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EFFECTIVENESS OF DISTRIBUTED DECISION (CROWDSOURCING) WILDFIRE DETECTION

EVALUATION OF THE HUMMINGBIRD NETWORK SMOKE DETECTION SERVICE

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February 2020

Not restricted

ABSTRACT:

Wildfire agencies are interested in new methods and technologies to improve wildfire detection and minimize wildfire impacts. Hummingbird Network is a commercial service that uses crowdsourcing to detect visible smoke. Several interested wildfire agencies requested FPInnovations to evaluate the effectiveness of the Hummingbird Network detection system in an operational environment.

301013106: EFFECTIVENESS OF DISTRIBUTED DECISION (CROWDSOURCING) WILDFIRE DETECTION
TECHNICAL REPORT NO. 6 (2020)

ACKNOWLEDGEMENTS
The project was supported by Alberta Agriculture and Forestry, BC Wildfire Service, and Hummingbird Network. The author would also like to thank following individuals: Michael Kakoullis, Jesper Albrecht, Jesse Spidell, Charles Walton, Cassie Corbin, Kim Kasper, Robert Atwood, Richard Sullivan, and Tanner Graham. Special thanks go to the Slave Lake and Lac La Biche initial attack crews, and Dustin Eissle-Lawrence for lighting up the test smokes.

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INTRODUCTION

Wildfire agencies often use multiple detection methods according to their needs and geographic challenges. The primary goal of all detection systems is to detect wildfires early and respond in an appropriate manner to limit the resulting loss. Exploring new and innovative detection technologies is paramount to improving wildfire detection.

The Alberta Agriculture and Forestry (AAF) *Lookout Observer Manual* (2015) states that there are two types of detection categories: planned and unplanned. Planned detection utilizes wildfire agency internal resources and/or external contractors to detect wildfires within a pre-determined area and time frame. Planned detection includes the use of fire lookouts, as well as aerial and ground patrols. Unplanned detection includes the reporting of fires through other resources, such as the public and industry personnel.

Hummingbird Network, a British Columbia company, presented its crowdsourcing wildfire detection concept (the Hummingbird Network Smoke Detection Service) during the 2016 Wildland Fire Canada conference. In January 2017, as a follow-up to the conference, Hummingbird Network provided a live demonstration to AAF, BC Wildfire Service, and FPInnovations in Edmonton, Alberta. After a successful demonstration, and at the request of the wildfire agencies, FPInnovations committed to working with Hummingbird Network to provide an evaluation of its wildfire detection system.

The objectives of this report project are as follows:

1. Develop methodologies to evaluate the effectiveness of the crowdsourcing wildfire detection concept as a smoke detection method in an operational environment.
2. Understand the Hummingbird Network Smoke Detection Service by analyzing and comparing the service with other existing wildfire detection methods.
3. Suggest improvements in areas to enhance the performance of the Hummingbird Network Smoke Detection Service and success in an operational environment.

THE HUMMINGBIRD NETWORK SMOKE DETECTION SERVICE

The Hummingbird Network Smoke Detection Service is a commercial venture that provides smoke detection as a service. Unlike traditional planned detection methods, in which smoke is visually detected and then reported to a forest dispatch centre, the Hummingbird Network Smoke Detection Service utilizes remote cameras to capture smoke images on the landscape, and then transmits those images over the Internet to its crowdsourcing engine for analysis. Once a smoke is confirmed, the appropriate forest dispatch centre is contacted with the information. Figure 1 illustrates the elements and the data flow of the service.

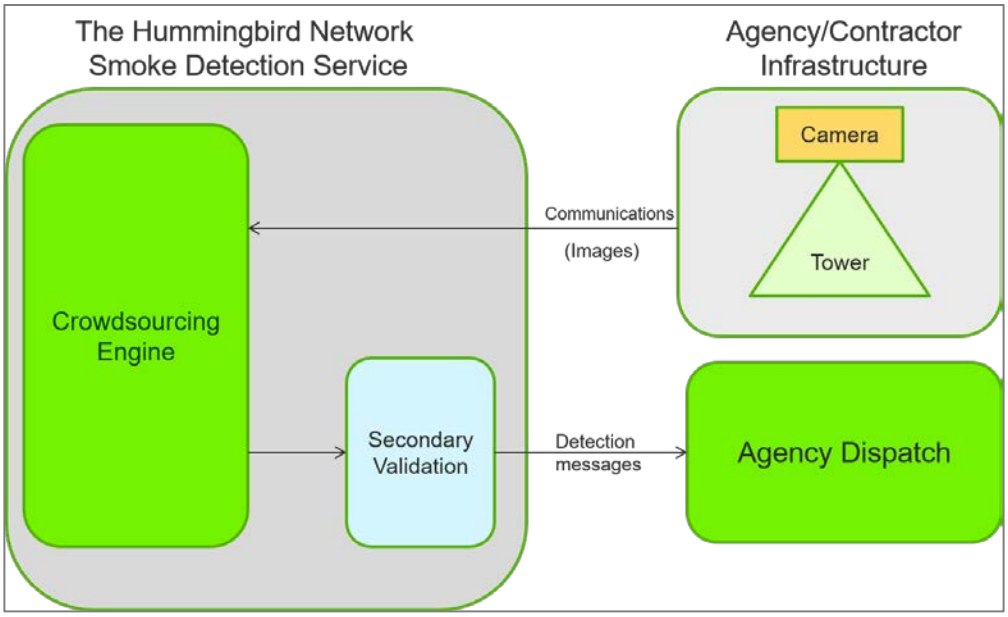


Figure 1. The elements and data flow of a detection system that uses the Hummingbird Network Smoke Detection Service.

The crowdsourcing engine within the Hummingbird Network Smoke Detection Service consists of paid workers and volunteers, depending on the platform used. The paid workers are referred to as “turkers” and must register with a crowdsourcing service provider, such as Amazon. The volunteers work because of their interest in wildfire, and they register with Hummingbird Network directly.

Turkers and volunteers are Internet workers worldwide, most of whom are residents of the United States. Although their identities are known to Hummingbird Network, they remain anonymous to the agency soliciting the service.

The crowdsourcing engine looks for smoke signatures on images to identify fires. When an image arrives at the crowdsourcing engine, a pre-set number of assigned turkers and/or volunteers examine the image simultaneously and deliver their individual results (as “true” or “false”). If the results from the crowdsourcing engine are positive, a secondary validator within the Hummingbird Network Smoke Detection Service confirms the find and sends a detection message to the agency dispatch centre. For more information on the Hummingbird Network Smoke Detection Service, visit https://www.hummingbirdnetwork.com.

METHODOLOGY

The Operational Trial Time Frame

The operational trials conducted in Alberta during the 2017 and 2018 fire seasons used various tower locations and camera configurations. The 2017 trial occurred from August 14 to September 20, and the 2018 trial occurred from August 1 to September 30. Both trials operated from 08:00 to 20:00 daily.

Camera Configuration and Image Transfer

During the 2017 trial, AAF provided access to a communications tower and five Ascendent 12MP-B-IR-416-MZ-AVA-CS cameras[1] mounted 100 m above ground level. All cameras were digital IP cameras with high definition and zoom capability, but they lacked pan and tilt functions. Cameras were positioned and pre-set to no zoom (1-power zoom setting), which provided an 80° field of view with slight frame overlap and 360° coverage.

With the AAF Telecommunications section's help, a network connection was established between the Hummingbird Network Smoke Detection Service and the cameras via a cellular modem. Hummingbird Network then set up an automatic batch process to capture images from five cameras on rotational time intervals. Once taken, the images were then transferred to the crowdsourcing engine for analysis.

For the 2018 trial, AAF provided access to three different lookout towers, each equipped with a high-definition digital IP camera with pan, tilt, and zoom capabilities and pre-set to no zoom. The AAF Telecommunications section established a batch process to rotate the cameras to pre-set positions, providing 360° coverage. The batch process also captured images and transferred them to an FTP site, where the Hummingbird Network Smoke Detection Service accessed the images and forwarded them to its crowdsourcing engine for analysis. Table 1 provides a breakdown of the camera model used on each tower and the number of pre-set camera positions required by each to provide 360° coverage.

Table 1. Towers, camera models, and number of pre-set positions for the 2018 trial

Camera location[a]	Camera model	Number of pre-set positions
Tower A	AXIX Q6045-E Mk II[2]	7
Tower M	AXIX Q8665-E[3]	6
Tower H	AXIX Q6045-E Mk II	5

a Tower locations not identified for security reasons

AAF directed the FPInnovations researcher to examine the image configuration and transfer process for future detection system integration considerations.

Use of Existing Versus Artificial Smoke

Possible existing smokes from wildfires, permits, and unplanned sources provided the necessary samples to evaluate the Hummingbird Network Smoke Detection Service. However, in some instances a smoke generator and controlled brush burning (Figure 2) had to be used to produce artificial smokes to augment the sample size. AAF wanted to identify the pros and cons of each method during the trial for future detection audits.

[1] https://www.ascendentgroup.com/store/configure/12MP-B-IR-416-MZ-AVA-CS/339
[2] https://www.axis.com/en-ca/products/axis-q6045-e
[3] https://www.axis.com/en-ca/products/axis-q8665-e

Figure 2. Artificial smoke produced by a smoke generator *(left)* and controlled brush burning *(right)*.

Smoke Discovery Process

The smoke discovery process involved the collection of camera images and image analysis by the crowdsourcing engine before secondary validation and dispatch notification. Identifying issues or difficulties in executing these steps provide important insight into system evaluation and potential system improvements.

Detection Reporting Process

Once the secondary validator confirmed the smoke in an image, the validator called the forest dispatcher to relay basic detection information, including the location of the tower and camera, and the bearing from the camera to the smoke. The secondary validator then followed up by sending an email containing an image of the smoke to the forest dispatch centre and to FPInnovations. The email contained specific detection information, including the reporting source, time that dispatch was called, tower name, time of smoke detection, and the bearing from the tower, as well as any relevant comments, such as georeferenced information (i.e., landmarks and approximate distance from the tower). This process is similar to how a lookout observer reports a smoke, where the initial notification is made to the dispatch centre and contains basic information, allowing the centre to quickly dispatch resources. This is then followed by a formal detection message, which captures and documents all relevant event information.

Detection Message Classification and Analysis

FPInnovations collected all detection messages submitted by the Hummingbird Network Smoke Detection Service, lookout observers, and public reporting over the course of the study. Detection messages underwent an accuracy check before being labelled as a) a detection success, b) a false positive alarm, c) a false alarm, or d) a detection failure. The compiled results helped to understand the ability of the Hummingbird Network Smoke Detection Service to detect smoke over the lengthy operational trial.

Detection successes included all smoke events detected and reported by Hummingbird Network, excluding false positive alarms and false alarms. False positive alarms included known or permanent smoke events (e.g., fire permits and industrial smoke). However, for the purpose of the study, and because Hummingbird Network did

not have access to information about fire permits and industrial smoke, the first reporting of a known or permanent smoke event was designated a detection success, and the second or additional reporting of the same smoke was marked as a false positive alarm. False alarms were errors or phenomena that resembled smoke, such as dust or shadows. Detection failures included all smoke events missed by the Hummingbird Network, and reasons for these failures were analyzed later.

Timeline Analysis

When conditions are favourable, the size of a wildfire can grow dramatically over a short period. The ability to discover wildfires early and forward detection messages quickly is critical. Understanding the time segments within the information transfer process would allow agencies to assess performance in meeting detection objectives.

Hummingbird detection messages, its smoke images, and turker reports provided the basis for measuring system performance. Simultaneous collection of AAF planned and unplanned detection messages, as well as additional camera images and ground-truthing information provided additional data and benchmarks to further assess the performance of the Hummingbird Network Smoke Detection Service. For the purpose of this trial, the information transfer process was broken down as shown in Figure 3.

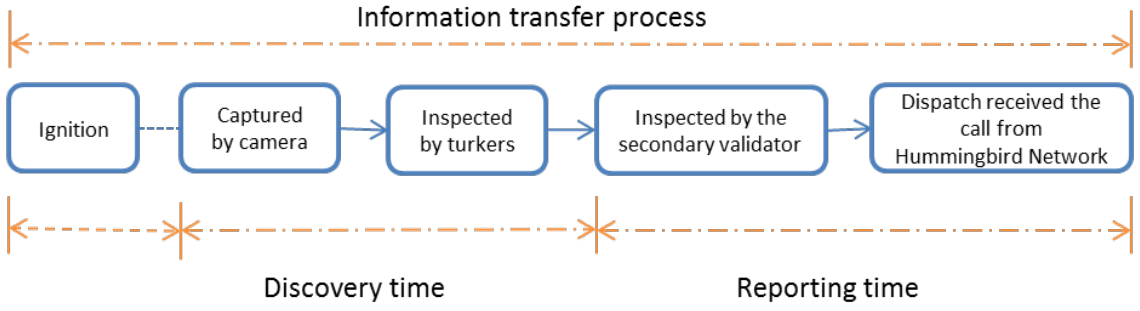


Figure 3. Information transfer process and reporting time.

Discovery Time

Discovery time was established by measuring the time taken to collect, transfer, analyze, and validate an image. This can be summarized into two basic steps, including:

1. Image collection, or the time taken to capture and transfer an image to the crowdsourcing engine.
2. Image analysis, or the time taken by the crowdsourcing engine to identify a possible smoke event and send a result of true or false to the secondary validator.

Reporting Time

Reporting time was established by measuring the time it took the Hummingbird Network Smoke Detection Service to notify dispatch once a smoke event was identified by the crowdsourcing engine.

Comparison of Reporting Time Between the Hummingbird Network and Lookout Observers

Reporting times from wildfire lookout observers and public reports were used to provide performance benchmarking and assist in the Hummingbird Network Smoke Detection Service evaluation. However, wildfire reports from the public did not occur in the coverage areas during the trial, so only reports from lookout observers were used for comparison. It is important to note that lookout observers were aware of smoke testing taking place within their coverage areas.

Service Availability

Service availability for wildfire detection is considered critical; therefore, system availability was examined during this trial. Hummingbird Network notified the researcher, dispatch, and the AAF Telecommunications section when service interruption occurred. Hummingbird Network then worked with the Telecommunications section to isolate and resolve the service interruption incidents. The researcher recorded the incident, or downtime, as well as the affected component(s), cause, and duration in a service log.

As per the system component breakdown provided in Figure 1, and given Hummingbird Network's reliance on system components outside its scope, service availability percentages for the Hummingbird Network Smoke Detection Service and for overall system components were calculated separately using the following formulas:

- Hummingbird Network Smoke Detection Service availability = 100% less the sum of Hummingbird Network Smoke Detection Service downtime divided by the trial period
- Overall detection system availability = 100% less the sum of all downtime divided by the trial period

RESULTS

During the 2017 trial, natural smoke events did not occur within the coverage area, so a smoke generator was necessary to produce artificial smoke for testing. However, due to road access, testing was restricted to distances more than 20 km from the camera locations, and the presence of thick haze during testing limited the ability of the cameras to capture images of the smoke. Because of this combination of circumstances, the Hummingbird Network Smoke Detection Service was unsuccessful generate any detection reports during the 2017 trial.

During the 2018 trial, 24 detection events were assessed. Events included smokes from wildfires, permit fires, permanent smokes, and artificial smokes. The use of artificial smokes generated by controlled brush burning helped increase the sample size. Appendix 1 includes all detailed detection messages generated during this period.

Camera Configuration and Image Transfer

During the 2017 and 2018 trials, camera configuration and image transfer were quickly established with help of the AAF Telecommunications section by using cellular modems and existing AAF cameras and infrastructure. No issues were encountered.

Camera Zoom Setting Effect

As stated in the Methodology section, all cameras were set at no zoom to establish an acceptable field of view and 360° detection coverage. During the study, the researcher hypothesized that a lower zoom setting could potentially affect detection success at greater distances. This theory seemed likely given general magnification principles and detection success results (i.e., eight smoke detection successes were found within 20 km versus only one discovered beyond the 20 km range). However, given the logistics involved in testing this theory, all camera settings remained at no zoom for the duration of the study.

Georeferenced Smoke Location

During this study, the Hummingbird Network Smoke Detection Service did not have the ability to provide the exact smoke location in latitude and longitude. Instead, it provided the bearing from the centre of camera's field of view. The dispatcher received this information and used this bearing and the bearing from an adjoining tower to complete a cross-shot to establish the smoke location.

Use of Existing Versus Artificial Smoke Events

In this study, the researcher first collected data from existing smokes and increased the sample size using artificial smokes. The pros and cons of both methods were identified during the trial and are listed below.

Existing Smoke

- Pros
    - Existing smokes made the discovery of smokes unpredictable.
    - Larger existing smokes provided an opportunity to test at greater distances.
- Cons
    - Smoke size was difficult to quantify.
    - Smoke ignition times were difficult, if not impossible, to identify.

Artificial Smoke

- Pros
    - Artificial smoke was easy to create; two people were required to run the smoke generator and three people were needed for brush pile burning.
    - The source size of an artificial smoke could be easily measured.
    - Ignition times were controlled and measurable down to the second.
    - According to fire crews assisting in the trial, the size of an artificial smoke was more representative of a small initial-attack fire.
- Cons
    - Anticipation of artificial smoke generation may have influenced detection efforts.

Smoke Discovery Process

The smoke discovery process of the Hummingbird Network Smoke Detection Service differed from traditional fixed and mobile smoke discovery processes in that there are additional steps. In the Hummingbird process, images must first be captured and then transferred to a crowdsourcing engine via the Internet for smoke identification before being sent for secondary validation. In a traditional fixed or mobile smoke discovery process, smoke is visually identified by the discovery agent and then reported. Actual smoke location is determined using several methods, depending on the agent (i.e., cross-shots in the case of lookout observers, GPS coordinates in the case of mobile detection, and description in the case of public reporting). The additional time associated with the Hummingbird Network Smoke Detection Service seemed short, but it added up in the overall assessment. Actual smoke location could not be determined during initial discovery beyond providing a camera bearing.

Other points noted in the smoke discovery process evaluation included would improve the detection results:

- The ability to magnify a smoke signature by some discovery agents (e.g., the use of binoculars by fixed and mobile discovery agents).
- The ability to observe a smoke signature over a period of time by some discovery agents (e.g., fixed and mobile detection agents are able to distinguish intermittent smoke or smoke movement, which could be missed or is not possible in a single smoke image).

Detection Reporting Process

After identifying a smoke, lookout observers radio dispatch to report the event. The first radio call only contains enough information to dispatch a fire crew; this information could include the bearing, distance, and a size estimate of the fire. After the initial call, lookout observers fill out a detection report form. The detection report form contains additional fields for describing the smoke, such as colour, size of column, and drift. After filling out the form, lookout observers then contact dispatch to relay the additional information.

During the trial, the initial call procedure was similar. The secondary validator of the Hummingbird Network Smoke Detection Service called dispatch by telephone to report a smoke. The initial call contained the tower name and the bearing of the smoke, which is enough information to dispatch wildfire crew.

The follow-up procedure was simplified during the trial. The secondary validator of the Hummingbird Network Smoke Detection Service sent an email to dispatch; the email specified the tower name, bearing, and time of the phone call of the initial report. The image of the smoke was attached to the email. The smoke was then marked with a red rectangle on the image.

At the project planning stage, Hummingbird Network was provided the detection report forms and was expected to follow the same procedures and data requirements. However, it was found there was no need to fill out the form to gather additional visual representation of smokes for reconstruction because the dispatcher saw the smoke directly in the image.

Detection Message Classification and Analysis

The study assessed 24 detection messages, including 9 detection successes, 14 detection failures, and 1 false positive alarm. Detection of false alarms did not occur during the study. Appendix 1 provides detailed information of the 24 smoke detection messages, their results, and associated comments. Appendix 2 contains detection messages reported by the Hummingbird Network Smoke Detection Service during installation, but these were not included in the results because they occurred outside the trial period.

Detection Successes Reviewed

The study encountered 9 detection successes; smoke signatures were visible in all nine.

False Positive Alarms Reviewed

The study encountered only 1 false positive alarm. The detection message generated from the smoke was associated with a permanent gas plant (i.e., a permanent smoke).

Detection Failures Reviewed

The study reviewed 14 detection failures. Smoke was not visible in 10 of the 14 failures encountered. In 1 of these 10, smoke was not visible due to the presence of a pole that obstructed the camera's view. In 2 of the 14 failures, the researcher discovered faint smoke signatures while reviewing the failures. For these 3 failures, very faint smoke signatures existed, and the failures occurred as a result of the small signature size and smoke dissipation within the intervals during which the camera took the next image. Confusion with a known permanent smoke accounted for another detection failure. Failed secondary validation accounted for the final detection failure; this involved a decision not to report due to cooler and damp weather and a reduced fire hazard.

Timeline Analysis

An analysis of smoke discovery and reporting times was undertaken during the study. However, the data set collected was deemed insufficient, and the following results are provided as a reference to the trends established within the study.

Discovery Time

Actual wildfire ignition times are often difficult to establish, making it very difficult to determine the true discovery timeline. For the purpose of this study, 3 artificial smoke records were used to calculate the discovery times of

the Hummingbird Network Smoke Detection Service; these were captured in Table 2, with detection record numbers 17, 19, and 21.

The time taken by a turker to discover smoke on an image is the performance measure used by the crowdsourcing engine to detect smokes. Table 2 also represents the 9 records of detection success.

Table 2. Summary of discovery time

Detection record number[a]	Ignition time	Time[b] smoke showed on image	Time of turker report	Time for turker to discover smoke on image	Discovery time from known ignition	Number of image sequence(s) missed before successful detection
3		09:12:31	09:23:58	00:11:27		1
7		16:22:00	16:24:32	00:02:32		0
8		10:12:31	10:13:15	00:00:44		0
9		10:32:11	10:33:19	00:01:08		0
10		10:42:31	10:43:21	00:00:50		0
17	15:32:00	15:52:31	15:54:11	00:01:41	00:22:11	0
18		13:05:00	13:50:31	00:45:31		3
19	10:50:00	11:20:31	11:21:10	00:00:39	00:31:10	0
21	14:05:00	14:10:31	14:22:15	00:11:44	00:17:15	1
Average				00:08:28		
Standard deviation				±00:13:46		

a Used as the record reference in Appendix 1
b All times reported in hh:mm:ss

The average time between a smokes showing on an image and the time of a turker report was 00:08:28 (hh:mm:ss), with a standard deviation of ±00:13:46. The number of image sequences missed before successful detection was also determined. The crowdsourcing engine detected smokes successfully six times during the first round of images, twice in the second round of images, and once in the fourth round of images. Using the 6 detection events in which the crowdsourcing engine detected smokes successfully in the first round of images, the average discovery time was 00:1:16, with a standard deviation of ±0:00:40. The fast discovery time shows that turkers are efficient in finding and reporting smoke if a smoke appears on an image.

Reporting Time

Reporting time captures the time it took the Hummingbird Network smoke secondary validators to notify the forest area dispatcher. The 9 records used to capture reporting times are summarized in Table 3.

Table 3. Summary of reporting time

Detection record number[a]	Time of turker report (hh:mm:ss)	Time of dispatch (hh:mm:ss)[b]	Responding time (hh:mm:ss)
3	09:23:58	09:53:00	00:29:02
7	16:24:32	16:24:00	00:00:00[c]
8	10:13:15	10:21:00	00:07:45
9	10:33:19	10:51:00	00:17:41
10	10:43:21	10:50:00	00:06:39
17	15:54:11	15:55:00	00:00:49
18	13:50:31	16:24:00	02:33:29
19	11:21:10	11:25:00	00:03:50
21	14:22:15	14:38:00	00:15:45
Average			00:26:07
Standard deviation			±00:45:53

a Used as the record reference in Appendix 1

b The log only records to minutes, so all third digits are zero

c The log showed that this smoke was reported to the dispatcher at 16:24; not knowing the exact second, but knowing that the turker sent the detection result during the same minute as it was sent to dispatch, the responding time was set to 0

The results illustrated an average reporting time of 00:26:07. However, the standard deviation was high, at 00:45:53, which also shows that reporting times were not consistent.

Comparison of Reporting Time between Hummingbird Network and Lookout Observers

The 2018 study captured two detection events that were seen by both the Hummingbird Network Smoke Detection Service and lookout observer(s). In both events, Hummingbird took longer to generate a detection report. Table 4 summarizes these two examples. No public reporting was submitted during the trial period for the same coverage area.

Table 4. Differences in reporting time between Hummingbird Network and lookout observer(s)

Detection Record number[a]	Reporting time of lookout observer(s) (hh:mm:ss)	Reporting time of Hummingbird Network (hh:mm:ss)	Reporting time difference (mins)	Comments
3	09:34:00	09:53:00	19	Lookout observer had quicker reporting time
17	15:34:00	15:55:00	21	Lookout observer had quicker reporting time

a Used as the record reference number in Appendix 1

Service Availability

Service availability results for both the Hummingbird Network and the whole detection system remained high throughout the study and increased to 100% in 2018. Service availability over the course of the study is captured in Table 5.

Table 5. Hummingbird Network service availability

Trial year	Hummingbird Network service availability[a] (%)	Whole detection system availability[b] (%)
2017	98.9	95
2018	100	100

a Hummingbird Network component within the whole detection system alone

b Several factors critical to overall operation, and outside of Hummingbird Network control, did not adversely affect the study (i.e., the cameras used, tower infrastructure, and telecommunications did not affect study results)

DISCUSSION

Camera-based Detection System Considerations

The following considerations were gathered during the evaluation and can be applied to any camera-based detection system in general, not only to the Hummingbird Network Smoke Detection Service.

Telecommunication systems must be reliable and provide adequate bandwidth to allow timely image transfer.

Technical support must be available to maintain systems and limit downtime, including support for telecommunications, equipment, and other systems that may be incorporated.

Infrastructure must provide a stable platform and viewpoint on which to mount the cameras. It needs to be of sufficient height, and the mounting of the camera(s) needs to be free of all obstructions that could potentially block the camera's view.

The camera model must have the necessary functions to meet the system objectives and be robust enough to function in an operational environment.

Camera settings must be capable of providing an adequate field of view and magnification to detect smoke within 40 km. The current AAF *Lookout Observer Manual* (2015) requires a lookout observer to report a 0.1 ha fire within a 40 km radius of their lookout, with consideration given to blind and screened areas, as well as local environmental conditions. Study results indicate that most of Hummingbird Network's detection successes occurred within 20 km of the cameras, which were pre-set to no zoom during scanner routines. These results suggest that given a set of equal conditions, smoke should be more detectable at greater magnification.

Intermittent smoke detection success can also be affected by the time interval setting between images. This flaw is inherent in any detection system that does not continuously monitor an area (e.g., a lookout observer who shifts their focus). Also, increasing the power of zoom on the camera will result in increasing the frequency of the time intervals, known as turnaround time, because the number of images required for the same coverage area are increased.

The above factors highlight the importance in striking a balance between the camera's field of view, coverage, acceptable image magnification, and turnaround time.

Other factors affecting system success include:

- Accurately defining detection objectives ahead of system development.
- Developing robust detection protocols, training, and system audit parameters.

Comments from Hummingbird Network regarding this report are in Appendix 3.

CONCLUSIONS

The conclusions reached in this study are meant to answer questions directly related to the project objectives developed for the testing of the Hummingbird Network Smoke Detection Service under a specific operational environment. Future system development and testing may require adjustment to methodologies to answer the same or similar questions. The conclusions listed below are not necessarily listed in order of their appearance or importance.

- Over the course of this study, the Hummingbird Network Smoke Detection Service and its crowdsourcing concept relied heavily on existing camera systems, infrastructure, and communication systems. Although these remained outside Hummingbird Network's control, they are important considerations for future system development.
- System availability increased over the course of the study for the Hummingbird Network Smoke Detection Service, the whole detection system, and the telecommunication system it relied on. This is largely attributed to the support provided by the AAF Telecommunications section and emphasizes the need for ongoing technical support in maintaining this type of system.
- Results indicated that the Hummingbird Network Smoke Detection Service is capable of detecting and reporting smoke. Even with this, further refinements are encouraged to address the issues identified in

the study, which include detection success (this could be increased) and reporting times (these could be shortened).

- Detection failures of the Hummingbird Network Smoke Detection Service resulted from several factors, including:
    - Camera positioning (i.e., the presence of obstructions affecting smoke image capture)
    - Smoke dissipation during camera image intervals
    - Camera lens reflection
    - Camera zoom setting (i.e., lower zoom settings provide less magnification and thus, the smoke on an image appears smaller, which in turn challenges detection success at farther distances. The presence of smoke and haze also adds to this challenge.)
    - Secondary validator training (i.e., this should include an understanding of permanent smokes within the urban interface and learning about when to report a suspected smoke.)
- Discovery time analysis showed that when a smoke signature is clearly visible on an image, the crowdsourcing engine can respond efficiently. If a faint smoke was not picked up by the crowdsourcing engine in an initial image, there will be a delay in the discovery time while waiting for sequential images to show a clearer smoke signature. The delay results from the time required for the camera to make a revolution. The only way to decrease the discovery time is to increase the scanning frequency.
- The mean times and standard deviations of the reporting times were high. After consultation with Hummingbird Network, the probable cause may be related to multitasking by the secondary validator, since this person is an internal employee with other responsibilities.
- Comparing the Hummingbird Network Smoke Detection Service with other detection methods:
    - Experienced wildfire lookout personnel have higher detection success and shorter reporting time for smoke detection than the Hummingbird Network Smoke Detection Service.
    - Public reporting did not report any smoke during the trial within the coverage area.
- Study findings suggest that the following improvements may enhance overall system performance and the success of the Hummingbird Network Smoke Detection Service:
    - Increased knowledge and understanding of the Hummingbird Network Smoke Detection Service, existing agency protocols, and standard operating procedures will increase awareness and yield higher degrees of detection success. This includes parameters and operational requirements of the detection system that contains the Hummingbird Network Smoke Detection Service, as well as clear understanding of agency detection coverage areas, discovery and smoke location techniques, reporting requirements, and smoke management protocols.
    - Establishing a balance between desired detection distances, field of view, camera zoom, the number of camera pre-set positions, image turnaround time, and cost will improve system operation.
    - System development should be aimed at determining actual smoke location (i.e., the ability to georeference a smoke location).
    - System development should be aimed at differentiating between smokes that present a wildfire threat or unauthorized burning and smokes that are acceptable (e.g., permanent smokes, permits). Development should be aimed at mitigating a continuous flow of unnecessary detection messages. The presence of numerous smoke situations (i.e., smoke detection within the wildland–

urban interface) can be challenging and often requires scrutiny in terms of determining what smoke represents a wildfire or unauthorized burning. Smoke from numerous short-term and seasonal permits, as well as permanent smokes, are recorded and monitored by lookout observers on a daily basis. This provides a level of scrutiny to identify those smokes that require a detection message and, ultimately, resource dispatch. In some cases, alternative detection systems are necessary to address this need.

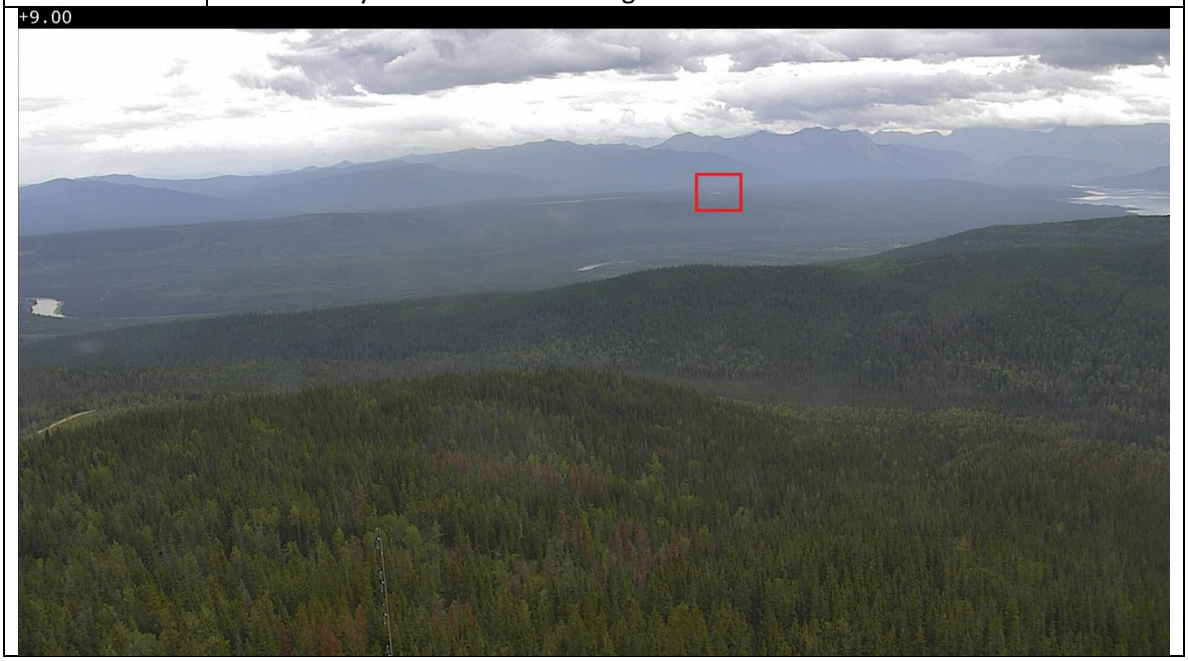
- Training on smoke recognition, reporting, and dispatch procedures is required for the secondary validator of the Hummingbird Network Smoke Detection Service to increase detection success and reporting time. Furthermore, the secondary validator needs to have local knowledge of permanent smokes and fire permits to reduce the number of false positive alarms.

REFERENCES

Alberta Agriculture and Forestry. (2015). *Lookout Observer Manual*. Hinton, AB: Hinton Training Centre.

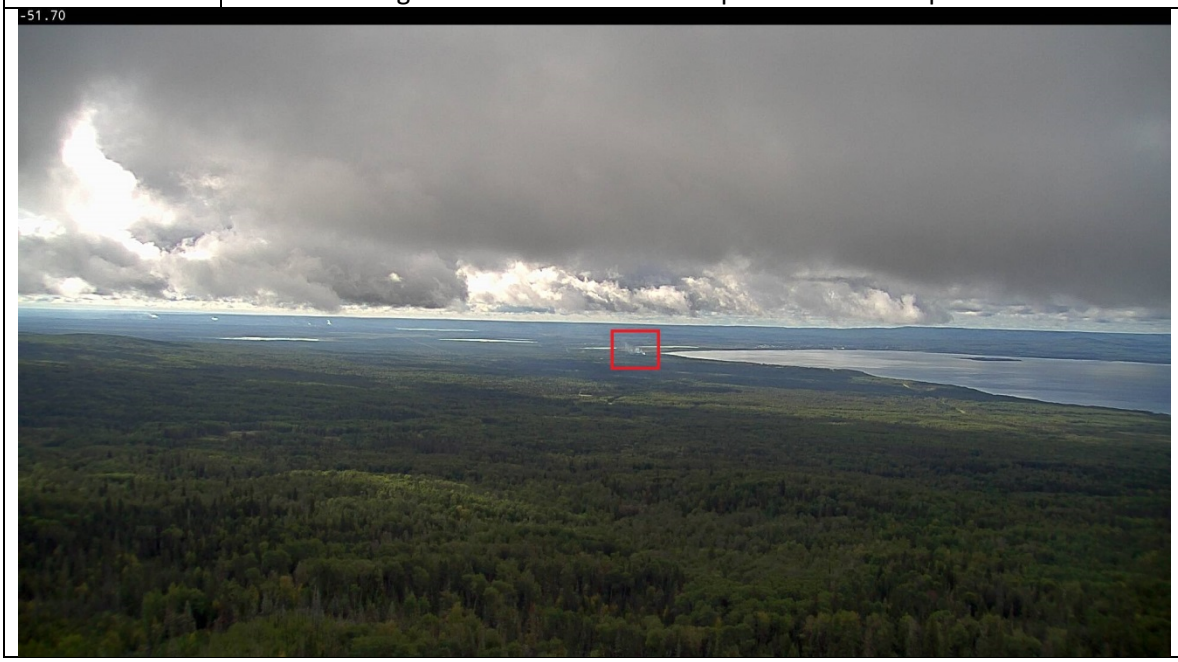
APPENDIX 1: DETAILS AND ANALYSIS OF DETECTION EVENT MESSAGES

Detection message record: 1				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
30/08/2018	A	11	Detection failure	Campfire; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	19:38:00	19:32:31	N/A	N/A
Note	This detection message was submitted by a lookout observer. Hummingbird Network did not detect nor report this smoke event (the smoke signature dissipated after one image). The smoke signature in the following image was identified by the researcher during the review.			



Detection message record: 2				
Date	**Tower**	**Distance from the tower/camera (km)**	**Result category**	**Origin and size of fire**
01/09/2018	H	35	Detection failure	Slash fire without a permit; size: 0.01 ha
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	13:28:00	N/A	N/A	N/A
Note	This detection message was submitted by a lookout observer and verified by ground crew. The smoke signature was not visible on the images.			

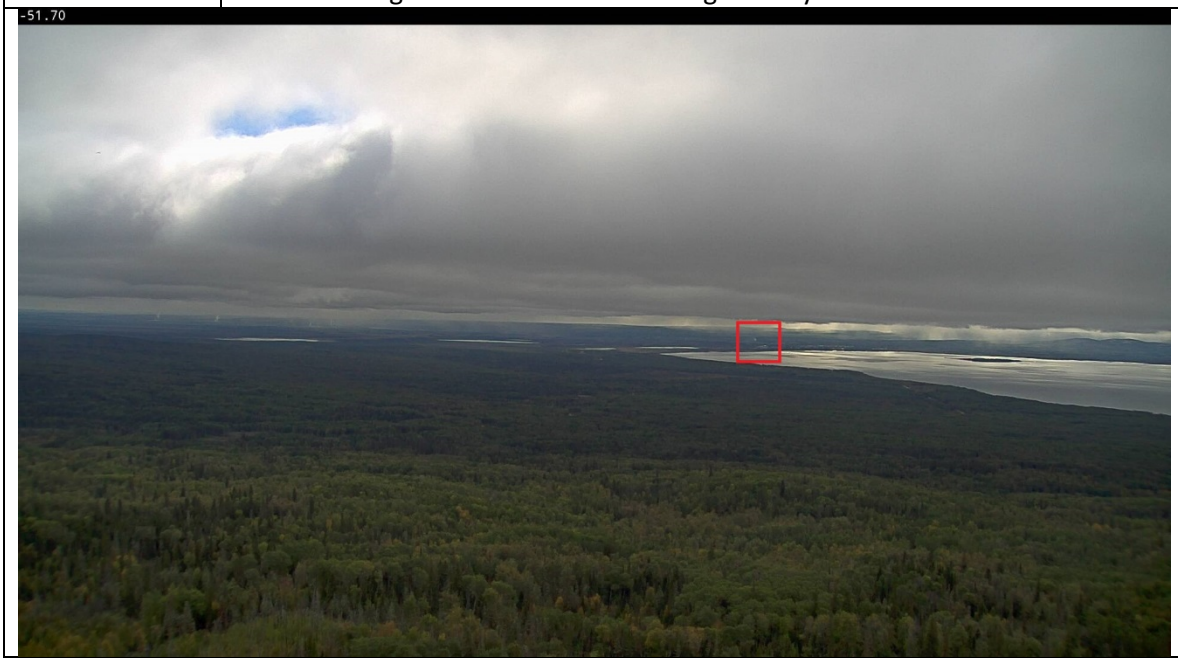
Detection message record: 3				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
04/09/2018	M	12	Detection success	Slash fire permit; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	09:34:00	09:12:31	09:23:58	09:53:00
Note	First Hummingbird Network detection report on slash fire permit.			



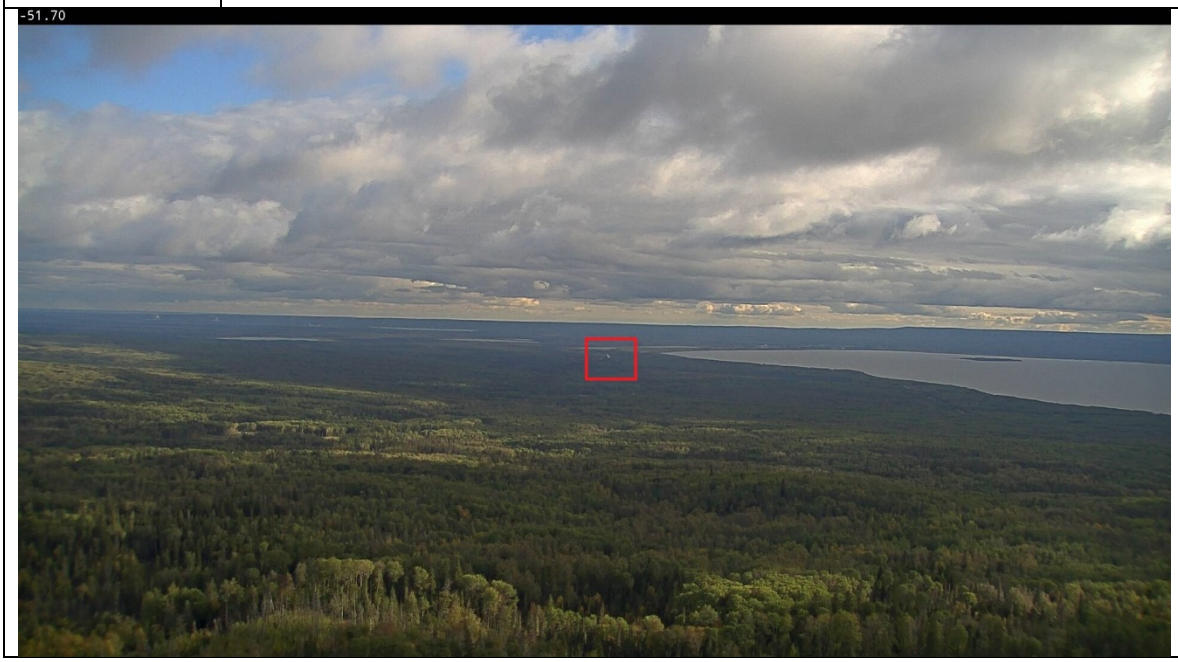
Detection message record: 4				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
04/09/2018	M	20	Detection failure	Expired slash fire permit; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	14:00:00	N/A	N/A	N/A
Note	This detection message was submitted by a lookout observer and verified by ground crew. Hummingbird Network did not detect this smoke event; it was not visible in the photo.			

Detection message record: 5				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
04/09/2018	M	7	Detection failure	Artificial smoke generated from a slash pile burning by local fire crew; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
10:42	10:43:00	N/A	N/A	N/A
Note	The camera's view of the smoke event was blocked by a metal pole on the tower structure.			

Detection message record: 6				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
17/09/2018	M	25	Detection failure	Slash pile burning; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	13:58:00	13:42:30	N/A	N/A
Note	The smoke signature shown on the image is very faint.			



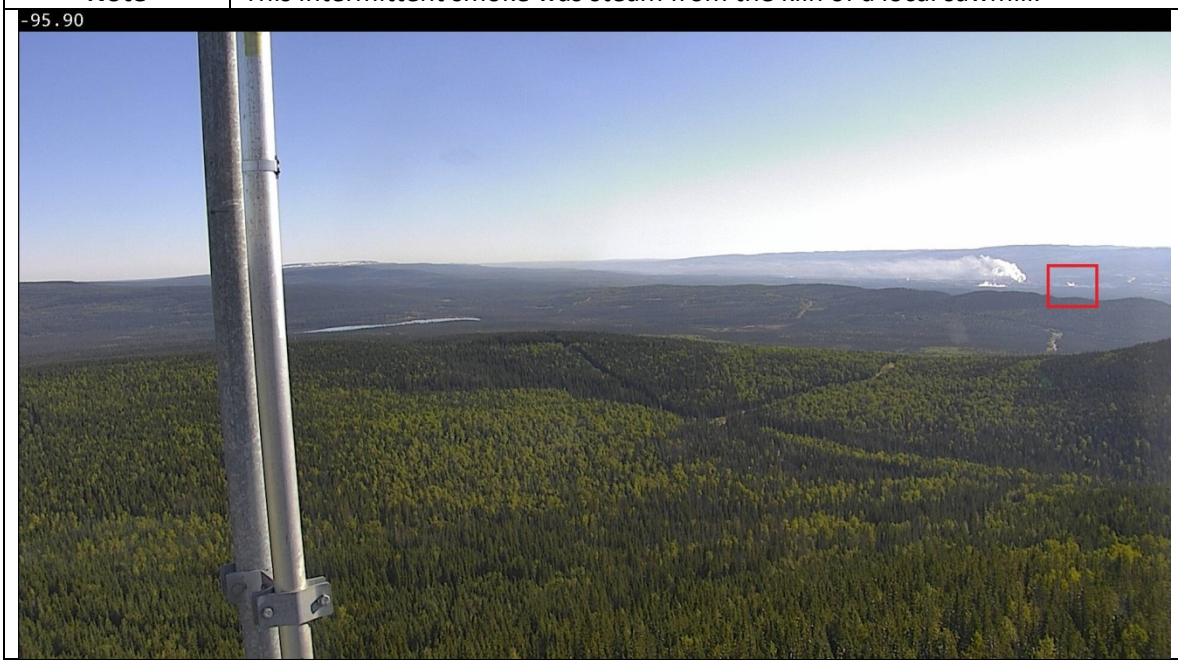
Detection message record: 7				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
18/09/2018	M	11	Detection success (first report)	Permanent smoke from gas plant; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	16:22:00	16:24:32	16:25:00
Note	This was a known permanent smoke, but Hummingbird Network had no prior knowledge of it. Therefore, it was deemed a detection success. This smoke was reported by Hummingbird Network again for the same location on September 20.			



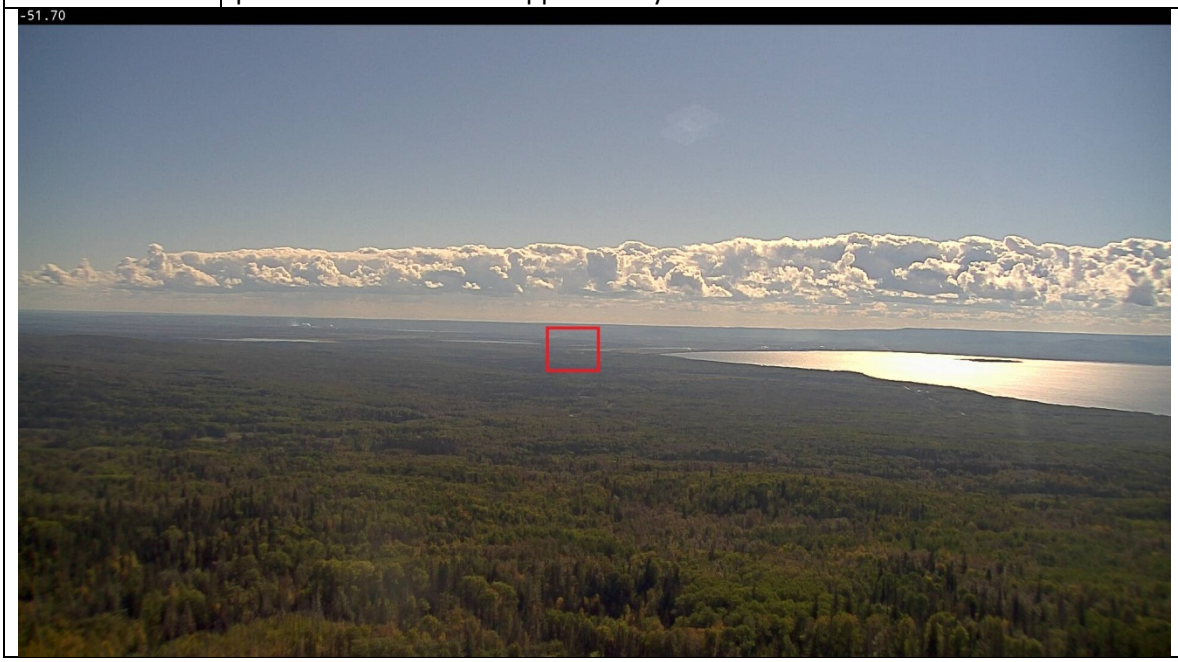
Detection message record: 8				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	A	13	Detection success (first report)	Permanent smoke from regional landfill; seasonal fire permit; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	10:12:31	10:13:15	10:21:00
Note	This was a known permanent smoke, but Hummingbird Network had no prior knowledge of it. Therefore, it was deemed a detection success.			

Detection message record: 9				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	M	21	Detection success (first report)	Permanent smoke from gas plant; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	10:52:31	10:55:50	10:51:00
Note	Hummingbird Network reported this smoke to the wrong dispatch office.			

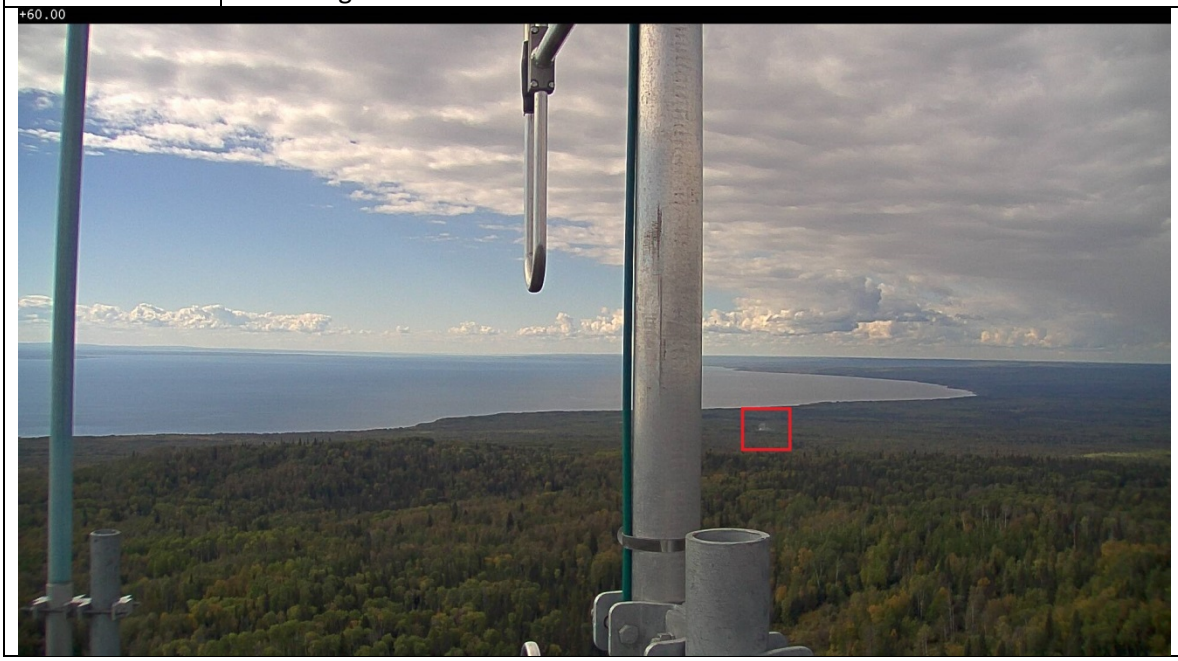
Detection message record: 10				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	A	13	Detection success (first report)	Smoke from sawmill; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	11:42:31	11:43:21	10:50:00
Note	This intermittent smoke was steam from the kiln of a local sawmill.			



Detection message record: 11				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	M	16	Detection failure	Artificial smoke from brush pile burning; size: 0.0004 ha (2 m x 2 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
13:46:00	13:50:00	14:02:31	14:03:18	N/A
Note	This smoke event was reported by a lookout observer but not by Hummingbird Network. The smoke signature on the image was located near a gas plant permanent smoke and appears very faint.			

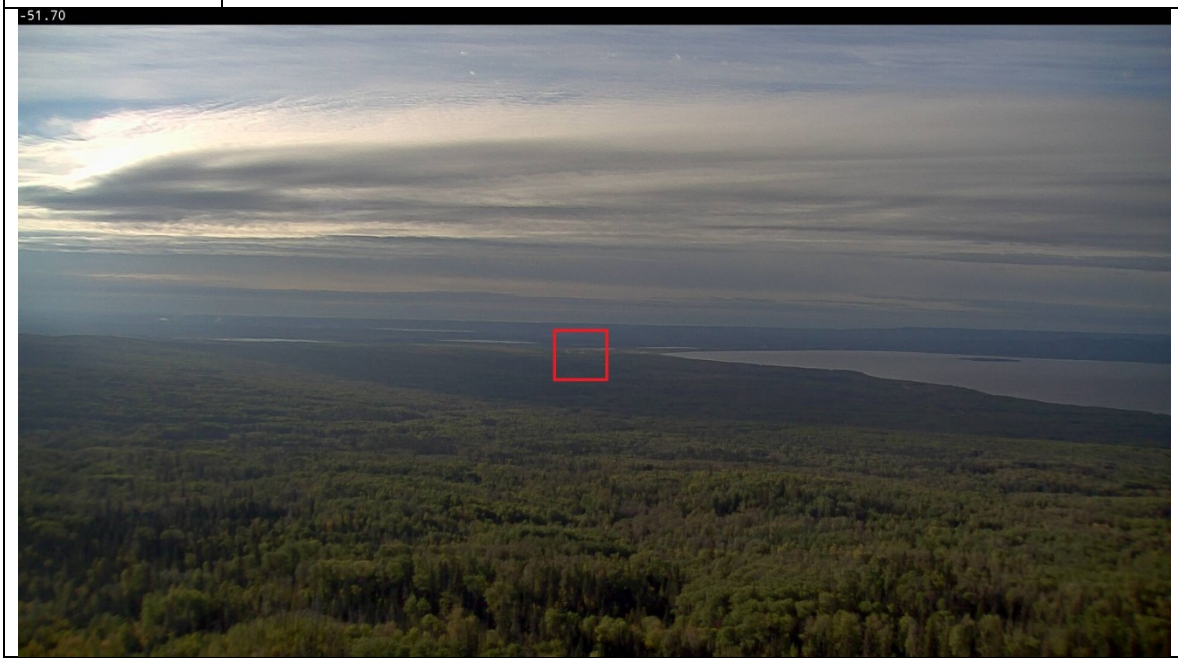


Detection message record: 12				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	M	5	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
14:41:00	14:48:00	14:52:00	15:02:31	N/A
Note	This artificial smoke was reported by a lookout observer but not by Hummingbird Network.			

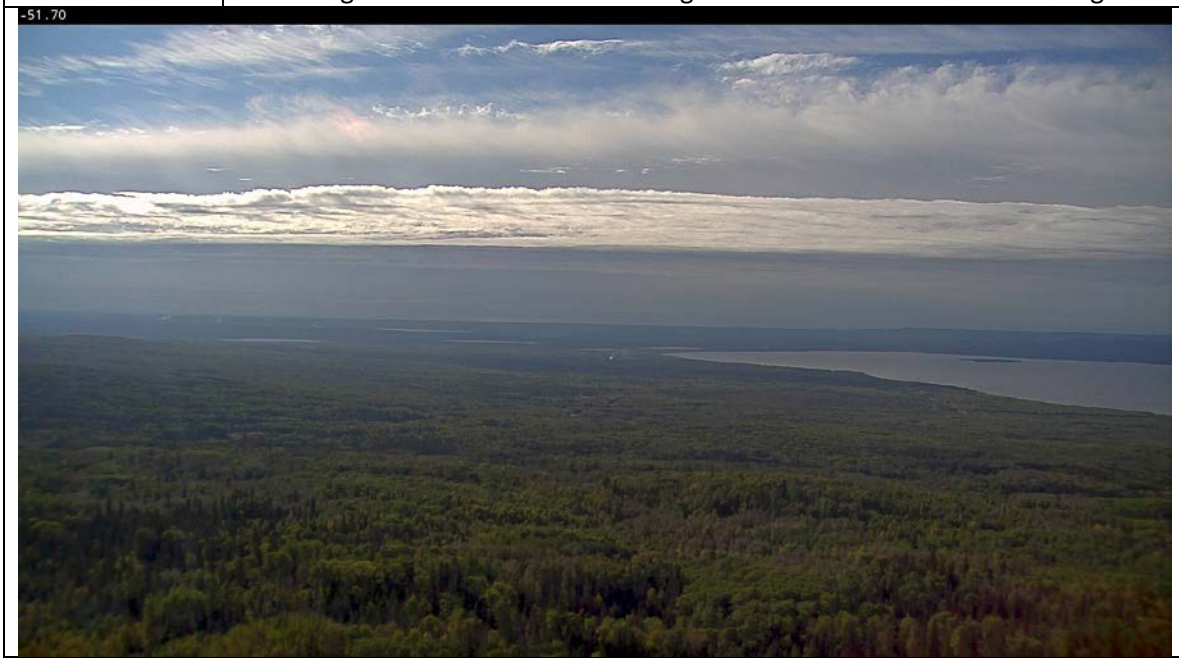


Detection message record: 13				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
19/09/2018	M	9	Detection failure	Artificial smoke from brush pile burning; size: 0.0006 ha (2.5 m x 2.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
15:31:00	15:48:00	N/A	N/A	N/A
Note	This fire was reported by a lookout observer but was not detected by Hummingbird Network. The smoke signature was not visible on the images.			

Detection message record: 14				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
20/09/2018	M	11	False positive alarm	Permanent smoke from gas plant; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	09:52:31	09:58:18	10:17:00
Note	This was a permanent smoke previously reported by Hummingbird Network on September 18. It was considered a false positive alarm as it had been detected previously, and Hummingbird Network had knowledge of this permanent smoke.			

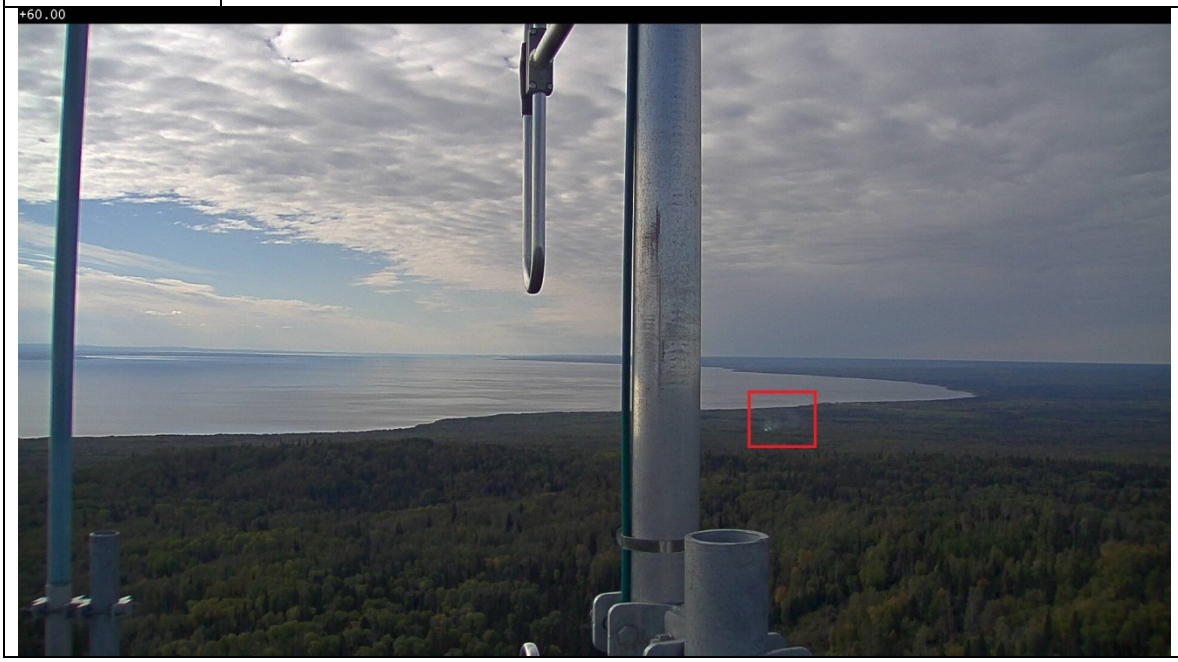


Detection message record: 15				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
20/09/2018	M	22	Detection failure	Artificial smoke from brush pile burning; size: 0.0006 ha (2.5 m x 2.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
10:32:00	10:35:00	N/A	N/A	N/A
Note	This smoke event was reported by a lookout observer but was not detected by Hummingbird Network. The smoke signature was not visible on the images.			



Detection message record: 16				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
20/09/2018	M	15	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
14:03:00	14:05:00	N/A	N/A	N/A
Note	This smoke event was reported by a lookout observer but was not detected by Hummingbird Network. The smoke signature was not visible on the images.			

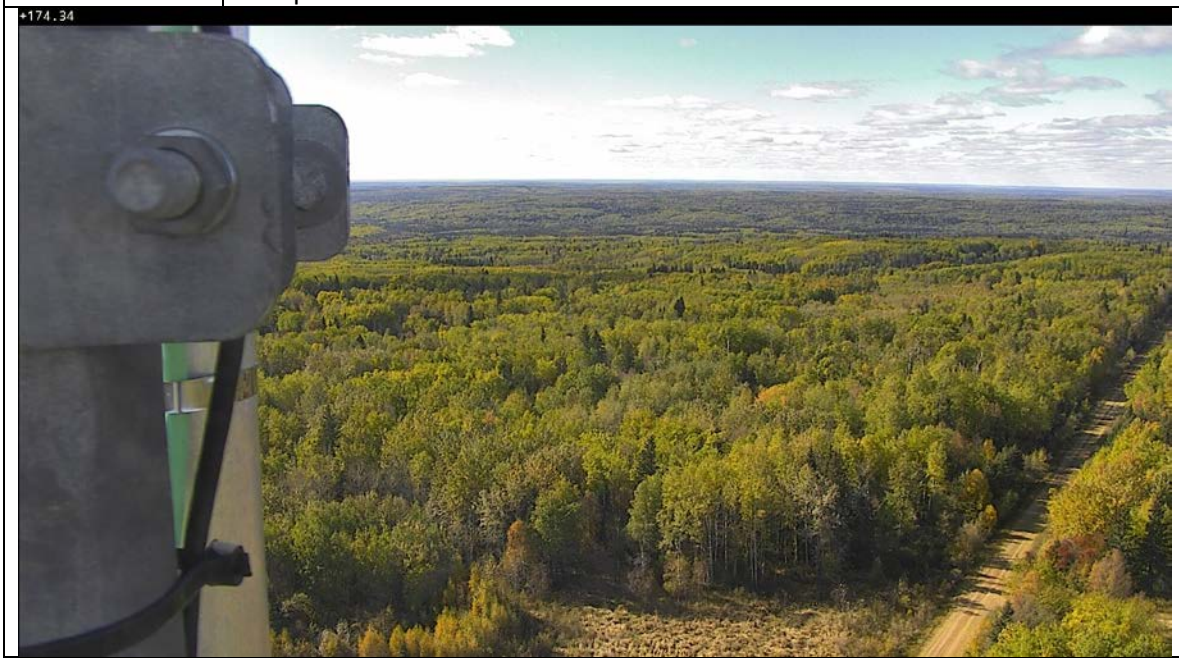
Detection message record: 17				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
20/09/2018	M	5	Detection success	Artificial smoke from brush pile burning; size: 0.0004 ha (2 m x 2 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
15:32:00	15:34:00	15:52:31	15:54:11	15:55:00
Note				



Detection message record: 18				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
22/09/2018	H	0.5	Detection success	Hunter fire pit; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	13:05:00	13:50:31	16:24:00
Note	Hummingbird Network detected and reported this nearby smoke.			

Detection message record: 19				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
27/09/2018	H	5	Detection success	Artificial smoke from brush pile burning; size: 0.0004 ha (2 m x 2 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
10:50:00	N/A	11:20:31	11:21:10	11:25:00
Note	The lookout was not occupied due to season end.			

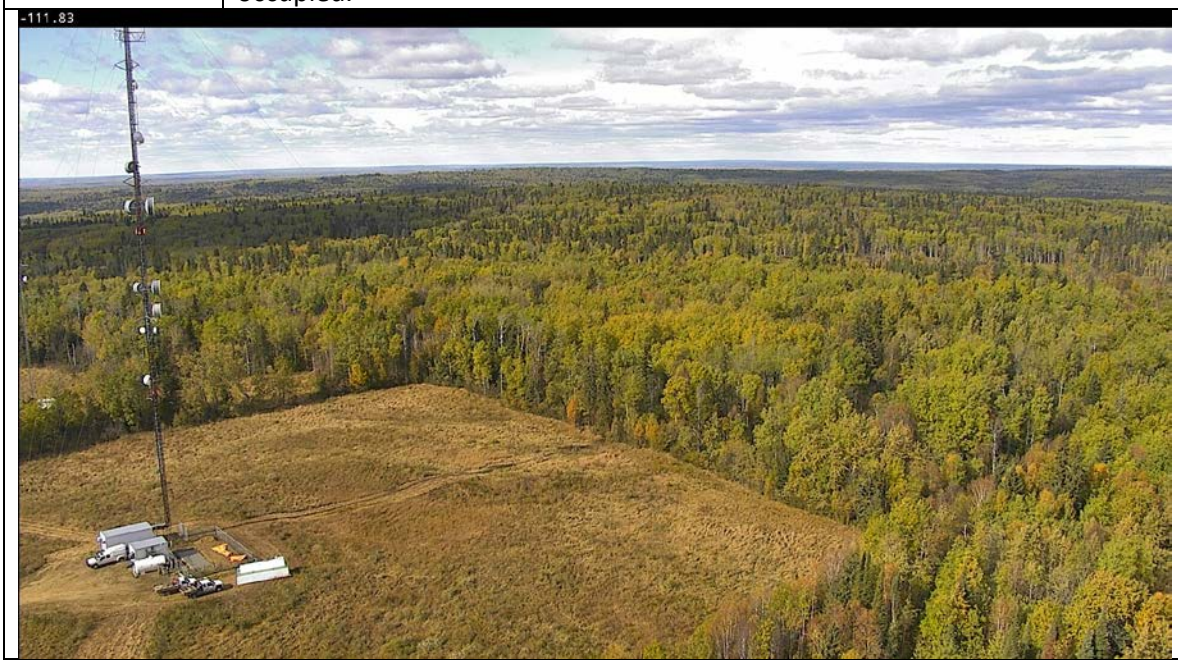
Detection message record: 20				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and Size of fire (m^2)**
27/09/2018	H	7	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
13:00:00	N/A	N/A	N/A	N/A
Note	This fire was not detected by Hummingbird Network. The smoke was not visible on the images. The researcher could not verify the existence of the smoke on the landscape with another detection method because the lookout was not occupied.			



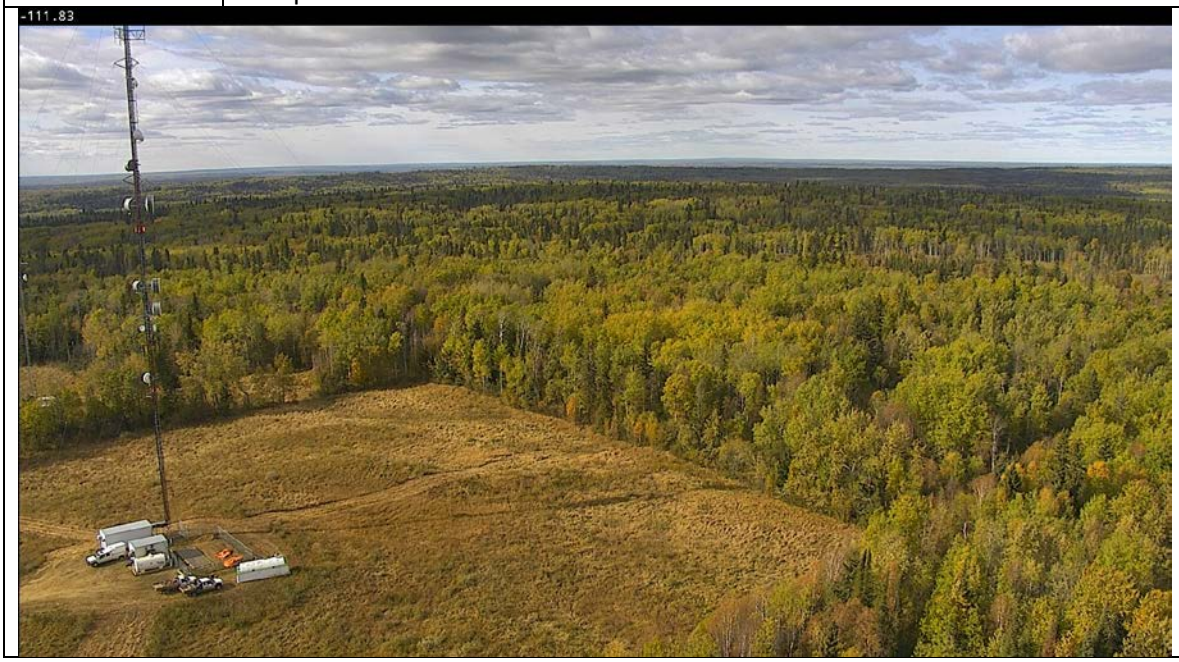
Detection message record: 21				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
27/09/2018	H	6	Detection success	Artificial smoke from brush pile burning; size: 0.0004 ha (2 m x 2 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
14:05:00	N/A	14:10:31	14:22:15	14:38:00
Note	The lookout was not occupied due to season end.			

Detection message record: 22				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
28/09/2018	H	7	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
11:18:00	N/A	N/A	N/A	N/A
Note	This fire was not detected by Hummingbird Network. The smoke was not visible on the images. The researcher could not verify the existence of the smoke on the landscape with another detection method because the lookout was not occupied.			

Detection message record: 23				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
28/09/2018	H	9	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
13:28:00	N/A	N/A	N/A	N/A
Note	This fire was not detected by Hummingbird Network. The smoke was not visible on the images. The researcher could not verify the existence of the smoke on the landscape with another detection method because the lookout was not occupied.			



Detection message record: 24				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
28/09/2018	H	16	Detection failure	Artificial smoke from brush pile burning; size: 0.00025 ha (1.5 m x 1.5 m)
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
14:53:00	N/A	N/A	N/A	N/A
Note	This fire was not detected by Hummingbird Network. The smoke was not visible on the images. The researcher could not verify the existence of the smoke on the landscape with another detection method because the lookout was not occupied.			



APPENDIX 2: DETECTION EVENT MESSAGES OUTSIDE THE EVALUATION PERIOD

Detection message record: A				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
09/07/2018	H	25	Detection success	Wildfire; size: 0.5 ha
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	14:12:00	14:40:00	14:41:14	14:41:15
Note	This detection message was submitted outside the trial period. Temperature: 22 °C; relative humidity: 40%; wind speed: 10 km/h.			

Detection message record: B				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
09/07/2018	A	14	Detection success	Permanent smoke from pulp mill; size unknown
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	14:40:00	N/A	14:41:00
Note	This detection message was submitted outside the trial period. It was reported to the wrong dispatch.			
(The image is not available because the images from tower A were not archived until July 31, 2018 within the system.)				

Detection message record: C				
Date	**Tower**	**Distance from tower/camera (km)**	**Result category**	**Origin and size of fire**
31/07/2018	H	N/A	False alarm	Reflection on camera lens
Ignition time	**Time of lookout observer report**	**Time smoke showed on image**	**Time of turker report**	**Time of Hummingbird report to the dispatch**
N/A	N/A	18:04:00	18:08:36	N/A
Note	This detection message was submitted outside the trial period. This detection message was considered a false alarm due to lens reflection.			

APPENDIX 3: COMMENTS FROM HUNNINGBIRD NETWORK REGARDING THIS REPORT

Compiled by: Robert Atwood
Date: February 05, 2020

A data point exists within the trial data which, in our opinion, should be removed from the dataset and inserted instead as a footnote.

For both metrics, Discovery Times by Turkers and Reporting Times, Detection Record Number 18 falls well outside of 2 standard deviations of the mean, indicating it as an abnormal value within the distribution, and can reasonably be determined to be an outlier.

Detection Record Number 18 was a hunter fire pit, clearly visible within the image (see page 37) and outside of the scope of parameters used by the crowdsourcing detection algorithm to identify wildfire smoke.

While we eventually filed a report, it is evidently not a wildfire.

The discovery and reporting times for this smoke drastically skew the average, standard deviation and assumptions of the report.

Table 1. Summary of Discovery Times (reflecting Table 2. Summary of discovery time, pg. 14)

	Average Time	Standard Deviation
Results including Detection Record Number 18 (current)	00:08:28	00:13:46
Results without Detection Record Number 18	00:03:51	00:04:31

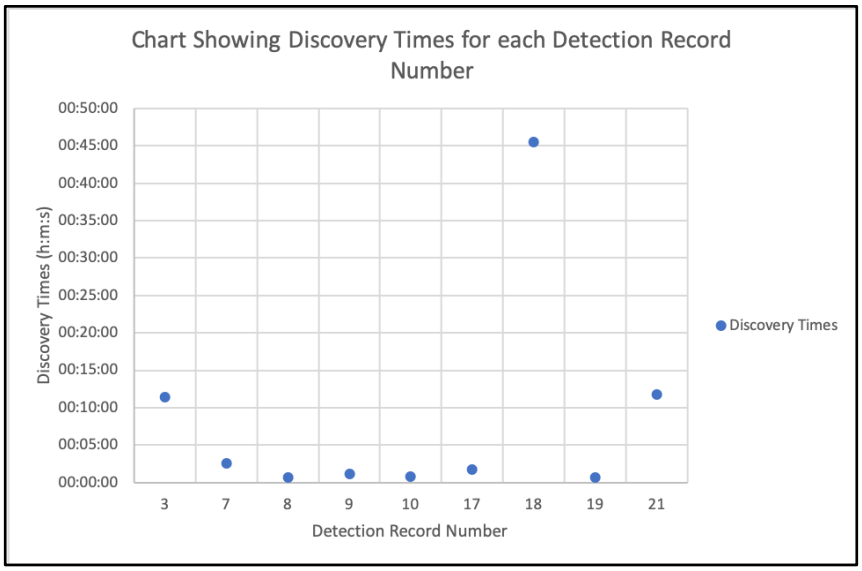


Figure 1. Scatterplot Chart showing the Discovery Times for each Detection Record Number (reflecting Table 2. Summary of discovery time, pg. 14)

Table 2. Summary of Reporting Times (reflecting Table 3. Summary of reporting time, pg. 15)

	Average Time	Standard Deviation
Results including Detection Record Number 18 (current)	00:26:07	00:45:53
Results without Detection Record Number 18	00:10:11	00:09:57

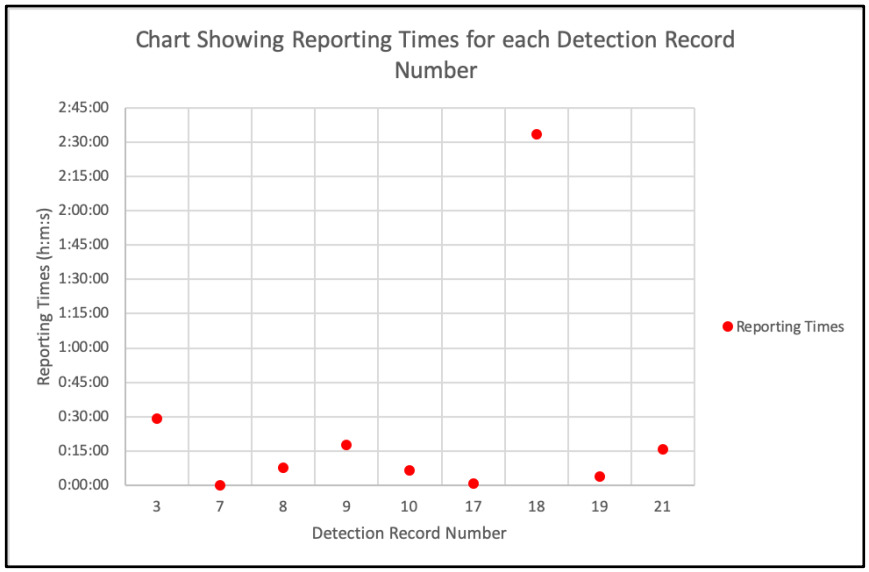


Figure 2. Scatterplot Chart showing the Reporting Times for each Detection Record Number (reflecting Table 3. Summary of reporting time, pg. 15)

We feel that the results table within this report and subsequent assumptions do not accurately reflect the capability of Hummingbird Network’s Smoke Detection Service.

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