Opportunities for Multisensor Integration in Public-Safety Answering Points

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ABSTRACT

Public-Safety Answering Points (PSAPs) coordinate emergency response by gathering critical information from 911 callers for dispatch to first responders. However, PSAPs fail to gather this information if 911 callers are unable, unwilling, or unavailable to report key details about an emergency. To address this problem, early-adopter PSAPs employ communication specialists to gather multimedia information from multiple sensing tools, including automated alarms, cameras, government databases, location systems, open-source websites, social media, and alternative communication channels such as text-to-911. Using preliminary usage data from an early-adopter PSAP, this study identifies 11 breakdowns in 911 call taking that create opportunities for multisensor integration. This study then characterizes use cases for multisensor tools based on usage patterns observed across five incident types. These findings highlight multisensor integration as a critical area for crisis informatics research.

Keywords

Emergency response, sensemaking, public safety, remote sensing, emergency management.

INTRODUCTION

In the United States, Public-Safety Answering Points (PSAPs) coordinate emergency response by gathering critical information from 911 callers for dispatch to first responders. This information includes the location and nature of the incident, details about involved persons, and, when necessary, information about weapons and other hazards to citizens and first responders (APCO, 2018; NENA, 2020). In many cases, the success of the emergency response depends on the timeliness and quality of information gathered from a single 911 caller.

Consequently, because PSAPs rely on one type of sensor—911 callers—they can lack critical information during emergencies. For PSAPs to detect an incident, citizens must observe and voluntarily report events by calling an emergency telephone number such as 911. After calling 911, citizens must then be able and willing to communicate critical information to telecommunicators. Unfortunately, however, some incidents lack eyewitnesses while others are reported by callers who lack knowledge about the situation or are physically unable to speak due to injury, stress, language barriers, or ongoing responsive actions (e.g., escaping a hazard). Moreover, callers may be unwilling to provide critical information if they perceive that doing so risks implicating themselves in a crime.

To compensate for these limitations, early-adopter PSAPs are leveraging Next-Generation 911 (NG911) infrastructures that allow communications specialists (or comm specialists) to use multisensor tools to detect and characterize incidents that occur in their jurisdictions. Among these, passive sensing tools include:

- **Alarms** that automatically notify PSAPs of vehicle collisions, building fires and intrusions, and injured persons (i.e., personal safety technologies such as Life Alert and Apple Watch).
- **Alternative communication channels** that allow citizens to send emergency (e.g., text-to-911) and non-emergency (e.g., ZipWhip) text and multimedia messages to PSAPs.

Comm specialists can also employ active sensing tools to gather information about emergencies that are

unreported or underreported by 911 callers and physical sensors such as alarms. These tools include:

- **Cameras** that provide PSAPs with real-time imagery of locations and events. These include fixed and point-tilt-zoom (PTZ) cameras on buildings and roadways, unmanned ariel vehicle (UAV) cameras, first responders' body-worn cameras (e.g., Axon), or cameras embedded in 911 callers' smartphones (e.g., C-Live).
- **Locators** that provide PSAPs with real-time location information for connected devices associated with persons, buildings, vehicles, and other tracked assets.
- **Databases** maintained by local, state, and federal agencies that provide PSAPs with contact, criminal history, and other historical information about persons and their assets and interactions with responders.
- **Open sources**, including social media, that can provide PSAPs with publicly available information related to persons, locations, and events relevant to emergency response operations.

Employed by comm specialists, these technologies can be regarded as sensors: human-machine subsystems that detect and characterize remote events. Working together with 911 call takers and dispatchers, comm specialists use multisensor tools to gather and process information for emergency dispatch and response (Grace, 2021). This aural, visual, and textual information has been variously referred to as multisource, multichannel, multimedia, or multimodal to indicate its collection from multiple, heterogeneous data sources (Algiriyage et al., 2021; Musaev et al., 2014; Nalluru et al., 2019). This paper refers to multisensor tools to describe the various NG911-enabled technologies that PSAPs are now adopting to detect and characterize incidents in addition to traditional 911 call taking and dispatch systems.

The adoption of multisensor tools confronts PSAPs with several challenges. Overall, PSAP officials need to understand the opportunities, workflows, and sociotechnical requirements for multisensor integration in emergency dispatch work. Multisensor integration refers to the "synergistic use of information provided by multiple sensory devices to assist in the accomplishment of a task by a system" (Lou and Kay, 1989, p. 903). In this regard, questions PSAP officials must answer include:

1. When and how can comm specialists use multisensor tools for emergency dispatch?
2. What competencies and training do telecommunicators require to become comm specialists?
3. How can telecommunicators, including 911 call takers and dispatchers, cooperate with comm specialists to enhance the effectiveness and efficiency of emergency dispatch and response?
4. What technologies, policies, and protocols are required to coordinate the work of cross-functional emergency dispatch teams using multisensor tools and information?

This study focuses on question #1 by analyzing preliminary usage data collected by an early-adopter PSAP as it began introducing comm specialists and multisensor tools into dispatch operations during the spring and summer of 2021. Findings highlight 11 breakdowns in 911 call taking that create opportunities for comm specialists to use multisensor tools for emergency dispatch. Findings also outline use cases for multisensor integration based on comm specialists' usage patterns during five types of incidents.

The following sections introduce research on multisensor integration in emergency dispatch and response before outlining the methods of data collection and analysis that resulted in the findings presented in this study. The discussion that follows highlights advantages and use cases for multisensor integration in PSAPs that, in turn, open directions for future research on questions #2-4.

BACKGROUND

PSAPs are undergoing a transformation. Implementation of the Emergency-Services IP Network and NG911 core services can allow citizens to call 911 using voice, text, or streaming video, and allow buildings, vehicles, and wearable medical devices to automatically provide real-time alarm, telematic, and health data to 911 dispatchers (APCO, 2014; National 911 Program, 2019). NG911 infrastructure creates opportunities to gather data from to a range of IoT sensor systems, including gunshot detectors, security cameras, and unmanned aerial vehicles, as well as open-source information such as social media. Together, these multisensor technologies stand to provide unprecedented situational awareness for PSAPs during emergencies (Grace and Kropczynski, 2020).

These changes create the challenge of multisensor integration: the interdependent use of multiple human and physical sensors to gather and process information that a system requires for situated interactions with(in) its environment. While multisensor integration typically serves as a theoretical foundation for the design of intelligent systems (Lou and Kay, 1989; Oates et al., 1997), the same conceptual advantages and processes define the work

of human-machine teams in sociotechnical systems such as PSAPs (Grace, 2021).

Leveraging opportunities provided by NG911 infrastructure, PSAPs seek to supplement information gathered from 911 callers with alternative physical and human sensors. In this regard, multisensor integration offers four general advantages over systems that rely on a single information source (Lou and Kay, 1989): *i*) Redundancy: information missing from one sensor can be provided by another sensor. *ii*) Complementarity: comparing information from multiple sensors can reveal insights, including uncertainties, not possible when using information gathered from a single sensor or multiple sensors independently. *iii*) Timeliness: information can be gathered more quickly by some sensors than others. *iv*) Cost: equivalent information can be gathered more efficiently when leveraging multiple redundant, complementary, and/or timely sensors.

While these advantages motivate PSAPs to adopt remote sensing tools, little is understood about when and how comm specialists use these tools alongside 911 call takers and dispatchers. On one hand, only a handful of early-adopter PSAPs employ multisensor tools, limiting opportunities for research on use cases and best practices that can encourage field-wide adoption (Grace and Kropczynski, 2020). On the other hand, researchers have historically neglected PSAPs despite the critical role dispatch centers play in emergency response and management systems (Gardner and McEntire, 2003).

Existing research appears in fields such as organizational studies, human factors, and emergency management (Baber and McMaster, 2016; Furniss and Blandford, 2006; Preusse and Gipson, 2016; Shahrah et al., 2017). These studies include research on stress experienced by telecommunicators (Bedini et al., 2017), characteristics of non-urgent emergency callers (Lehm et al., 2017), factors influencing 911 call volume (Viglino et al., 2017), use of visuals in emergency medical dispatch (Linderoth et al., 2019), procedures for the identification of active silent callers (Kevoe-Feldman and Sutherland, 2018), and studies that simulate call center workflows (Petitdemange et al., 2020; Petitdemange et al., 2020). Except for a few studies that examine the design and use of social media monitoring applications in emergency dispatch centers (Boersma et al., 2019), including studies that examine the availability of hyperlocal social media data suitable for emergency dispatch (Grace, 2020), and the cooperative work and distributed sensemaking required to gather and process information from 911 callers and social media users (Grace et al., 2019), few studies look to PSAPs as nexuses for the deployment of multisensor systems, heterogenous big data processing, or distributed, human-in-the-loop sensemaking.

METHODS

To understand when and how comm specialists use multisensor tools, this study examines preliminary usage data collected by emergency dispatch officials in Chandler Police Department (or Chandler PD), located in the City of Chandler (southwest of Phoenix), Arizona, USA. The following sections describe the collection, coding, and analyses of these data.

Data Collection

Over the spring and summer of 2021, Chandler PD trialed its Multimedia Emergency Communications Specialist Program, which involved staffing select shifts with both 911 telecommunicators and comm specialists responsible for the use of multisensor tools adopted by the PSAP. During these trial shifts, comm specialists were asked to complete a short web-based form whenever they used a multisensor tool. The form included fields for the type of call (i.e., incident) and multisensor tool(s) used, and a synopsis of the use of the tool(s) during the incident.

Due to general staffing shortages exacerbated by the COVID-19 pandemic, the PSAP irregularly staffed the comm specialist position and, as a result, usage data was irregularly collected during the spring and summer months of 2021. Furthermore, comm specialists entered inconsistent information into the synopsis field. Some left the field blank, while others provided brief notes (e.g., “located suspect”) or detailed descriptions of how and why they employed sensing tools. As a result, the PSAP gathered usage data during select periods throughout the year when staff were available and data collection activities were compatible with the workload and operational tempo of the administrative and dispatch staff. In the conclusion, this paper outlines implications for future data collection that would allow a more robust analysis of multisensor tool use than performed in this preliminary study.

Overall, usage data was collected over three non-consecutive weeks during which comm specialists made 115 web form submissions (after removing nine submissions with blank synopsis fields) describing their use of multisensor tools to help 911 telecommunicators gather and process critical information for emergency dispatch. The 115 web form submissions constitute the *full dataset* and describe the type of incident, tool employed, and information need. A subset of 55 submissions with synopses that also describe breakdowns in 911 call taking (and not just uses of multisensor tools) resulted in the *sample dataset*. Significantly, these data provide the first opportunity for research into the use of multisensor tools and information in emergency dispatch operations.

Data Analysis

The *sample dataset* was analyzed to answer the first research question (RQ1): When do comm specialists use multisensor tools? The 55 synopses were iteratively coded to identify breakdowns in 911 call taking that resulted in gaps in critical information required for emergency dispatch. As previously described, some comm specialists submitted brief but detailed synopsis information that explained not only how (i.e., incident, tool, purpose) but why they employed multisensor tools. For example:

> Caller reporting a vehicle jumped a curb and was stuck on the median J/W of Galleria/Frye. Traffic cameras did not locate anything J/W. Used RapidSOS to confirm where the caller was (breadcrumbs). [Via traffic camera] Vehicle was eventually located on Galleria, south of Frye in the landscaping area. Provided information to responding units while en route.

In the coding scheme that emerged, the 911 caller in the synopsis was coded as "unreliable" because the caller provided inaccurate information to the telecommunicator: the vehicle was located to the south, not west, of Frye Road. In this situation, the comm specialist stepped in to confirm and correct the location of the accident using the location service RapidSOS and nearby traffic cameras. Overall, we identified 11 breakdowns in 911 call taking that created opportunities for comm specialists to use multisensor tools.

The *full dataset* was analyzed to answer the second research question (RQ2): How do comm specialists use multisensor tools? Coding each of the 115 incidents in the full dataset by type of incident, tool, and user goal revealed patterns of multisensor tool use (Table 1). Coding involved organizing the multiple call types (e.g., theft) into five incident categories (e.g., criminal). The multiple tools and goals identified in the incident synopses were also organized into five and three code categories, respectfully. The adopted incident, tool, and goal codes align with those regularly employed by the PSAP. Lastly, the categories for each code were summed to describe patterns of multisensor tool use observed over the three-week period.

Table 1. Usage Data Classifications

CATEGORY | TYPE	DESCRIPTION
TOOL	
Camera	Point-Tilt-Zoom (PTZ) cameras mounted along roadways and on buildings, e.g., shopping mall.
Database	Multiple external (e.g., Accurint) and internal (e.g., CAD/RMS) databases that allow telecommunicators to identify subjects, assets, and relatives, and historical data about responder interactions with subjects and locations.
Locator	Devices and services used to locate persons, vehicles, or incidents. In particular, PSAPs use RapidSOS, a data platform and web-based portal that offers real-time location data for connected devices, e.g., smartphones.
Open Source	Publicly accessible websites and social media, including people search websites and utility company and state transportation department alert maps
Miscellaneous	All other tools identified by telecommunicators (e.g., Axon)
INCIDENT	
Alarm	Automatic or responder-initiated alarm received by telecommunicators (e.g., building alarm)
Criminal	Criminal offense that requires a law enforcement response (e.g., domestic violence, road rage, theft, trespass, etc.)
Welfare check	In-person visit from a first responder in response to a 911 call from a friend or family member concerned about the person (e.g., call requesting check on senior citizen living alone)
Traffic	Traffic accidents and roadway hazards that require emergency response (e.g., disabled vehicle)
Other	All other incidents (e.g., missing person, suspicious activity, etc.)
GOAL	
Awareness	Need for situational awareness information (e.g., "Monitored parking lot")
Identification	Need to identify a person or their assets, relatives, or historical interactions with responders (e.g., "Located name of party involved by phone number")
Location	Need to locate a person or incident (e.g., "Located suspect(s) and relayed location")

FINDINGS

RQ1: When do Communications Specialists use Multisensor Tools?

Comm specialists use multisensor tools when 911 callers fail to provide critical information. Comm specialists' synopses of incidents that describe breakdowns in 911 call taking (n=55) highlight nine limitations of 911 callers and two limitations of alarms and non-traditional callers as remote sensors.

Limitations of 911 Callers

In 15 (27%) of the incidents, **unaware** callers simply did not know the answer to telecommunicators' questions. Some of these instances resulted when callers could not visually ascertain details requested by telecommunicators. For instance, when a caller requesting a welfare check for a neighbor not seen for several days observed "food delivery and papers left at the front door," neither the caller nor the apartment complex could provide "a phone number for the subject because the lease was under another name." In this case, the comm specialist used an internal database to locate two possible phone numbers for the subject.

In 10 (18%) of the incidents, **unreliable** callers intentionally or unintentionally provided inaccurate or imprecise information to telecommunicators. A caller reporting a stolen vehicle "claimed that she had GPS on the vehicle and provided an address in Chandler where the vehicle was mapping." However, the comm specialist searched internal and external databases to discover aliases for the caller that linked her to the reported location of the vehicle. This information was dispatched to police officers assigned to the call who "were able to question the RP [Reporting Person] in depth to determine the report was false." Unreliable callers are also observed when multiple callers reported different information for the same incident. During a traffic collision involving a motorcycle, "one party reported CPR [on the injured motorcyclist] was in progress by a citizen while other callers reported different information." To ascertain the situation, the comm specialist "used traffic cameras to verify CPR was not in progress" and the injured person "was wearing a helmet." These details were confirmed by later callers "with the victim [who] reported he was alert and speaking."

In 7 (13%) incidents, **stationary** callers speaking from a fixed position could not provide information about moving persons, vehicles, and, in one case, a coyote interrupting highway traffic. Conversely, in 2 (4%) cases, **moving** callers reported incidents they passed by while driving, but could not adequately describe the scene they observed. In one instance, after a caller reported passing "a male walking in the roadway covered in blood," the comm specialist "used traffic cameras to locate him walking S/B on the sidewalk, stumbling."

In 4 (7%) of the incidents, **disconnected** callers voluntarily hung up or involuntarily lost connection with telecommunicators before providing information needed to dispatch first responders. In a case of the latter, a "female called from wireless 911, asked for help, provided an address and then disconnected abruptly." The comm specialist used open-source information and a motor vehicle department (MDV) database to identify the caller and confirm the address. Responders arrived to discover a domestic violence incident that resulted in an arrest.

In 3 (5%) cases, telecommunicators failed to gather information from **uncooperative** callers who refused to provide information about the nature, location, or persons involved in the incident. These callers included a Chinese-speaking individual who would not provide his name or address to the translator. The on-duty comm specialist used an internal database to match his phone number with a possible name and location.

Alternatively, in 2 (4%) of the incidents, **unresponsive** callers did not audibly reply to telecommunicators' questions. In addition to people who unknowingly call 911, unresponsive callers include people who are physically unable to speak or are in a situation in which speaking may put them in danger. In one case, the PSAP received multiple, silent 911 calls from a Non-Service Initiated (NSI) phone—a device with no service plan but still able to call 911. The on-duty comm specialist used RapidSOS to confirm a location and locate an associated phone number for the parent of the assumed child caller.

In 2 (4%) cases, **lagging** callers provided telecommunicators with information slowly, allowing comm specialists to quickly look up critical information before the call taker gathered these details from the caller. When the location of a traffic collision remained unclear, the comm specialist used nearby traffic cameras "while the call taker was gathering information" to locate and "articulat[e] lanes of traffic, obstructions, and notifi[y] officers once the vehicles were moved out of the roadway."

PSAPs also assist first responders during incidents that go unreported by 911 callers. In 4 (7%) of the incidents, the comm specialists answered responder queries for information when 911 callers were **unavailable**. These included requests for the contact information of the parents of an intoxicated minor and the owner of an empty lot where homeless people were encamping. In another case, police requested information on vehicles registered to a suspect in a criminal damage incident. Using the state MDV database, the comm specialist provided officers with a second address associated with the suspect.

Limitations of Alternative Sensors

In 4 (7%) incidents comm specialists used multisensor tools when requests for service were initiated by **nontraditional "**callers" who used alternative channels such as text-to-911 and non-emergency messaging services (e.g., ZipWhip). In one case, an "RP sent a text message via ZipWhip that there was a metal drawer in the roadway at Price/Ray." The comm specialist employed a "PTZ [camera] at the intersection… to locate the drawer W/B, J/E in the #2 left turn lane." Alternative channels also include live-stream video links (e.g., C-Live) which telecommunicators can send to 911 callers. This occurred during one incident in which a man live-streamed video of his wife's condition after she suffered a seizure while driving away from their home.

Lastly, in 2 (4%) cases, **alarms** prompted the comm specialist to use multisensor tools. One case involved the activation of a GPS-enabled alarm system used to track high-value merchandise. Tracking the activated device as it moved around a shopping mall "before eventually stopping at the [mobile phone] store's address," the comm specialist used a nearby PTZ camera to identify "a FedEx truck parked at the same location as [the tracked device]. FedEx confirmed they were making a delivery to the location which may have included the device that activated."

In addition to requests for service initiated by nontraditional callers and alarms, the limitations of 911 callers as remote sensors create opportunities for multisensor integration. The following section describes the incidents, tools, and goals describing how comm specialists use multisensor tools in emergency dispatch work.

RQ2: How do Communications Specialists use Multisensor Tools?

Comm specialists used multiple types of tools during all five types of incidents (Table 2). Each incident type involved the use of three or more types of tools. However, some incidents involved the use of more diverse tools than others. Criminal incidents involved relatively frequent uses of all five types of tools, while traffic incidents and alarms typically involved the use of cameras and location services such as RapidSOS. Deployed in 79 (69%) of the 115 incidents, cameras located along roadways and atop buildings (e.g., shopping mall) are the most frequently used tool overall and for each type of incident.

Table 2. Types of Tools used per Incident

INCIDENTS	CAMERA		DATABASE		OPEN SOURCE		LOCATOR		MISC.	
Alarm (9)	5	56%*	0	0%	0	0%	4	44%	1	11%
Criminal (36)	23	64%	10	28%	4	11%	4	11%	3	8%
Traffic (37)	36	97%	0	0%	1	3%	4	11%	0	0%
Welfare check (17)	8	47%	7	41%	0	0%	1	6%	1	6%
Other (16)	7	44%	7	44%	4	25%	2	13%	0	0%
Total (115)	79	69%	24	21%	9	8%	15	13%	5	4%

*Do not add up to 100% as incidents can involve the use of multiple tools

Furthermore, examining how many tools were used during incidents shows that 80% of all incidents involved the use of a single multisensor tool (Table 3). Traffic incidents, in addition to relying heavily on one type of tool—cameras—are also the least likely to involve multiple types of tools during the same incident. In contrast, criminal incidents are more likely to involve diverse and multiple tools than other incident types. It should be noted, however, that while comm specialists may primarily rely on cameras during traffic accidents, they often use multiple cameras when available.

Table 3. Number of Tools used per Incident

INCIDENT	SINGLE TOOL		MULTIPLE TOOLS	
Alarm (9)	7	78%	2	22%
Criminal (36)	26	72%	10	28%
Traffic (37)	33	89%	4	11%
Welfare check (17)	14	82%	3	18%
Other (16)	12	75%	4	25%
Total (115)	92	80%	23	20%

Goals Motivating Multisensor Tool Use

Comm specialists used multisensor tools to gather awareness, identification, and location information for all five types of incidents. However, the frequencies of these goals vary by incident (Table 4). Observed in 74 (64%) of

115 incidents, locating an incident or person was the most common goal motivating the use a multisensor tool(s). Traffic incidents, for example, frequently involved the use of cameras to locate the exact position of damaged or abandoned vehicles along roadways. However, criminal and other incidents were more likely to require the identification of persons. For example, comm specialists looked up information provided by 911 callers in various databases to identify the names, vehicle ownership, criminal history, firearm registration, etc. of suspects to dispatch to law enforcement officials.

In contrast, multisensor tools were used to gather situational awareness information in only 30 (26%) incidents. However, needs for situational awareness often motivated the use of multisensor tools during responses to traffic incidents and alarms. When an automated alarm sounded, comm specialists deployed cameras for "documentation of scene details," such as the presence of suspicious activity. During traffic incidents, telecommunicators again deployed cameras to gain awareness of traffic obstructions, ingress/egress routes, and real-time traffic flow information.

Table 4. Goals Motivating Tool Use

INCIDENT	AWARENESS		IDENTIFICATION		LOCATION	
Alarm (9)	5	56%*	2	22%	3	33%
Criminal (36)	2	6%	16	44%	22	61%
Traffic (37)	16	43%	7	19%	31	84%
Welfare check (17)	3	18%	6	35%	11	65%
Other (16)	4	25%	7	44%	7	44%
Total (115)	30	26%	38	33%	74	64%

*Do not add up to 100% as tools can be used for multiple purposes

DISCUSSION

These findings offer a preliminary glimpse into opportunities for multisensor integration in PSAPs that can improve the efficacy and efficiency of emergency dispatch and response. These opportunities appear in the use cases and advantages of multisensor integration described below.

Uses Cases for Multisensor Integration in PSAPs

This study provides preliminary insight into the use cases for multisensor integration in PSAPs. When examined according to the types of incidents (n=5), goals (n=3), and tools (n=5) defined in this study, 75 possible situations arise in which comm specialists might gather information from a single, alternative physical or human sensor to supplement information gathering from 911 callers. As preliminary findings, however, this section highlights the most common use cases, based on the two most observed goals, tools, and breakdowns in 911 call taking for each type of incident over the three-week period (Table 5).

Table 5. Use Cases for Multisensor Integration in PSAPs

INCIDENT	USE CASES
Alarm	Comm specialists used cameras and locators for awareness and location information about events reported by automated alarms. In these situations, 911 callers were often unavailable and, as a result, dispatch teams looked to gather information from alternative sources.
Criminal	Comm specialists used cameras and databases to locate and identify suspects reported by 911 callers. These incidents were often reported by unaware and stationary callers who could not fully identify or report the whereabouts of moving vehicles and suspects.
Traffic	Comm specialists used cameras and locators such as RapidSOS to locate disabled or damaged vehicles and for awareness of traffic flows and ingress/egress routes for first responders. Traffic incidents often involved unaware callers who did not know their location or unreliable callers who reported an incorrect or inexact location.
Welfare check	Comm specialists used cameras and databases to locate and identify persons that 911 callers believed to be in danger or distress. Welfare checks were often reported by unaware callers who did not know, for example, the location of a missing family member or the phone number of an acquaintance.
Other	Comm specialists used cameras and databases to locate and identify suspicious persons reported by 911 callers, including uncooperative and unresponsive callers (e.g., active silent calls) who failed to provide call

takers with requested information.

Observed across 115 incidents during three non-consecutive weeks, these uses cases offer important but provisional insight into emerging patterns of multisensor tool use in PSAPs. Additional and longitudinal data collection efforts are required to rigorously examine the relationship between types of incidents and opportunities for multisensor integration. This study's findings motivate these efforts by pointing to advantages of multisensor integration that, to be realized, require future studies that can inform the design of systems and protocols necessary to perform and coordinate multisensor integration in emergency dispatch.

Advantages of Multisensor Integration in PSAPs

Comm specialists use multisensor tools when telecommunicators cannot gather critical information from 911 callers, citizens using alternative communication channels, or physical sensors such as alarms. This study identifies nine limitations of 911 callers as remote sensors, and two additional limitations of alternative physical and human sensors that constrain the ability of telecommunicators to gather critical information during emergencies. These breakdowns, however, create opportunities for comm specialists to use multisensor tools that can be organized according to the four advantages of multisensor integration: redundancy, complementarity, timeliness, and cost (Grace, 2021; Lou and Kay, 1989).

First, multisensor tools provide PSAPs with redundant sources of information when telecommunicators cannot gather information from 911 callers. Redundancy is critical considering the limitations of 911 callers as human sensors. As observed in this study, 911 callers can fail to provide critical information when unavailable, unaware, unreliable, uncooperative, stationary, moving, disconnected, unresponsive, or lagging. Furthermore, this study observed that nontraditional callers and automated alarms notified PSAPs of an emergency but failed to provide additional, critical information required for emergency dispatch and response. In these situations, comm specialists can use redundant physical and human sensors—cameras, databases, locators, open sources and other multisensor tools—to actively search for identification, location, or awareness information required by first responders. Without these tools, PSAPs must passively wait for traditional 911 callers or non-traditional physical and/or human sensors to report this information.

Second, multisensor tools provide PSAPs with complementary sources of information that create opportunities to recognize inconsistencies and uncertainties. This study observed that comm specialists used multisensor tools to check, confirm, or correct information gathered from 911 callers. The use of complementary sensors allowed PSAPs to identify unreliable 911 callers who intentionally or unintentionally reported inaccurate information to telecommunicators. Comm specialists also verified information provided by uncooperative or unresponsive callers. Examples include occasions when comm specialists cross-checked names, phone numbers, and addresses reported by 911 callers with information available from databases, open sources, and location services such as RapidSOS.

Third, multisensor tools provide PSAPs with timely sources of information that can speed information gathering during emergencies. This study observed that multisensor tools can offer more timely information compared to lagging 911 callers who, for varying reasons, slowly reported information while on speaking with telecommunicators. These occasions saw comm specialists working in parallel with telecommunicators. For example, while a telecommunicator asked a 911 caller about injuries she suffered in a car collision, a comm specialist gathered situational awareness information to identify traffic obstructions caused by the accident.

Fourth, the breakdowns in 911 call taking observed in this study suggest that PSAPs may reduce costs of information gathering by leveraging the redundancy, complementarity, and timeliness of multisensor tools. Particularly during incidents reported by multiple 911 callers, comm specialists can gather timely information to prioritize and filter the questions telecommunicators ask subsequent 911 callers. For example, if comm specialists can confirm the nature and location of an incident, telecommunicators can question and possibly triage callers based on their knowledge of suspects and/or injured persons.

CONCLUSION

This exploratory study presents preliminary findings on comm specialists' uses of multisensor tools in emergency dispatch operations. Findings on breakdowns in 911 call taking, and the resulting use cases and advantages of multisensor integration in PSAPs, present new opportunities for crisis informatics researchers to engage with issues such as the *i*) coordination of sensemaking within human-machine and cross-functional emergency dispatch and response teams, *ii*) detection and characterization of incidents by intelligent systems that gather and process (such as through data fusion) heterogenous data, and *iii*) design of sociotechnical systems that can support processes of multisensor integration in the many command and control centers that, like PSAPs, require real-time

situational awareness to coordinate complex emergency and disaster operations. Although these issues remain outside the limited scope of this study, they present the broad outlines of research programs required to address emergent and near-future challenges of emergency response and management.

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