource Allocation Algorithm Pseudo Code

3.2 Implementation Details

3.2.1 Serial Priority Sorting

The basic sorting works as follows: the first criterion sorts the serials by the fewest sick students. Note that serials with sick students are not scheduled for any activity and are thus always pushed to the end of the sorted list. The routine then checks if a serial has only partially finished its most recent mission. If not, then it finds the serial that has waited idly the longest, then which one has the fewest activities until graduation (but only if both compared serials are from the same type of course), and finally it selects the serial with the earliest start date. On top of these criteria, course priority may be used to bias resource allocation toward a certain course. These course criteria are added in the sorting algorithm in various places depending on the behavior that is sought.

3.2.2 Daily Sorties Scheduling

As only a few planes are available and several sorties may need to be scheduled on a specific day, the model requires an algorithm to allocate the available flying hours to the sorties. However, to respect the priorities, the main algorithm assigns resources to one serial at a time. Sorties are thus also assigned one serial at a time. For each such serial, verifications need to be made first to ensure that enough resources are available to complete the individual sorties required. A sortie cannot be split between two aircraft and the remaining hours of several flight crews and/or instructors cannot be combined to obtain a complete flight crew and instructor compliment. A sortie will always be assigned to the plane that has the least flying hours left for the day but still enough for the sortie. A more complex bin packing (Garey and Johnson 1979) optimization algorithm that would take into account serial priorities and other constraints could theoretically be designed, but as the number of planes involved and the number of flight lengths are low, the number of possible combinations are quite small. Since such an algorithm would rarely produce improvements, the payoff would be small in comparison with the added complexity of the tool.

3.2.3 Partial Completion of Activities

Although there may not be enough resources available to accomplish all the planned flights of a serial on a specific day, resources may be sufficient to accomplish at least one flight. In that case, the activity will be partially accomplished and continued the next day. To ensure that a partially finished activity is completed as soon as possible, the sorting algorithm gives absolute priority to partially completed activities.

3.2.4 Instructors

The tool simulates the posting of instructors by removing one instructor per week during posting season, starting on the first posting week and continuing until the required number of instructors has been posted. At the start of the simulation, the tool pre-calculates a probability of not being available for teaching duties. This includes leave, training, professional development, secondary duties, etc. Note that during the posting season and summer period, as the number of available instructors is significantly reduced, the simulation limits training or professional development leave. Furthermore, in the period while newly posted instructors are in training, only a certain percentage of instructors are allowed to participate to non-teaching activities. Finally, to prevent unrealistic situations, the simulation will cap the number of instructors that are on leave or on non-teaching activities concurrently. The number of instructors on sick leave on a given day follows a Binomial distribution with parameters n and p where n is the number of instructors and p the probability of each instructor being sick on a given day.

3.2.5 Aircraft

The aircraft may be used for a fixed number of hours each day or they can be used during daylight hours. This allows more flights during the summer as days are longer and fewer in winter. As aircraft are prone to breakdowns, a list of repairs that may need to be performed on aircraft is used. The list specifies the number of hours needed for the repair and the probability of the associated breakdown occurring for each aircraft everyday. Repairs can last more than a day.

3.2.6 Away Trips

Special considerations need to be given to the away trips that happen once or twice during a course where the whole class leaves with one of the aircraft. For these periods the aircraft and its crew need to be reserved with exclusive usage. If the trip is long and the aircraft is not required for the whole stay, the tool allows for the aircraft to return to the school to be used for other tasks but priority is given back to the trip as soon as the aircraft is needed.

3.2.7 Remedial Activities

When a student fails, he/she has to go through to some remedial activities. In practice, the precise remedial activities needed depend on the severity of the failure, how often the student has failed an activity before, which course is being followed, how far along the student is and the type of mission that was failed. The complexity of this process is far too great to be replicated closely by the simulation tool. However, as one is interested by the delays caused by the failures rather than the precise paths followed by individual students, it is possible to simulate the remedial delays.

The frequency of two, three and four day delays vary depending on the factors mentioned above but certain rules can generally be applied supplemented by some randomization. The following activities may be used in remedial: 1) assessment of the student's situation and classroom instruction, 2) a remedial simulation activity, 3) a remedial flight activity if the failed activity was a flight mission and, 4) the original failed activity (simulation or flight). Any of these will add a one day delay to the course duration and each will obviously require the appropriate resource.

3.2.8 Weather

Flying missions are affected by weather and delays are regularly incurred due to adverse weather conditions. To be able to account for these delays the tool needs to be able to realistically simulate the weather effects.

Currently, there are three different sets of weather requirements used by the school. Flight missions in Set 1 are flown at low level (1000 feet above ground level (AGL)) and require VFR conditions in the vicinity of Lake Manitoba and Lake Winnipeg, in a region of about 30,000km^2. Missions in Set 2 are flown at medium altitude (20,000 feet AGL) and require IFR conditions on a return trip from Winnipeg to a destination 500km away either to the West, the Northwest or the Northeast. Missions in Set 3 are flown at various altitudes (between 1000 and 12,000 feet AGL) and require VFR conditions at destination but transit to the destination only requires IFR conditions. The destination is usually at least 200km away and can be as far as 500km from Winnipeg. It can be in any direction that does not involve crossing the American border. Favorable conditions in only one of these destinations are sufficient. Obviously, takeoff and landing conditions must always be available in Winnipeg, MB where the school is located.

The tool looks at the weather the day of the flight and decides if the mission can be flown or not using historical weather data. To decide if a weather requirement is met for a specific mission, average monthly weather condition probabilities are used. Determining if a specific condition is met at a specific location is not difficult but determining if the weather conditions described in the three weather requirement sets used by the school is a harder task. These sets are constituted of location-condition pairs and the pairs are organized in complex Boolean clauses and are not always independent. Whether the locations used for a mission are geographically close or not, one has to consider the probability that these locations may be under the influence of the same weather system. If so, then the weather probabilities at these locations cannot be considered independent.

The following equations are used to evaluate the probability of each requirement set being satisfied:

$$\boldsymbol{P}(Set\ 1) = \boldsymbol{P}(Pair\ A) \times \min\{\boldsymbol{P}(Pair\ B), \boldsymbol{P}(Pair\ C), \boldsymbol{P}(Pair\ D), \boldsymbol{P}(Pair\ E)\},$$

$$\boldsymbol{P}(Set\ 2) = \boldsymbol{P}(Pair\ A) \times (1\text{-}\{[1\text{-}\boldsymbol{P}(Pair\ F)] \times [1\text{-}\boldsymbol{P}(Pair\ G)] \times [1\text{-}\boldsymbol{P}(Pair\ H)]\}) \text{ and}$$

$$\boldsymbol{P}(Set\ 3) = \boldsymbol{P}(Pair\ A) \times (1\text{-}[(1\text{-}\boldsymbol{P}(Pair\ I)] \times [1\text{-}\max\{\boldsymbol{P}(Pair\ J), \boldsymbol{P}(Pair\ K)\}] \times [1\text{-}\max\{\boldsymbol{P}(Pair\ L), \boldsymbol{P}(Pair\ M), \boldsymbol{P}(Pair\ N)\}])$$

where the terms in the clauses have the following high level interpretations:

- Pair A represents takeoff conditions at the school airfield,
- Pairs B to E represent VFR conditions in geographically close locations,
- Pairs F to H represent IFR conditions in geographically distant locations, and
- Pairs I to N represent VFR conditions in a mixture of geographically close and distant locations (for example, Pair I is distant from all other pairs but Pairs L to N are close to one another).

4 ANALYSIS RESULTS

To ensure that all potential interactions between the serials are experienced, the tool is fed with a few years' worth of serials of each course type. It is fed data from mid 2005 to the end of 2015. Older serials are used to seed the simulator, as meaningful course length and graduation dates can only be obtained once a realistic set of serials are simultaneously being offered. The historical portion of the data can also be used to validate the simulation tool as observed graduation dates are known. Furthermore, since factors such as resource availability are stochastic, 100 runs are done to obtain average behavior.

Table 1 provides information about each of the different courses. Typically, a course syllabus has a planned number of instruction days as shown in the second column of the table. For each course, a certain number of serials are scheduled every year as shown in the third column. The school is currently in the middle of a program overhaul as both occupations are being significantly changed. The BANC and BAC course flows are being replaced by the ACSO, BAQC and IAQC course flows and the SANC was offered until 2009 but is not for the time being. The FIC course flows are for the new instructors. A few scenarios will be tested to measure the impact on course duration and resource bottlenecks. The school is mainly interested in the scenarios with varying number of ACSO, BAQC and IAQC serials per year. The variation in BANC, BAC and SANC are historical fluctuations.

Figure 2 shows course duration for the 11 BAC serials. The average durations obtained with the tool (shown with triangles) generally track the observed durations (shown with diamonds). The error bars are for the 5th and 95th percentiles. There are instances where the two curves diverge significantly. These are explained by temporary changes in resource availability or the school's operational procedures. For example, the last BAC serial that was actually run was a trial experiment; it was a combination of two different courses which was in the end much longer than a normal BAC course. As the objective of the simulation tool is not to replicate exactly every event that was observed but rather determine average future course duration and most significant bottlenecks, that specific one of a kind course flow was not created. Note that this figure is typical of the performance for all course flow types.

The next set of results provides information on the causes of serial delays for the scenario where five ACSO and four AESOp courses are offered per year. The results are similar for the other scenarios. Table 2 shows the number of times delays were caused by insufficient resources or external factors. For any of the school/squadron resources, a delay can be recorded not only because there is an insufficient quantity of the resource but also because there are not enough hours available for this resource due to breakdown, sickness, leave, etc. The values presented are the average number of delays per run for all serials combined over the whole period of simulation.

Table 1: Courses and serials characteristics.

Course type	Planned number of instruction days	Number of serials per year	Total number of serials for the simulation
BANC	215	4, 5 or 6	28
ACSO	145	4, 5 or 6	16, 20 or 24
BAC	105	2 or 3	11
BAQC	55	3 or 4	17 or 21
IAQC	73	3 or 4	17 or 21
FIC Shared	10	1	11
ACSO FIC	16	1	11
AESOp FIC	35	1	11
SANC	25	1 or 2	7
Total		11 to 17	129 to 145

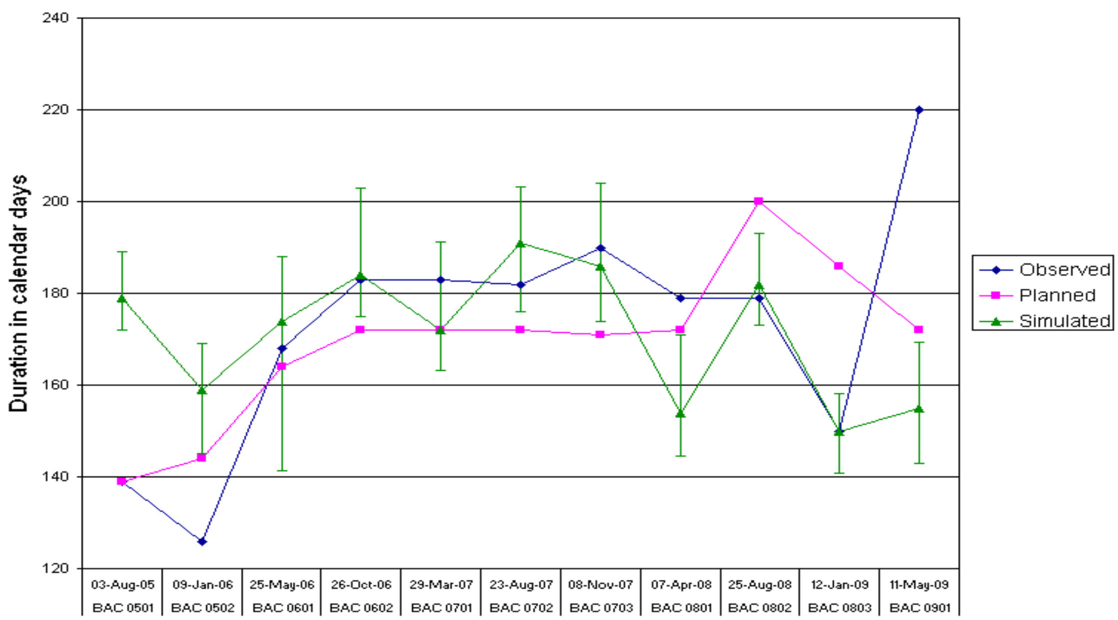

Figure 2: Course duration for BAC serials

In the left portion of Table 2 (the cumulative columns), all possible causes for a delay were taken into account. For example, for a flying mission, if on a specific day, the weather was bad, no aircraft was available and all the instructors were assigned to other serials, then a delay would be counted for each of these three causes. In the right portion of the table (the hierarchical columns), only one cause was recorded for each delay. Since there could be multiple possible causes for a delay, a hierarchy of causes has to be used and, of all possible causes observed on a specific day, the cause that sits highest on the list is the one recorded. Such a hierarchy is useful to separate external causes on which the school has very limited control from the causes on which it could be possible to act. The hierarchy can also bring to light some interdependencies between resources. The hierarchy that was used for the simulation is the one shown in Table 2. For the flying mission example cited above, the cause that would be recorded out of the three would be weather as it is the one that is closer to the top of the list. As only one cause per delay is recorded, the total number of occurrences is smaller for the hierarchical column. The second percentage column in the cumulative section has been obtained by dividing the occurrences in the cumulative section by the total number of delays in the hierarchical section. This gives a more precise indication of how frequently a cause may be the reason for a delay.

Table 2: Statistics for causes of serials delays for five ACSO and four AESOp courses per year.

	Cumulative			Hierarchical	
Delay Causes	Number of occurrences	Percent. of cum. total	Percent. of hier. total	Number of occurrences	Percent. of hier. total
Weather	299	6.6%	9.0%	299	9.0%
Student Sickness	21	0.5%	0.6%	21	0.6%
Aircraft	1863	41.1%	56.5%	1767	53.6%
Flight crews	811	17.9%	24.6%	49	1.5%
Simulators	181	4.0%	5.5%	180	5.5%
ACSO Instructors	392	8.6%	11.9%	108	3.3%
AESOp Instructors	154	3.4%	4.7%	99	3.0%
Met Instructors	170	3.8%	5.2%	135	4.1%
Remedials & Refreshers	641	14.1%	19.4%	641	19.4%
Total	4533			3300	

The main causes for serial delays when looking at the cumulative columns are: aircraft, flight crews and remedials/refreshers. Secondary causes are: ACSO instructors and weather. When looking at the hierarchical columns, the main causes of delays are: aircraft, remedials/refreshers and to a lesser extent, weather. All other causes are much less frequent. The major impact of recording the causes differently is that flight crews are seen as a very minor cause of delays with the hierarchical method. This indicates that very often, when there is not enough flight crew time to complete all the flights on a day, then there is likely not enough aircraft hours either; however, only the aircraft is recorded as a cause of delay as it is positioned higher in the hierarchy.

The results shown in Table 2 help the school quantify the importance of the scarcity of some of its resources as the cancellation statistics it traditionally produces are not appropriate for the task. This is mainly due to the fact that these statistics are based on what has actually been scheduled rather than what could have been scheduled. What is meant here is that the simulation tool is not trying to find out why cancelled missions were cancelled but rather why missions could not be scheduled in the first place. The tool highlights the bottlenecks of the system. One obvious illustration of the inadequacy of the cancellation statistics is when a plane is broken for a few days, the scheduler knows that and does not schedule flights for the plane and thus no cancellations are registered for this plane. In contrast, the tool will consider the broken plane as a possible cause of serial delay (as no flights could be scheduled on it) and it will register a delay for any serial that was due to fly and could not be scheduled.

Table 3 shows statistics about course duration for the different scenarios, combining four to six ACSO serials per year with three or four BAQC and IAQC serials per year. The first row with entries shows the number of training days that were planned for each of the courses. As can be seen the average BAQC and IAQC course durations are quite stable over the range of scenarios. This was to be expected as these courses were given priority. On the other hand, the average ACSO course duration varies slightly as the number of serials of either type is increased. However, the change is not very significant: only a 13 training days difference between the most and the least demanding scenarios. This means the school can handle a larger number of students per year without too much impact on the course duration. What is more interesting is the average length obtained compared to the planned duration. For BAQC and IAQC, the obtained durations are quite close to the planned numbers: 7 days shorter and 5 days longer respectively. However, the average durations for the ACSO are significantly longer, even for the least demanding scenario which is 27 training days longer. For the most demanding scenario, the courses are two full months longer. This is a significant result for the school as students will have to spend much more time than anticipated in training.

Figure 3 provides detailed information about specific ACSO serial duration for the most demanding scenario. The box plot displays the 1st and 3rd quartiles. The horizontal markers on the vertical bars are the 5th and 95th percentiles and the extremities are the minima and maxima for each serial. The curve shows mean values. As can be seen, the variations are significant from one run to the other and extreme values can be quite large. This shows how the various factors affecting the operations of the school can combine to have very disruptive effects. This scenario does not even consider the case where one of the aircraft may be unavailable for a long period such as mid-life upgrade. In practice, when the school experiences one of these wild variations it often decides to not offer one of the serials. Another point that is worth mentioning is the cyclic nature of the course duration over the year. Serials that start in May are always the longest while those that start in January are usually the shortest. This is mainly explained by the timing of the flying-intensive phase of the serial which coincides with the short winter days for the May serial and with the long summer days for the January serials. Similar graphs were produced for the BAQC and IAQC courses showing the same effects but to a somewhat lesser extent.

Table 3: Course duration for different scenarios.

		Course duration					
Number of serials per year		Training days	Calendar days	Training days	Calendar days	Training days	Calendar days
ACSO	AESOp	ACSO		BAQC		IAQC	
Planned duration		145		73		55	
6	4	185	279	66	97	60	88
5	4	180	271	66	98	59	87
5	3	176	265	65	97	61	87
4	4	175	265	65	97	59	86
4	3	172	261	65	96	60	87

As aircraft availability was found to be the major source of delays, and by far, a sensitivity analysis of this resource was performed for course duration. Currently, the school is allocated two planes but these are subject to failures. On average, one aircraft is unavailable one day every week and one aircraft is unavailable for a week every 3 months. Table 4 shows the impact of the availability of the planes on course duration for the scenario of five ACSO and four AESOp courses per year. Having two planes fully available every day has a significant impact. The average duration for IAQC courses is reduced by about a week and for ACSO by close to 3 weeks. The durations of all courses still show large variations but not as much when the availability is higher. The extreme cases are much reduced. The spread for duration of an ACSO serial has been reduced from 124 to 80 days.

Table 5 presents the causes of delays when the two aircraft are always available. The table shows similarities to Table 2: first, aircraft, flight crews and remedials/refreshers are the main causes for the cumulative columns with weather and ACSO instructors as secondary causes, and second, flight crews stop being a major cause of delays when causes are considered in a hierarchical manner. Note, however, that remedial/refreshers are now a cause of delays as significant as aircraft.

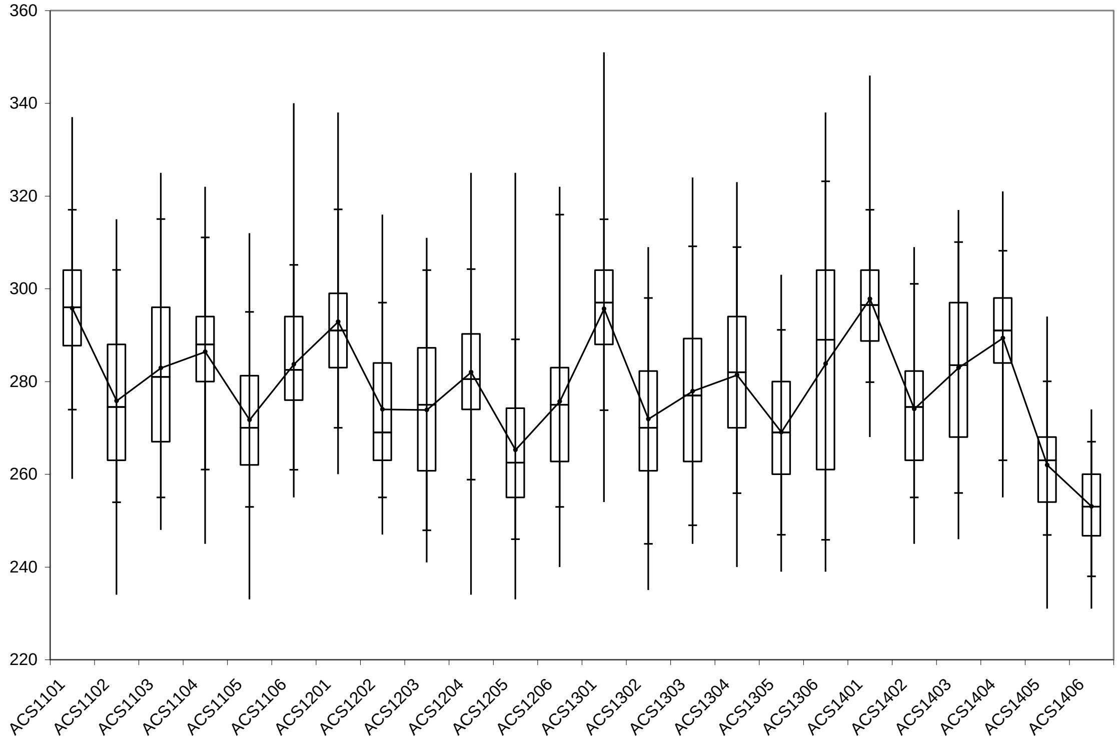

Figure 3: ACSO course duration for the most demanding scenario

Table 4: Course duration results with varying A/C availability (in calendar days).

	Current A/C Availability			Full A/C Availability		
Course Flow Type	ACSO	BAQC	IAQC	ACSO	BAQC	IAQC
Planned	218	110	83	218	110	83
Overall Minimum	221	84	69	211	85	63
Average Minimum	239	89	71	223	89	66
Average	270	98	87	250	96	80
Average Maximum	312	115	115	278	108	102
Overall Maximum	345	148	134	291	133	119
Overall Spread	124	64	65	80	48	56

The percentage of delays caused by aircraft has obviously gone down as their availability has gone up and, as the aircraft are now a much less important cause of delays, the other causes see an increase in their percentage. However, this is not the case for flight crews and ACSO instructors in the cumulative columns. This is due to the fact that delays caused by aircraft inevitably imply that flights will have to be re-flown thus creating an extra demand not only for aircraft but for flight crews and instructors. This creates the potential for additional delays for these resources. Reducing the number of delays caused by aircraft thus also eliminates some of the delays caused by flight crews and instructors. Finally, it is worth noting, that the impact of a somewhat small improvement in availability (about 14%) is quite significant: the number of delays caused by the aircraft has gone from 1767 to 567 (a reduction of 68%). Overall, the number of delays has dropped from 3300 to 1860 (a reduction of 44%). This is another sign that the aircraft availability is a very significant bottleneck for the school.

Table 5: Statistics for causes of serials delays for five ACSO and four AESOp courses.

	Cumulative			Hierarchical	
Delay Causes	Number of occurrences	Percent. of cum. total	Percent. of hier. total	Number of occurrences	Percent. of hier. total
Weather	220	9.4%	11.8%	220	11.8%
Student Sickness	19	0.8%	1.0%	19	1.0%
Aircraft	594	25.3%	31.9%	567	30.5%
Flight crews	354	15.1%	19.0%	56	3.0%
Simulators	128	5.5%	6.9%	128	6.9%
ACSO Instructors	189	8.1%	10.2%	85	4.6%
AESOp Instructors	119	5.1%	6.4%	87	4.7%
Met Instructors	152	6.5%	8.2%	126	6.8%
Remedials & Refreshers	571	24.4%	30.7%	571	30.7%
Total	2346			1860	

5 CONCLUSION

A tool has been built that allows for realistic simulation of the school operations. It has been used to obtain useful insights on causes of delays and course durations. The simulations clearly showed that aircraft and flight crew availabilities are the most significant “controllable” bottlenecks for the school. Remedials/refreshers are also a significant cause of delays. However, these cannot be easily controlled as they depend on the strength of the students or are caused indirectly by other delays. The simulations also showed that planned course durations should be increased for ACSO serials to obtain more reliable expected graduation dates. The results were instrumental in helping decision makers select an appropriate plan for implementation of the new program for the first year. The tool will now be used to study how best to mitigate the cyclical variation in course duration and verify if synchronization of serial start dates and instructor posting could have a beneficial effect.

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AUTHOUR BIOGRAPHY

RENÉ SÉGUIN holds a Ph.D. in Operations Research from the University of Montréal. Since 2002, he has been a Defence Scientist in the Centre for Operational Research and Analysis of Defence Research and Development Canada. He is currently working on training issues with 2 Canadian Air Division in Winnipeg, MB. He is an associate editor of *INFOR*. His current research interests are resource allocation, scheduling and simulation. His email address is rene.seguin@drdc-rddc.gc.ca.