2016 IEEE International Symposium on
Safety, Security, and Rescue Robotics (SSRR)
EPFL, Lausanne, Switzerland, October 23-27, 2016

Two Case Studies and Gaps Analysis of Flood Assessment for Emergency Management with Small Unmanned Aerial Systems

Robin Murphy, Jan Dufek, Traci Sarmiento, Grant Wilde, Xuesu Xiao
Center for Robot-Assisted Search and Rescue
Texas A&M Engineering Experiment Station
College Station, TX, USA
{robin.r.murphy, dufek, tsarmiento, gwilde1}@tamu.edu

Jeff Braun, Lachlan Mullen
Fort Bend County Office of Emergency Management
Richmond, TX, USA
{jeff.braun, lach.mullen}@fortbendcountytx.gov

Richard Smith, Sam Allred
CartoFusion
Corpus Christi, TX, USA
{rick.smith, sam.allred}@cartofusiontech.com

Justin Adams
US DataWing
San Antonio, TX, USA
justin@usdatawing.com

Adam Wright
Fort Bend County Drainage District
Rosenberg, TX, USA
adam.wright@fortbendcountytx.gov

Jess Gingrich
USAA
San Antonio, TX, USA
jess.gingrich@usaa.com

***Abstract*—This paper documents the successful use of small unmanned aerial systems (SUAS) for two floods in Fort Bend County, Texas, and identifies gaps in informatics, manpower, human-robot interaction, and cost-benefit analysis. The case studies focus on how emergency managers can use SUAS for flood assessment including flood mapping and projection of impact, verification of flood inundation models, providing justification for publicly accountable decisions, and public information. The case studies are particularly informative because they were flown at the direction of County experts during two actual flood events and represent 21 flights over four days.**

Keywords—unmanned aerial vehicles, disaster response, robotics, human-robot interaction

I. Introduction

Floods are the number one natural disaster in the United States [1] and in the world [2]. In the US, floods account for the largest loss of life and the highest property damage [3]. While the immediate risk to loss of life often motivates the use of small unmanned aerial systems (SUAS), floods also motivate their use for general emergency management and recovery operation. SUAS could revolutionize flood prevention, preparedness and recovery as well as emergency response.

Emergency managers need aerial assets before and during the flooding to predict and monitor the flood to initiate evacuation and mitigate flooding. They also need to project damage in order to prepare for requesting assistance, and to provide compelling visuals to educate public on evacuation. During the flood or after the flood has crested, aerial assets can help emergency managers estimate the damage, document the damage in order to qualify for disaster funds, and document the damage for use at future events and for educating the public about land use. Note that identifying people in distress and initiating immediate life-saving functions often comes from cellphones which are generally resilient to floods.

This paper reports on how small UAS were deployed for two major flooding events in Fort Bend County, Texas. Fort Bend is the 10th largest populated county in Texas and is both a suburb of Houston, Texas, and a major agricultural region. Thus it provides a good test case of how urban, suburban, and rural emergency managers would use SUAS. Three SUAS were provided by the TEES Center for Robot-Assisted Search and Rescue (CRASAR) and its Roboticists Without Borders program, with CartoFusion, USAA, and US DataWing volunteers, at the request of the Fort Bend County Office of Emergency Management (OEM). CRASAR pilots

This work was supported in part by NSF grant CNS-0923203 and donations from CartoFusion, USAA, and US DataWing.

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and scientists teamed with Fort Bend OEM and Fort Bend County Drainage District personnel in the field, providing two case studies of how SUAS were actually used, what was useful, and what could be improved to accelerate adoption.

II. Related Work

The use of SUAS for flooding, versus general storm damage from wind and water, has been reported since 2005 Hurricane Katrina [4], and includes 2005 Hurricane Wilma [4], 2009 Typhoon Morakot [5], 2011 Thailand floods [6], 2013 Typhoon Haiyan [7], 2013 Boulder Colorado [8], 2014 Oso mudslides, and 2014 Balkans flooding [9]. Those publications or reports did not focus on a gaps analysis, especially in terms of the role of SUAS in the data-to-decision process, which is the focus of this paper.

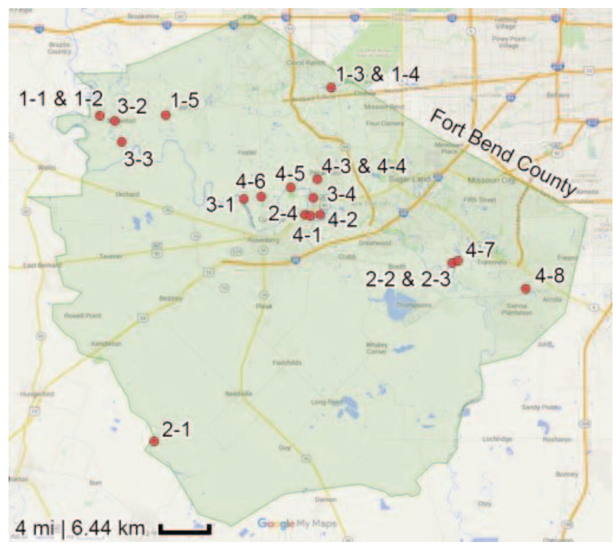
This paper builds on our previous direct experience in deploying to floods or events involving flooding, such as determining flood cresting at Hurricane Katrina (2005), estimating flow rate and possible mitigation strategies at the Oso mudslides (2013), and the Louisiana floods (2016, unpublished). Murphy in [10] gives 3 case studies of emergency informatics for floods, one of which is the use of a SUAS for a missing persons search after a major flood of the Blanco River in 2015; the missing person search mission is not relevant to this paper which concentrates on flood assessment. However, the article describes challenges due to data volume, which is also seen in the case studies described in this paper.

III. Case Studies

Fort Bend County experienced two major flood events in 2016. The first occurred in April 2016, causing a presidentially declared disaster (DR4269); and reaching the fourth highest historic crest measured at the Brazos River gauge located in Richmond, Texas. Just over one month later, the County experienced another major flood. This second flood caused another presidentially declared disaster (DR4272). Additionally, this flood recorded the highest crest (over four feet more than the previously highest crest set in 1994) ever measured at the Brazos River gauge located in Richmond, Texas. CRASAR flew a total of 21 flights at 17 locations over four days, two days per flood, and generated 129 GB of raw and processed data. Twenty of the 21 flights were conducted in manual mode, where County experts directed the flight. The remaining flight was an autonomous survey to generate photogrammetric product. The team drove an average of 58 miles each day to reach the locations for that day, highlighting the need for easily transportable field solutions.

A. *Overview of Flights and Operations Tempo*

Figure 1 shows the locations of the flights and statistics; the missions are defined in Sec. IV. All four days followed the general operation tempo of the experts identifying target areas to assess in the county in the morning (generally around 8AM), the team driving 10-45 minutes to a site, flying, driving another 20-45 minutes to the next site, and so on until all targeted areas were covered (generally around 5PM). The team would return to the emergency operations center when nearby or at the end of the day to drop off data. The set up time at each site was less than 15 minutes though the field team often had to visit several sites to find a suitable space to serve as a launch and landing zone near the targeted area. One site with sufficient space and distance from power lines was rejected due to massive insect and reptile swarms fleeing the rising water. The flights were at 390’-395’ above ground level (AGL) in order to maximize keeping the SUAS within visual line of sight and stay below the 400’ AGL restriction imposed by the Federal Aviation Agency. Each flight generally operated within a circle with a radius of 0.5 miles, the limit of visual line of sight. The wind for all flights was favorable, estimated to be well under 20 knots at the flight altitude with little gusting observed via the movement of tall trees or sudden uncontrolled movements of the platform.



DATE	FLIGHT	MISSION	MANUAL OR AUTO	FLIGHT TIME (MIN)
20-Apr-16	1-1	flood mapping and projection of impact	M	12.3
	1-2		M	6.9
	1-3		M	12
	1-4		A	18
	1-5		M	9.4
23-Apr-16	2-1	flood mapping and projection of impact	M	19.8
	2-2		M	14.3
	2-3		M	14.6
	2-4		M	14.5
30-May-16	3-1	verification of flood inundation models	M	9.3
	3-2		M	6.8
	3-3		M	5.9
	3-4		M	6.9
31-May-16	4-1	flood monitoring; justification for publicly accountable decisions; public information	M	9.4
	4-2		M	7.2
	4-3		M	1.9
	4-4		M	6.5
	4-5		M	10.4
	4-6		M	10.6
	4-7		M	11.3
	4-8		M	11

Figure 1 Summary of the 21 flights by location (top) and flight (bottom).

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B. April 20 and 23, 2016, Flights

CRASAR flew two separate days under the US DataWing Section 333 exemption. The purpose was to assess the actual state of the rising flood as the flood gauges and other indications were not matching predictions. Initially the first day was considered sufficient for preparing for the rising flood waters, but the team was recalled on April 23 to provide assessment at the flood's expected crest.

On April 20, 2016, a DJI Phantom 3 Professional was used for the total of 5 flights in 3 different locations in the county. Total flight time for all the flights was 59 minutes, for a total of 19 GB of raw data, and average flight time of 12 minutes. Twenty GB of raw data and data products were produced. The flight crew consisted of Justin Adams as pilot, with Robin Murphy, Jan Dufek, and Xuesu Xiao taking turns as visual safety observer. Lach Mullen, Fort Bend County OEM, and Adam Wright, Fort Bend County Drainage District, served as County experts. Drone Deploy and Pix4D were used for generating photogrammetric products.

On April 23, 2016, a DJI Inspire 1 was used for the total of 4 flights in 3 different locations in the county. Total flight time for all the flights was 63 minutes, for a total of 27 GB of raw data, and average flight time of 16 minutes. 40 GB of raw data and data products were produced. The flight crew consisted of Justin Adams as pilot, with Murphy, Dufek, Jess Gingrich, Traci Sarmiento, and Xiao taking turns as visual safety observer. McMullen and Wright served as County experts. A dedicated data management team worked from the RESPOND-R mobile lab: Rick Smith and Sam Allred from CartoFusion on visualization tools, Dufek and Sarmiento on photogrammetrics and general post-processing with AgiSoft, and Xiao as support.

C. May 30-31, 2016, Flights

CRASAR flew two days under the Lone Star FAA UAS Center blanket COA. The purpose was to confirm predictions made by flood innudation models, assess risks, and document flooding. CRASAR used a DJI Phantom 3 Professional for both days.

On May 30, 2016, CRASAR flew for a total of 4 flights in 3 different locations of the county. Total flight time for all the flights was 26 minutes, for a total of 12 GB of raw data, and average flight time of 8 minutes. In two flights, communications was lost and autonomous return to home was enabled. The flight crew consisted of Murphy as pilot and Sarmiento as visual safety observer. Wright with Juling Bao, First Assistant to Chief Engineer Fort Bend County Drainage District, served as the County experts. Grant Wilde served as an embedded data manager with the field team.

On May 31, 2016, CRASAR flew for a total of 8 flights in 4 different locations of the county. Total flight time for all the flights was 68 minutes, for a total of 35 GB of raw data, and average flight time of 8 minutes.. The flight crew consisted of Murphy as pilot and Sarmiento as visual safety observer. Wright served as the County experts, and engineers from the EDP Water Utility Services and Jones & Carter directed two flights. Xiao served as the embedded data manager.

IV. Data Curation

The purpose of the SUAS flights was to provide information. The SUAS produced raw data products (low resolution imagery, high resolution video and images) and derived data products (visualization of flight coverage, interactive measurement tools, and photogrammetry) which generally added $1,000 to $3,500 in costs. The SituMap was an effective visualization and measurement tool. While the SUAS successfully provided information, data management required dedicated data managers in addition to the flight crew and three different strategies (flight crew serves as data manager, dedicated data manager, embedded data manager) were used. The value of the data depends on the availability to the appropriate decision makers and thus a chronology of when the data was available is provided.

A. Data Products and Costs

The data products produced by the SUAS were low resolution video, high resolution video, high resolution images, visualization of flight coverage, interactive measurement tools, and photogrammetry. These products can be divided into *raw data products* and *derived data products*. The case studies suggest that the derived data products run the risk of being too expensive, too procedurally complex, or time consuming to use in an emergency.

Raw data products are those that are intrinsic to the SUAS and are provided without extra processing or internet connection. This is the data that the SUAS is guaranteed to produce if it is a successful flight. The raw data products can be further subdivided into *ephemeral (not recorded)* and *recorded.* The SUAS provided ephemeral low resolution video from the SUAS cameras in real-time and recorded high resolution video and geotagged images onboard to a SD card. Ephemeral data was often sufficient for the embedded expert to make decisions or judgments (e.g., that the flooding innudation was following predictions).

Derived data products are produced by post-processing of the raw data products. The post-processing may be handled by third party software, in this case SituMap for visualization of where the SUAS had flown and where the images were taken, and Agiscan for photogrammetry products. These products incur an additional charge. SituMap costs around $1,000 for a software license. An AgiSoft Photoscan professional license which eliminates having to upload files to the cloud is around $3,500. This does not factor in the manpower costs or training costs.

B. SituMap

CartoFusion's SituMap is a spatial planning and management tool used for visualization of different, co-located data sources. The goals for SituMap for the floods were to measure the amount of flood water at locations of interest as well as support a visual damage assessment. SituMap provided two interactive data products: a map of where the images were taken and an interactive measurement tool that allowed experts to compare base photographic and

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digital elevation maps of the area with the imagery and measure distances and areas.

The interactive map displayed dots at photograph locations, which were linked to the image. This map was generated using geographic EXIF tags from all photographs which were read and converted to a comma separated value document that listed Latitude, Longitude, and photograph file name. There were slight positional errors because other EXIF tags were of the SUAS location and the camera was not always facing straight down, but close enough that it helped experts comprehend what data was available of what areas. Visualizing what the SUAS saw was more valuable than visualizing the path of the SUAS.

The measurement tool allowed users to rectify (rotate and scale) the raw images from the SUAS and attach them to the base map thereby providing a pre-flood and post-flood view of the situation on the ground, as shown in Figure 2. SituMap used the EXIF tags from the photographs to automatically position the images on the base map, then the user could change the transparency to manually align and scale the image to match landmarks. With the photograph rectified and attached to the map, and area distance measurements were taken from the rectified photograph which represented a reasonable accuracy considering the very short time required to review and rectify the photograph.

As an example of a measurement derived quickly from a SUAS photograph using SituMap, the width of the water flow near a bridge was taken both on the base map (pre-flood) and SUAS photograph (post-flood) to determine the magnitude of the increase of water being held by the bayou. Figure 2 shows the two measurements as well as the base map and rectified SUAS photograph. Time-wise, once a SUAS photograph was identified, it took less than one minute to rectify the photograph to the map and derive measurements.

C. Manpower Costs in Data Management

The large volume of raw data led to three different strategies for managing the data: the flight crew doubles as data managers (April 20 flights), there is a dedicated data management team at the EOC (April 23 flights), and a dedicated data manager embedded in the flight crew (May 30-31 flights). The data manager role is to:

- backup the raw data,
- organize the recorded data and field data into folders with consistent naming convention to facilitate clarity as to what data was from what locations on what dates,
- segregate or edit high-value data so that the most valuable data was easily available,
- produce flight summaries serving as a synoposis of missions, coverage, and findings,
- physically transport and hand off the data to County representatives, also called “sneakernet”, and

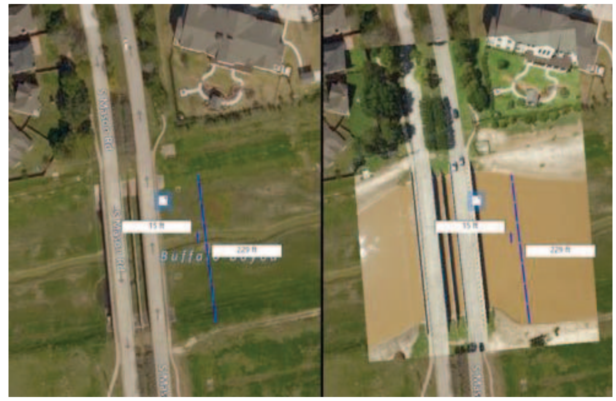

Figure 2 Pre-flood view of a base map (left) of S Mason Rd crossing Buffalo Bayou in Katy, TX and post-flood view with superimposed SUAS image (right). Pre- and post-flood water width measurements are shown on both.

- apply any post-processing software packages and update flight summaries.

The flight crew during the April 20 flights were unable to keep the rapid operations tempo, outbrief and prep for the next flight, and simultaneously backup, organize, and annotate the data. This led to the second strategy on April 23 of a dedicated data management team shown in Figure 5. This level of personnel were not available for the May flights but there was sufficient personnel to embed a student with the field team and they were able to keep with backup, organization, and segregation of data without slowing the op tempo; however flight summaries had to be completed at the end of the day so the embedded data manager still did not completely keep up. The embedded data managers and flight team were too busy to download and use SituMap.

D. Data Products Chronology

The release chronology and timing was as follows:

In flight (immediate). Low resolution video was continuously available to the field team. Real-time streaming of video to the OEM was attempted on April 20 but was unsuccessful due to technical difficulties.

Upon landing (12-20 minutes after launch). High resolution video and imagery from the onboard SD card were available to the field team upon landing.

Upon transfer to EOC (2-6 hours after flight). High resolution video and imagery from the onboard SD card were available to the OEM upon transfer. The large volume of data made it prohibitive to transfer the data over cell data connections. Therefore the transfer was done physically when the field team returned to the EOC and simultaneously uploaded to Dropbox or Google Drive. The upload times varied. This transfer could have been faster with couriers to drive thumb drives of the data. For the April and May cases, the county experts embedded in the field team could abstract the decision enabled by the data and call the EOC if needed.

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Upon post-processing (1-5 hours after return to EOC). Data visualization tools were available from two post-processing tools plus manually constructed summaries of the day's flights in PowerPoint. Situ Map was able to show image locations and provide interactive data measurements in about an hour, which some of that time due to file transfers and file compatibility issues. Photogrammetric processing with AgiSoft took five hours using a dedicated workstation.

V. Missions, Platforms, and Team Organization

Six distinct missions have emerged from working with emergency managers, of which the floods exercised five. Three of those five missions- flood mapping, verification of flood models, and flood monitoring- are not new missions and have been known for some time. However, the missions of collecting data for justification of publicly accountable decisions and for public information appear to be novel. Four out of the five missions flown favor remote presence styles of control versus autonomous path execution. The locations and need for rapid setup times favored very SUAS. The flight team consisted of a two person flight crew plus additional expert.

A. Six Types of Flood Assessment Missions

One possible mission is for *property damage assessment,* but was not practical. In this mission, the SUAS could help document the number of houses damaged and the amount of damage in terms of height of water into the houses while there is still flooding in order to qualify the area for disaster assistance. CRASAR's previous unpublished deployment in March, 2016, Louisiana, with the American Red Cross suggests that UAS of any size are not a good fit because the UAS cannot see an water line on houses in a subdivision crowded with trees or cover sufficient area within the line of sight restriction.

Three other missions were requested and were flown. One is *flood mapping and projection of impact*, where the sUAS could help document the extent of the flood, the impact on residents, roads, levees, etc. SUAS appear to have advantages over manned aircraft for forested regions where the platform can operate safely at lower altitudes and hover and stare to detect flowing water in between trees. An expert can use the SUAS in order to identify possible causes of unexpected flooding and mitigation. The second request was for *verification of flood inundation models*, where the experts match projections with the actual boundaries of the flood. The third mission was for *flood monitoring* over time: This is related to flood inundation modeling and one of the reasons why Fort Bend County had CRASAR fly multiple days. Both the mapping and verification missions were remote presence missions, where a drainage or flooding expert needed to be in the loop in case they needed to opportunistically investigate why the flood was not behaving as modeled.

Two missions emerged after the initial April deployment. One was to gather data for *providing justification for publicly accountable decisions*. The documentation of flooding is useful for future land use planning. Fort Bend County was particularly interested in capturing compelling video of the floods in the western part of the county which were severely flooded to show residents in the eastern part of the county which had not been yet been flooded so that they could see why evacuations were mandated. The second mission was for *public information*. Fort Bend County immediately posted the video to YouTube and began pointing citizens to the video to answer questions about their neighborhood. One of the neighborhoods filmed had an assisted living facility and relatives calling into the OEM were directed to look at the video and see that the flooding wasn't going to impact their family member. Both of these missions favored remote presence missions, because they were essentially videography—insuring that the SUAS captured views that would make the most visceral impact.

Four of the five types of missions for SUAS flown were remote presence. The orthomosaics and digital elevation maps (DEM) were not a priority. The emergency managers generally have DEM already (though they may be outdated). The area that they want to look at is so large that a sUAS team is unlikely to reach all of the areas if restricted to line of sight operations— this is where larger UAS or Civil Air Patrol can be of great value. Another problem is that the file size of orthomosaics is unwieldy for OEMs to handle, share, and post among themselves. Not that many mangers have laptops that can handle a 55GB file and the upload times are slow.

B. Choice of SUAS

The choice of platforms and crew organization was guided by the COPIED heuristic following [1]: ***c***onstraints, ***o***perator factors, ***p***enetration or distance, ***i***nformation the SUAS provides to whom and when, work ***e***nvelope for the SUAS, and ***d***uration.

The constraints and work envelope were the prime factors in chosing a platform. The physical constraints of the landing zones and the altitude and line of sight requirements imposed by Federal Aviation Agency regulations. There was limited access to areas because of the flooding and rarely any space suitable for a hand-thrown fixed-wing. Flying near rivers or from residential areas was hard because of trees and power lines. Empty lots without trees were rare, especially in older and urban parts of town, though suburban areas may have soccer fields suitable for launching and recovering fixed-wing sUAS. The floods showed that the work envelope is not the open space between the tree line and the maximum altitude of 400 feet above ground level, but rather the open space plus the landing zone.

The information that the SUAS provided was a second driver. The OEM wanted video and images. Thermal imagery was not likely to be of use. Digital elevation maps were not a priority. They preferred rapid data acquisition where low resolution data was available during the flight and

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Figure 3 Example of a typical launch and landing zone in a residential area. Note trees, an active road, and houses.

high resolution data available upon landing versus an informatics model of flying, processing in the cloud, and then seeing the data. The data was for immediate or near-term decision making. Real-time streaming to at least the expert embedded with the flight crew was desirable.

As a result of the constraints and information needs, CRASAR chose to use the DJI Phantom 3 and DJI Inspire quadcopters because they were small vertical takeoff SUAS. Both platforms had high resolution cameras for capturing video and images. However, even with these small platforms, there were still problems. Access points such as raised roads or levees generally had high tension powerlines which can induce interference- indeed, flight 4-3 had an uncontrolled flyaway during takeoff.

The distance and duration were moot as the line of sight restriction coupled with an altitude restriction of 400 feet above ground level meant that the SUAS could only cover about a 0.5 mile radius. This requires about 15 minutes of flight time so a platform such as a DJI Phantom 3 or Inspire had sufficient battery time.

C. *Team Organization*

The operator factors led to a two person flight crew, with an expert as a de facto third person, which was acceptable for this situation. The baseline safe human-robot ratio was 3 as computed by $N_{humans}=N_{vehicles}+N_{payloads}+1$. The FAA regulations stipulated a pilot and visual observer. Because the missions involved examining the video feed in real-time to opportunistically gather the best viewpoints, a domain expert was engaged to direct the payload but had no direct flight responsibilities.

VI. Gaps Analysis

The observations of the use of SUAS by emergency management personnel and follow up discussions indicate that the primary gap is due to mismatches in informatics and the data-to-decision process for flood missions. The current use of SUAS also requires a large number of people, especially data managers. SUAS platforms can be improved by separate real-time displays for emergency management personnel. The gaps analysis is intended to help agencies develop standard operating guidelines on how to collect data; post data for others to view; and archive data for historical purposes (e.g. perhaps to avoid litigation if something bad would happen during a mission). The case studies do not touch on how data would be shared with other emergency management partners or larger considerations such as interoperability of equipment.

A. *Informatics*

The biggest gap is in data curation, specifically in data processing, data transmission and chain-of-custody, and data storage and dissemination. This has been noted as a problem in previous deployments of SUAS to disasters, most notably [10].

Post-processing photogrammetics had limited value. The limited value was due to relatively small areas covered by the SUAS and the types of fusion errors due to collecting data at unfavorable times of day when shadows are present and due to the presence of running water.

The value of real-time streaming is dependent on the situation but was not supported by the available connectivity in rural areas of the county. Real-time streaming could have tremendous benefits for immediate life safety situations but might interrupt or distract experts working at the operations center for flood assessment missions.

Using SUAS to gain the ability to see a person floating down the river during a flood could be critical to provide new information and perspectives to emergency responders at an Incident Command Post; or simply to a responder vehicle with Wi-Fi access on a laptop computer. Real-time streaming back to an Emergency Operations Center (EOC) may be useful at times, but is probably an “added value” and not an essential need for an EOC.

Data storage and playback emerged as a significant problem. Fort Bend OEM did not have sufficient storage space on available computers to absorb the data products and CRASAR had to loan a 1TB external hard drive. Fort Bend, and other agencies, would likely need to purchase upgraded computer hardware and software to reap the most benefits from the data that future flights can provide.

B. *Manpower: Embedded Agency Expert*

Another gap is the significant manpower needed to manage the data. The two case studies suggests a current high cost in manpower to effectively use SUAS.

The strategy of having an agency expert embedded in the team offers three benefits. First, they ensure that the right

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data is collected. Second, they can help the team gain access to locations that might have access limited by the disaster conditions. Third, a County embedded person can provide information to citizens who approach and ask the team questions when deployed in field. On each day of flying, the field team was approached by property owners who were concerned about damage to property and homes. The SUAS flight crew was unable to answer those questions but an embedded local government representative could provide information and guidance to citizens.

The disadvantage of having an agency expert or representative embed with the field team is that it removes that expert away from other tasks, though they can work over the phone en route and in lulls. It is unclear if this is a good trade-off or if real-time streaming to that expert who was on-call would lead to a better allocation of resources. Consulting with an expert over the phone is acceptable if manpower does not allow for person to go in the field; however, team loses perspective of a local representative who has history of local conditions. That local representative may also know aspects of the flooding event that would not be known to the team of technical experts. Value is lost--- both in the information to be collected and perhaps, with certain aspects of team safety.

C. Platform Support of Good Human-Robot Interaction

Figure 4 County experts Wright and Mullen direct a flight by watching real-time video from DJI Inspire from a separate monitor.

The case studies suggest that SUAS platforms should provide a separate display to allow OEM experts to view the output and provide directions. The DJI Inspire used on April 23 supported this by allowing a separate monitor (see Figure 4) but the DJI Phantom 3 Pro used on April 20 and May 30-31 did not. The desirability and value of a separate display is consistent with studies with hazardous materials experts and SUAS [11].

D. Manpower: Data Managers

The inclusion of a dedicated data manager embedded with the team appears to be excessive. It is not clear if it is more time and cost effective to slow down the operations tempo to permit the flight crew to curate data in the field; that is, hold up the next flight until all the data is backed up, labeled, and stored. A well-trained team may be able to work more effectively.

The use of dedicated data managers is also excessive (see Figure 5). One way to reduce this type of manpower is to create data systems which seamlessly integrate into existing OEM GIS programs and handled by existing personnel. However, in each of the 25+ CRASAR deployments, the robots increased the workload of the existing informatics personnel. Even if the data can be integrated, it is hard to imagine how a TB of data would not stress the current workload and ultimately require more people. An alternative is to focus on creating snippets and value-added visualizations independently of integrating the data into information management systems. If better and more intelligent tools existed, then the upfront manpower would be reduced and the data, once integrated, would already be in a useful form.

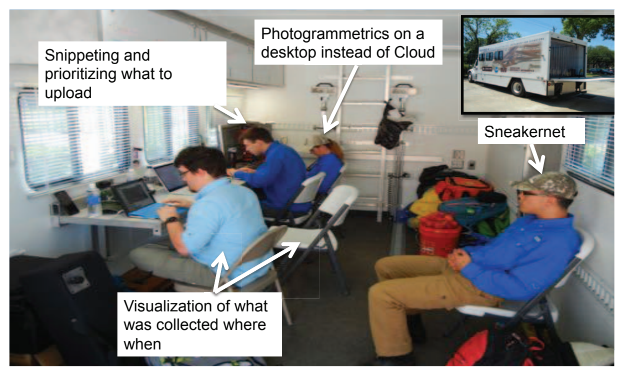

Figure 5 Data management team working in RESPOND-R Mobile Lab parked at Fort Bend County EOC. Photo courtesy of Rick Smith, CartoFusion.

E. Lack of Formal Cost/Benefit Analysis

The two case studies highlight the lack of a formal analysis of a return on investment (ROI). This is not surprising given the formative nature of new applications but a clear ROI will be necessary for County agencies to justify their use and purchase. An ROI analysis might show that SUAS are more cost effective as a shared resource between multiple agencies.

The case studies illustrated four potential benefits beyond providing eyes-on awareness of the flooding. The data can potentially save lives and mitigate property damage by viewing a dangerous situation and correcting the problem area before a catastrophe happens. Videos produced out in the field can enhance public information dissemination to the public and assist in answering citizen inquiries. For example, relatives worried about family members in an assisted living facility near the flooding were directed to YouTube video

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from the SUAS showing that the facility was not in imminent danger. The data could inform engineering projects and save money. They can help inform rational economic development and land-use decisions.

However, the case studies also illustrated that a County will incur significant costs. There are the direct robot-related costs of purchasing and maintaining the platform and training existing personnel or adding new personnel to use the platform. But there will be indirect costs in additional software for advanced data products, implicit addition of computer hardware and upgrades, and additional manpower.

VII. Conclusions

This paper describes two case studies of 21 successful SUAS flights for two different flood events in Fort Bend County, Texas. The large number of flights under the direct supervision of the Fort Bend County Office of Emergency Management and Fort Bend County Drainage District provide a unique perspective on best practices and gaps that pose a barrier to adoption. The SUAS were used as "spotlights" to examine specific areas of interest rather than to produce county-wide maps.

The paper presents a taxonomy of six missions for flood assessment and gives two case studies where five of these missions were flown. It offers a hierarchy of ephemeral data, raw recorded data, and derived data and their costs and chronology of availability. It shows that flights were short (average 10.4 minutes), frequent, and locations scattered over 60 miles.

Five categories of gaps were identified. The biggest gap was in the general informatics process of data curation, specifically in data processing, data transmission and chain-of-custody, and data storage and dissemination. SUAS operations have been designed to optimize flights, not the data-to-decision process. The second gap is in the manpower for the field team; these case studies suggest that an agency representative is valuable and should be included. An agency may not be to delegate data gathering for experts to non-experts. That gap leads to the third gap, which is that platforms need to support the inclusion of an expert mission specialist. The DJI Inspire supported this by providing separate video displays but the Phantom 3 did not. Fourth, curating the data from SUAS requires additional manpower. In practice, embedding a dedicated data manager with the field team and having another data manager at the base of operations may be the most effective way of streamling the flow of data to decision makers. Finally, formal methods for analyzing the return on investment are needed in order to allow agencies to justify the purchase. For example, derived data products such as photogrammetrics run the risk of being too expensive, procedurally complex, or time consuming to use effectively while lower cost tools such as SituMap which are designed to be used within minutes and by novices offer a better cost-benefit.

Acknowledgment

Roboticists Without Borders (RWB) members CartoFusion, US DataWing, and USAA donated time, platforms, and computer hardware and software to these flights. In addition, RWB members Donan, US DataWing and USAA donated the costs of a manned flight to acquire a county-wide digital elevation map to supplement the "spotlight" data from the SUAS.

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