Risk analysis of serious air traffic incident based on STAMP-HFACS and fuzzy sets

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Plan

1. The goal
2. Human factors in STAMP
3. Human Factors Analysis and Classification System (HFACS)
4. Serious air traffic incident 344/07
5. Causal Analysis using STAMP (CAST)
6. Conclusions

The goal

1. Find the human factor, technical and organizational causes of an air traffic incident using STAMP-HFACS approach,
2. Define safety measures using STAMP-HFACS approach,
3. Assess risk level for the proposed measures by calculating fuzzy probability of transformation of this incident into an accident.

Human factors in STAMP

According to [4]:

The element of human factors of STAMP is somewhat limited and under-specified,

The model of human behaviour implicit in STAMP is somewhat deterministic.

[4] Harris, D., Li, W.-C., An extension of the Human Factors Analysis and Classification System for use in open systems, Theoretical Issues in Ergonomic Science, 12 (2), March-April (2011) 108-128.

Human factors in STAMP

In CAST analysis of Simmons Flight 3641

- Upper management level:
  - FAA
  - NTSB
  - Simmons Airlines/American Eagle
- Middle management level:
  - Operations Manager
  - Pilots
  - Cabin Crew
  - Air Traffic Control

in [2].

[2] CAST Tutorial, Causal Analysis using System Theory, STAMP approach to accident analysis, 2nd STAMP Workshop, MIT, 2013.

Human factors in STAMP

Applying human mental model of Rasmussen to STAMP/STPA has been given in [5].

[5] Hoshino, N, Applying human mental model to STAMP/STPA, 3rd MIT STAMP/STPA Workshop, 2014.

Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System (HFACS) is widely used in human factors accident analysis framework.

It is based on Reason's "Swiss Cheese" model of human behaviour and Rasmussen's human error taxonomy.

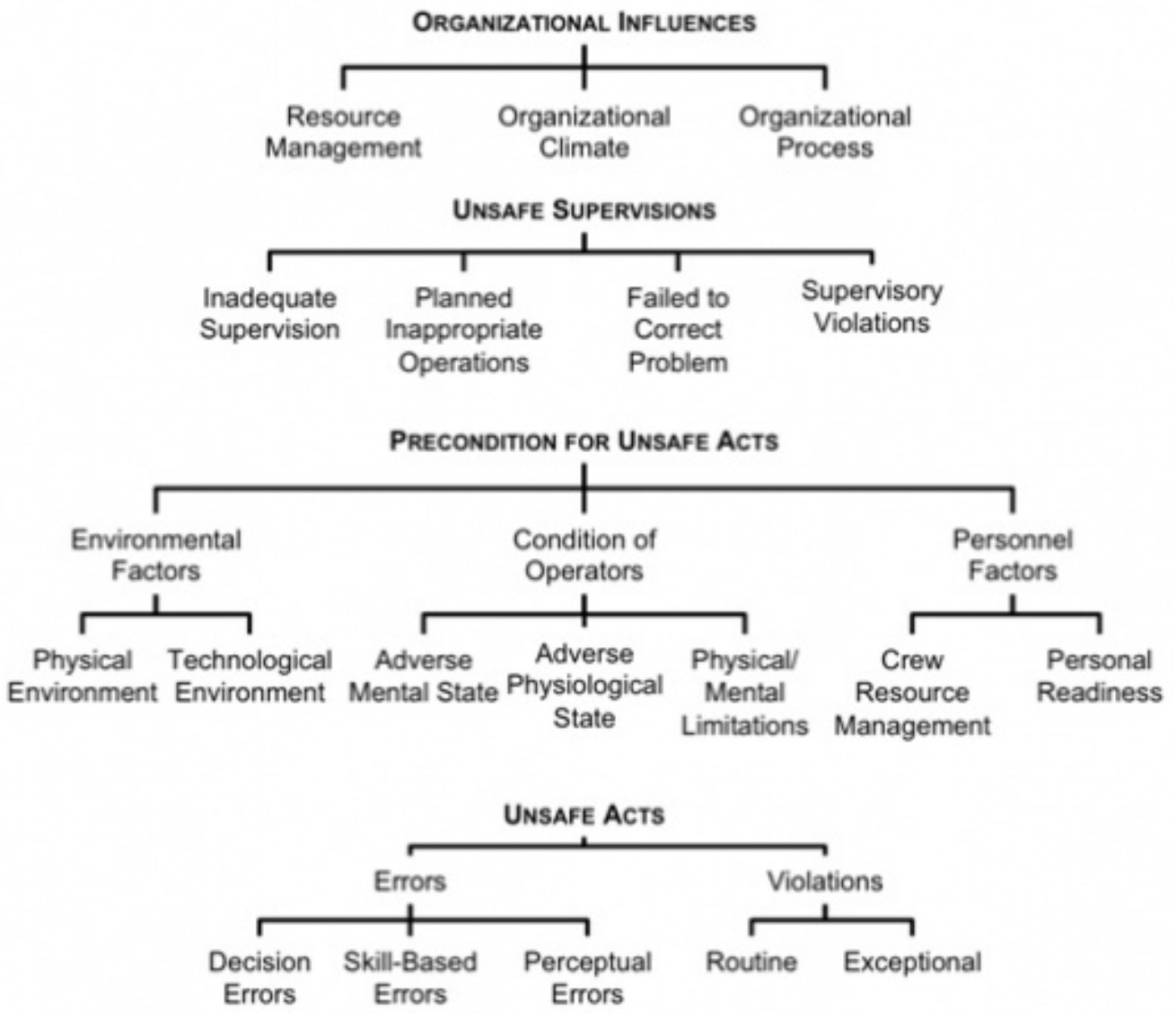
The levels of human errors are as follows:

- Level 1 – "Unsafe acts of operators",
- Level 2 – "Preconditions for unsafe acts",
- Level 3 – "Unsafe supervision" (lower management layer in Reason's model),
- Level 4 – "Organisational influences" (higher management layer in this model).

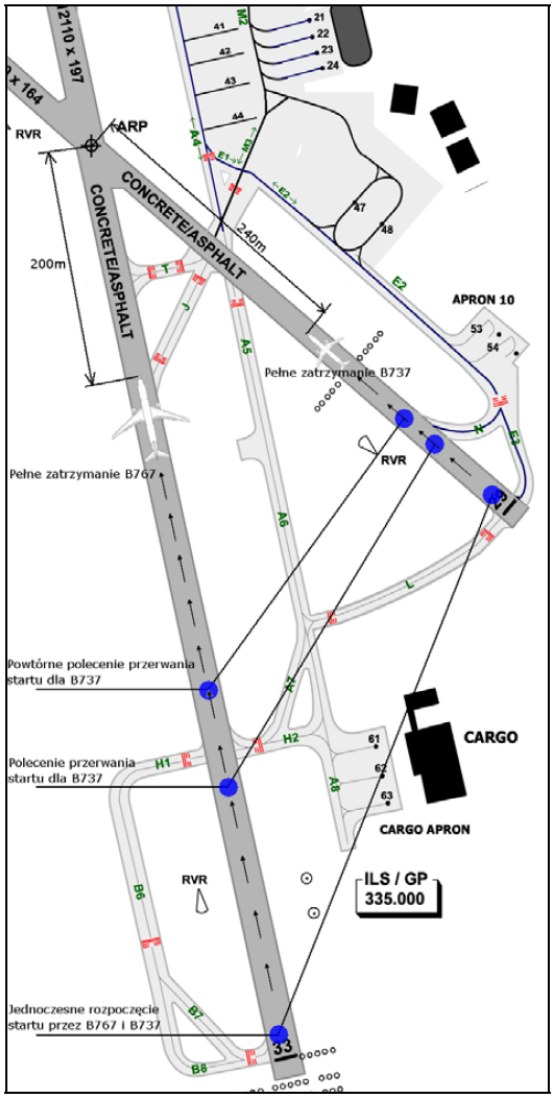
Each higher level affects the next downward level. This influence represents not only chains of events. It has recognized statistical dependencies between the levels

Human Factors Analysis and Classification System (HFACS)

Influence from top to bottom



Serious air traffic incident 344/07



1. The Boeing 737 (B737) crew receives permission to line-up runway RWY 29, which they properly acknowledge.
2. The Boeing 767 (B767) crew receives permission to line-up runway RWY 33 after landing of Embraer 170 aircraft.
3. B767 crew receives take-off clearance which they properly acknowledge.
4. Both aircraft B767 and B737 begin the take-off at the same time.
5. The pilot of ATR72 aircraft, which was standing in queue for departure, observes the situation of simultaneous take-off and reacts on the radio.
6. TWR (Tower) controller orders B737 to break the take-off.
7. B767 crew interrupts the take-off from their own initiative.
8. Both planes stop at about 200 meters from the intersection of runways.

Causal Analysis using STAMP (CAST)

CAST schema is as follows:

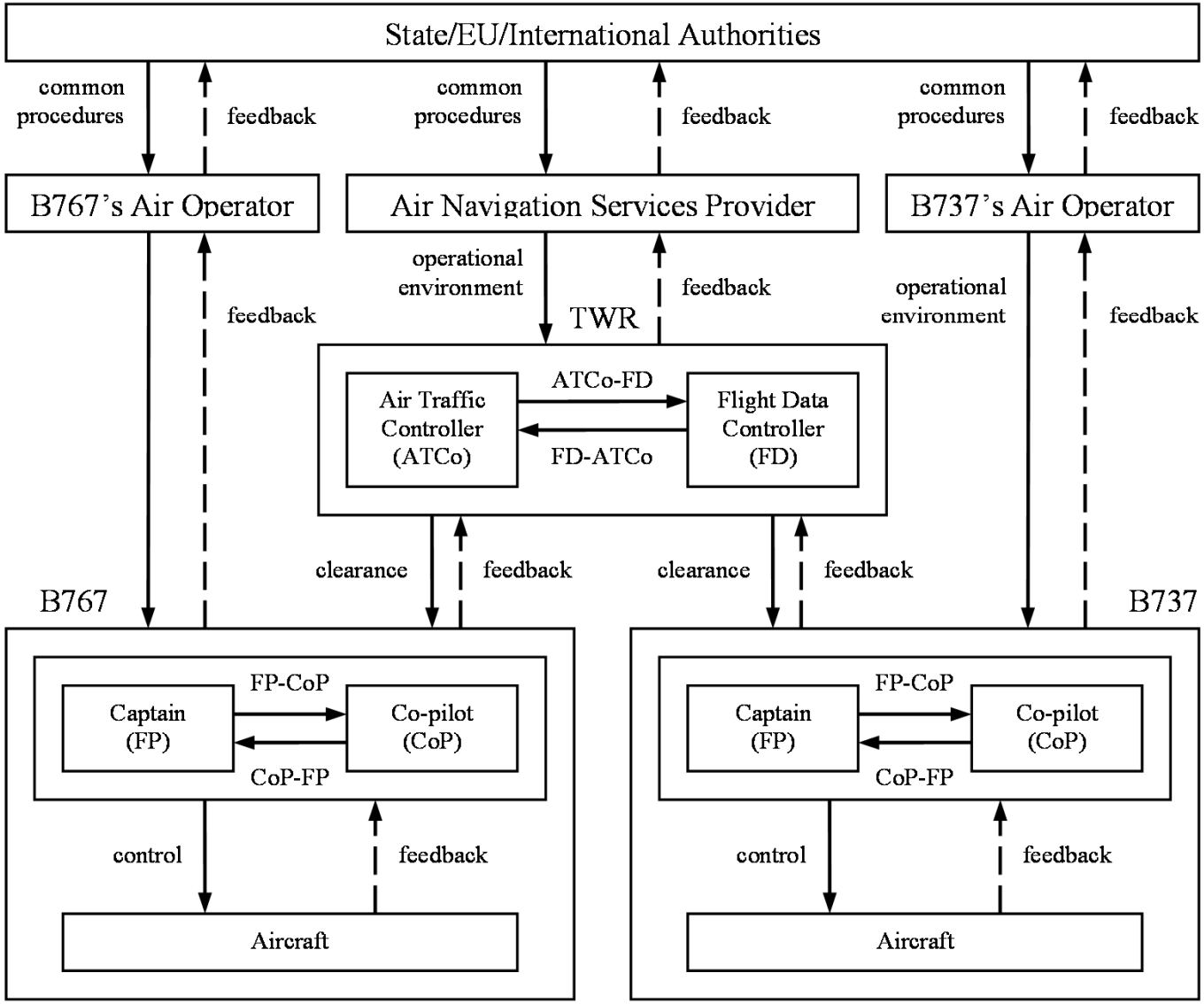
1. Identify system hazard violated and the system safety design constraints,
2. Construct the safety control structure as it was designed to work,
3. For each component, determine if it fulfilled its responsibilities or provided inadequate control,
4. Examine coordination and communication,
5. Consider dynamics and migration to higher risk,
6. Determine the changes that could eliminate the inadequate control (lack of enforcement of system safety constraints) in the future,
7. Generate recommendations.

1. Identify system hazard violated and the system safety design constraints

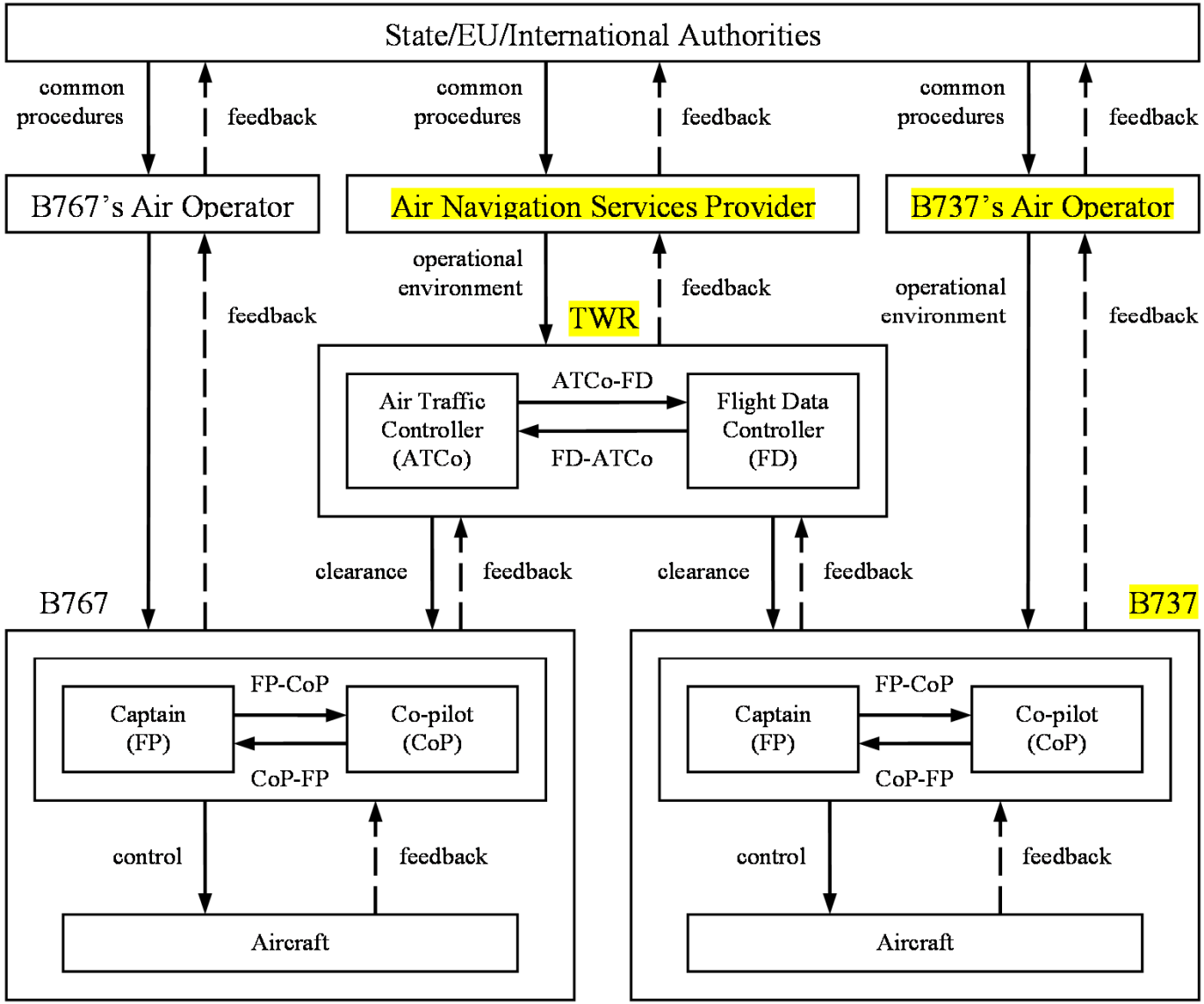
The next aircraft may begin the take-off after the previous one (rolling on the other runway) passes the runways intersection.

In the case of medium weight category aircraft (B737) taking-off behind the heavy weight category of aircraft (B767), the air traffic controller must also take into account the separation due to the wake turbulence. It specifies that the follower aircraft may occupy the same point as the preceding aircraft after at least 2 minutes.

2. Construct the safety control structure as it was designed to work



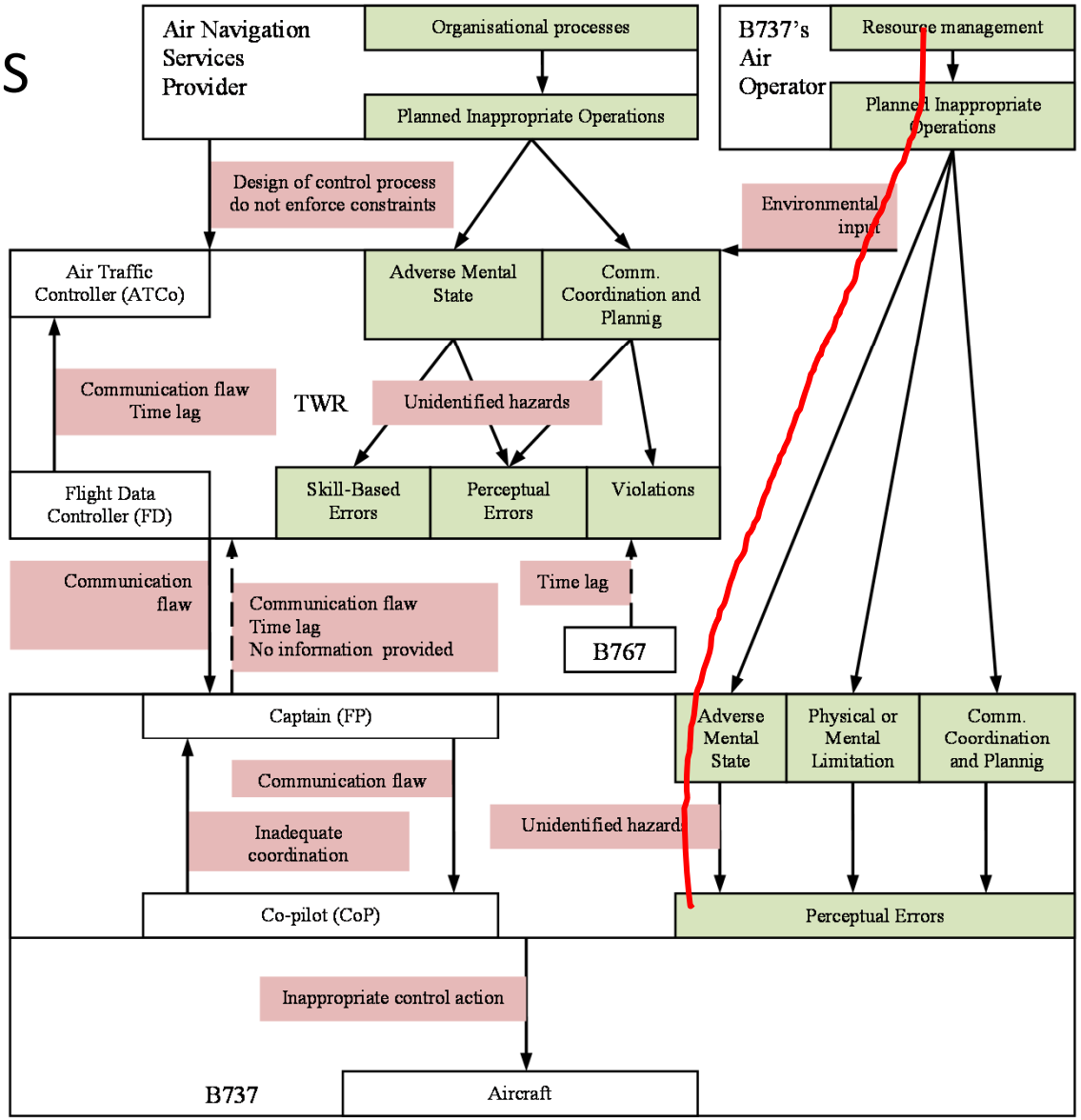
2. Construct the safety control structure as it was designed to work



3. For each component, determine if it fulfilled its responsibilities or provided inadequate control

4. Examine coordination and communication

STAMP-HFACS diagram



3. For each component, determine if it fulfilled its responsibilities or provided inadequate control
4. Examine coordination and communication

Properties of STAMP component:

- Safety Related Responsibilities
- Context
- Unsafe Decisions and Control Actions
- Process Model Flaws

3. For each component, determine if it fulfilled its responsibilities or provided inadequate control
4. Examine coordination and communication

How to incorporate HFACS levels into STAMP properties of component B737 crew?

HFACS level of B737	STAMP property of component B737 crew
Preconditions for Unsafe Acts Level 2	Context
Unsafe Acts Level 1	Unsafe Decisions and Control Actions

3. For each component, determine if it fulfilled its responsibilities or provided inadequate control
4. Examine coordination and communication

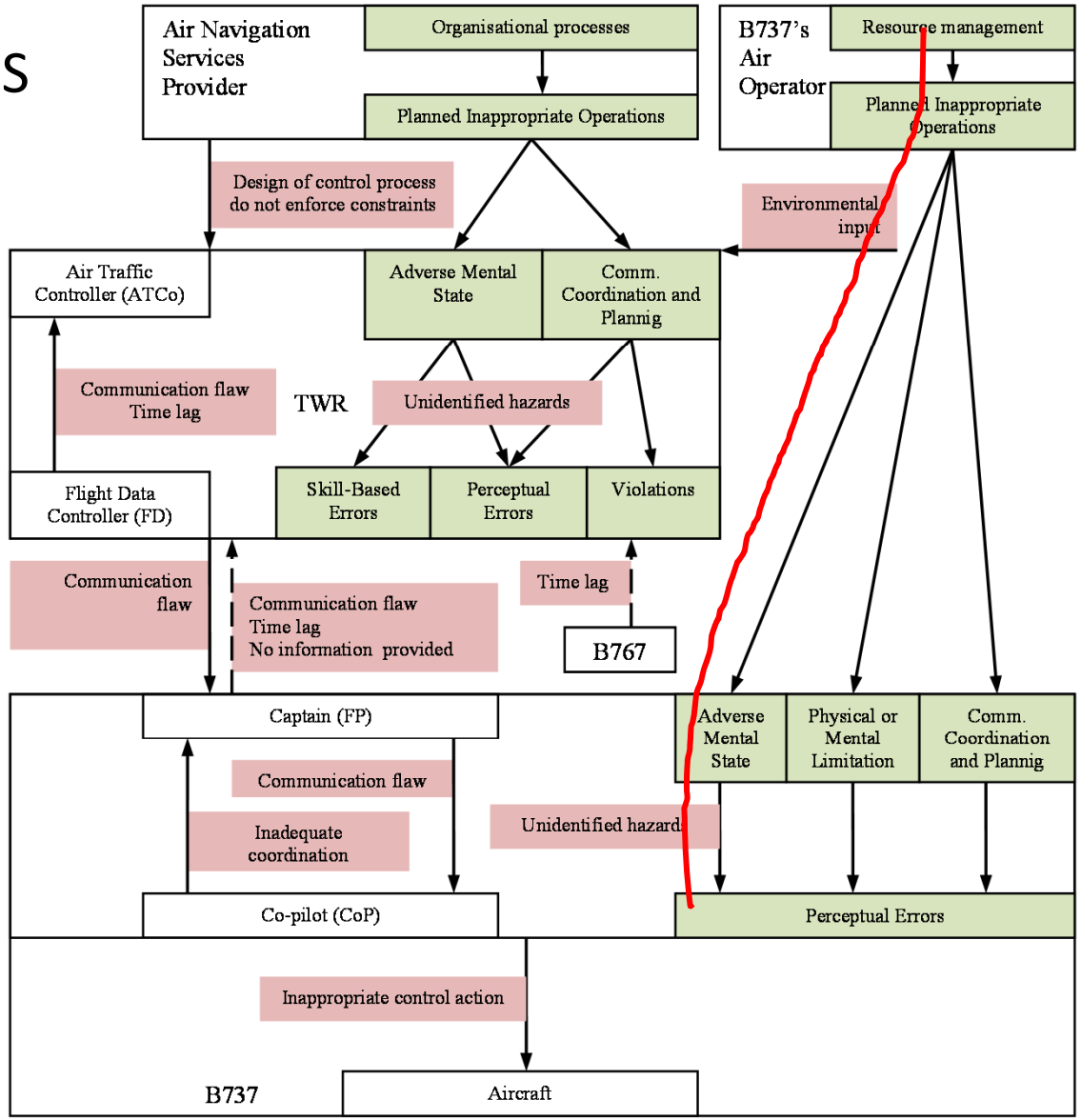
How to incorporate HFACS levels into STAMP safety control structure?

1. Select all such components of the safety control structure that contain a human factor,
2. For each component selected in point 1., choose such levels of HFACS structure that will be included in this component model,
3. For each level selected in point 2., incorporate it into suitable property of the component,
4. For each level chosen in point 2., select its categories that should be considered in the incident analysis,
5. Add influences between HFACS categories for:
   - Interactions between components,
   - Influence inside the components.

3. For each component, determine if it fulfilled its responsibilities or provided inadequate control

4. Examine coordination and communication

STAMP-HFACS diagram



3. For each component, determine if it fulfilled its responsibilities or provided inadequate control

4. Examine coordination and communication

Influence	Source		Target	
	Component	Component's HFACS category	Component	Component's HFACS category
Inappropriate selection of crew	B737's Air Operator	Resource Management	B737's Air Operator	Planned inappropriate operations
Inappropriate influence on mentality	B737's Air Operator	Planned inappropriate operations	B737	Adverse mental state
Unidentified hazards	B737	Adverse mental state	B737	Perceptual errors

Influence between components' HFACS categories (fragment)

5. Consider dynamics and migration to higher risk

In selection process of safety measures the risk analysis need to be executed. **The knowledge about statistical features of factors associated with an incident or an accident is often uncertain and imprecise.**

When analysing systems with uncertain information, the following approaches:

probability,
interval probability,
probability bound,
Dempster-Schafer theory,
fuzzy set theory,
possibility theory

are used.

Fuzzy set theory is applied in the present paper.

In aviation safety studies, dynamics of aircraft behavior often need to be studied. Fuzzy set theory is accommodated to this expectation.

5. Consider dynamics and migration to higher risk

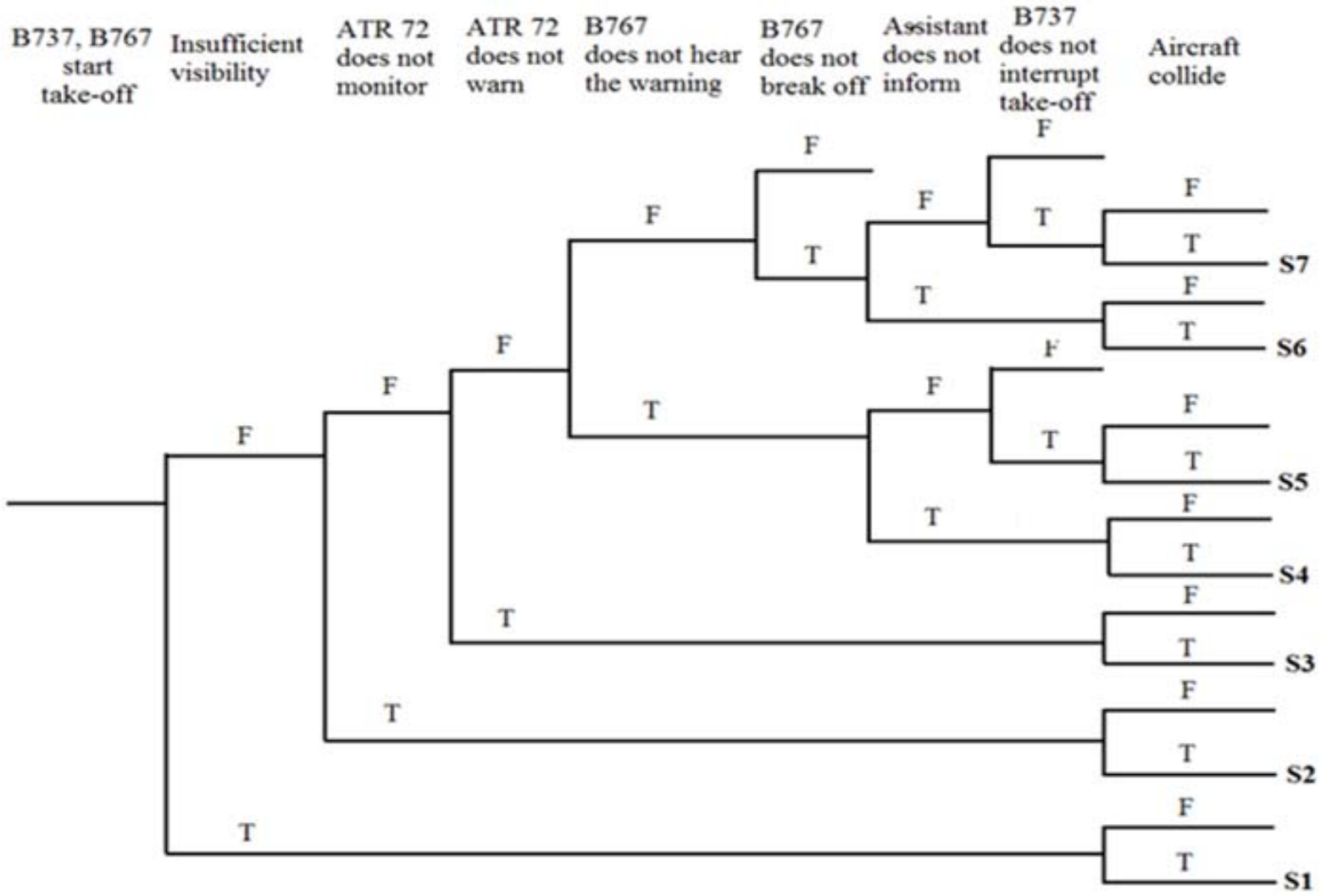
Migration to higher risk is studied by two approaches:

1. Qualitative (analysis of system events sequence without real time factor),
2. Quantitative (timing analysis).

Both approaches use fuzzy set theory. They, respectively, are based on:

1. Event tree with fuzzy probabilities
2. Fuzzy inference.

5. Consider dynamics and migration to higher risk



Event tree presenting scenarios leading to an accident

6. Determine the changes that could eliminate the inadequate control (lack of enforcement of system safety constraints) in the future

Changes that could eliminate the inadequate control have been derived using STAMP-HFACS approach:

1. When there are runway crossings, no more than one aircraft can be waiting for permission to take-off on the runway and, as a general principle, waiting should be on the taxiway before the runway threshold,

2. Selection of Captain and Co-pilot should be improved,

3. Selection of Air Traffic Controller and Flight Data Controller should be improved.

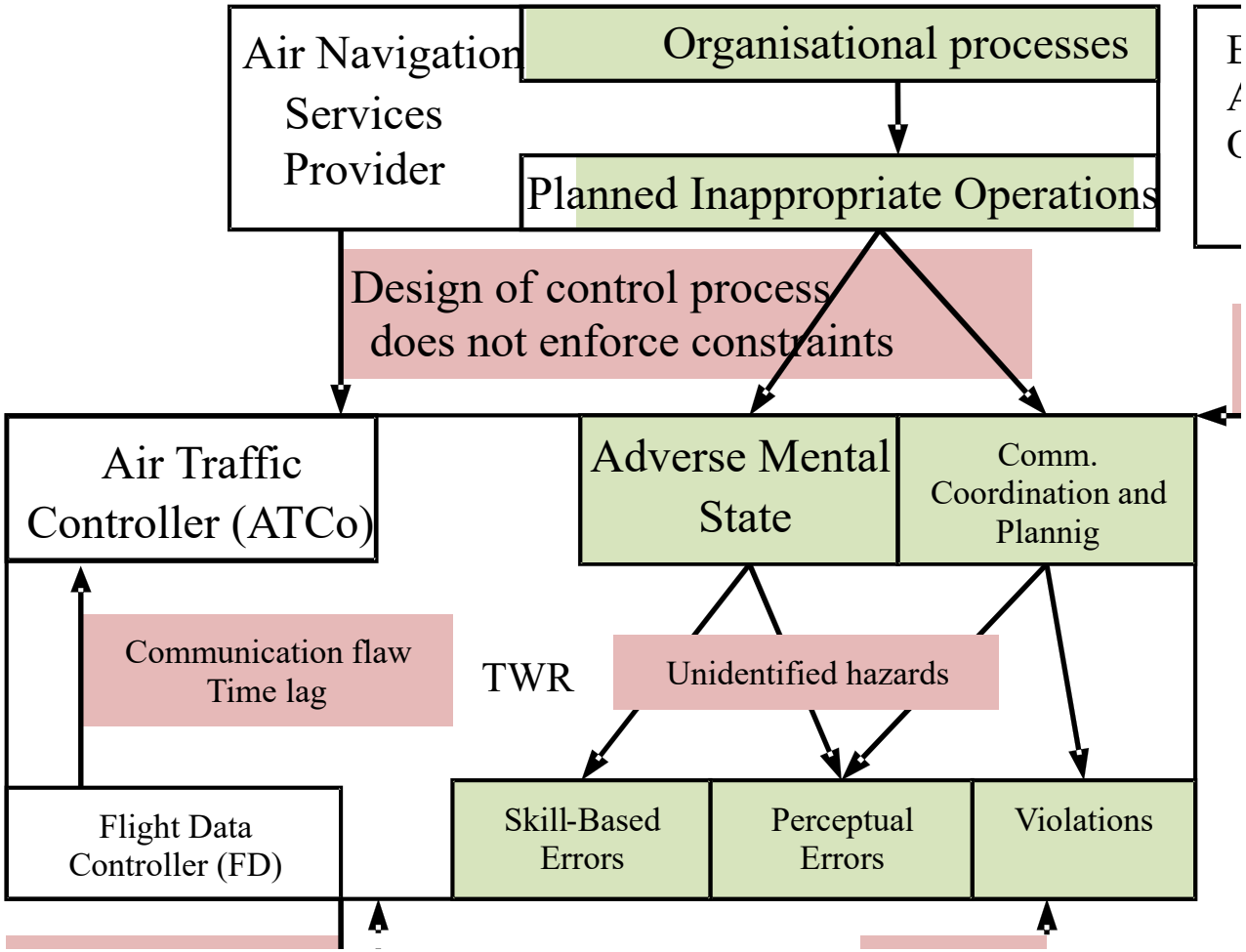
The first was the Recommendation defined by State Commission for Aircraft Accident Investigation.

Risk analysis for the first change only will be presented.

6. Determine the changes that could eliminate the inadequate control (lack of enforcement of system safety constraints) in the future

Recommendation:

When there are runway crossings, no more than one aircraft can be waiting for permission to take-off on the runway and, as a general principle, waiting should be on the taxiway before the runway threshold.



6. Determine the changes that could eliminate the inadequate control (lack of enforcement of system safety constraints) in the future

Probability scale with qualitative values given by fuzzy sets:
Very small, Small, Average, Big, Very big

K - an accident with fatalities,

$P(K)$ - the **fuzzy probability of transformation of the incident into an accident**,

$P(K)$ is between *Average* and *Big*

After implementation of the recommendation, the probability of an accident similar to the incident is:

$P(A)$ is *Very small*

7. Generate recommendations

The first change is accepted as the recommendation.

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Conclusions

- Our methodology enables incorporating:
  - HFACS levels and categories,
  - HFACS inter-level influence

  into STAMP.
- Human factor uncertainty represented using fuzzy set theory.
- The methodology developed for the analysis of the incident seems to be applicable to many of Runway Incursions. It allows to find important gaps in the safety system and to determine their significance.
- The proposed two methods of estimating risk using fuzzy sets: qualitative and quantitative can be applied for evaluation of recommendation proposals derived with application of STAMP, HFACS, STAMP-HFACS, HFACS-STAMP.