From BERTopic to SysML: Informing Model-Based Failure Analysis with Natural Language Processing for Complex Aerospace Systems

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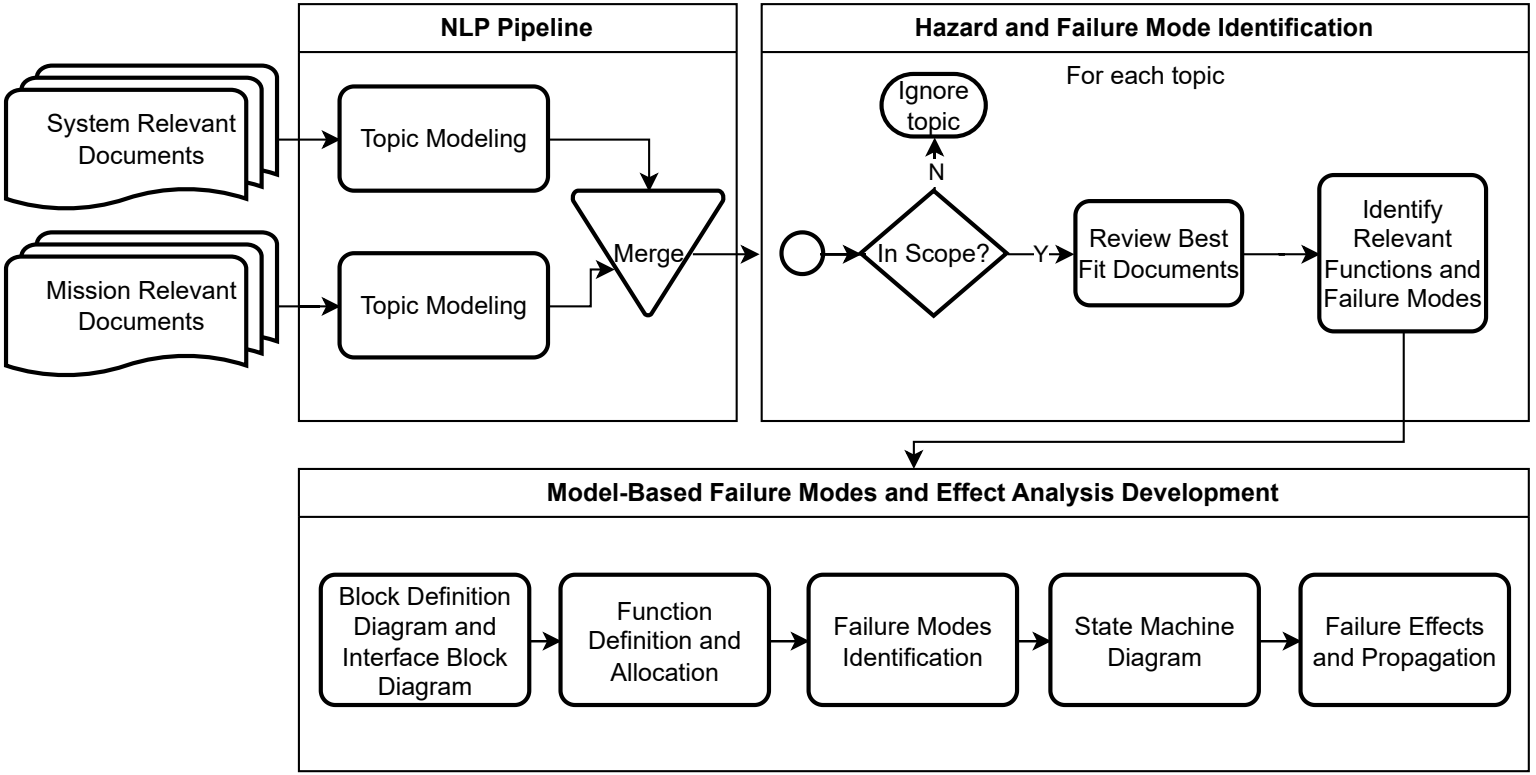
Introduction

- In-time Aviation Safety Management Systems (IASMS) will facilitate the safe integration of complex emerging operational concepts into the National Airspace System through sets of services, functions, and capabilities (SFCs) that will continuously monitor the NAS, assess safety risks, and mitigate them in time
- To accomplish that, most, if not all, safety incident scenarios will need to be considered during the design phase
- Applying natural language processing (NLP) to historical documents enables a broader coverage of safety incident scenarios considered during design phase
- However, for novel systems, information extracted will not be identical to the failures present in the system under design
- When integrated into a rigorous model-based systems engineering (MBSE) process, it is possible to gain the benefits of learning about failures from past missions while ensuring the identified failures are relevant and rigorously modeled

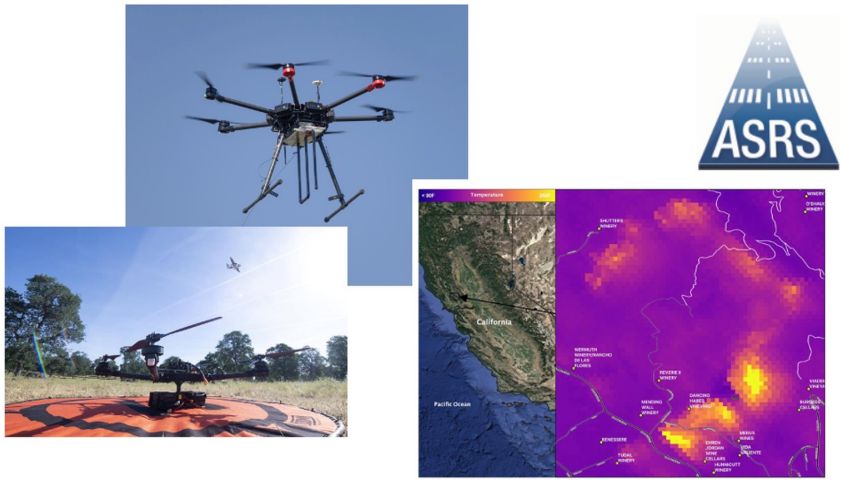
Background

- Model-Based Systems Engineering
  - Recent extensions to Model-Based Mission Assurance, including generation of reliability diagrams and analyses
- Failure Modes and Effects Analysis (FMEA)
  - Can be applied within MBSE framework
  - Primarily limited to expert input or by reasoning from model
- NLP for Failure Analysis and MBSE
  - Leverage large sets of historical documents to anticipate more possible failures
  - State-of-the-art NLP techniques have emerged as effective means of rapidly extracting meaningful information from large sets of documents

Methodology

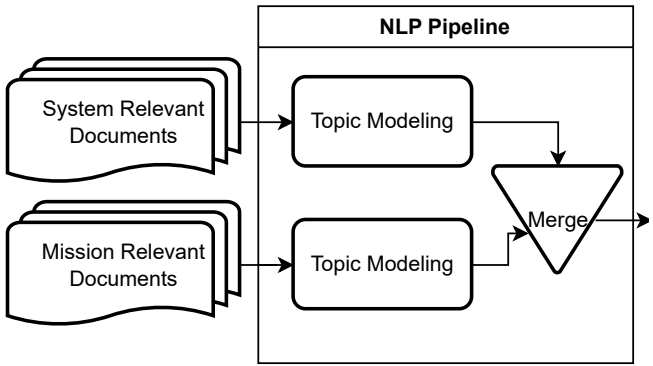


Methodology – Use Case and Data Sets



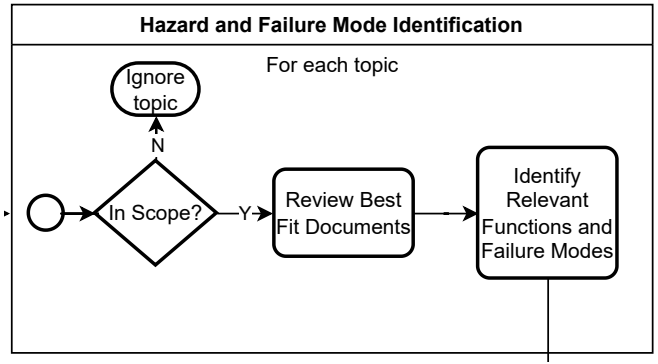
- Wildfire response mission in which an unmanned aircraft system (UAS) is used for surveillance and fire line monitoring
- Two datasets to cover aspects of an emerging application area for UAS:
  - Mission relevant – ICS-209-PLUS (set of ICS-209 reports) for wildfire response
  - System relevant – NASA Aviation Safety Reporting System (ASRS) filtered for UAS missions

Methodology – Natural Language Processing Pipeline



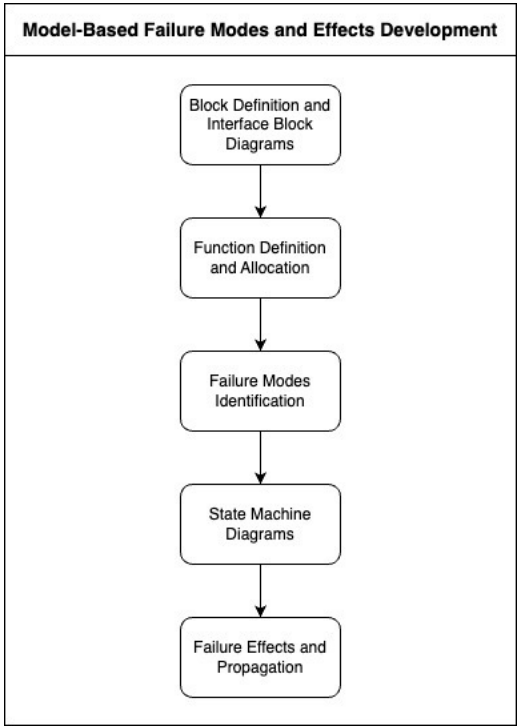
- Topic modeling: extracts a list of themes from a large set of documents
  - Multiple algorithms available
  - BERTopic used in this study
- Labeling: top *n* words to represent the topic
- Topic models applied separately to both datasets
- Similar topics merged, low-quality topics removed

Methodology – Hazard and Failure Mode Identification



- For each topic:
  - Review for in-scope according to use case
  - Review best fit documents for detail and context
  - Use topic and relevant documents to identify functions and failure modes

Methodology – Model-Based Failure Modes and Effects Development



- Identification of system architecture and interfaces using Block Definition Diagrams (BDD) and Interface Block Diagrams (IBD)
- Identification of the nominal functions of the system and allocation functions to the components performing those functions
- Identification of the possible failures of the system's components and creation of failure mode and effects signals
- Capture of components' behavior and creation of States and State Machine Diagrams
- Identification of the activity occurring on entering each state as an entry activity to the state
- Identification of triggers causing transition between nominal or from nominal to fail states
- Identification of the effects of component failure and propagation of this failure to other components

Methodology – Updating with New Data

- Re-run periodically with new documents as they come available
- Update topic repository, model, and FMECA as appropriate
- To simulate this process in this study: withhold a subset of documents from the original analysis and run the full set afterwards

Results

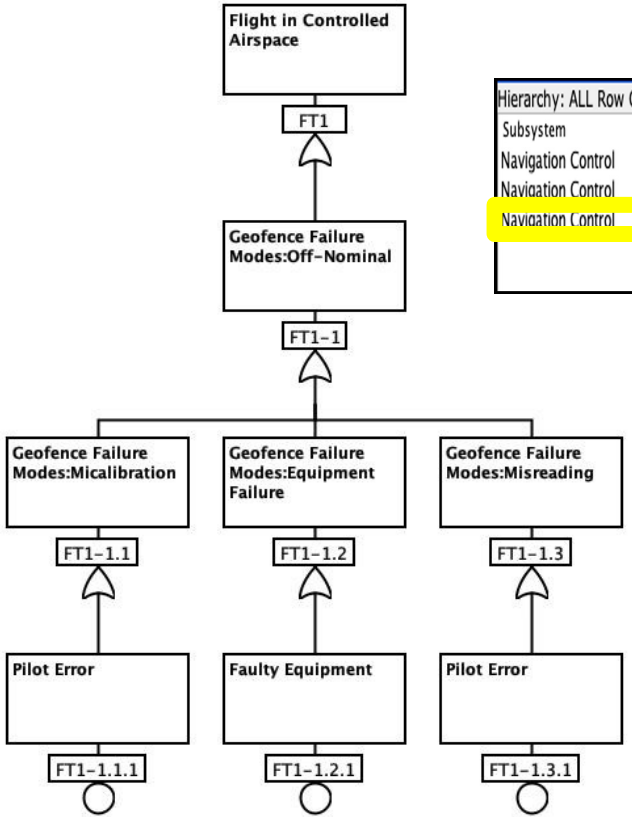
No.	Topic Words
1	type, team, transition, type team, organization
2	acres, acreage, mapping, acre, accurate
3	demobilization, resourced, demobilized, released, crew
4	numerous spot overs, numerous spot, spot overs, overs, numerous
5	authorization, time, Low Altitude Authorization and Notification Capability (LAANC), request, flight
6	bridge, link, drone, lost, lost link
7	airspace, controlled, controlled airspace, discussed, management
8	operator, tree, adverse, state, left

Eight of twenty-nine final topics shown (four from each dataset)

	ASRS	ICS-209-PLUS	Total
Original	11	37	48
Merged	3	7	10
Removed	0	1	1
Final	*7*	*28*	*35*
In Scope	***7***	***22***	***29***

No.	Topic Words
3	demobilization, resourced, demobilized, released, crew
	resources, released, resources released, resources demobilized, demobilization
	declared, controlled, called, declared controlled, contained

Results



Hierarchy: ALL Row Count: 3

Subsystem	Item	Potential Failure Mode	End Effect	Potential Cause(s)
Navigation Control	Geofencing Sensor	Miscalibration	EFFECT: Geofencing Sensor Flight in Controlled Airspace	EVENT: Geofencing Sensor Pilot Error
Navigation Control	Geofencing Sensor	Equipment Failure	EFFECT: Geofencing Sensor Flight in Controlled Airspace	EVENT: Geofencing Sensor Faulty Equipment
Navigation Control	Geofencing Sensor	Misreading	EFFECT: Geofencing Sensor Flight in Controlled Airspace	EVENT: Geofencing Sensor Pilot Error

Narrative	Failure Mode	Potential Cause	Effect
…I was not aware I was flying in controlled airspace until management reviewed my flight and made me aware of the situation…	Geofence Failure	Pilot Error	Flight in controlled airspace
Got to location failed to research the airspace. Was relying on the manufacture's Geo fencing to guide me with airspace…	Geofence Failure	Faulty Equipment	Flight in controlled airspace

Discussion, Conclusions, & Future Work

- Proposed framework for informing FMEA using NLP pipeline applied to relevant historical data sets
- NLP pipeline functions as brainstorming assistant
  - Identifies new model elements
  - Justifying inclusion of model elements
- Future work will extend the proposed framework to a digital assistant
  - Studies will be necessary with human users
  - Other application areas

Thank you! Questions?

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