



NLR Air Transport Safety Institute

Research & Consultancy

Agent-based modelling for analysis of resilience in ATM

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Contents

Resilience and the objective of MAREA

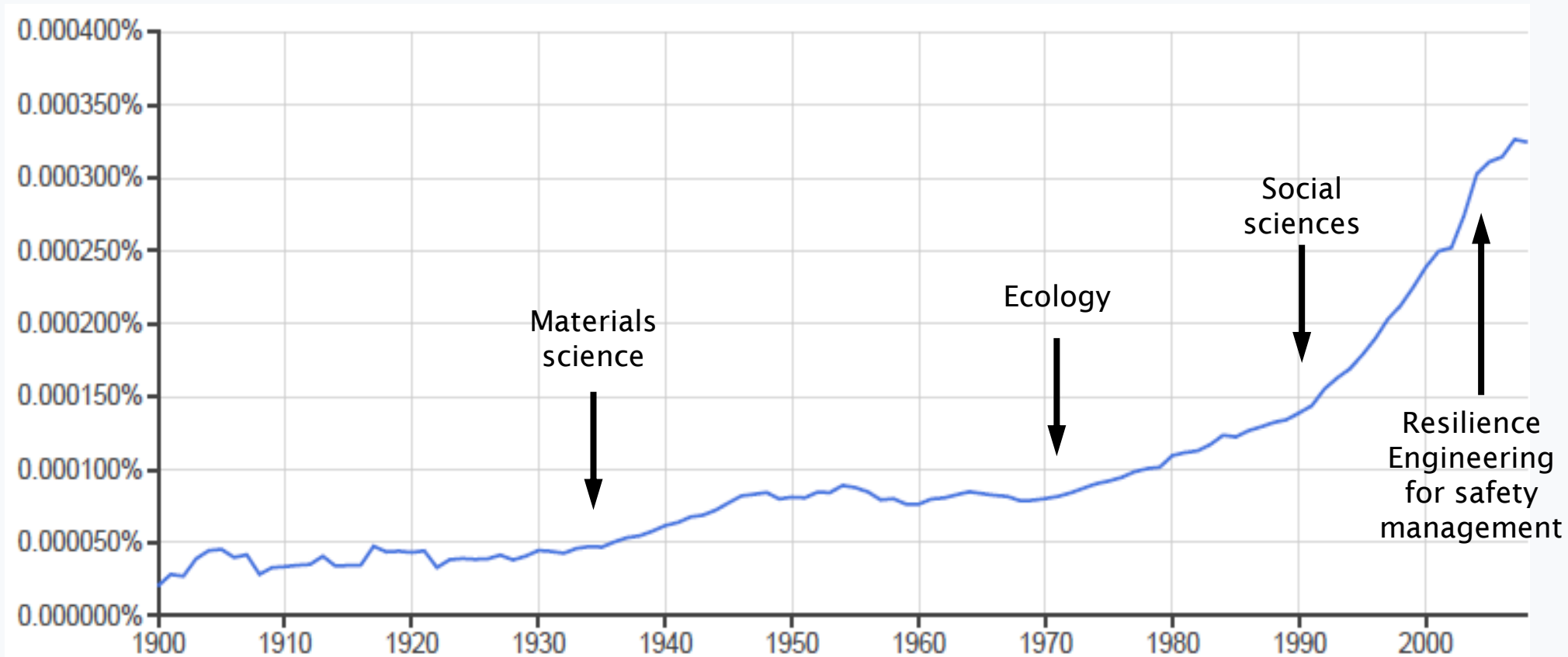
Agent-based modelling for analysis of resilience in ATM

Development of a library of model constructs

Integration and application agent-based model constructs

Conclusions

'Resilience'



Google ngram diagram for the term 'resilience'

Resilience definitions

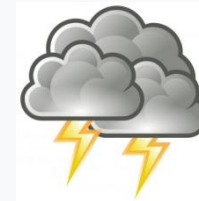
Socio-ecological systems (Folke, 2006)

- Capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedback



Resilience Engineering for ATM (Eurocontrol, 2009)

- The intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions



Human role in resilience

Flexibility and system oversight by human operators in ATM are essential for efficient and safe operations in normal and rare conditions



Resilience Engineering emphasises the performance variability of human operators in normal and rare conditions

- Accounting for a broad range of human factors
- Away from human error thinking

Mathematical Approach towards Resilience Engineering in ATM (MAREA)

Aim

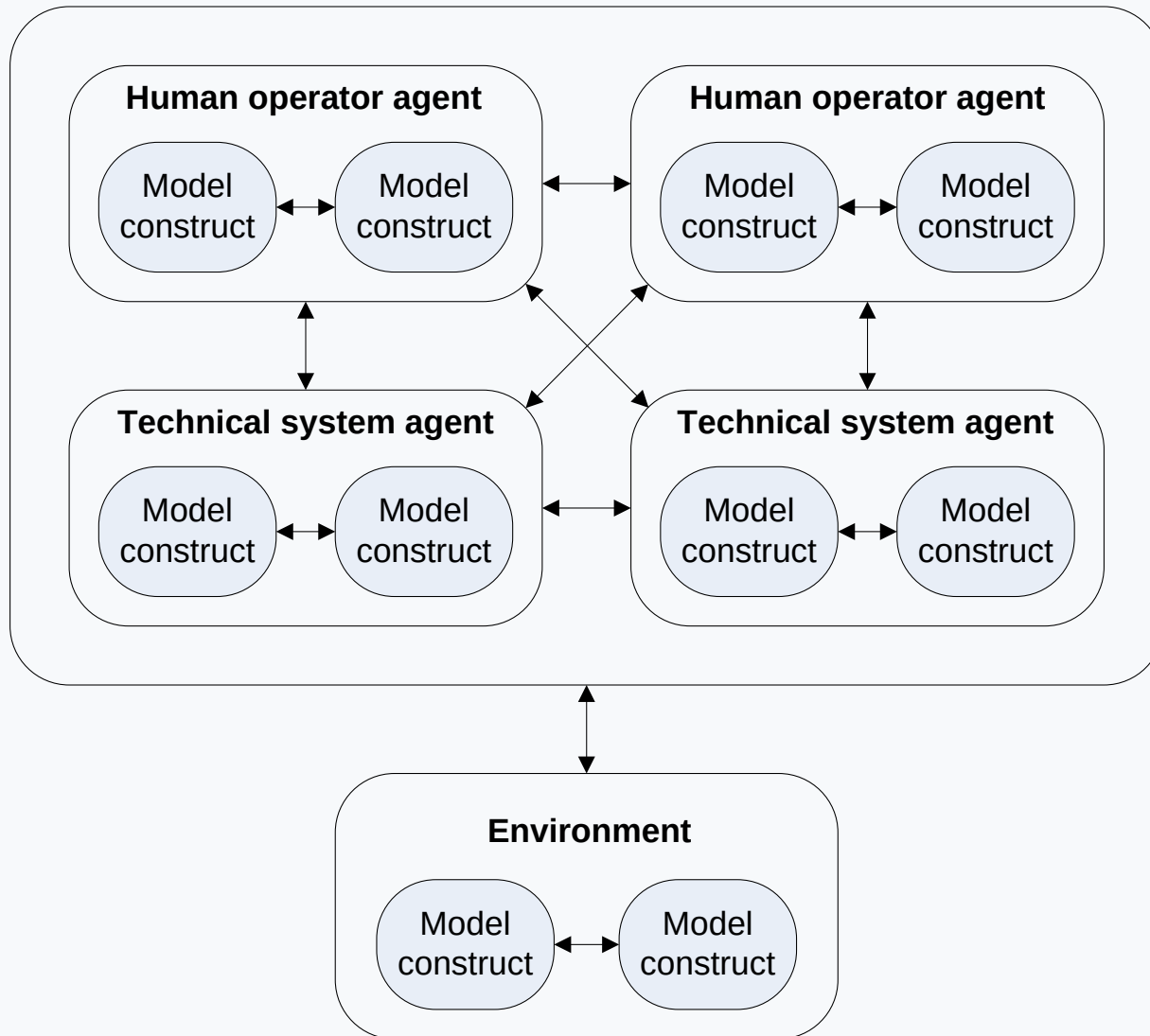
To develop a mathematical modelling and analysis approach that allows to bring Resilience Engineering at work for the complex ATM system



Focus on human performance

- Humans dealing with uncertainties and non-nominal conditions
- Psychological and organizational models

Agent-based modelling of the ATM sociotechnical system for analysis of resilience

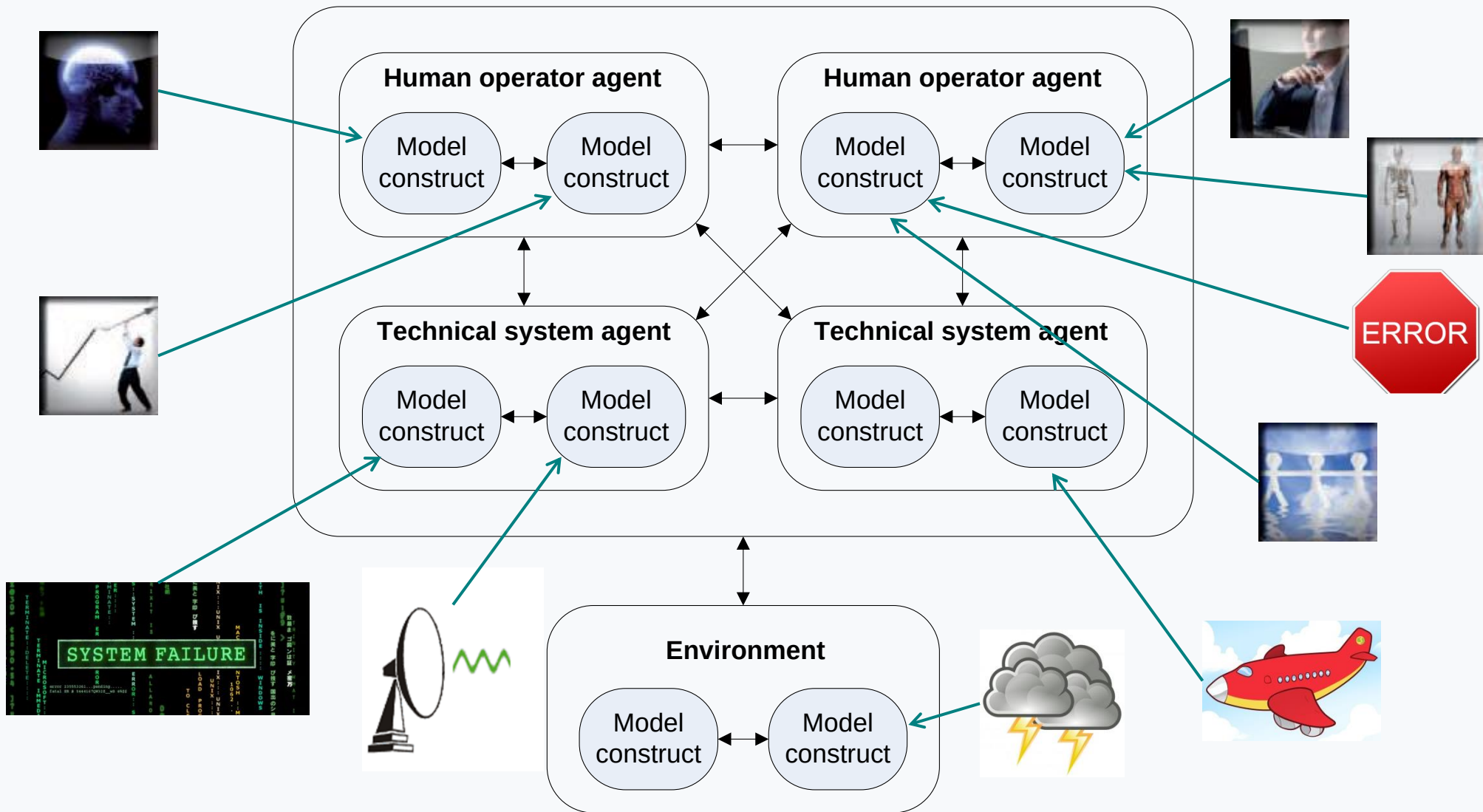


Agent-based model of a sociotechnical system

Emergent properties

- Micro-level: behaviour described by model constructs & interactions
- Macro-level: resilience indicator for “required operations are sustained”
- Macro-level properties are the resultant of interacting micro-level properties

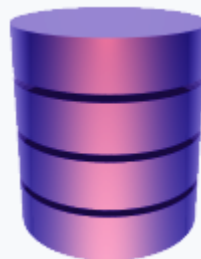
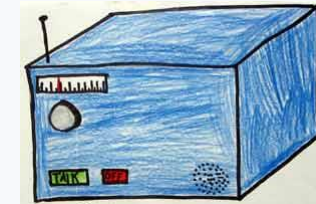
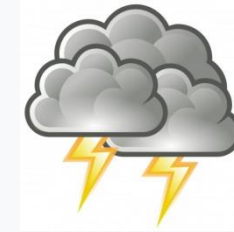
Need for model constructs of disturbances and performance variability in the sociotechnical system



Hazards as descriptions of disturbances and performance variability in ATM

Hazard = “Anything that may influence safety”

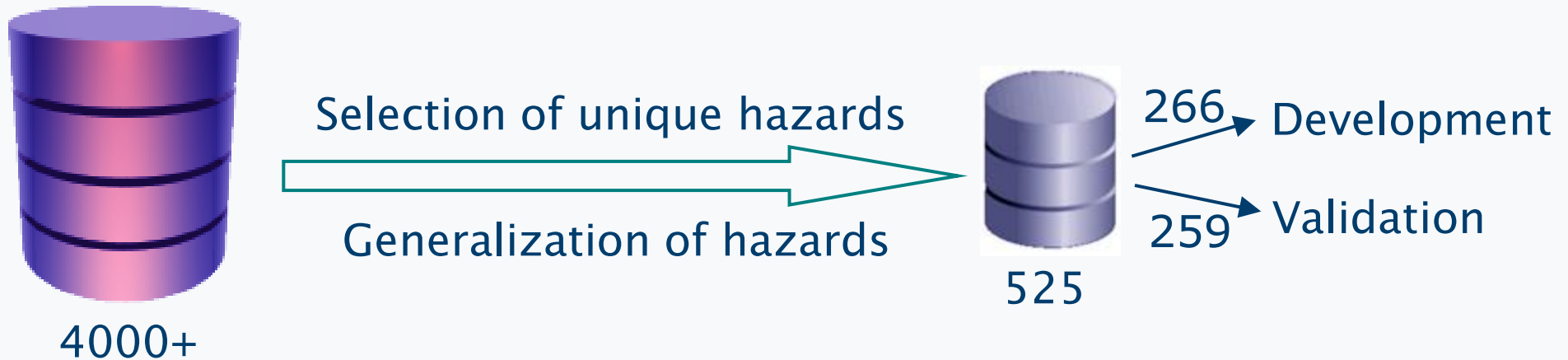
- Events / conditions / performance aspects
- Humans / systems / environment
- Interactions



NLR ATM Hazard Database

- ATM safety assessments
- Hazard brainstorm sessions
 - Pilots / Controllers / Experts
 - No analysis allowed
- 4000+ hazards

A set of generalized hazards



Pilot mixes up ATC clearances

Flight plans of ATC system and FMS differ

Controller has wrong SA about intent of aircraft

Wrong waypoints in database

Pilot validates without checking

Transponder sends wrong call-sign

Alert causes attentional tunneling

Resolution of conflict leads to other conflicts

Contingency procedures have not been tested

False alert of an airborne system

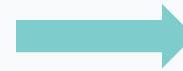
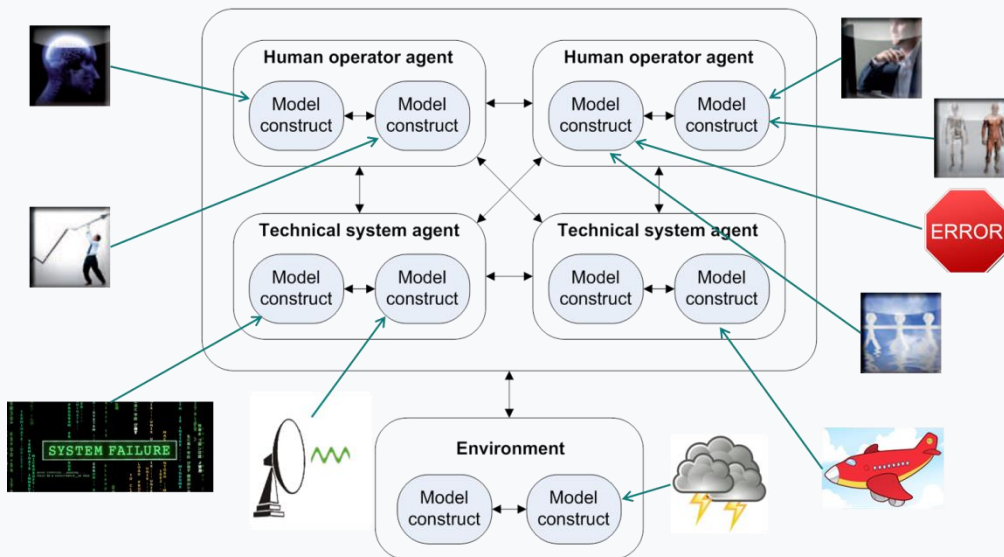
Weather forecast is wrong

Development of a library of model constructs

Identification of model constructs in three sources/phases

1. NLR TOPAZ multi-agent dynamic risk modelling
2. Agent system research at VU University Amsterdam
3. Other sources

Which model constructs can model the set of hazards?



Library of model constructs



1. TOPAZ MA-DRM	2. VU agent system research	3. Complementary
Human information processing	Object-oriented attention	Approach
Multi-agent situation awareness	Experience-based decision making	Handling inconsistent information
Task identification	Operator functional state	Group emotion
Task scheduling	Information presentation	Confusion/ Surprise – Complex Procedures
Task execution	Safety culture	Confusion/ Surprise – Changed Procedures
Cognitive control mode	Situation awareness with complex beliefs	Deciding when to take action
Task load	Trust	Access rights
Human error	Formal organisation	Merging or splitting ATC sectors
Decision making	Learning	Bad weather
System mode	Goal-oriented attention	Weather forecast wrong
Dynamic variability	Extended mind	Turbulence
Stochastic variability		Icing
Contextual condition		Influence of many agents on flight planning
		Uncontrolled aircraft

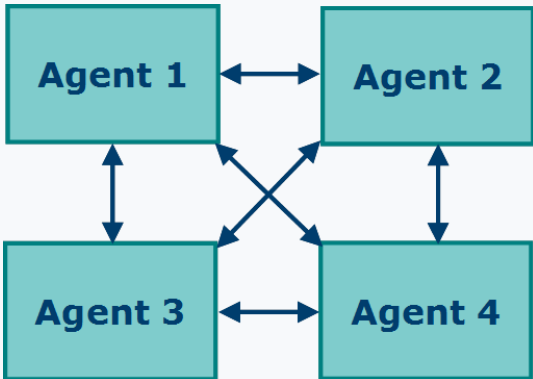
Initial model set (13)

Final model set (38)



Examples of model constructs: Multi-agent situation awareness

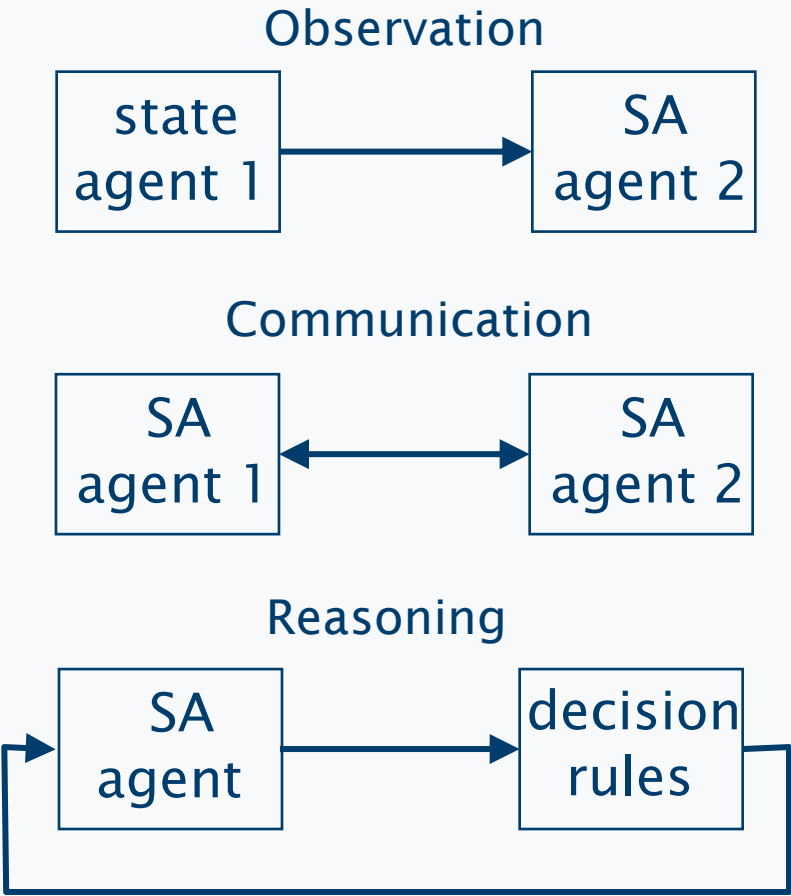
Multi-agent
system:

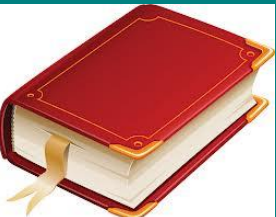


SA of agent k
at time t about
agent j :

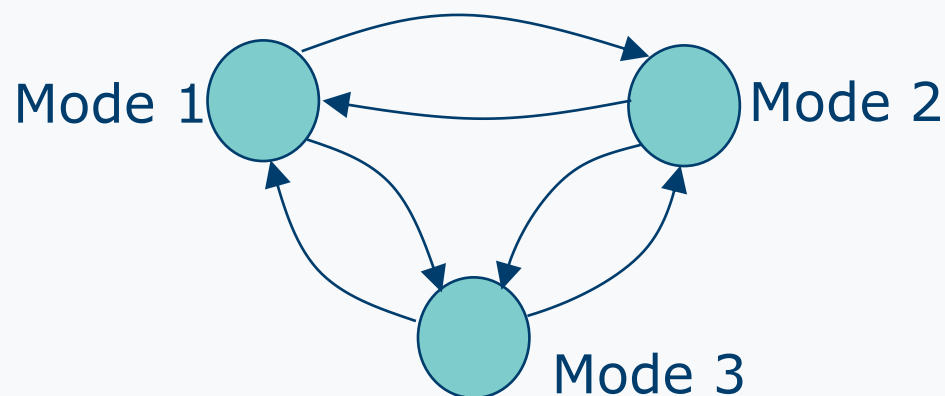
$$\sigma_{t,k}^j = \begin{pmatrix} \text{identity} \\ \text{state} \\ \text{mode} \\ \text{intent} \end{pmatrix}$$

SA updating processes:

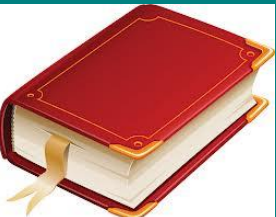




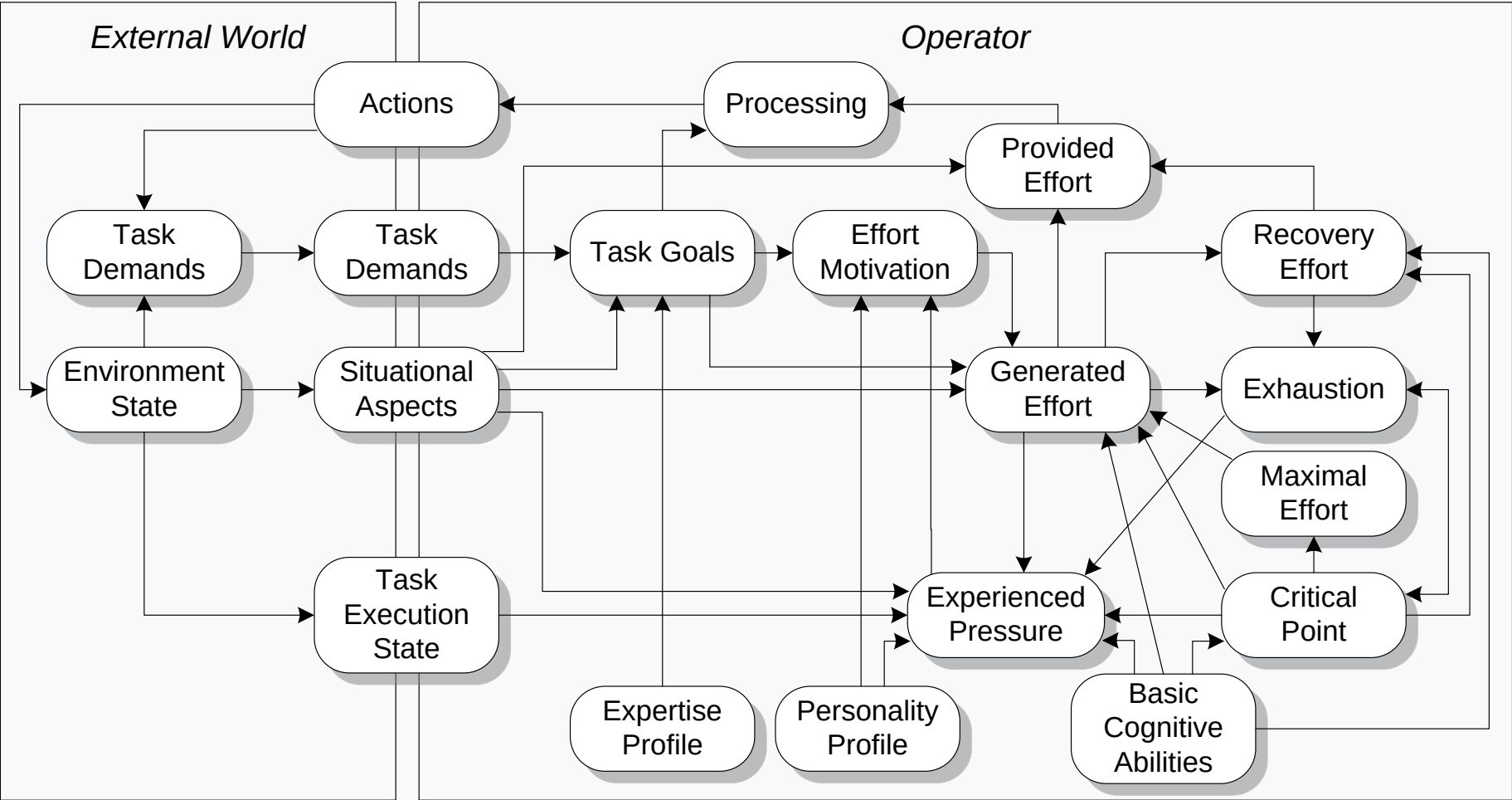
Examples of model constructs: System mode



- Failure modes of technical systems
- Normal working modes of technical systems

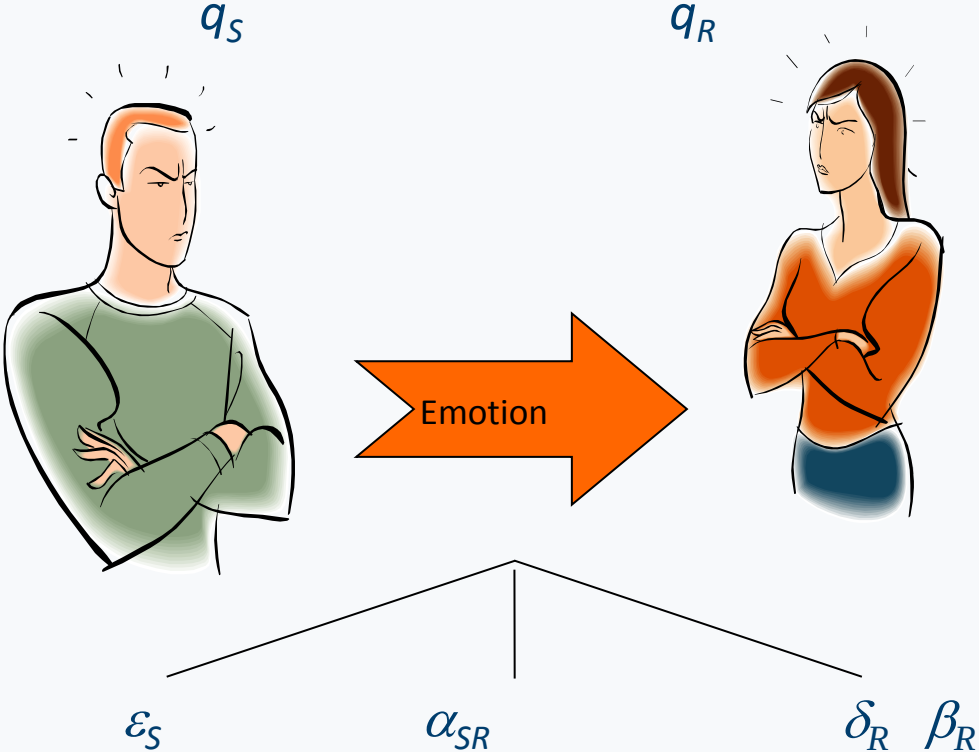


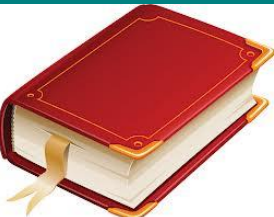
Examples of model constructs: Operator functional state



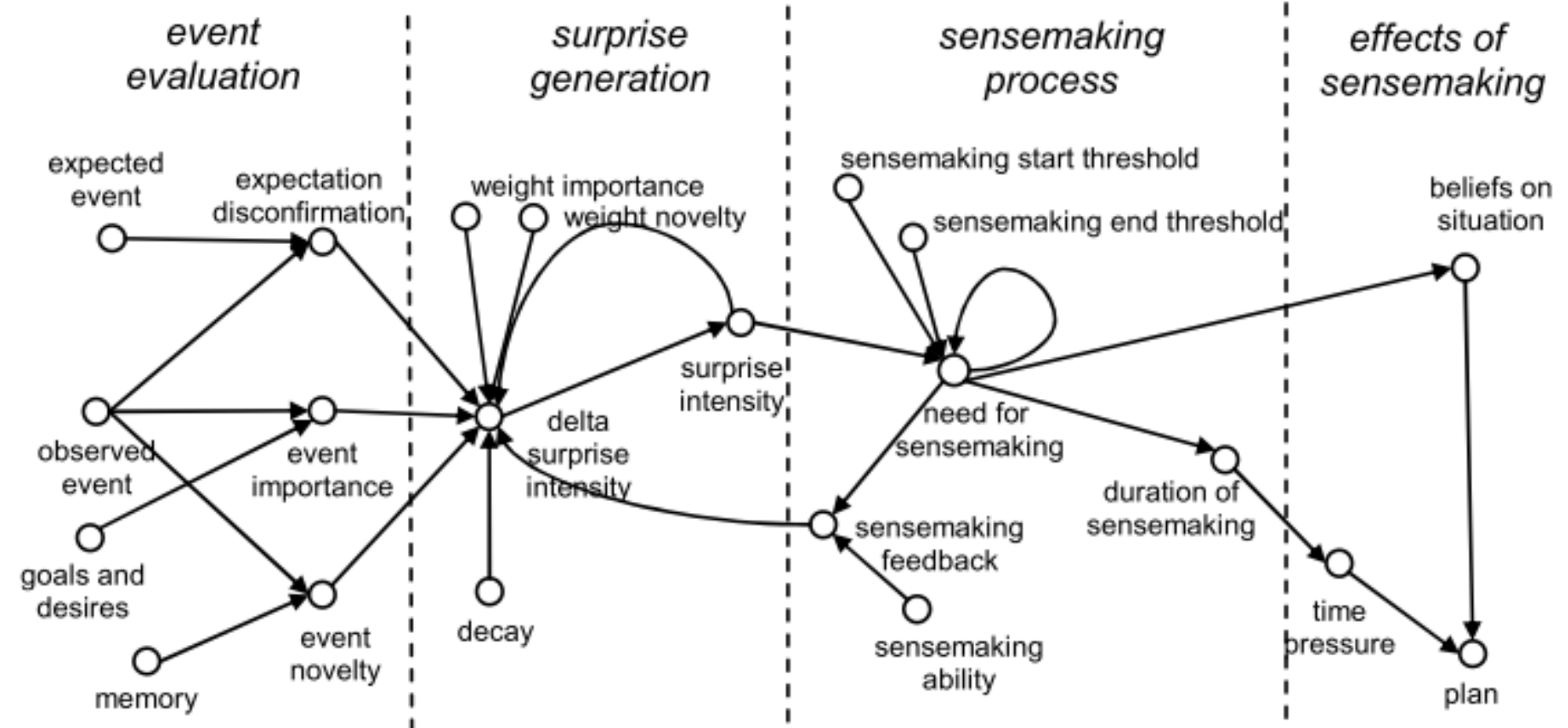


Examples of model constructs: Group emotion





Examples of model constructs: Confusion / Surprise



Matching model constructs with hazards: Mental simulation process

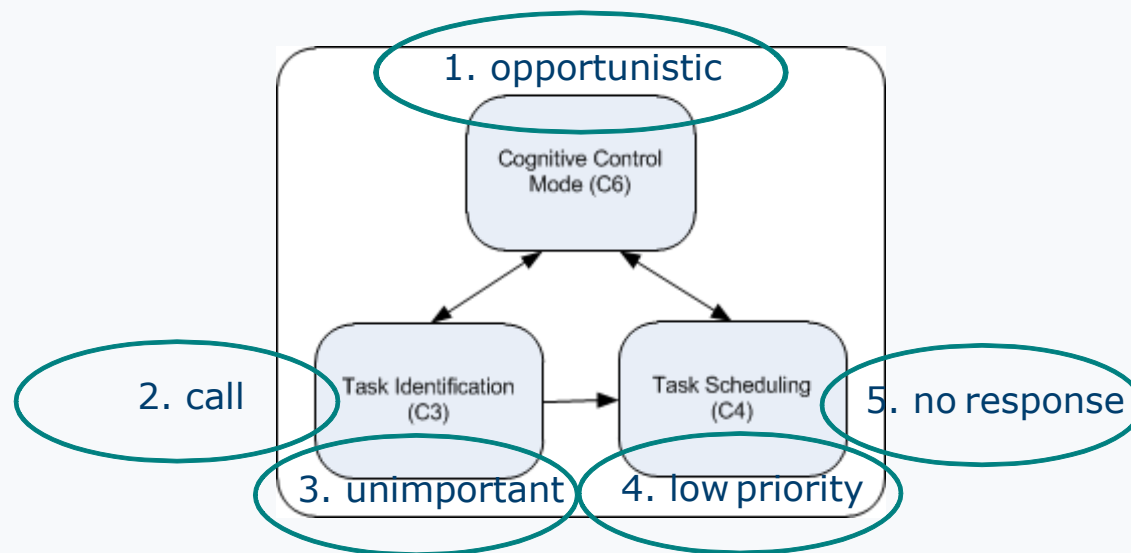
Mental simulation of all hazards by multiple analysts

Result of a mental simulation per hazard:

- The relevant model constructs
- Category: Well modelled / Partly modelled / Not modelled

Example hazard

- 'Pilots do not react to controller call due to high workload'



Matching model constructs with hazards (examples)

Hazards



Pilots do not react to controller call due to high workload

Failure of GPS system

Pilot reports wrong position

Pilot performance is affected due to alcohol, drugs or medication



Models



- Task scheduling
- Task execution
- Cognitive control mode

- System mode

- Human error
- Multi-agent SA

- Operator functional state
- Safety culture

Matching model constructs with hazards (examples)

Hazards



Confusion due to many sources that provide you with information



Controller does not use alert system



Controller is frustrated with employer



Models

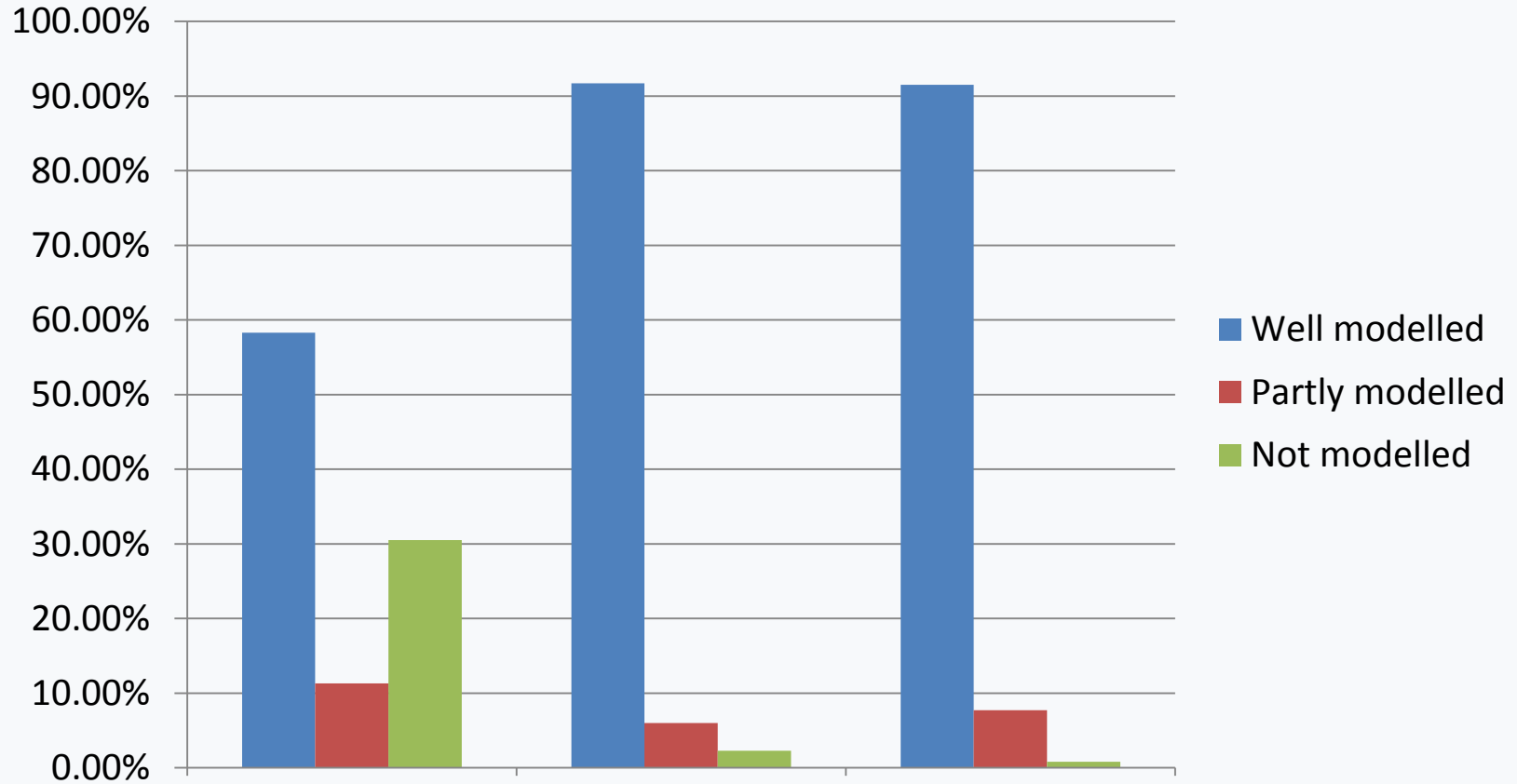


- Multi-agent SA
- SA complex beliefs
- Trust
- Confusion/Surprise (A)

- Human error
- EB decision making
- Trust

- Formal organisation
- Group emotion

Hazard modelling results



Model set:

Initial

Final

Final

Hazard set:

Development

Development

Validation

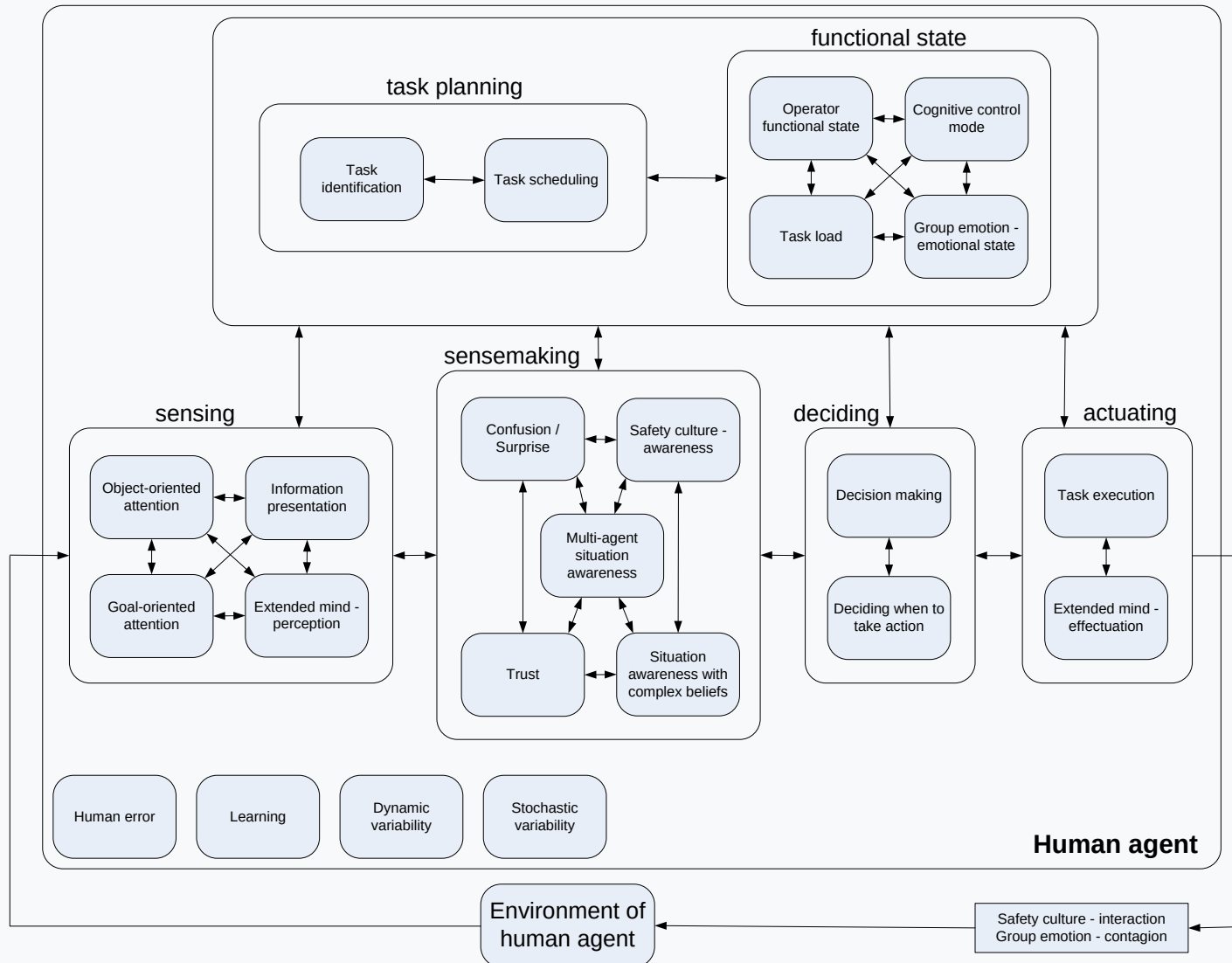
Top 15 of frequency of model constructs for hazard modelling (all hazards)

Rank	Model construct	Total	
		No.	Perc.
1	Multi-agent situation awareness	219	41.7%
2	System mode	118	22.5%
3	Human error	117	22.3%
4	Human information processing	95	18.1%
5	Task execution	57	10.9%
6	Dynamic variability	53	10.1%
7	Situation awareness with complex beliefs	50	9.5%
8	Operator functional state	49	9.3%
9	Stochastic variability	48	9.1%
10	Contextual condition	48	9.1%
11	Experience-based decision making	40	7.6%
12	Formal organisation	37	7.0%
13	Task scheduling	31	5.9%
14	Trust	31	5.9%
15	Confusion / Surprise (A)	28	5.3%

Initial models

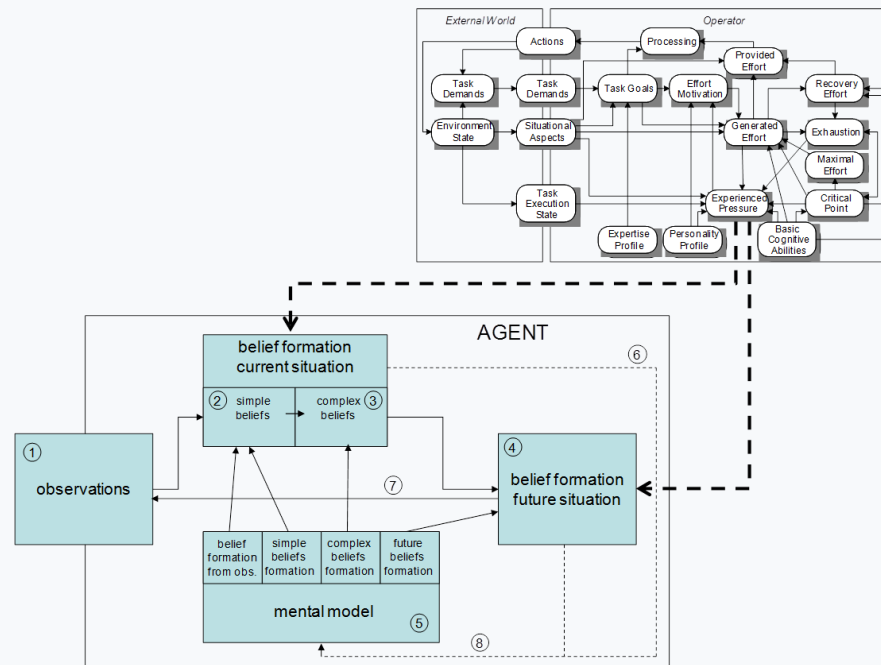
Additional models

High-level integration of model constructs for human agents

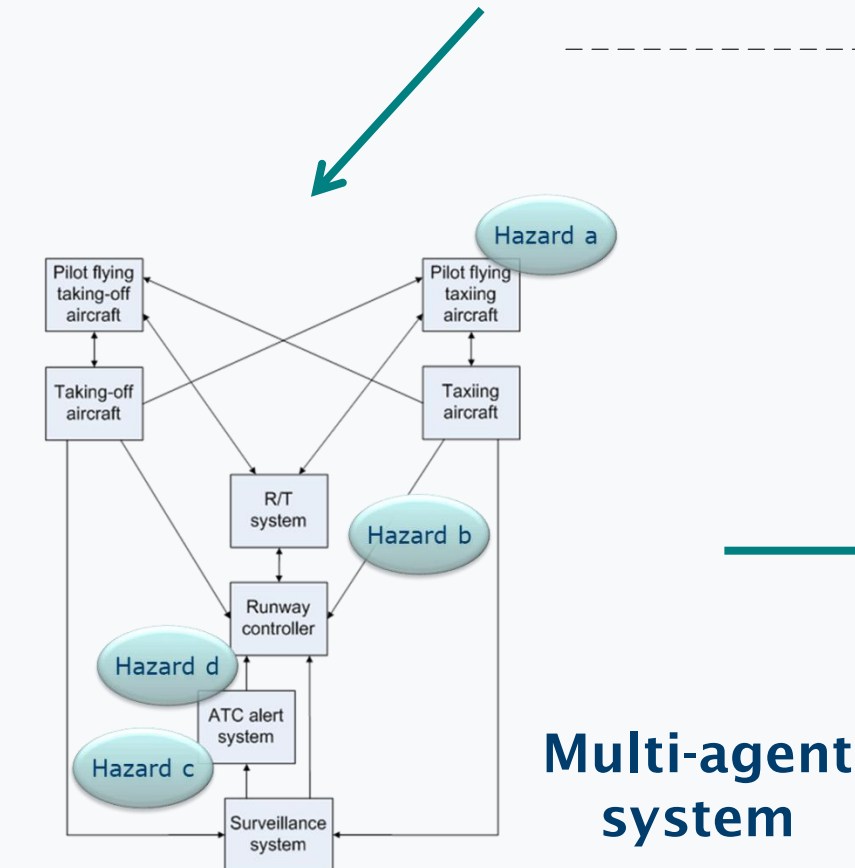


Formalisation and simulation of integrated model constructs

- Illustrations of formalisation and simulation of integrated model constructs are presented in MAREA deliverables and papers
- Formalisation and simulation of the model constructs are also shown in various papers on TOPAZ multi-agent dynamic risk modelling and VU agent-based modelling applications

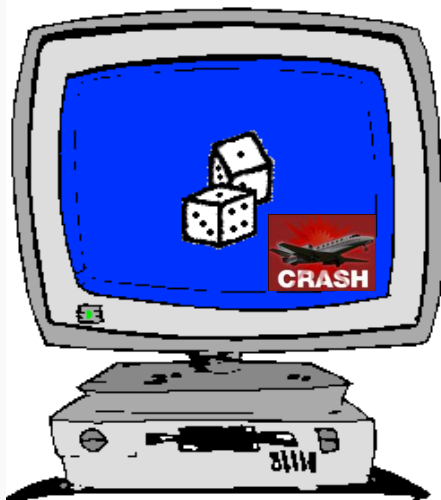


Runway incursion scenario



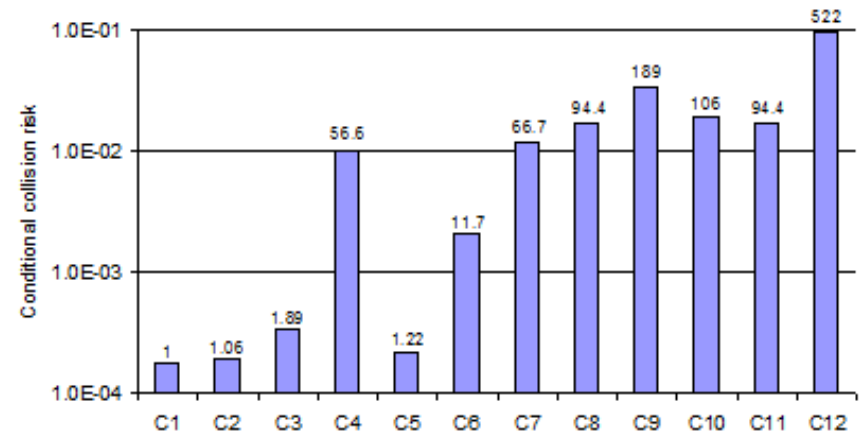
Formalisation and integration of model constructs in TOPAZ multi-agent dynamic risk modelling (example)

Monte Carlo
simulation +
speed-up



Risk results

How well can agents contribute to avoiding an accident in a runway incursion?



Alerts												
ATCo-R												
PF-TO (monitor)												
PF-TX (monitor)												

(Stroeve et al., 2013)

Conclusions

An extended library of agent-based model constructs has been developed with a variety of human, environmental and organizational models

- From 13 model constructs to 38 model constructs
- The constructs can well model about 92% of a large set of hazards, and partly model about 7%
- Model construct “Multi-agent situation awareness” is used mostly (42% of hazards)

The model constructs have been integrated and it has been shows that they can be formalised

Agent-based modelling supports analysis of resilience in ATM

- Practical feasibility has been shown by multi-agent dynamic risk modelling for safety-focused resilience

Future research: application of the enhanced model set

Questions / Discussion



Further reading:

<http://complexworld.eu/wiki/MAREA>



Questions?