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Application of DSM for Integrating Modern Technology into Operational Architecture of Aerial Firefighting

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Abstract: Aerial firefighting plays an integral role in containing wildfires, which have been growing rapidly in frequency and intensity over the past decades. However, the current aerial-resource management models were developed decades ago, based on the technology available then. This research aims to investigate how and what modern technologies can be integrated into aerial firefighting operation to help it keep up with the worsening situation. DSM has been used as an engineering tool to decompose the complex problem space into separate manageable segments. Using a task-based DSM, the interdependencies which give rise to unnecessary complexities are visualized, and the potential to integrate new technologies in resolving these complexities is discussed. Finally, unmanning the airtanker and "co-placing" the airtanker-pilot and the Incident-Commander is proposed as a new operational concept. The new arrangement will provide the Incident-Commander with time critical situational awareness, speed up the operation, and eliminate the risk of pilot fatality.

Keywords: Aerial firefighting, airtanker, operational architecture, modern technology, DSM

1 Introduction

Wildland fire burns millions of acres of United States forests annually (USFS, 2012), and costs above a billion dollars to suppress (USFS, 2015). In comparison to 1970s, fire seasons are 78 days longer, burn more than twice the area, and cost considerably more (USFS, 2012).

According to the National Interagency Aviation Council (NIAC, 2009), a 1% decrease in the success rate of "initial attack" (the first response to a fire incident), leads to a 200 million dollar increase in the overall cost of fire suppression. The primary assets in the initial attack are airtankers (aircrafts carrying water or chemical retardants), since they enable a fast response with large payload capacity. Studies have shown that the success rate of the operation of airtankers in initial attack depends primarily on the speed of the operation (Calkin et al., 2014).

On the other hand, a field survey on 135 firefighting experts (USDA, 1998) demonstrated that 108 out of 135 experts believe that the most important problem of aerial firefighting lies in the category of "Operations and Management", and 94 experts added "Communications" to the list. Also, the National Interagency Aviation Council (NIAC, 2009) stated that the current fire operation management models were developed decades ago, based on the technology available at that time, and "in a much different and more benign atmosphere" than what is faced today. The council called for an investigation on the possibility of enhancing the aerial resource management model by integrating modern technology and new methods (NIAC, 2009).

An unpleasant symptom of the current aerial firefighting system is its high fatality rate. The complicated maneuvers in the often turbulent, smoky and congested fire environment (NIAC, 2009), accompanied with excessively high stress levels experienced by airtanker pilots (Melton et al., 1968), have made aerial firefighting a dangerous career. According to the National Transportation Safety Board (NTSB), in the 1955 to 1999 period, 250 airborne firefighting personnel have lost their lives (NTSB, 2016). Accident investigation data in a 20 year period shows that in 74.5% of the aviation related accidents, “human error” was the primary cause (USDA, 1998). To the contrary of what one might expect, the increased aviation safety of the 21st century did not decrease the trend of aerial firefighting casualties; and 82 more airborne personnel passed away in the 2000-2015 period (Butler, 2015) (NTSB, 2016).

This paper aims to investigate the operational architecture of aerial firefighting; and propose how and what new technologies can be introduced in the mission to improve its speed, effectiveness, and safety. Dependency Structure Matrix (DSM) is an effective tool in visualizing the complexities and interdependencies of a process architecture (Eppinger and Browning, 2012). A binary task-based DSM will be used in this research to provide a system view on the aerial firefighting operational architecture. The focus of the DSM model will be on detecting the unnecessary interdependencies among tasks that can increase the operation time, reduce its effectiveness, and increase the risk of human error; and to investigate how modern technology can aid in resolving the detected complexities.

2 DSM Modeling

The data used to develop the DSM model is extracted from “Interagency Aerial Supervision Guide” (NIAC, 2008), and the “National study of tactical aerial resource management to support initial attack and large fire suppression” (USDA, 1998). In these Studies, the activities and the flow of information among parties present at a typical wildfire fighting mission is described. Additional information regarding the tasks of airtanker pilots were obtained from direct contact with firefighting experts and pilots.

A task-based binary DSM has been used in this research to model a typical initial attack operation. The inputs are put in rows and feedbacks above diagonals (Eppinger and Browning, 2012). Figure 1 shows the task-based DSM model of the operational architecture. The roles involved in this mission are introduced in Table 1 along with the abbreviations used in naming their tasks. Each task includes the sender and receiver of the information, respectively at the beginning and end of its name.

Table 1. Roles and Abbreviations

Role	Abbreviation
Air Tactical Group Supervisor	ATGS
Incident Commander	IC
Leadplane Pilot	LP

Airtanker Pilot	Pilot
Ground Firefighting Crew	GC
Dispatch staff	Disp

The “Project DSM” software version 2.0.1 was used to sequence the original task-based DSM. As it can be seen in Figure 1, the process can be divided into four segments: 1) Developing Tactics and making decisions, 2) Relaying the decisions to the airtanker pilot, 3) Performing the cooperative drop maneuver, and 4) Evaluation and adjustments. The DSM model shows that the first three segments are the major contributors of complexity in the operation. The colored blocks represent the interrelated tasks.

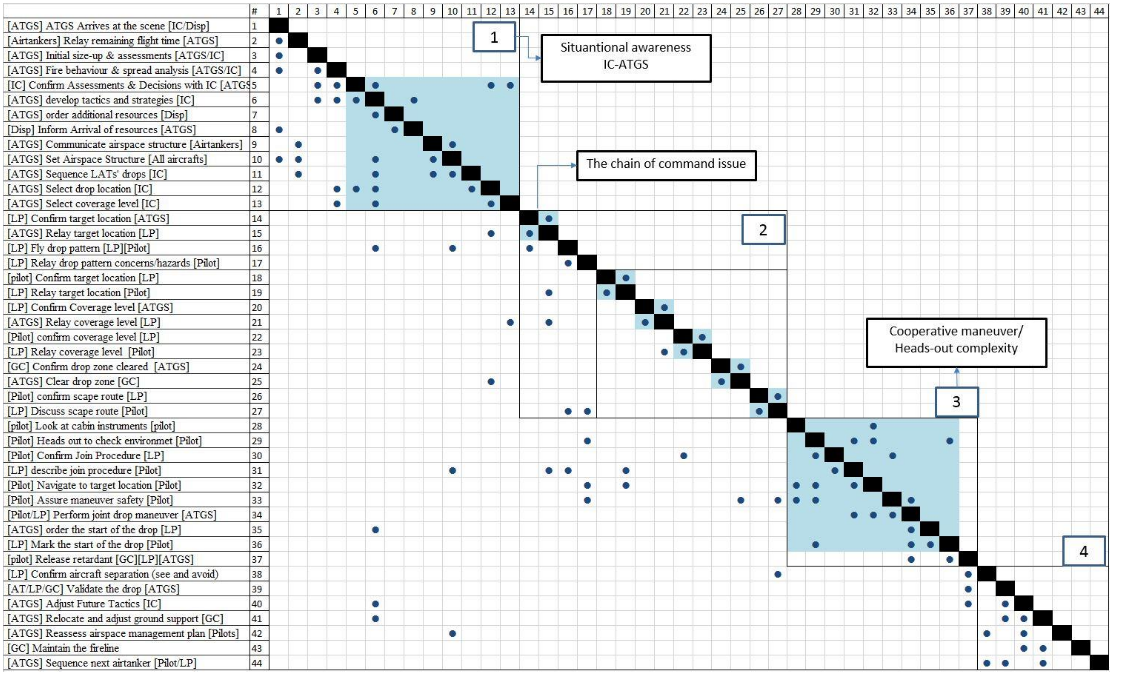

Figure 1. Task-based DSM of a typical firefighting operation

However, not every interrelation and complexity is undesirable in a process (Eppinger et al., 2013). Sometimes interrelations are necessary to achieve higher accuracy or effectiveness (Browning, 1998). Nonetheless, in the case of an outdated management model, equipped with outdated technology, it may happen that the existing complexities are unnecessary; Which means they can be resolved via integration of modern technology, while keeping at least the same level of accuracy and effectiveness. These supposedly "unnecessary complexities" are investigated in each segment of the operation, with more detail, to see how modern technology can be helpful in resolving them.

2.1 Developing tactics and making decisions

After the Aerial Supervisor (ATGS) arrives at the scene, he establishes contact with the ground crew and aerial resources, performs size-up, assesses the environment and risks, analyses fire behavior and spread pattern, and receives updates of incoming resources from the dispatch center. Then he should relay all the "situational awareness" information to the Incident Commander through voice communication. Verbal description of the quickly-changing and hostile environment of the fire incident, not only takes precious minutes, but also interferes with the ATGS's other roles, as he has to constantly keep track of ground resources and set and manage the air-traffic. As it can be seen in Figure 2, this phase of the operation exhibits task-complexity, mainly because IC needs situational awareness to confirm tactics and strategies, but he is not present at the scene; and the ATGS has to describe every required information via voice communication.

Figure 2. Inter-dependencies in developing tactics and making decisions

		1	2	3	4	5	6	7	8	9	10	11	12	13
[ATGS] ATGS Arrives at the scene [IC/Disp]	1												1	
[Airtankers] Relay remaining flight time [ATGS]	2	●												
[ATGS] Initial size-up & assessments [ATGS/IC]	3	●												
[ATGS] Fire behaviour & spread analysis [ATGS/IC]	4	●		●										
[IC] Confirm Assessments & Decisions with IC [ATGS]	5			●	●		●						●	●
[ATGS] develop tactics and strategies [IC]	6			●	●	●			●					
[ATGS] order additional resources [Disp]	7						●							
[Disp] Inform Arrival of resources [ATGS]	8	●						●						
[ATGS] Communicate airspace structure [Airtankers]	9		●								●			
[ATGS] Set Airspace Structure [All aircrafts]	10	●	●				●			●				
[ATGS] Sequence LATs' drops [IC]	11		●				●			●	●			
[ATGS] Select drop location [IC]	12				●	●	●					●		
[ATGS] Select coverage level [IC]	13				●		●						●	

2.2 Relaying the decided tactics to the pilot

When the ATGS and IC come to a mutual decision about the location of the drop, and the coverage level, their decision must be clarified for the airtanker pilot. So the ATGS relays the desired drop location to the leadplane pilot via voice communication. After the leadplane pilot understands and confirms the drop location, the same process should be repeated between the leadplane pilot and the airtanker pilot. The coverage level of the drop is another important parameter that travels the same route. The back and forth voice communications take time and increase the risk of human error. Presumably, modern technology can be used to shortcut the information flow route, while ensuring the accuracy of the transferred information.

2

		14	15	16	17	18	19	20	21	22	23	24	25	26	27
[LP] Confirm target location [ATGS]	14	■	●												
[ATGS] Relay target location [LP]	15	●	■												
[LP] Fly drop pattern [LP][Pilot]	16	●		■											
[LP] Relay drop pattern concerns/hazards [Pilot]	17			●	■										
[pilot] Confirm target location [LP]	18					■	●								
[LP] Relay target location [Pilot]	19		●			●	■								
[LP] Confirm Coverage level [ATGS]	20							■	●						
[ATGS] Relay coverage level [LP]	21		●					●	■						
[Pilot] confirm coverage level [LP]	22									■	●				
[LP] Relay coverage level [Pilot]	23								●	●	■				
[GC] Confirm drop zone cleared [ATGS]	24											■	●		
[ATGS] Clear drop zone [GC]	25											●	■		
[Pilot] confirm scape route [LP]	26													■	●
[LP] Discuss scape route [Pilot]	27			●	●									●	■

Figure 3. Inter-dependencies in the chain of command

2.3 Performing the cooperative drop maneuver

After the target location is made clear for both pilots, the airtanker and leadplane must join together to form a chase maneuver, flying over the drop zone. During this maneuver, which requires elaborate synchronization, the pilots have to watch the outside environment (heads-out function) to clear terrain and obstacles, as they are too close to the ground; and simultaneously pay attention to the flight instruments inside the cabin. Since the altitude of the aircrafts in the drop maneuver is usually below 300 ft (above ground level) and they are flying at the speed of 200 to 250 ft/sec in a smoky, congested airspace, the margin for error is extremely small. Furthermore, the current way that the payload release is triggered makes the situation more complex. The ATGS must follow the cooperative maneuver, and order the start of the drop to leadplane pilot by voice. The leadplane then should mark the start of the drop for the airtanker pilot. This is usually done by leaving a smoke trail behind its path, or shaking a control surface or by voice command (NIAC, 2008). The latter two methods will result in a dislocated drop-line due to parallax view problem (USDA, 1998), and the first method requires the airtanker pilot to keep looking at the leadplane, and therefore the cabin instruments get overlooked (NIAC, 2009).

3

		29	30	31	32	33	34	35	36	37	38
[pilot] Look at cabin instruments [pilot]	29	■				●					
[Pilot] Heads out to check environmet [Pilot]	30		■		●	●				●	
[Pilot] Confirm Join Procedure [LP]	31		●	■			●				
[LP] describe join procedure [Pilot]	32			●	■						
[Pilot] Navigate to target location [Pilot]	33	●	●		●	■					
[Pilot] Assure maneuver safety [Pilot]	34	●	●				■	●			
[Pilot/LP] Perform joint drop maneuver [ATGS]	35				●	●	●	■			
[ATGS] order the start of the drop [LP]	36							●	■		
[LP] Mark the start of the drop [Pilot]	37		●					●	●	■	
[pilot] Release retardant [GC][LP][ATGS]	38							●		●	■

Figure 4. Interdependencies in the cooperative drop maneuver

The very existence of the leadplane, which was meant to facilitate the operation, is increasing the complexity of the drop maneuver, as it requires continuous, elaborate coordination and synchronization with the airtanker pilot, in a highly stressful atmosphere. Figure 4 depicts the coupling of tasks in the cooperative drop maneuver.

Although the functions performed by a lead role are necessary, the physic to support those functions do not necessarily need to be an aircraft; And while the airtanker needs to be piloted, it does not necessarily mean that its pilot should sit in the airtanker cabin. The latter two sentences would have looked bizarre decades ago, but are common practices for modern technology today.

3 Modern Technology Solutions

The DSM model demonstrated that the current operational architecture has three issues:

1. The information exchange between Incident Commander (IC) and the Supervisor (ATGS) about the situational awareness, tactics and strategies.
2. The chain of command, from the Supervisor, to the lead role, to the airtanker pilot.
3. The complexity of the cooperative drop maneuver, which requires the pilot to look outside and inside the cabin at the same time.

The authors propose that the pilot be removed from the cabin of the airtanker, and be placed in the ground-station, near the IC. The authors prefer to call the new role "In-Station Pilot" or "ISP", in order to distinguish it with the pilot who sits inside the airtanker. Unmanned flight and remote piloting has already been practiced in UCAVs (Unmanned Combat Air Vehicles). The "co-placement' of the ISP (In-Station Pilot) and the IC is a new concept in aerial-resource management of firefighting operation, enabled by modern technology. The ISP will be seated in a ground-station, flying the airtanker remotely anywhere in the U.S. In this case, the ISP would need a live video feed from the airspace he is flying into. This can be provided via a "wide-angle" camera attached to the airtanker, and SATCOM technology (Satellite Communication) to send and receive data.

The primary outcome of this arrangement is that the *IC will be able to see the same video feed as the ISP*. This will provide the IC with invaluable situational awareness over the fire incident, and save considerable amount of time; which had to be squandered while ATGS described the scene "verbally" to the IC. Therefore, the workload of the ATGS will be reduced, as he can use the extra time to focus on his other tasks; and instead of supporting the IC, he is now being supported by the IC. It is also proposed that the camera attached to the airtanker be augmented by Forward Looking Infra-Red (FLIR) to enhance the fire spread awareness of the IC, and help him make better informed-decisions.

Another benefit of this "co-placement" is that the IC can directly relay drop location information to the ISP, which solves the second problem, regarding the chain of command. After the IC decides the target location and coverage level with the help of the ATGS, the data can be sent "visually" to the ISP; instead of the undesirable, time-consuming verbal contact and involvement of the leadplane pilot, The IC can simply draw a line on his "touch screen monitor", and the pattern becomes visible in ISP's monitor. Pilots are well used to this way of navigation. The landing process in low light conditions in airports with the help of runway lights is a similar practice. Moreover, setting the coverage level, and triggering the payload release, can both be carried out by the IC, and the ISP can be left focused on controlling his/her aircraft.

The third complexity will also be resolved as a direct result of the new arrangement. Since the ISP is looking at a digital monitor instead of the cabin window, all the required flight instrument data can be shown digitally (like a glass cockpit) in the monitor. In other words, ISP's monitor will be providing a composite view of a live video from the scene, the flight instruments, and the drop pattern.

Also, if the pilot is stationed on the ground, instead of the airtanker cabin, he will experience lower stress levels. Lower stress leads to lower fatigue and lower human error, and therefore, a safer, and more effective mission.

The last but not least benefit of the proposed concept is that no airtanker pilot will lose his life on the line of duty anymore. In case of any mishaps, the airtanker may be damaged or lost, but the pilot is always saved.

4 Conclusion

The main reason behind application of DSM in any work is usually to visualize the complexities of the operation at hand; as current aerial firefighting operations are. At its least outcome, DSM helps clarify blocks of interrelated tasks, inefficient interfaces and outdated tasks that have traditionally been used without logical evaluations. In this work, we have been able to systematically identify the main contributors to the success of the firefighting activities and the sources of complexities involved. In fact, DSM model has helped us to better understand the numerous fatal accidents relevant to the long history of aerial firefighting. A new look at the selected accidents, in one side, and emerging new technologies on the other side, has also led us to propose a new concepts named as "Remote Aerial Fire Fighting Station (RAFFS)". In this concept, the pilot is remotely placed in a station next to the IC. The video-link provides proper views to the fire from air-tanker. Such information provides the necessary, time-critical awareness and decision-making ingredients for both IC and the pilot. The camera attached to the airtanker can be equipped with FLIR technology to enhance IC's situational awareness. The ISP's monitor could help resolve any need to simultaneously observe both inside and outside the aircraft cabin. A composite digital view involving surrounding environment and flight instruments could also enhance mission effectiveness. Any tactical decisions made by IC is then transferred visually to the ISP; and therefore, any air-tanker and lead-plane cooperative maneuver would not be necessary. Obviously, this helps reduce the existing risk of fatal accidents.

The RAFFS concept is also expected to reduce the mission associated cost and help increase the drop accuracy through decreasing human error. Although, the risk associated with air-tanker maneuvers still very much depends on the nature of the fire at hand, nonetheless, ISP is no-longer at risk. Moreover, a new air-tanker design, similar to that of large UAV's, could definitely change the whole approach to the firefighting throughout the world.

In this work, task-based DSM has been effectively used to model the operation of an air-tanker role in a general aerial firefighting mission and the associated fatal accidents. The work, however, could definitely be enhanced by adding other types of DSM to create a complete model, involving (1) firefighting parameters and (2) firefighting team to reach an overall cost-estimate for firefighting budgeting. This approach could help one of the main stumbling blocks for most needed passive defense to prevent wild-forest fires. In fact, authors propose to have a comprehensive cost-estimator model for aerial firefighting based on DSM. In this approach, then governments have two clear choices; (1) they could use that budget to prevent wild-forest fires or (2) to actually use that budget to put-out wild-forest fires they encounter every year. Obviously, the next logical step is to integrate the three matrices to form a Multi-Domain Matrix (MDM), which is beyond the scope of the current work.

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