System-Wide Safety

What Went Wrong: A Survey of Wildfire UAS Mishaps through Named Entity Recognition

November 3rd, 2022

Sequoia Andrade

Hannah Walsh, PhD

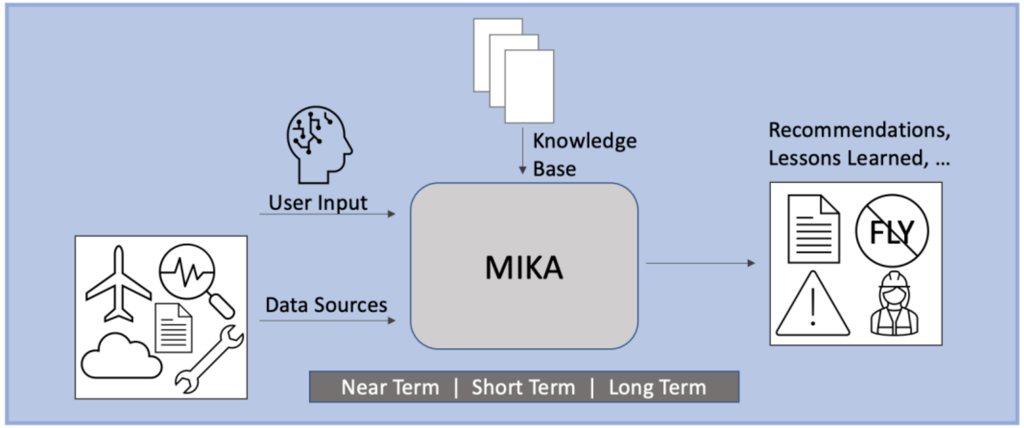
SMARt Research Project

Objective

Support safety assurance in emerging, complex aviation operations using techniques from artificial intelligence and machine learning.

Hazard analysis frequently relies on historical knowledge of failure modes for prevention. Advances in natural language processing (NLP) enable extraction of knowledge stored in large, unstructured sets of documents of lessons learned and accident reports.

MIKA: ***Manager for Intelligent Knowledge Access***. An assistive knowledge manager for decision support and formulating recommendations in the In-Time Aviation Safety Management System (IASMS).



Approach

(1) Support user in identifying hazards in emerging aviation operations by leveraging knowledge in historical documents and data

(2) Packaged as an assistive knowledge management toolkit, ***MIKA***

(3) Current application domain is wildfire response (SWS SD-1)

Current Milestones

(1) Detailed concept of operations for MIKA applied to wildfire response

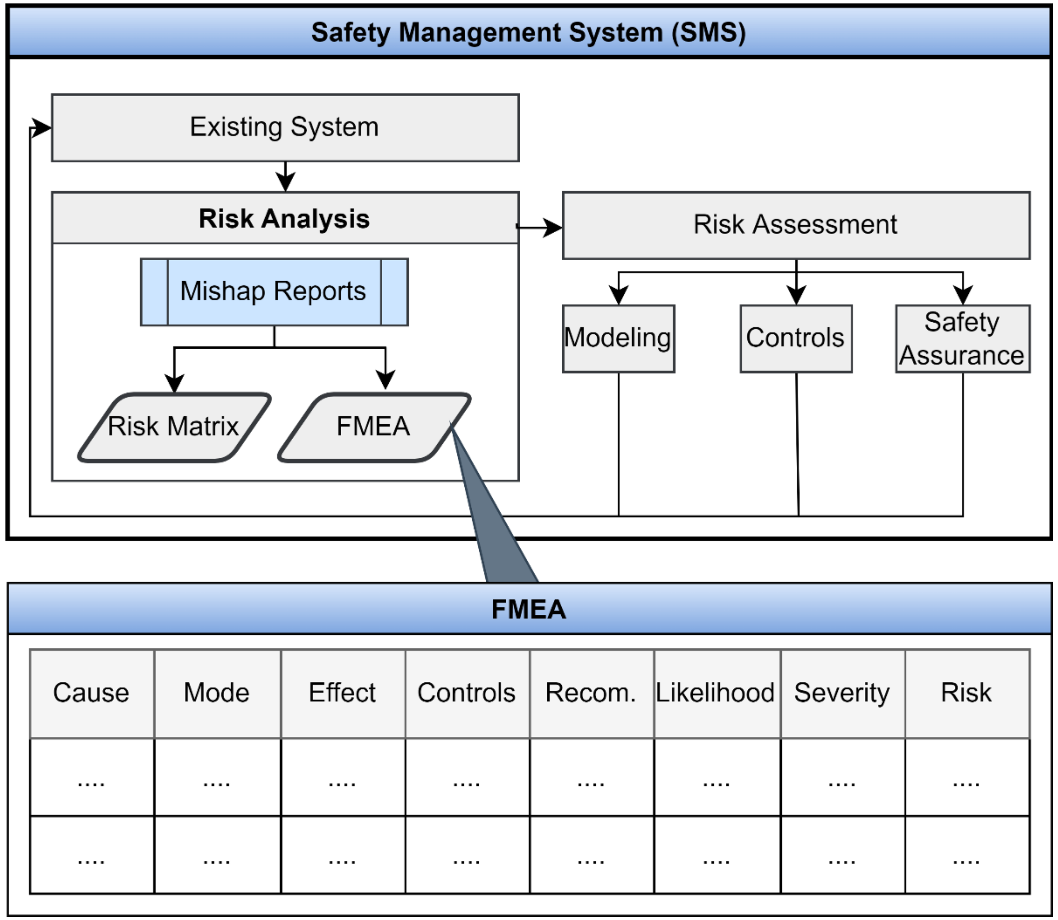
(2) Evaluate potential data sources and knowledge bases for wildfire response

(3) Trade studies for individual capabilities of MIKA

(4) Software development and simple user interface (UI) – aiming for v0 release later this year

Safety Management Systems

- **A key component of a SMS is risk analysis**
- **A common method of risk analysis is the Failure Modes and Effects Analysis (FMEA)**
- **Information from an FMEA informs formal risk assessment, which identifies necessary changes to an existing system**



Failure Modes and Effects Analysis (FMEA)

- **Conventionally performed manually by an expert for safety assurance during system verification process**
- **Growing body of research on augmenting this process:**
  - Rehman et al (2020) generate FMEAs from an ontology built from FMEA worksheets
  - Spreafico and Russo (2021) semi-automatically generate FMEAs from a custom syntactic-based model
  - Andrade and Walsh (2021) used hierarchical topic modeling to extract an FMEA-style failure taxonomy

Named-Entity Recognition

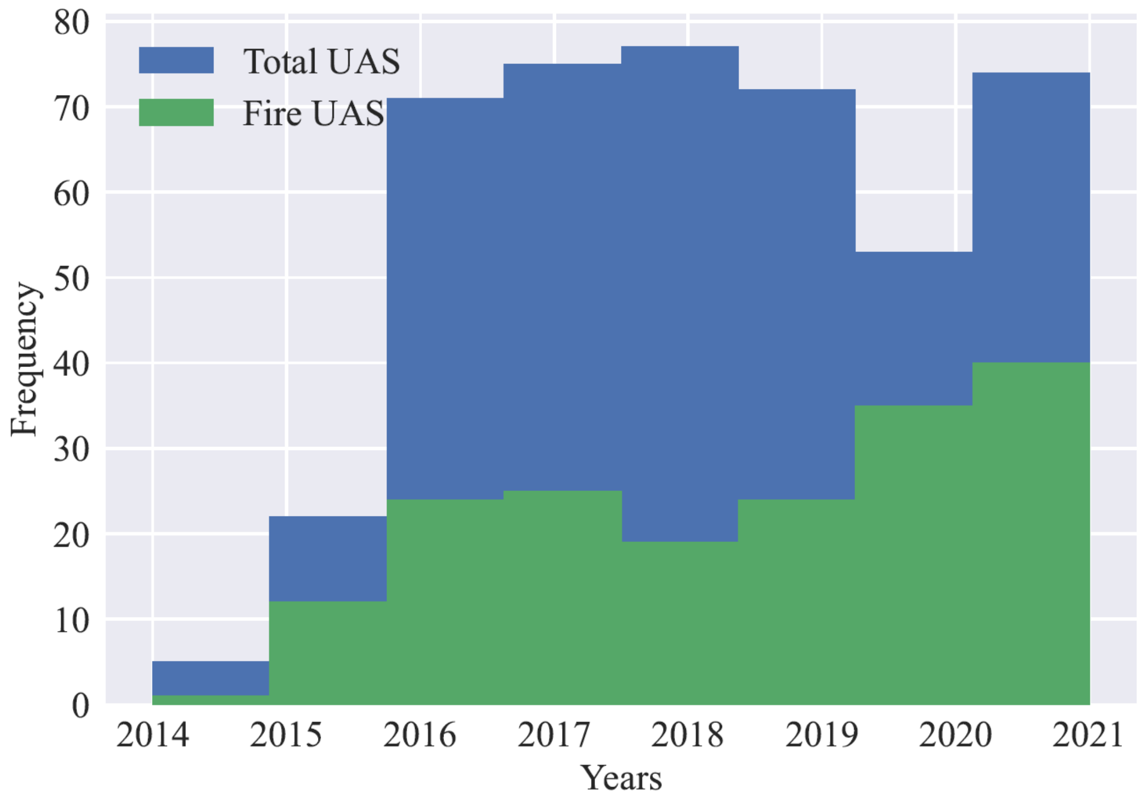
- **Named-entity recognition (NER) is an information extraction method used to label specific entities, such as “person”, “location”, or “date”**
- **Developed in 1990:**
  - ➢ Began as rule-based
  - ➢ Shifted to binary classification (2000s)
  - ➢ State-of-the-art now is transformer models
- **Can use NER to extract FMEA components**

21-0098

A full inspections was conducted CON on the M600 motors prior to the flight to ensure the aircraft was operational. The motor appears normal with no issues during this check. The flight conditions during the time of the incident was sunny, temps of 67, with winds from the north at 3-4 mph and elevation of 5000 ft. Operations was normal during the first 3 flights. After finishing up the last flight with aerial ignitions, I started bringing the aircraft back to launch for landing. At approximately 1317 at 200 ft AGL and 300 yards from the landing site, both pilot and visual observer heard a loud snap EFF coming from the direction of the UAS. Immediately after the snap, the visual observer witnessed a piece of unknown debris falling EFF from the aircraft. The aircraft began to yaw hard EFF in a counter clockwise rotation and uncontrollably descended EFF and impacted the ground EFF . Upon observation of the M600, the arm of the 4/5 propeller completely snapped MOD where it meets the motor. The mishaps related to the M600 are addressed in the following Interagency Aviation Safety Alert CON :

SAFECOM Reporting System

- **Aviation Safety Communique (SAFECOM) is a system for reporting aerial hazards, mishaps, and near misses in operations including wildfire response and search and rescue**
- **Hosted by the Department of the Interior and United States Forest Service**
- **Voluntary**

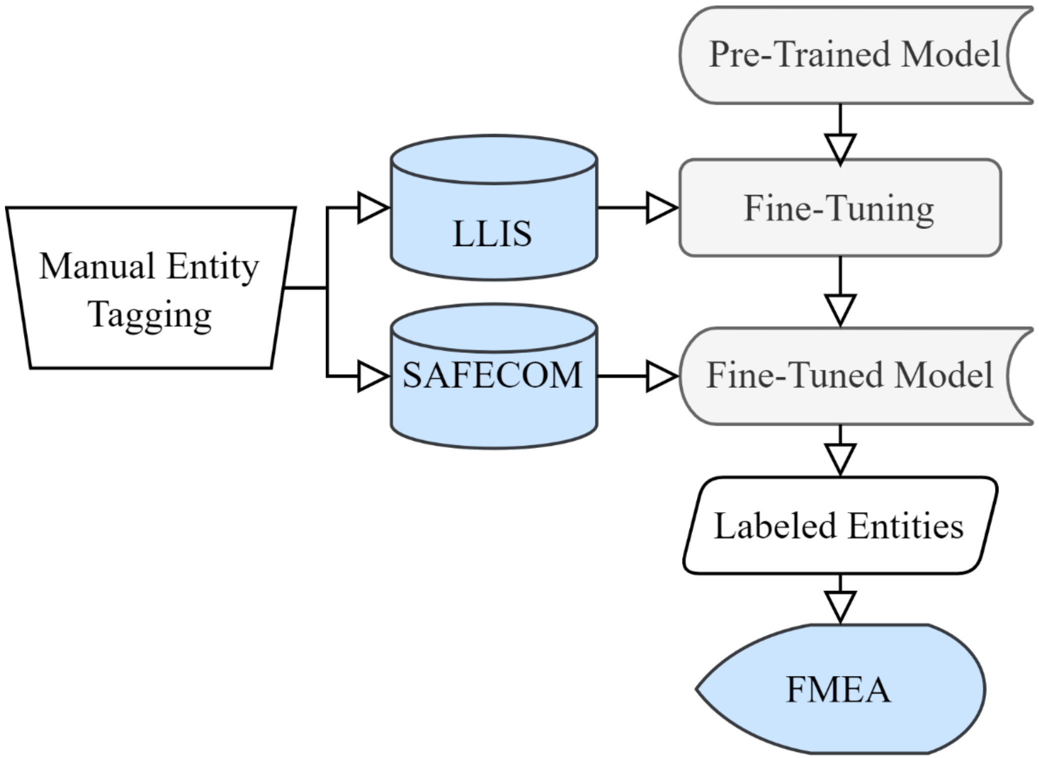


SAFECOM Example Reports

SAFECOM ID	Aircraft Model	Mission Type	Mishap Category	Mishap Narrative	Corrective Action
21-0098	M600 Pro	Aerial Ignition	Aircraft Damage, Forced Landing (engine)	Operations was normal during the first 3 flights. At approximately 1317 at 200 ft AGL and 300 yards from the landing site, both pilot and visual observer heard a loud snap coming from the direction of the UAS. Upon observation of the M600, the arm of the 4/5 propeller completely snapped where it meets the motor.	The mishaps related to the M600 are addressed in an Interagency Aviation Safety Alert.
21-0899	Matrice 600	Infrared Imagery	Loss of GPS	After the LED turned solid red, the aircraft then started flying in the complete opposite direction it was being piloted (SW). Remote Pilot Trainee was unable to pitch forward or backwards to stop the aircraft from flying in the SW direction it was heading. VO called out "fly away" at which point pilot trainee immediately hit the return to home button. The aircraft was piloted back to its "home location" and safely landed.	Suspected GPS Interference. OAS, USGS, and BLM SMEs will review the data. R5 AMS will follow up on data review for any possible information bulletin needs.

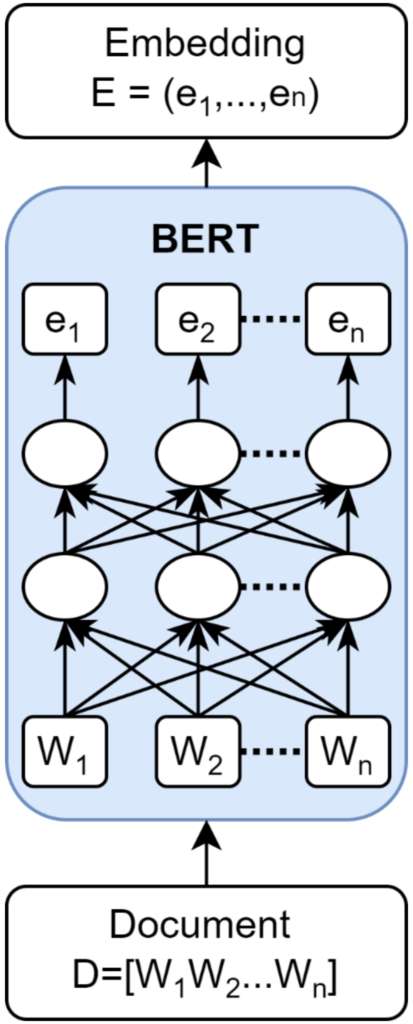
Method Overview

- **Pre-train BERT model**
- **Fine-tune pre-trained model for custom Named-Entity Recognition**
  - ➢ Train set: LLIS
  - ➢ Validation set: LLIS
  - ➢ Test set: SAFECOM
- **Extract FMEA with custom model**



Pre-training BERT Model

- **Bidirectional Encoder Representations from Transformers (BERT): pretrained on large corpus of text, including Wikipedia pages**
- **Additional pre-training for seven epochs on:**
  - ➢ 2,102 LLIS documents from 1985 to 2021
  - ➢ 21,503 SAFECOM reports from 1995 to 2021
- **Improves the masked-language model to understand word context in highly specialized engineering documents**

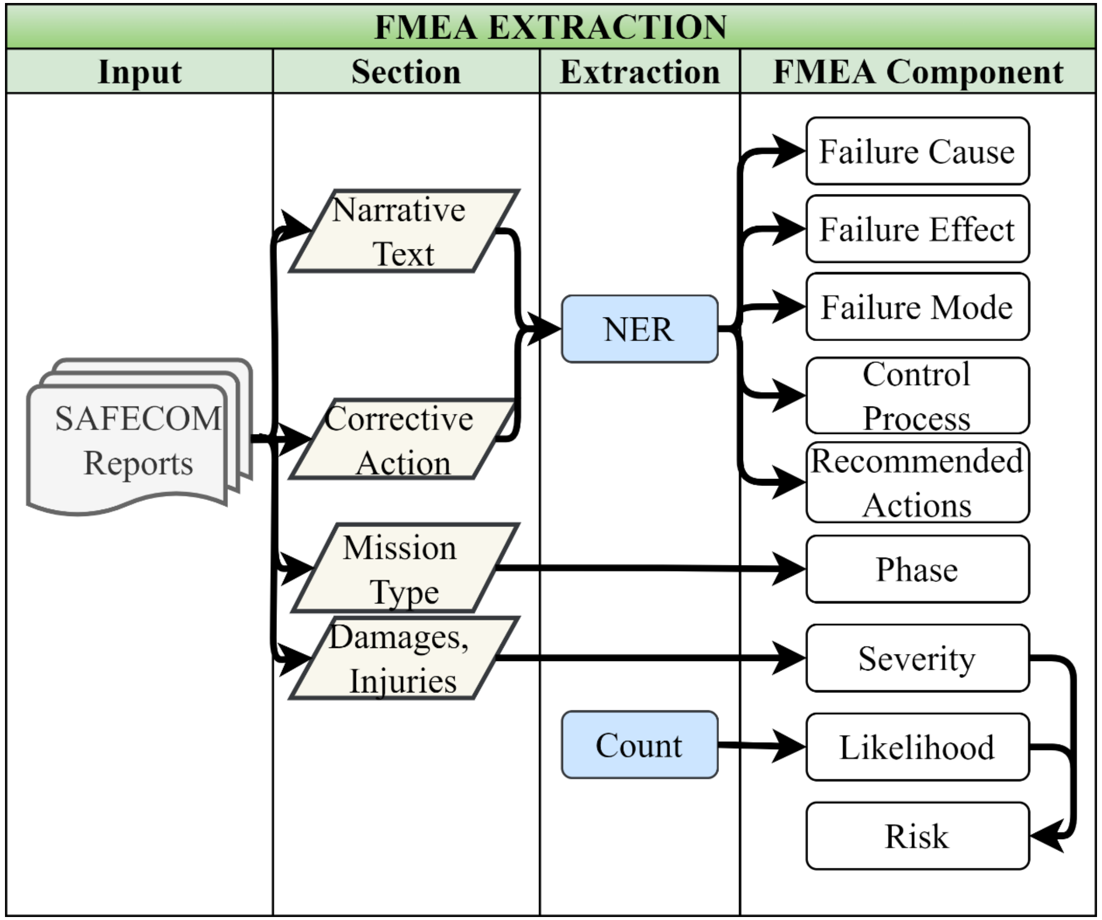


Custom NER Model

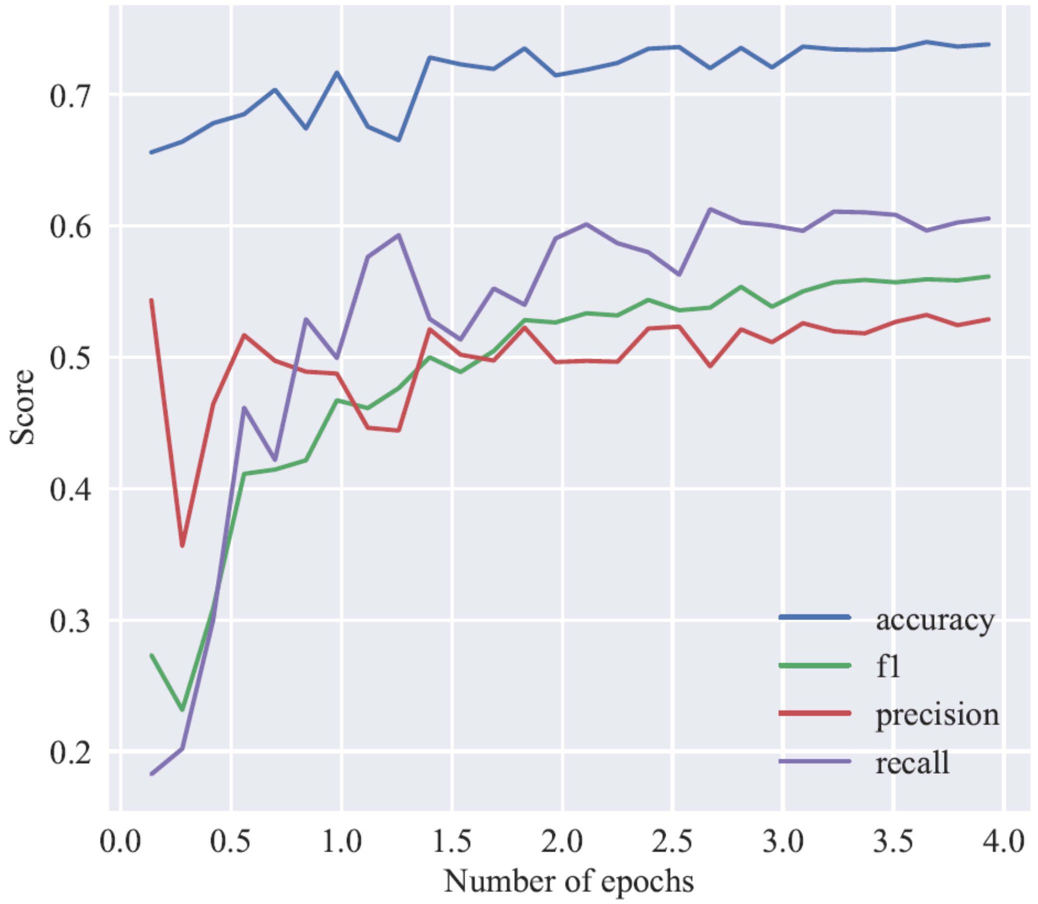
- ***Failure Mode (MOD):*** **The particular manner in which a component or system fails to perform its intended function**
- ***Failure Cause (CAU):*** **Why the failure mode occurs; a condition or defect (a physical defect, a defect in a process or design, an environmental condition, or human error) that initiates a process leading to a failure mode**
- ***Failure Effect (EFF):*** **The impact/consequence of the failure mode; an impact can be component level, subsystem level, system level, or mission level.**
- ***Control Processes (CON):*** **Existing systems or processes that are intended to prevent the occurrence of the failure mode or control the severity of the effect (i.e., a mitigation).**
- ***Recommendations (REC):*** **Future actions required to prevent the occurrence of the failure mode or its effects; i.e., how should the existing control processes be augmented.**

FMEA Extraction

- $S = I + D + H$
  - $I = \begin{cases} 1 \; if \; Injuries = True \\ 0 \; if \; Injuries = False \end{cases}$
  - $D = \begin{cases} 1 \; if \; Damages = True \\ 0 \; if \; Damages = False \end{cases}$
  - $H = \begin{cases} 1 \; if \; Hazardous \; Materials = True \\ 0 \; if \; Hazardous \; Materials = False \end{cases}$
- $R = S * L$



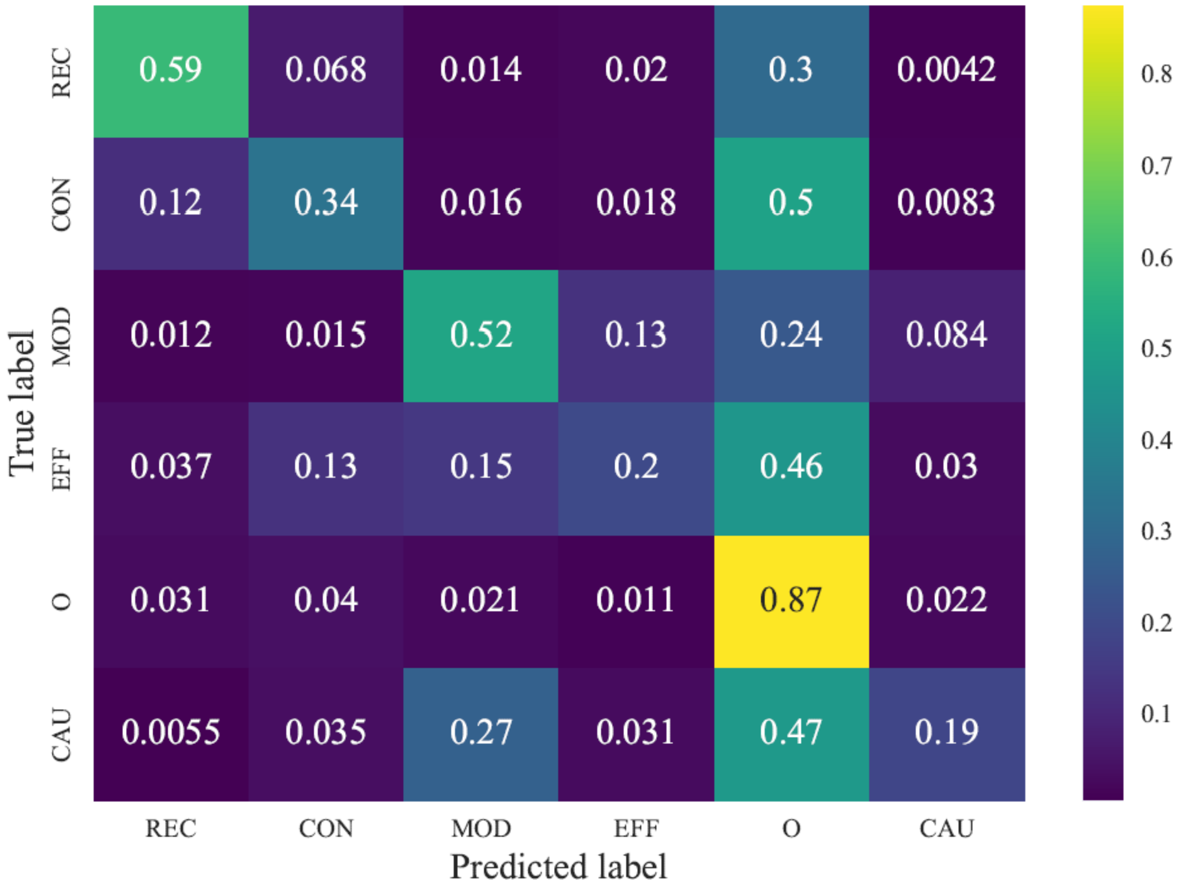
Results: Custom NER Model



Results: Custom NER Model

- Most false predictions are non-entity labels (``O'')
- Failure causes also have a large proportion (27%) of entities incorrectly classified as failure modes

Entity	Precision	Recall	F-1	Support
CAU	0.31	0.19	0.23	1634
CON	0.49	0.34	0.40	3859
EFF	0.45	0.20	0.28	1959
MOD	0.19	0.52	0.28	594
REC	0.30	0.59	0.40	954
Average	0.41	0.32	0.33	9000



Results: NER Example

Manual Annotation:

21-0098

A full inspections was conducted CON on the M600 motors prior to the flight to ensure the aircraft was operational. The motor appears normal with no issues during this check. The flight conditions during the time of the incident was sunny, temps of 67, with winds from the north at 3-4 mph and elevation of 5000 ft. Operations was normal during the first 3 flights. After finishing up the last flight with aerial ignitions, I started bringing the aircraft back to launch for landing. At approximately 1317 at 200 ft AGL and 300 yards from the landing site, both pilot and visual observer heard a loud snap EFF coming from the direction of the UAS. Immediately after the snap, the visual observer witnessed a piece of unknown debris falling EFF from the aircraft. The aircraft began to yaw hard EFF in a counter clockwise rotation and uncontrollably descended EFF and impacted the ground EFF . Upon observation of the M600, the arm of the 4/5 propeller completely snapped MOD where it meets the motor. The mishaps related to the M600 are addressed in the following Interagency Aviation Safety Alert CON :

NER annotation:

21-0098

A full CON inspections CON was conducted CON on the M600 motors prior to the flight to ensure the aircraft was operational. The motor appears normal CAU with no issues during this check. The flight conditions during the time of the incident was sunny, temps of 67, with winds from the north at 3-4 mph and elevation of 5000 ft. Operations was normal during the first 3 flights. After finishing up the last flight with aerial ignitions, I started bringing the CON aircraft back to launch CON for landing. At approximately 1317 at 200 ft AGL and 300 yards from the landing site, both pilot and visual observer heard a loud MOD snap EFF coming from the direction of the UAS. Immediately after the snap, the visual observer witnessed a piece of MOD unknown MOD debris EFF falling MOD from the EFF aircraft EFF . The aircraft began to yaw MOD hard MOD in a counter clockwise rotation MOD and un EFF con EFF tro EFF lla EFF bly EFF descended and EFF impacted the EFF ground EFF . Upon observation of the M600, the arm of the MOD 4 EFF /5 MOD propeller EFF completely MOD snapped MOD where EFF it meets the MOD motor. The mishaps related to the M600 are addressed in the following Interagency Aviation Safety Alert:

Results: FMEA Extraction

Cluster	Phase	Cause	Mode	Effect	Control Process	Recommendations	L	S	R	ID
Battery	Reconnaissance; Infrared Imagery	button, not, could, issue, battery level status, showing	hard, landing, depleted, battery, 40 percent, battery level, sufficient power	dropping, 10, percent, lost, fell at close to free, fall	assumed manual, control, bringing it down, manually, the, uas	batteries will be, tracked on an individual, level, be, removed	2	0.33	0.67	17-0977
Hang Fire	Aerial Ignition	form of, visible, hang fire, functioned, melted, sphere, was still	a, hang, fire, on, aircraft gave a, hatch motion, error	in, flight, fires	vo assisted the pilot, resetting the ignis per, took control	follow, immediately using the, camera, identify any, ensure that you	1	0.00	0.00	20-0872
Loss of GCS	Aerial Ignition; Reconnaissance; Infrared Imagery	error, combination, thermal, signal, controller and, feedback, gcs did not	in flight, failure, gsc, disconnection, error, video, loss, motor, wine	immediately, ignis, warning, crash from, separated, motor, home, not, turned	reset the home, point, noted the gps, location, up, plan	management, pulling flight logs and, video, ensure that, are, done	3	0.33	1.00	21-0172
Loss of GPS on UAS	Other; Reconnaissance; Infrared Imagery	erratic, nose of the aircraft was pointed at, lack of	of, solo made contact with, solo lost, gps, winds, battery	experienced loss, gps, tree, loss of, control, and, crash, shifted	autonomous, regain manual flight, control, initiate " return to home	should have been, suspended, or, cancelled, having eyes on the	3	0.40	1.20	21-0138
Loss of Line of Sight (LOS)	Aerial Ignition	had, lost, of the aircraft, position, and the, pad, could	with a, broken, broken arm locking, ignis housing was, cracked	aircraft, collided, tree, tilted and, fell about 15'to the, ground	a hand held led, light, spot the, pad, exactly, analysis	having the, visual observer 90, degrees, off of the landing	1	1.00	1.00	20-0949
Parachute Landing Failure	Infrared Imagery	chu, fully, parachute was packed, incorrectly, drogue chute was packed	deploy, partial, opening, the, canopy	hard, fuselage was, damaged, been	checked all parachute, on, confirmed proper	site, packing, use a, buddy, check	1	1.00	1.00	18-0821

Discussion

- The custom NER model shows promise for automated FMEA extraction
- The resulting FMEA on UAS mishaps in wildfire response is insightful
- Some components of an FMEA cannot be automatically extracted (i.e., detectability, criticality)
- Different levels of granularity, such as cascading failures, can lead to a confused model
- ML metrics for long-tailed entity recognition are sub-par

Future Directions

- **Additional training on existing FMEA repositories and ontologies**
- **Apply model to more data and evaluate results**
- **Expand model to include Relation Detection (RD) and Causality Mining (CM)**
- **Compare information extraction results between the custom NER model and topic modeling algorithms**

Concluding Remarks

- **Built a custom named-entity recognition (NER) model to extract failure-relevant entities, including failure cause, mode, effect, control process, and recommendations, from mishap reports**

- **Entities identified from the custom model can be used to automatically construct a data-driven failure modes and effects analysis (FMEA)**

- **Applied this process to the SAFECOM reporting system to analyze UAS mishaps in wildfire response operations**

References

[1] P. E. Dennison, S. C. Brewer, J. D. Arnold, and M. A. Moritz, "Large wildfire trends in the western united states, 1984–2011," Geophysical Research Letters, vol. 41, no. 8, pp. 2928–2933, 2014.

[2] "2021 Incident Review Summary," Tech. rep., Wildland Fire Lessons Learned Center, 2022.

[3] "Three Fire Fighters" Microsoft PowerPoint, 2022.

[4] "Wildfire UAS" Daniel Rutter, NASA Ames Research Center

[5] "Wild Fire Burning" Microsoft PowerPoint, 2022.

Contact Information

- Sequoia.r.Andrade@nasa.gov
- Hannah.s.Walsh@nasa.gov

- **Robust Software Engineering:**

https://ti.arc.nasa.gov/tech/rse/