The Impact of Utilizing Aerial Tankers in Fighting Forest Fires

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Summary of Research Findings

The research results reported herein find that shorter time lapses between a fire being initially reported and the first air tanker assignment being filled are correlated with shorter fires. Importantly, results indicate that fires responded to quickly are less likely to "get out of control". These results also show that the air tanker response approach used by the State of California has achieved greater effectiveness in reducing the duration of forest fire than the approach used by the U.S. Forest Service. The research findings presented here suggest that the duration of forest fires could likely be reduced by the early deployment of air tankers.

Air Tanker Utilization and Forest Fire Duration

The focus of this analysis is on how the timing of air tanker utilization influences the duration of forest fires. The research question is, does rapid air tanker utilization correlate with shorter fires? Therefore, the timing of filled air tanker assignments was used as the primary discriminator to define the database to be analyzed. While demonstrating a causal relationship between rapid air tanker response and fire duration is outside the scope of this study, results presented herein suggest further analysis towards this end is warranted.

Data Selection

The original database was obtained from the U.S. Forest Service and includes data on aircraft transactions for fixed wing aircraft and air tankers for forest fires for the five years 2014 through 2018. To answer the research question, the database was cleaned before it was pared using four major criteria. First, the database was narrowed to include only information on air tankers. Other aircraft such as "fixed wing" aircraft were removed. Second, only data on filled assignments were used. Data relating to other transactions such as when an air tanker was released or reassigned were removed from the database. Third, data referring to incidents such as training and preparedness were excluded. Fourth, the data were reduced to focus on the fire season. Fires that were initially reported in December, January, and February were removed from the database.

In addition to major data selection criteria, there were several less influential reductions to the database. Other data removed include those reporting that an air tanker's time of arrival was *prior* to the initial date and time that the fire was reported, fires lasting longer than 4 months (which appeared inaccurate), and missing data. The appendix provides a more complete description of the database cleaning and reductions.

Analysis of Air Tanker Utilization by the Duration of Fires

The influence of air tanker utilization on the duration of forest fires is the core research interest. Summary statistics for air tanker utilization and forest fire durations are provided before analyzing how these two primary variables correlate with one another.

Summary Statistics

The number of fires by the total number of filled air tanker assignments are reported in Table 1. Among the 11,655 fires analyzed, the large majority received only a few filled air tanker assignments. There were 2,344 fires (20.1%) that had only a single filled air tanker assignment. Another 5,649 fires (48.5%) had only two filled air tanker assignments. A total of 84.5 percent of fires analyzed had 4 or fewer air tanker assignments filled. It is important to note that these data do not include fires that had unfilled requests for air tankers.

Table 1. Fires by the Number of Filled Air Tanker Assignments

Total Filled Air Tanker Assignments	Fires	Percent
1	2,344	20.1
2	5,649	48.5
3	970	8.3
4	889	7.6
5-9	1,161	10.0
10-24	472	4.1
25-49	126	1.1
50-99	33	0.3
100-249	10	0.1
250 or more	1	0.0
Total	11,655	100.0

The duration of fires in the database is reported in Table 2. The duration of fires is defined as the elapsed time between the initial date and time that the fire was reported and the arrival time of the final filled air tanker assignment. While any given fire could have burned well after

the final air tanker assignment was filled, this is not reported in the database. Consequently, if no new air tankers are requested to fight the fire, it is assumed that the fire was sufficiently under control to not warrant deployment of additionally air tankers.

Based on this definition, the majority of fires lasted for less than 24 hours, as shown in Table 2. Of the 11,655 fires analyzed, 10,537 (90.4%) were controlled within the first 24 hours, as no new air tankers were requested during subsequent days. The duration of fires are highly skewed, there were 10,537 fires that burned for one day and only 23 fires that are known to have burned for 50 or more days. The highly skewed nature of these data is central to the following analysis.

Table 2. Duration of Fires (Days)

Days	Fires	Percent
<1	10,537	90.4
1-4	746	6.4
5-9	141	1.2
10-19	109	0.9
20-49	99	0.9
50 +	23	0.2
Total	11,655	100.0

Initial Air Tanker Response Time and Fire Duration

This section analyzes how the duration of the fires varied with initial air tanker response. Here, the term "initial air tanker response" is defined as the time elapsed time between when a fire was initially reported and when the first filled air tanker assignment arrived at the fire.[1] While the analysis focuses on the initial response time of air tankers, it is important to note that air tanker response time is contingent on air tankers being available and being requested. The principal findings of this research are subsequently supported by several robustness checks.

To determine how the duration of fires varied with the initial air tanker response, the median, mean, and 90th percentile of the duration of fires in the database are reported by initial air tanker response time in Table 3. The results clearly show that fire duration is positively correlated with initial air tanker response.

- Fires that had a filled air tanker assignment arrive within 1 hour of being reported had a median duration of 0.02 days (≈28.8 minutes).

[1] As before, the duration of a fire is defined as the time between the initial date and time that the fire was reported and the arrival time of the final filled air tanker assignment.

- Fires that had a filled air tanker assignment arrive only after 72 hours of being initially reported had a median duration of 12.71 days.

Regression analysis confirms a positive, statistically significant, correlation between the response time of air tankers and the duration of fires (see Appendix – Table 1).[2]

The highly skewed nature of the data reveals that fires responded to more slowly are more likely to burn for much longer durations. The 90th percentile increases rapidly with initial air tanker response, revealing a substantial increase in the share of longer fires as the initial air tanker response time increases.[3] Among analyzed fires, 90 percent of fires that had a filled air tanker assignment arrive within one hour had a duration of just 0.6 days. In contrast, 90 percent of fires that had a filled air tanker assignment arrive only after 72 hours had a duration of up to 47 days, or for fires that had a filled air tanker assignment arrive only after 72 hours 10 percent burned for more than 47 hours. The rapid increase in the 90th percentile appears to support the intuition that fires are far more likely to "get out of control" if an air tanker does not arrive quickly.

Table 3. All Fires by Initial Air Tanker Arrival

Time Elapsed Between Initial Reporting and Arrival of Air Tanker (Hours)	Fires	Fire Duration (Days)		
		Median	Mean	90th Percentile
<1	8,234	0.02	0.15	0.06
1-3	2,156	0.11	0.67	1.08
4-6	223	0.25	0.85	1.91
7-12	152	0.56	1.78	3.71
13-24	451	0.90	2.60	3.99
25-48	136	1.90	4.94	10.03
49-72	88	2.90	6.80	18.79
>72	215	12.71	20.05	47.00
Total	11,655	0.03	0.85	0.96

Robustness Checks

In order to check the robustness of results in Table 3, fires for which only one assignment was filled were dropped for two reasons. First, data recorded during the earlier stages of a fire are more like to be of lesser quality. For example, a fire that did not have a name when the first air tanker assignment was filled but was assigned a named by the time that subsequent air tanker

[2] While the relationship is statistically significant, correlation does not imply causation.
[3] The maximum is not reported as it is influenced by a single fire and is, therefore, too noisy.

assignments were filled would be reported as two different fires. Such erroneous data could result from instances such as "lightening sieges" where numerous fires are started in proximity to one another in a short period of time due to a series of lightning strikes from a storm. Second, as discussed in the appendix, the data obtained by USFS were converted into an analyzable format. While significant effort was put forth to improve data quality, minor issues remain. Relying on more than one record ensures that the data confirm each other.

The overall results from Table 3 hold after dropping fires with only a single filled air tanker assignment. Fires that do not receive a filled air tanker quickly are correlated with fires that get out of control and burn for lengthy periods. The medians, means, and 90th percentiles reported in Table 3 do not change substantially when a subset of data less prone to error is analyzed, as shown in Table 4. To further check the robustness of the results, Table 4 was recreated dropping fires with fewer than 5 filled air tanker assignments (see Appendix – Table 2). The results are qualitatively similar to those in Table 4.

Table 4. Fires with 2 or More Filled Air Tanker Assignments by Initial Air Tanker Arrival

Elapsed Time Between Initial Reporting and Arrival of Air Tanker (Hours)	Fires	Fire Duration (Days)		
		Median	Mean	90th Percentile
<1	6,599	0.02	0.19	0.08
1-3	1,712	0.13	0.83	1.32
4-6	173	0.26	1.03	2.28
7-12	128	0.61	2.04	4.63
13-24	355	0.96	3.09	5.03
25-48	98	2.12	6.28	18.01
49-72	68	3.65	8.09	22.74
>72	178	14.06	20.95	47.72
Total	9,311	0.03	0.97	1.08

Table 3 was recreated examining only fires that were fought by the State of California. This was done by excluding data whose region codes that did not end with a "u" (Table 5a). The reason for this analysis stems from the fact that the State of California owns a fleet of air tankers and follows a rapid response procedure that may produce different results than fires that are handled by the United States Forest Service. For direct comparison with the fires fought by the State of California (Table 5a), the fires that were not fought by the State of California are shown in Table 5b.

Results show that fires fought by the State of California have a much shorter duration between the fire being initially reported and the arrival of a filled air tanker assignment. Of the 6,495

fires in the database that were fought by the State of California, 96.7 percent (6,278 fires) had an air tanker fill an assignment for that fire within one hour of being reported. Only 37.9 percent of fires not fought by the State of California had a filled air tanker assignment within one hour of the incident being reported. Only 76.6 percent of fires not fought by the State of California had a filled air tanker assignment arrive in fewer than 4 hours of the fire being reported. In fact, of the 215 fires in the database that lasted longer than 72 hours, only 4 were fought by the State of California. The effectiveness of State of California's rapid response actually improves the overall (all forest fire) response times when all data are considered together. Given that response times and fire duration are correlated, the overall duration of fires could likely be shortened if all agencies followed the State of California's rapid response procedure.

Table 5a. Duration Fires Fought by the State of California by Initial Air Tanker Arrival

Elapsed Time Between Initial Reporting and Arrival of Air Tanker (Hours)	Fires	Fire Duration (Days)		
		Median	Mean	90th Percentile
<1	6,278	0.01	0.09	0.04
1-3	160	0.06	0.47	0.23
4-6	14	0.25	0.24	0.28
7-12	19	0.57	1.16	4.48
13-24	16	0.77	3.04	7.90
25-48	2	1.86	1.86	1.86
49-72	2	2.89	2.89	3.00
>72	4	7.67	8.09	12.83
Total	6,495	0.01	0.12	0.05

Table 5b. Duration Fires Not Fought by the State of California by Initial Air Tanker Arrival

Elapsed Time Between Initial Reporting and Arrival of Air Tanker (Hours)	Fires	Fire Duration (Days)		
		Median	Mean	90th Percentile
<1	1,956	0.03	0.35	0.71
1-3	1,996	0.12	0.69	1.09
4-6	209	0.25	0.89	2.14
7-12	133	0.56	1.87	3.71
13-24	435	0.91	2.59	3.99
25-48	134	1.91	4.99	10.03
49-72	86	2.90	6.89	18.79
>72	211	13.01	20.27	47.00
Total	5,160	0.11	1.77	2.97

Conclusion

The research results reported herein find that shorter initial time lapses between a fire being initially reported and the first air tanker assignment being filled are correlated with shorter fires as measured by the time stamp on the last filled air tanker assignment. More importantly, fires with rapid initial air tanker response are less likely to "get out of control," as indicated by longer duration times. These findings are supported by performance data on fires fought by the State of California. The research findings presented here suggest that the duration of forest fires could be reduced by the early deployment of air tankers.

Future Research

The analysis presented in this research focus on the correlations between air tanker use and the duration of fires. To determine a causal relationship, future analysis could focus on the difference in outcomes between fires that had an assignment request filled and fires whose assignment requests went unfilled.

Appendix

Data Notes

Data were acquired from the United States Forest Service using a Freedom of Information Act request. The data were provided from the United States Forest Service in a series of pdf images that were converted to an analyzable database. Work was done to clean the database and remove erroneous data. Data categorizing the fire type and aircraft types were standardized. The incident (fires) names and numbers were separated and cleaned to the best degree possible. Issues related primarily to mis-converted data (for example, "5" was frequently converted from the PDF as an "S"). After cleaning the components of the fire number, the number was re-created and used for analysis. The request number for data was also cleaned; similar issues existed.

Data were then reduced by several criteria to a final database for analysis. The final database includes only aircraft are classified in the "air tanker" category, as this is the primary focus of this analysis. Additional aircraft that were excluded included 415s, 215s, and OV-10s. Only data with a transaction type equal to "fill" were kept. Transactions types that were dropped included "Enter", "Place", and "Release", among others. The fires included in the database were: "Complexes", "Debris/Product Fires", "Other Fires", "Structure Fires", "Vehicle Fires", "Wildfires", "Out of Area Responses", and "Severe Winter Weather". Among these classes of fires, 97.7 percent were categorized as "Wildfires", 1.4 percent was categorized as "Complexes", and 0.9 percent was divided among the remaining categories. Including or excluding the remaining categories did not qualitatively change the final results. The remaining

criteria only marginally reduced the size of the database. The final reductions excluded: data on fires that were initially reported outside of fire season (December, January, and February), data with missing timestamps, data with arrival times of aircraft that were prior to the initial date and time the fire was reported, records missing data on the aircraft make and model, data with request numbers greater than 630 (which appear to be erroneous), and fires named "False Alarm".

Appendix Tables

Appendix Table 1.
Regression Analysis Summary for Air Tanker Response Time Predicting Fire Duration (Days)

Variable	β	95% CI		t	P-Value
Constant	0.423	0.366	0.479	14.67	0.000
Air Tanker Response Time (Hours)	0.047	0.046	0.048	124.96	0.000

N =11,665. Adjusted R^2 = 0.57. CI = Confidence Interval.

Appendix Table 2.
Duration Fires with 5 or More Filled Air Tanker Assignments by Initial Air Tanker Arrival

Elapsed Time Between Initial Reporting and Arrival of Air Tanker (Hours)	Fires	Fire Duration (Days)		
		Median	Mean	90th Percentile
<1	762	0.14	1.37	2.88
1-3	589	0.77	2.00	4.46
4-6	52	1.13	2.59	6.12
7-12	66	1.24	3.39	10.18
13-24	161	1.95	5.48	14.15
25-48	43	3.99	9.56	30.46
49-72	34	7.80	11.54	28.92
>72	96	17.35	23.49	47.93
Total	1,803	0.80	3.61	9.13