Mathematical Approach towards Resilience Engineering in ATM

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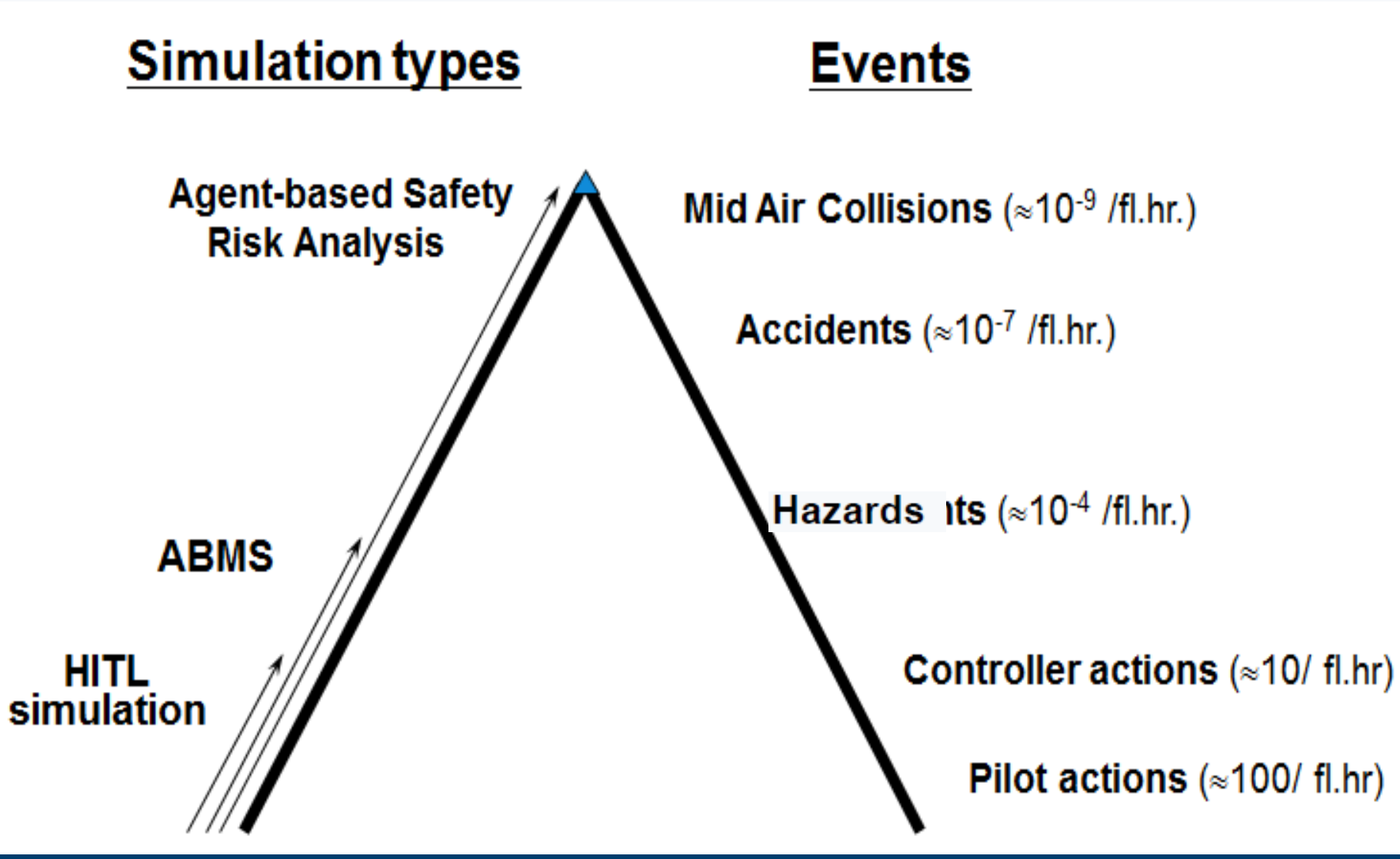
Resilience in the literature

- **Ecological Resilience**
  - Focus on Absorption of disturbances
- **Engineering Resilience**
  - Focus on Restoration from disruptions
- **Resilience Engineering (Hollnagel et al., 2006)**
  - Focus on Adaptation in response to disturbances
- **Unifying Resilience framework (Francis & Bekera, 2014)**
  - A resilient critical infrastructure system has three capacities:
    - Absorptive capacity,
    - Restorative capacity, and
    - Adaptive capacity.

Resilience vs. Robustness and Dependability (Blom & Bouarfa, 2015)

Resilience capacities (Francis & Bekera, 2013)	Robustness	Dependability	Resilience
Absorptive	Yes	Yes	Yes
Restorative	-	Yes	Yes
Adaptive	-	-	Yes

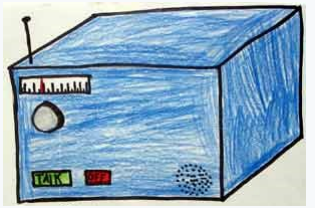
Safety Pyramid



Data Base of Aviation Hazards

Hazard = "Anything that may influence the operation"

- Events / conditions / performance aspects
- Humans / systems / environment
- Interactions



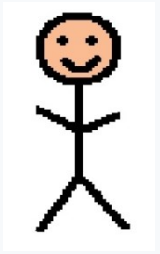
TOPAZ Hazard Database

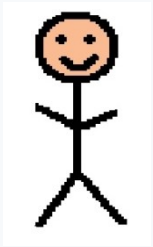
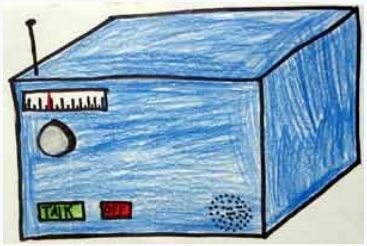
- Conducted safety assessments
- Hazard brainstorm sessions
- 4000+ hazards

Agent Based Modelling and Simulation

- Effective in modelling a complex open socio-technical system
- Effective in modelling interactions and external influences
- Capability to reveal and analyse emergent behaviour
- Mathematical framework enables rare event simulation



Agent-based hazard modelling

- **MAREA delivered 38 agent-based hazard models**
  - Bosse et al. (2012)
  - 13 from TOPAZ applications (NLR)
  - 11 from LEADSTO applications (VU)
  - 14 newly identified by MAREA

- **Together these 38 can model 98% of aviation hazards**
  - Stroeve et al. (2013)

- **Integration of agent-based hazard models**
  - Bosse et al. (2013)

- **Agent-based evaluation of unmodelled hazards**
  - Blom et al. (2013)

Top 5 of agent based hazard models

Rank		% of hazards
1.	Multi Agent Situation Awareness differences	41%
2.	System Modes (Configurations, Failures)	20%
3.	Basic Human Errors (Slips, Lapses, Mistakes)	18%
4.	Human Information Processing (human simulation models)	14%
5.	Dynamic Variability (aircraft dynamics simulation)	9%

- **Models ranking 2 through 5 are familiar**
- **Highest ranking model is a multi agent extension of Endley's (1995) Situation Awareness model**
- **Several other valuable models, such as e.g. Surprise, Learning, Access Rights, Group Emotion.**

Conclusion and Follow-up

- **Resilience literature is divided; Francis & Bekera (2013) give a unifying resilience view for complex socio-technical systems**
- **Mathematical approach towards resilience reveals that interactions between multiple agents are of key value**
  - Highest ranking agent-based hazard model is least familiar !
- **Follow-up**
  - Multi-agent Situation Awareness model has been formalized (Blom & Sharpanskykh, 2015)
  - Modelling of coordination between multiple agents (Bouarfa et al., 2014)
  - Identifying Pilot and ATCo roles in responding to disturbances (Stroeve et al., 2015)

Questions

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