

Appendix A: Formal Agent-Based Organizational Model for Safety Occurrence Reporting at an ANSP

In this appendix a complete mathematical formulation of the agent-based model for safety occurrence reporting at an ANSP is provided. The appendix is structured as follows. In Section 1 the modelling language used is introduced. A high-level specification of the organizational layer is provided in Section 2. An overview of agents and relations between them in the organization is described in Section 3. In the following sections 4-13 detailed specifications of the agents of different types are provided. Finally, in the last section of the appendix lists with model structural assumptions and parameter values are given.

A.1 Modelling language

The first-order sorted predicate logic serves as a formal basis for defining dedicated modelling languages for each view. These languages provide high expressivity for conceptualizing a variety of concepts and relations and allow expressing both quantitative and qualitative aspects of different views. Syntactically each language is defined by a signature that specifies the vocabulary to represent and reason about a system. It comprises sets of sorts (types), sorted constants, functions and predicates.

To express temporal relations in specifications of the views, the dedicated languages of the views are embedded into the Temporal Trace Language (TTL) (Sharpanykh and Treur 2006), which is a variant of the order-sorted predicate logic. In TTL the organizational dynamics are represented by a trace, i.e. a temporally ordered sequence of states. A state of a system at a certain point in time is an indication of which of the state properties of the system and its environment are true (hold) at that time point. State properties are specified using the dedicated language(s) of the view(s). To express state properties the language TTL includes special sorts such as: TIME (a set of linearly ordered time points), STATE (a set of all state names of an agent system), and STATPROP (a set of all state property names) and the function $\text{has_state}: \text{AGENT} \times \text{STATPROP} \rightarrow \text{STATE}$.

To indicate that a state of a system holds at some time point the relation $\text{at}: \text{STATE} \times \text{TIME}$ is used. For example, “for agent A, at time t property p holds” is formalized by $\text{at}(\text{has_state}(A, p), t)$. TTL terms are constructed by induction in a standard sorted predicate logic way from variables, constants and functional symbols typed with TTL sorts. Dynamic properties are expressed by TTL-formulae defined by:

- (1) If v_1 is a term of sort STATE, and u_1 is a term of the sort TIME, then $\text{at}(v_1, u_1)$ is an atomic TTL formula.
 - (2) If τ_1, τ_2 are terms of any TTL sort, then $\tau_1 = \tau_2$ is an atomic TTL formula.
 - (3) If t_1, t_2 are terms of sort TIME, then $t_1 < t_2$ is an atomic TTL formula.
 - (4) The set of well-formed TTL-formulae is defined inductively in a standard way based on atomic TTL-formulae using boolean propositional connectives and quantifiers.
- For example, the dynamic property

Notice that also within states statements about time can be made (e.g., in state properties representing memory). To relate time within a state property to time external to states a functional symbol `present_time` is used.

To formalise dynamic properties of agents in this report the LEADSTO language is used, which is a sublanguage of TTL. Dynamic properties specified in LEADSTO can be executed and can often easily be depicted graphically. The format is defined as follows. Let α and β be state properties of the form ‘conjunction of atoms or negations of atoms’, and e, f, g, h non-negative real numbers. In the LEADSTO language the notation $\alpha \rightarrow_{e, f, g, h} \beta$ (also see Figure 10), means:

If state property α holds for a certain time interval with duration g , then after some delay (between e and f) state property β will hold for a certain time interval of length h .

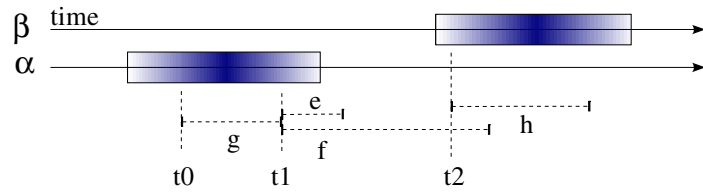


Figure 10: Timing relationships in LEADSTO

For example, the dynamic property

‘if agent A observes that it is dark in the room for 0.5 time points, then after one time point s/he switches on a lamp’

is expressed in LEADSTO as:

`has_state(A, observed(dark_in_room)) →1, 1, 0.5, 1 has_state(A, action(switch_on_lamp))`

For specifying communication between agents, the interface ontologies for all agents include the following function:

`communicated_from_to: AGENT x AGENT x MSG_TYPE x STATPROP → STATPROP`

where the first argument denotes the agent-source of information, the second argument denotes the agent-recipient of information, the third argument denotes the types of the communication (which may be one of the following {observe, inform, request, decision, readback}) and the fourth argument denotes the content of the communication (a state property). For instance, to specify the communication of the decision of the agent allocated to the Aircraft’s Controller role on the request

for the clearance to cross the runway r_w from the agent allocated to the role Crew Representative the following relation is used:

`communicated_from_to(Aircraft's Controller, Crew Representative, decision, instruction(position_and_hold,  $r_w$ ))`

To specify beliefs of agents the function `belief: STATPROP x TIME  $\rightarrow$  STATPROP` is used, where the first argument specifies the content of the belief (a state property) and the second argument designates the time point, when the state property held.

A.2 High-level specification of organizational layer

A.2.1 Organizational tasks and their relations

In Table 9 the names, the short descriptions and the durations of the tasks considered in the case study are described. Furthermore, this table identifies relations between the lowest level tasks and goals. Sets of goals that correspond to higher level tasks are formed by combination of all goals that correspond to the subtasks of these tasks. The tasks and their characteristics have been identified primarily based on the Safety Occurrence Assessment Procedure of ANSP-3, also the description of the Safety Management System and information gained during the interviews at ANSP-3 have been used.

Table 9: The tasks considered in the case study, their characteristics and the relations to the goals

#	Task name	Short description	Durations
1	Safety occurrence reporting and the report handling	The occurrence reporting loop initiated by a controller.	Depends on the duration of the subtasks
2	Create a notification report	When a controller observes an occurrence that may be classified as an incident/accident, s/he is obliged to create a notification report.	Min: 3 min Max: 24 hours
Goal: 17, 18.2, 19, 20			
3	Preliminary processing of a notification report	A notification report created by a controller is examined and improved by his/her supervisor.	Min: 2 min Max: 2 days
Goal: 19, 13.3, 20			
4	Making decision about the notification report assignment	A notification report is classified and provided to a role responsible for handling of the report.	Min: 2 min Max: 1 days
5	Preliminary assessment of an occurrence	A safety investigator performs a preliminary assessment of an occurrence based on a notification report, assigns a preliminary event classification and prepares a preliminary safety occurrence assessment report. If a serious occurrence is reported, the responsible safety	For severe occurrences: Max: 48 hours For less severe occurrences: Max: 72 hours

#	Task name	Short description	Durations
		investigator should notify the Regulator role.	
6	Making decision about the investigation necessity	If the occurrence is of a high severity, the incident/accident investigation will be initiated. The lower the level of severity of the occurrence, the less the chance that the occurrence will be immediately investigated. Other factors that influence the decision are the number or frequency of previous identical (or similar occurrences) and the likelihood of a more severe occurrence in the future from the case causes if remedial action is not identified and taken.	Min: 1 min Max: 1 day
Goal: 19, 20			
7	Investigation of an occurrence	During the investigation the (possible) causes of the incident/accident are identified and an interim safety occurrence assessment report is produced.	Min: 3 days Max: 90 days
Goal: 18.3, 18.4, 20			
8	Discussion of the intermediate occurrence investigation results	Safety Recommendations and Concerns Group shall consider the appropriateness of the severity classification of the interim safety occurrence assessment report, analyse the causes of the occurrence and formulate safety recommendations.	Min: 1 day Max: 10 days
Goal: 11.5, 12			
9	Update an interim safety occurrence assessment report	An interim safety occurrence assessment report is updated with the final severity classification, the causes, and the safety recommendations.	Min: 1 day Max: 5 days
10	Distribute the final safety occurrence assessment report among all concerned roles	The final safety occurrence assessment report is distributed among the Safety Recommendations and Concerns Group, Regulator, and the controller-notifier of the safety occurrence.	Min: 1 hour Max: 15 days
Goal: 21.2, 21.3, 21.1			
11	Safety Monitoring	Aims at the identification of	Continuously

#	Task name	Short description	Durations
		safety hazards, problems and trends based on the collected notification reports and the occurrence investigation results.	repeated task, subjective estimations for every execution: Min: 17 days Max: 1 month and 8 days
Goal: 11.3, 11.4, 15, 11.2, 20			
12	Safety data collection and pre-processing	In this study only safety occurrence reports are considered among the data to be collected.	Min: 15 days Max: 1 month
13	Safety data analysis	Identification of hazards, safety problems and trends based on the collected data.	Min: 1 day Max: 3 days
14	Preparation and distribution of a monthly safety overview report	Preparation and distribution of a monthly safety overview report.	Min: 1 day Max: 5 days
15	Making decision on the occurrence reporting	The decision is made by a controller.	Min: 1 min Max: 24 hours
16	Implementation of safety recommendations	Safety recommendations are formulated based on a notification report. If recommendations concern important changes, the latter should be approved by Regulator before their implementation.	Depends on the type of recommendations

In Figure 11 the decompositions of the identified composite tasks are depicted.

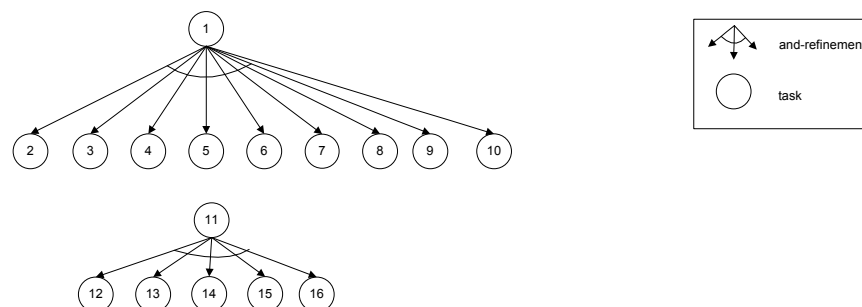


Figure 11: The refinement of composite tasks into subtasks

The relations between the identified tasks and resource types are given in Table 8. Note that only the relations between the simple tasks and resource types are shown. The resource types that are used/consumed/produced by a composite task

comprise all the resource types that are used/consumed/produced by all the subtasks of this task.

Table 10: The relations between the identified tasks and the resource types that these tasks use/produce

Task	Task uses	Task produces
2	the observation from the environment of an occurrence that may be classified as an incident/accident, the incident classification database	a notification report
3	a notification report	a processed notification report
4	a processed notification report	a decision about the assignment of the processed notification report
5	a processed notification report	a preliminary safety occurrence assessment report
6	a preliminary safety occurrence assessment report, occurrence database	a decision on the initiation of the occurrence investigation
7	a preliminary safety occurrence assessment report, additional data about the occurrence (optional)	an interrim safety occurrence assessment report
8	a processed notification report, an interrim safety occurrence assessment report; occurrence database	evaluated appropriateness of the severity classification of the interrim safety occurrence assessment report; results of the analysis of causes of the occurrence (optional); safety recommendations
9	Evaluated appropriateness of the severity classification of the interrim safety occurrence assessment report; results of the analysis of causes of the occurrence (optional); safety recommendations	a final occurrence assessment report
10	a final occurrence assessment report, the list of all concerned roles, an electronic communication system (optional)	-
12	-	collected notification reports, final occurrence assessment reports, previous monthly safety overview reports
13	collected notification reports, final occurrence assessment reports, previous monthly safety overview reports; occurrence database	a monitoring report
14	a monitoring report	a monthly safety overview report
15	the observation from the	a decision on the initiation of the

Task	Task uses	Task produces
	environment of an occurrence that may be classified as an incident/accident	occurrence reporting
16	safety recommendations from a final occurrence assessment report	information about the progress of the implementation of the safety recommendations

Authority relations

The *responsibility relations* of the roles on different aspects of the identified tasks are given in Table 11. The responsibilities of the roles indicated by the symbol ‘*’ have been determined based on the formal documents provided by ANSP-3 and on the interviews held at ANSP-3.

Table 11: The responsibility relations of the roles on different aspects of the identified tasks

Task	Execution	Monitoring	Consulting	Technological decisions	Managerial decisions
2	Controller*	Controllers Supervisor*		Controller*	
3	Controllers Supervisor				
4	Occurrence Manager*				
5	Safety Investigator*	Safety Manager*; Safety Investigator*	Safety Manager*	Safety Investigator*	
6	Safety Investigator*	Safety Manager*		Safety Investigator*	
7		Safety Manager*, Occurrence Manager*	Safety Manager*		
8	Safety Recommendations and Concerns Group*, Safety Manager*				
9	Safety Investigator*				
10	Safety Investigator*				
12	Safety Officer*				
13	Safety Monitoring Group*				
14	Safety Officer*				
15	Controller				
16	Responsible unit	Operation Management Team, Safety Manager, Safety Monitoring Group*	Head of the responsible unit	Head of the responsible unit	Head of the responsible unit, Operation Management Team

In Table 12 the superior-subordinate relations on the identified roles with respect to the tasks are specified.

Table 12: The superior-subordinate relations on the identified roles with respect to the tasks

Subordinate role	Superior role	Task
Safety Investigator	Safety Manager	6, 7
Responsible unit	Operation Management Team	16

A.2.3 Flows of control

A workflow that describes the execution of the safety occurrence reporting and the report handling task (task 1 from Step 6) is depicted in (a) (b)

Figure 4. This workflow is executed every time when an occurrence has been identified by a controller. The workflow has been specified based on the Safety Occurrence Assessment Procedure of ANSP-3 and the interviews conducted at ANSP-3.

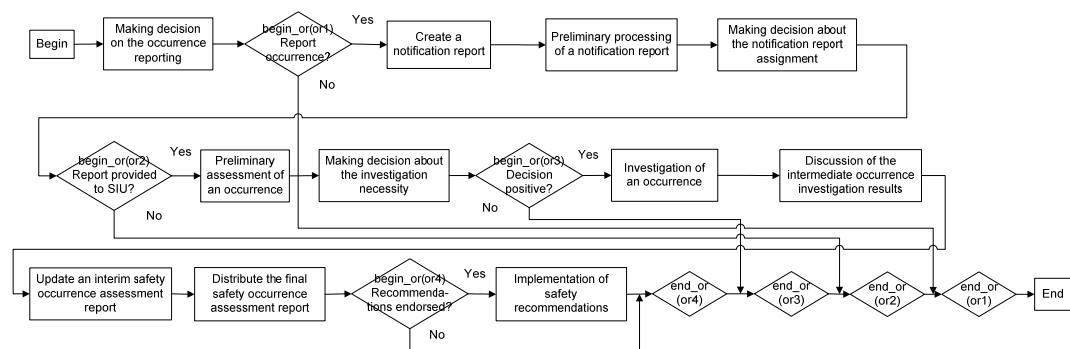


Figure 12: The workflow that defines the execution of the safety occurrence reporting and the report handling task initiated by a controller

The process of occurrence identification is not modelled in this study in detail. However, the output of this process (occurrence data) is used by processes from the workflow in (a) (b)

Figure 4. The estimation of the quality of these data is considered at step 15.

A workflow for the safety monitoring task is depicted in Figure 13. This workflow is executed continuously in a cycle, i.e., whenever the current instance of the workflow finishes, a new instance of the workflow starts. The workflow has been specified based on the Safety Monitoring Procedure of ANSP-3.

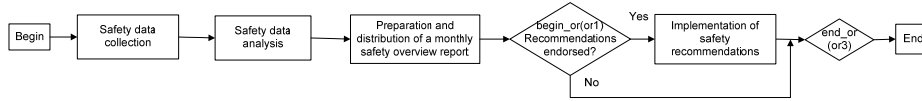


Figure 13: The workflow that defines the execution of the safety monitoring task

A.2.4 Agents in the organization

The agent-based organizational model includes the following agents:

- Controller_i : an air traffic controller, with $i = 1 \dots N_{ag,cont}$
- Controller Team_j : a team of air traffic controller, with $j = 1 \dots N_{ag,team}$
- Supervisor_k : a supervisor, with $k = 1 \dots N_{ag,sup}$
- Manager: one aggregated agent representing the management
- Safety Investigator: one safety investigator agent
- Safety Officer: one safety officer agent
- SRCG: one agent for the Safety Recommendations and Concerns Group
- Safety Monitoring Group: one agent for the Safety Monitoring Group

The agents exist in the following entity:

- Environment & Technical Infrastructure: representing the working environment and technical infrastructure of the other agents

The details of the agents modelling are provided in the following sections.

A.3 Agent Controller

Number of agent controllers is $N_{ag,cont}$.

Input ontology

Information type	Source of information
observed(env_occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, sec:SECTOR)	Environment & Technical Infrastructure
final_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	Safety Investigator
monthly_report(m: MONTH, v1: VALUE)	Safety Officer
e1 _a : Priority of safety-related goals in the role description	Manager
e7: Sufficiency of amount of safety investigators	Manager
e8: Sufficiency of the amount of controllers	Manager
e9: Availability of reliable and ergonomic technical systems for controllers	Environment & Technical Infrastructure
e10: Sufficiency and timeliness of training for changes	Manager
e11 : Regularity of safety meetings	SRCG
e12: Developed and implemented SMS	Manager
e13 _a : Commitment to safety of the supervisor	Supervisor
e14 _a : Level of development of managerial skills of supervisor	Supervisor
e17: Quality of technical systems	Environment & Technical Infrastructure
e28 _{o, ot, ag} : Amount of knowledge on similar safety-related issues of the supervisor	Supervisor

e34 _G : Contribution of informal discussion of controllers in the team	Controller Team
e35 _G : Intensity of informal interactions in the team of controllers	Controller Team
e39 _{o,cl} : Severity of an occurrence	Environment & Technical Infrastructure
e41 _{a,G} : Average commitment to safety of team members	Controller Team
e57 _G : Perception of the positive attitude to reporting in a team	Controller Team
e60 _a : Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the management	Manager
e65 _a : Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the team of the controller	Controller Team
e70 _a : Average perceived degree of influence of controllers on safety arrangements	Controller Team
reprimand_amount	Manager
reward_amount	Manager

Output Ontology

Information type	Destination of information
notification_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	Supervisor
e3 _{a,G} : Perception of commitment to safety of team	Controller Team
e4 _a : Influence degree of controllers on safety arrangements	Controller Team
e6 _a : Commitment to safety of a controller	Controller Team
e15 _{o,ot,a} : Quality of a processed notification report	Supervisor

Variables

Variable	State space	Initial value	Explanation
Evidence variables			
e2 _a	[0,1]	None (dependent)	Perception of the commitment to safety of management
e3 _{a,G}	[0,1]	None (dependent)	Perception of commitment to safety of team
e4 _a	[0,1]	e4 _{ini}	Influence degree of controllers on safety arrangements
e5 _a	[0,1]	None (dependent)	Maturity level w.r.t. ATC task
e6 _a	[0,1]	None (dependent)	Commitment to safety of a controller
e15 _{o,ot,a}	[0,1]	None (dependent)	Quality of a processed notification report
e16 _{o,ot,a}	[0,1]	None (dependent)	Information contribution on an occurrence from others
e18 _G	[0,1]	None (dependent)	Acceptability of the workload level in a team
e19 _a	[0,1]	U(e19 _{min} ,e19 _{max})	Self-confidence for ATC task
e20 _a	[0,1]	e20 _{ini}	Commitment to perform ATC task
e21 _a	[0,1]	U(e21 _{min} ,e21 _{max})	Development level of skills for ATC task
e22 _a	[0,1]	None (dependent)	Adequacy of knowledge about safety issues
e27 _{o, ot, a}	[0,1]	None (dependent)	Amount of knowledge on similar safety-related issues of a controller
e43 _a	[0,1]	None (dependent)	Belief of the average quality of the received monthly safety overview reports

e44	[0,1]	e44 _{ini}	Average commitment to safety of the agents involved in safety analysis
e59 _{cl,a}	[0,1]	None (dependent)	Belief of the average quality of the final safety occurrence assessment reports for occurrences similar to the observed occurrence provided to the controller
e61 _a	[0,1]	U(e61 _{min} ,e61 _{max})	Individualism (IDV) index of a controller
e62 _a	[0,1]	U(e62 _{min} ,e62 _{max})	Power Distance Index (PDI) of a controller
e63 _a	[0,1]	U(e63 _{min} ,e63 _{max})	Masculinity (MAS) index of a controller
e64 _a	[0,1]	U(e64 _{min} ,e64 _{max})	Uncertainty Avoidance Index (UAI) of a controller
e66 _a	[0,1]	e66 _{ini}	Perception of the confidentiality of reporting
e67 _a	[0,1]	None (dependent)	Perceived severity of the provided reprimand
e68 _a	[0,1]	None (dependent)	Perceived amount of the provided reward
Expectancies & Instrumentalities for reporting option			
E{1,2} _a	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in administrative reprimand
E{1,3} _a	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in own group appreciation
E{1,4} _a	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in management appreciation of the action
E{1,5}	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in material reward
E{1,6}	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in improvement of safety
E{17} _a	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in decrease of own professional status in own group

$E\{1,8\}_a$	[0,1]	None (dependent)	Expectancy that reporting the occurrence will result in decrease of own professional status in management's opinion
$I\{1,2,1\}_a$	[-1,1]	None (dependent)	Instrumentality that administrative reprimand will result in the satisfaction of extrinsic needs
$I\{1,5,1\}_a$	[-1,1]	None (dependent)	Instrumentality that material reward will result in the satisfaction of extrinsic needs
$I\{1,3,2\}_a$	[-1,1]	$ri32_{ini}$	Instrumentality that own group approval of reporting will result in satisfaction of the own group approval need
$I\{1,3,5\}_a$	[-1,1]	None (dependent)	Instrumentality that own group appreciation of reporting will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{1,7,2\}_a$	[-1,1]	None (dependent)	Instrumentality that decrease of own professional status in own group due to reporting will result in the satisfaction of own group approval needs
$I\{1,7,5\}_a$	[-1,1]	None (dependent)	Instrumentality that decrease of own professional status in own group will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{1,4,5\}_a$	[-1,1]	None (dependent)	Instrumentality that management appreciation of the action will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{1,8,3\}_a$	[-1,1]	None (dependent)	Instrumentality that decrease of own professional status in management's opinion will result in the satisfaction of the management approval needs
$I\{1,8,5\}_a$	[-1,1]	None (dependent)	Instrumentality that decrease of own professional status in management's opinion will result in the satisfaction of

			self-esteem, self-confidence and self-actualization needs
$I\{1,6,5\}_a$	$[-1,1]$	None (dependent)	Instrumentality that improvement of safety will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
Expectancies & Instrumentalities for not reporting option			
$E\{2,6\}_a$	$[0,1]$	None (dependent)	Expectancy that not reporting an occurrence will result in administrative reprimand
$E\{2,2\}_{ag}$	$[0,1]$	None (dependent)	Expectancy that not reporting an occurrence will result in own group disapproval of the action
$E\{2,3\}_a$	$[0,1]$	None (dependent)	Expectancy that not reporting an occurrence will result in decrease of own professional status in own group
$E\{2,1\}_a$	$[0,1]$	None (dependent)	Expectancy that not reporting an occurrence will result in decrease of own professional status in management's opinion
$E\{2,5\}_a$	$[0,1]$	None (dependent)	Expectancy that not reporting an occurrence will result in harmful consequence to safety
$I\{2,6,1\}_a$	$[-1,1]$	None (dependent)	Instrumentality that administrative reprimand will result in the satisfaction of extrinsic needs
$I\{2,2,2\}_a$	$[-1,1]$	None (dependent)	Instrumentality that own group disapproval of the action will result in the satisfaction of own group approval needs
$I\{225\}_a$	$[-1,1]$	None (dependent)	Instrumentality that own group disapproval of the action will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{2,3,2\}_a$	$[-1,1]$	None	Instrumentality that decrease of own professional status in own group will result

		(dependent)	in the satisfaction of own group approval needs
$I\{2,3,5\}_a$	$[-1,1]$	None (dependent)	Instrumentality that decrease of own professional status in own group will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{2,4,3\}_a$	$[-1,1]$	None (dependent)	Instrumentality that management disapproval of the action will result in the satisfaction of management approval needs
$I\{2,4,5\}_a$	$[-1,1]$	None (dependent)	Instrumentality that management disapproval of the action will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{2,1,3\}_a$	$[-1,1]$	None (dependent)	Instrumentality that decrease of own professional status in management's opinion will result in the satisfaction of the management approval needs
$I\{2,1,5\}_a$	$[-1,1]$	None (dependent)	Instrumentality that decrease of own professional status in management's opinion will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
$I\{2,5,4\}_a$	$[-1,1]$	None (dependent)	Instrumentality that harmful consequence to safety will result in the contribution to organizational safety-related goals
$I\{2,5,5\}_a$	$[-1,1]$	None (dependent)	Instrumentality that harmful consequence to safety will result in the satisfaction of self-esteem, self-confidence and self-actualization needs
Valances, satisfaction values and forces for reporting options			
$v\{1\}_a$	$[0,1]$	None (dependent)	Valence of extrinsic needs
$v\{2\}_a$	$[0,1]$	None (dependent)	Valence of own group approval needs

$v\{3\}_a$	[0,1]	None (dependent)	Valence of management approval needs
$v\{4\}_a$	[0,1]	None (dependent)	Valence of contribution to organizational safety-related goals
$v\{5\}_a$	[0,1]	None (dependent)	Valence of self-esteem, self-confidence and self-actualization needs
$v\{1\}_a^b$	[0,1]	$U(v1_{min}, v1_{max})$	Basis valence of “Extrinsic needs” for agent a
$v\{2\}_a^b$	[0,1]	$U(v2_{min}, v2_{max})$	Basis valence of “Own group approval” for agent a
$v\{3\}_a^b$	[0,1]	$U(v3_{min}, v3_{max})$	Basis valence of “Management approval” for agent a
$v\{4\}_a^b$	[0,1]	$U(v4_{min}, v4_{max})$	Basis valence of “Contribution to safety-related goals” for agent a
$v\{5\}_a^b$	[0,1]	$U(v5_{min}, v5_{max})$	Basis valence of “Self-esteem, self-confidence and self-actualization” for agent a
F1		None (dependent)	Force to report an occurrence
F2		None (dependent)	Force to not report an occurrence

Internal mappings and dynamics

Organizational tasks

The controller is involved in the following organizational tasks:

- Task 15: Making decision on the occurrence reporting
- Task 2: Create a notification process

TTL relations for tasks

(1) `has_state(a, observed(env_occurrence(o, cl))) & present_time(t)`

→ $0, 0, 1, 1$ began_process_of_type_for(TASK15, occurrence(o, cl, a)) & has_state(a, belief(force(report(o, cl), F1), t)) & has_state(a, belief(force(not_report(o, cl), F2), t))

F1 and F2 are calculated using the decision making model described below.

(2) began_process_of_type_for(TASK15, occurrence(o, cl, a))

→ $(T_{TASK15,min}, T_{TASK15,max}, 1, 1)$ finished_process_of_type_for(TASK15, occurrence(o, cl, a))

(3) finished_process_of_type_for(TASK15, occurrence(o, cl, a)) &

has_state(a, belief(force(report(o, cl), F1), t1)) & has_state(a, belief(force(not_report(o, cl), F2), t2)) & $F1 > F2$

→ $0, 0, 1, 1$ began_process_of_type_for(TASK2, occurrence(o, cl, a1))

(4) began_process_of_type_for(TASK2, occurrence(o, cl, a))

→ $(T_{TASK2,min}, T_{TASK2,max}, 1, 1)$ finished_process_of_type_for(TASK2, occurrence(o, cl, a))

TTL relations for generated resources

(33) finished_process_of_type_for(TASK2, occurrence(o, cl, a))

→ $0, 0, 1, 1$ resource_produced_by(TASK2, notification_report_for(occurrence(o, cl, a), e15(o, cl, a)))

where e15 is “Quality of processed notification report”

Beliefs

has_state(env, env_occurrence(o, cl, sec)) & is_responsible_for(a, sec)

→ $0, 0, 1, 1$ has_state(a, observed(env_occurrence(o, cl)))

has_state(a, observed(env_occurrence(o, cl))) & present_time(t)

→ $0, 0, 1, 1$ has_state(a, belief(occurrence(o, cl, a), t))

has_state(a, observed(env_occurrence(o, cl))) & is_in_team(a, gr)

→ $0, 0, 1, 1 \forall ag:AGENT_CONTROLLER [is_in_team(ag, gr) \& ag \neq a$

→ has_probability(has_state(ag, belief(occurrence(o, cl, a), t)), $1-p3_{cl}$)]

has_state(a, belief(occurrence(o, cl, a1), t))

→ 0, 0, 1, 1 has_state(a, belief(occurrence(o, cl, a1), t))

resource_produced_by(TASK2, notification_report_for(occurrence(o, cl, a), v)) &

is_supervisor_of(as, gr) & is_in_team(a, gr) & present_time(t)

→ 0, 0, 1, 1 has_state(a, communicated_from_to(a, as, inform,
notification_report_for(occurrence(o, cl, a), v)) & has_state(a,
belief(notification_report_for(occurrence(o, cl, a), v)), t)

has_state(a, communicated_from_to(ag, a, inform, info)) & present_time(t)

→ 0, 0, 1, 1

has_state(a, belief(communicated_from_to(ag, a, inform, info), t)

communicated_from_to(ag, a, inform, info)

has_state(ag_safety_investigator, communicated_from_to(ag_safety_investigator, a,
inform, final_report_for(occurrence(o, cl, a), v))

→ 0, 0, 1, 1

has_state(a, communicated_from_to(ag_safety_investigator, a, inform,
final_report_for(occurrence(o, cl, a), v))

has_state(ag_safety_officer, communicated_from_to(ag_safety_officer, a, inform,
monthly_report(m, v))

→ 0, 0, 1, 1

has_state(a, communicated_from_to(ag_safety_officer, a, inform, monthly_report(m, v))

Average quality of the final safety occurrence assessment reports for occurrences similar to the observed occurrence provided to the controller (when the average is calculated, the quality of not received feedback = 0):

$$e_{59_{cl, a, t}} = \sum s_i / |S1|,$$

$$s_i \in S1$$

where $S1 = \{ v \mid \text{has_state}(a, \text{belief}(\text{final_report}(\text{occurrence}(o, cl, a), v), t)) \}$

Here and further in the text the subscript t is used to indicate a time point.

Average quality of the received monthly safety overview reports:

$$e43_{a,t} = \sum_{s_i \in S1} s_i / |S1|,$$

$$s_i \in S1$$

where $S1 = \{ v \mid \text{has_state}(a, \text{belief}(\text{monthly_report}(m, v), t)) \}$

Perceived severity of the provided reprimand:

$$e67_{a,t} = \text{reprimand_amount}$$

Perceived amount of the provided reward:

$$e68_{a,t} = \text{reward_amount}$$

Perception by a controller agent of the commitment to safety of management:

$$e2_{a,t} = w6 * e7_t + w7 * e8_t + w8 * e1_{a,t} + w9 * e9_t + w10 * e70_{a,t} + w11 * e10_t + w12 * e11_t + w13 * e12_t$$

Self-confidence for ATC task:

$$e19_{a,t} = \max(e19_{a,t-1} - s1, 0), \text{ if } \text{has_state}(\text{ag}, \text{observed}(\text{env_occurrence}(o, \text{cl}, \text{sec}))) \text{ holds at } t-1 \text{ and } \text{cl} = A$$

$$e19_{a,t} = \max(e19_{a,t-1} - s2, 0), \text{ if } \text{has_state}(\text{ag}, \text{observed}(\text{env_occurrence}(o, \text{cl}, \text{sec}))) \text{ holds at } t-1 \text{ and } \text{cl} = B$$

$$e19_{a,t} = \max(e19_{a,t-1} - s3, 0), \text{ if } \text{has_state}(\text{ag}, \text{observed}(\text{env_occurrence}(o, \text{cl}, \text{sec}))) \text{ holds at } t-1 \text{ and } \text{cl} = C$$

Adequacy of knowledge about safety issues:

$$e22_{a,t} = w28 * \sum_{s_i \in S1} s_i / |S1| + w29 * \sum_{s_i \in S2} s_i / |S2|,$$

where $S1 = \{q1 \mid \text{has_state}(a, \text{belief}(\text{final_report}(\text{occurrence}(o, \text{cl}, \text{ag1}), q1))) \text{ holds at } t\}$
and $S2 = \{q2 \mid \text{has_state}(a, \text{belief}(\text{monthly_report}(m, q2))) \text{ holds at } t\}$

Adequacy of mental models for ATC task:

$$e23_{a,t} = w26 * e10_t + w27 * e22_{a,t}$$

Maturity level w.r.t. ATC task:

$$e5_{a,t} = w22 * e19_{a,t-1} + w23 * e20_{a,t} + w24 * e21_{a,t} + w25 * e23_{a,t}$$

Perception by a controller agent a of commitment to safety of its team G:

$$e_{3_{a,G,t}} = w_{16} * e_{13_{a,t}} + w_{17} * e_{41_{a,G,t-1}}$$

Commitment to safety of a controller a in team G:

$$e_{6_{a,t}} = w_1 * e_{1_{a,t}} + w_2 * e_{2_{a,t-1}} + w_3 * e_{3_{a,G,t-1}} + w_4 * e_{4_{a,t-1}} + w_5 * e_{5_{a,t-1}}$$

Acceptability of the workload level:

$$e_{18_{G,t}} = w_{39} * e_{8_t} + w_{40} * e_{14_{a,t}}$$

where a is a notation for the supervisor of team G: is_supervisor_of(a, G)

Amount of knowledge on similar safety-related issues of a controller:

IF rule (33) fires for any occurrence(o, ot, a) THEN

$$e_{27_{o, ot, a, t}} = 0, \text{ when } \max_{ag \in H} |S_{ag}| = 0;$$

$$e_{27_{o, ot, a, t}} = 1, \text{ when } \max_{ag \in H} |S_{ag}| > \text{sufficient_similar_occur};$$

$$e_{27_{o, ot, a, t}} = 1 / \max_{ag \in H} |S_{ag}|, \text{ when } \max_{ag \in H} |S_{ag}| > 0 \text{ and } \max_{ag \in H} |S_{ag}| \leq \text{sufficient_similar_occur}$$

where $H = \{a \mid \text{is_in_team}(ag, gr) \ \& \ \text{is_in_team}(a, gr) \ \& \ a \neq ag \text{ holds at } t\}$, $S_a = \{\text{has_state}(a, \text{belief}(\text{occurrence}(o_1, ot, a_1)))\}$

Information contribution from others:

IF rule (33) fires for any occurrence(o, ot, a) THEN

$$e_{16_{o, ot, a, t}} = w_{33} * (w_{34} * e_{6_{a,t}} + w_{35} * e_{27_{o, ot, a, t}}) + w_{36} * (w_{37} * e_{28_{o, ot, a, t}} + w_{38} * e_{13_{a,t}})$$

Quality of a processed notification report:

IF rule (33) fires for any occurrence(o, ot, a) THEN

$$e_{15_{o, ot, a, t}} = w_{18} * e_{16_{o, ot, a, t}} + w_{19} * e_{5_{a,t}} + w_{20} * e_{17_t} + w_{21} * e_{18_{G,t}}$$

Decision making

has_state(a, observed(env_occurrence(o, cl))) & present_time(t)

→ 0, 0, 1, 1 has_state(a, belief(force(report(o, cl), F1), t)) & has_state(a, belief(force(not_report(o, cl), F2), t))

Expectancies and instrumentalities for the reporting option

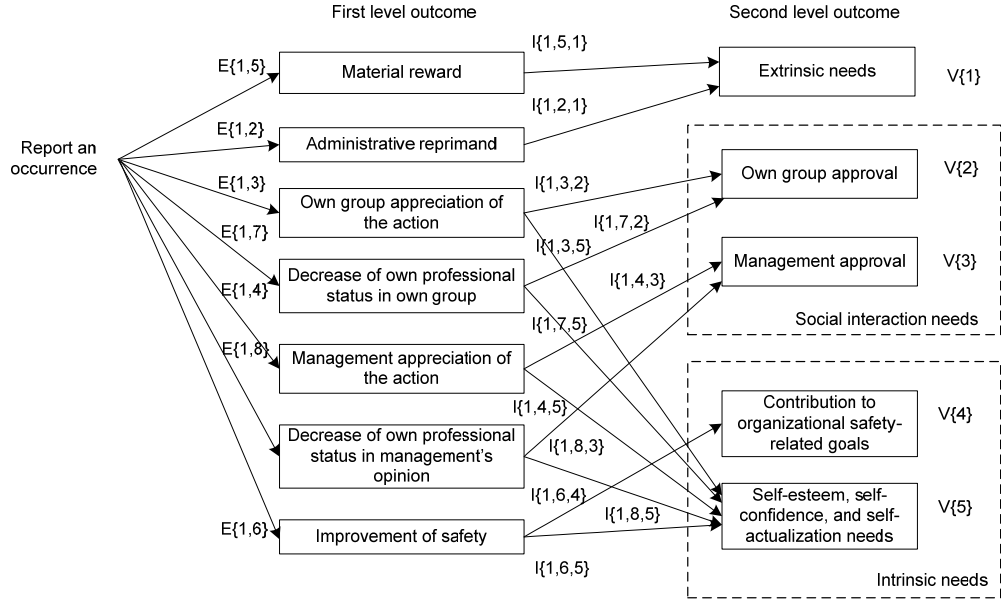


Figure 14: Decision making model for reporting an occurrence by a controller

IF $|OCC_A_a| \geq occ_A_rep$ OR $|OCC_B_a| \geq occ_B_rep$ OR $|OCC_C_a| \geq occ_C_rep$ OR $|OCC_OTHER_a| \geq occ_other_rep$ THEN $E\{1,2\}_{o, cl, a, t} = 1$ ELSE $E\{1,2\}_{o, cl, a, t} = 0$,

where

$OCC_A_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=A \& t1 \leq t \text{ AND } t1 > t - T_{eval_man} \}$

$OCC_B_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=B \& t1 \leq t \text{ AND } t1 > t - T_{eval_man} \}$

$OCC_C_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=C \& t1 \leq t \text{ AND } t1 > t - T_{eval_man} \}$

$OCC_OTHER_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl \neq A \& cl \neq B \& cl \neq C \& t1 \leq t \text{ AND } t1 \geq t - T_{eval_man} \}$

$$E\{1,3\}_{a,t} = (1 - e66_{a,t}) * (dw1 * e57_{G,t} + (1 - dw1) * e3_{a,G,t})$$

where G is such that $is_in_team(a, G)$ holds.

$$E\{1,4\}_{a,t} = dw2 * e2_{a,t} + (1 - dw2) * e13_{a,t}$$

IF $|OCC_A_a| \geq occ_A_rew$ OR $|OCC_B_a| \geq occ_B_rew$ OR $|OCC_C_a| \geq occ_C_rew$ OR $|OCC_OTHER_a| \geq occ_other_rew$ THEN $E\{1,5\}_{o, cl, a, t} = 1$ ELSE $E\{1,5\}_{o, cl, a, t} = 0$, where

$OCC_A_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=A \& t1 \leq t \text{ AND } t1 > t - T_{eval_man}\}$

$OCC_B_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=B \& t1 \leq t \text{ AND } t1 > t - T_{eval_man}\}$

$OCC_C_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl=C \& t1 \leq t \text{ AND } t1 > t - T_{eval_man}\}$

$OCC_OTHER_a = \{o \mid has_state(a, belief(notification_report_for(occurrence(o, cl, a), t1), t2)) \& cl \neq A \& cl \neq B \& cl \neq C \& t1 \leq t \text{ AND } t1 > t - T_{eval_man}\}$

$$E\{1,6\}_{o,cl,a,t} = dw3 * e39_{o,cl,t} + dw4 * e59_{cl,a,t} + dw5 * e2_{a,t} + (1 - dw3 - dw4 - dw5) * e43_{a,t}$$

$$E\{1,7\}_{a,t} = (1 - e66_{a,t}) * (e65_{a,t} * e61_{a,t} + (1 - e35_{G,t}) * (1 - e61_{a,t}))$$

where agent a is in team G.

$$E\{1,8\}_{a,t} = e60_{a,t}$$

$$I\{1,2,1\}_{a,t} = -e67_{a,t}$$

$$I\{1,5,1\}_{a,t} = dw6 * e68_{a,t}$$

$$I\{1,3,5\}_{a,t} = dw7 * e61_{a,t}$$

$$I\{1,7,2\}_{a,t} = dw8 * (e65_{a,t} * e61_{a,t} + (1 - e35_{G,t}) * (1 - e61_{a,t}))$$

where agent a is in team G.

$$I\{1,7,5\}_{a,t} = dw9 * e61_{a,t} * (e65_{a,t} * e61_{a,t} + (1 - e35_{G,t}) * (1 - e61_{a,t}))$$

where agent a is in team G.

$$I\{1,4,5\}_{a,t} = dw10 * e62_{a,t}$$

$$I\{1,8,3\}_{a,t} = dw11 * e60_{a,t}$$

$$I\{1,8,5\}_{a,t} = dw12 * e62_a * e60_{a,t}$$

$$I\{1,6,5\}_{a,t} = dw13 * e6_{a,t} * e39_{o,cl,t}$$

Expectancies and instrumentalities for the not reporting option

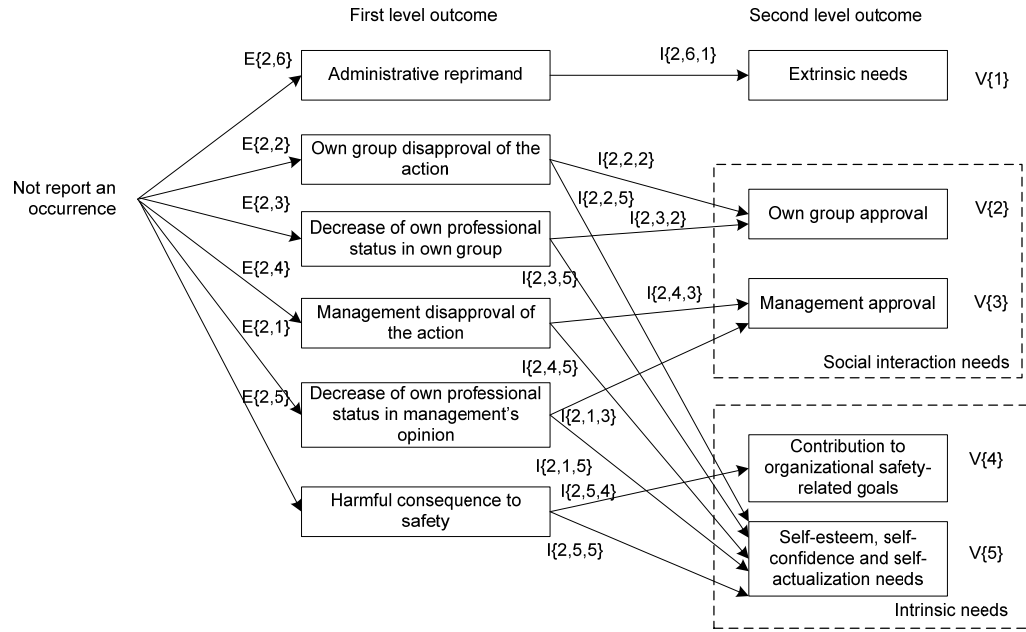


Figure 15: Decision making model for not reporting an occurrence by a controller

$$E\{2,6\}_{o,cl,a,t} = (1-p2_{cl}) * E\{1,2\}_{o,cl,a,t}$$

$$E\{2,2\}_{a,t} = (1-p3_{cl}) * (dw1 * e57_{G,t} + (1-dw1) * e3_{a,G,t})$$

where G is such that is_in_team(a, G) holds.

$$E\{2,4\}_{a,t} = (1-p2_{cl}) * (dw2 * e2_{a,t} + (1-dw2) * e13_{a,t})$$

$$E\{2,3\}_{a,t} = (1 - p3_{cl}) * (e65_{a,t} * e61_{a,t} + (1-e35_{G,t}) * (1-e61_{a,t}))$$

where agent a is in team G.

$$E\{2,1\}_{a,t} = (1 - p2_{cl}) * e60_{a,t}$$

$$E\{2,5\}_{o,cl,a,t} = dw14 * e39_{o,cl,t} + dw15 * e59_{cl,a,t}$$

$$l_{\{2,6,1\}a,t} = dw16 * e_{67a,t} + \alpha$$

$$l_{\{2,2,2\}a,t} = dw17 * e_{39o,cl,t}$$

$$l_{\{2,2,5\}a,t} = dw18 * e_{61a,t}$$

$$l_{\{2,3,2\}a,t} = dw19 * (e_{65a,t} * e_{61a,t} + (1 - e_{35G,t}) * (1 - e_{61a,t}))$$

where agent a is in team G.

$$l_{\{2,3,5\}a,t} = dw20 * e_{61a,t} * (e_{65a,t} * e_{61a,t} + (1 - e_{35G,t}) * (1 - e_{61a,t}))$$

where agent a is in team G.

$$l_{\{2,4,3\}a,t} = dw21 * e_{39o,cl,t}$$

$$l_{\{2,4,5\}a,t} = dw22 * e_{62a,t}$$

$$l_{\{2,1,3\}a,t} = dw23 * e_{60a,t}$$

$$l_{\{2,1,5\}a,t} = dw24 * e_{62a,t} * e_{60a,t}$$

$$l_{\{2,5,4\}a,t} = -e_{39o,cl,t}$$

$$l_{\{2,5,5\}a,t} = dw26 * e_{6a,t} * e_{39o,cl,t}$$

Valences

The valences are evaluated as:

$$v\{need\}_{a,t} = \begin{cases} v\{need\}_a^b \cdot \frac{sat_accept_{need,a}}{sat_{need,a,t}}, & sat_{need,a,t} \geq sat_accept_{need,a} \\ v\{need\}_a^b + v\{need\}_a^b \cdot \frac{sat_accept_{need,a} - sat_{need,a,t}}{sat_accept_{need,a}}, & sat_{need,a,t} < sat_accept_{need,a} \end{cases}$$

here need $\in \{1, 2, 3, 4, 5\}$

Motivational force

In general, the motivational force for an option is

$$F_i = \sum_{j=1}^n E\{i, j\} \cdot \sum_{k=1}^m V\{k\} \times I\{i, j, k\}$$

Here $E\{i, j\}$ is the strength of the expectancy that act $A\{i\}$ will be followed by outcome j ; $V\{k\}$ is the valence of the second level outcome k ; $I\{i, j, k\}$ is perceived instrumentality of outcome j for the attainment of outcome k for act i .

In reference to Figure 14, the motivational force for the reporting option is:

$$\begin{aligned} F_{1,a,t} = & E\{1,5\}_{a,t} I\{1,5,1\}_{a,t} V\{1\}_{a,t} + E\{1,2\}_{a,t} I\{1,2,1\}_{a,t} V\{1\}_{a,t} + E\{1,3\}_{a,t} I\{1,3,2\}_{a,t} V\{2\}_{a,t} + \\ & + E\{1,3\}_{a,t} I\{1,3,5\}_{a,t} V\{5\}_{a,t} + E\{1,7\}_{a,t} I\{1,7,2\}_{a,t} V\{2\}_{a,t} + E\{1,7\}_{a,t} I\{1,7,5\}_{a,t} V\{5\}_{a,t} + \\ & + E\{1,4\}_{a,t} I\{1,4,3\}_{a,t} V\{3\}_{a,t} + E\{1,4\}_{a,t} I\{1,4,5\}_{a,t} V\{5\}_{a,t} + E\{1,8\}_{a,t} I\{1,8,3\}_{a,t} V\{3\}_{a,t} + \\ & + E\{1,8\}_{a,t} I\{1,8,5\}_{a,t} V\{5\}_{a,t} + E\{1,6\}_{a,t} I\{1,6,4\}_{a,t} V\{4\}_{a,t} + E\{1,6\}_{a,t} I\{1,6,5\}_{a,t} V\{5\}_{a,t} \end{aligned}$$

In reference to Figure 15, the motivational force for the not reporting option is:

$$\begin{aligned} F_{2,a,t} = & E\{2,6\}_{a,t} I\{2,6,1\}_{a,t} V\{1\}_{a,t} + E\{2,2\}_{a,t} I\{2,2,2\}_{a,t} V\{2\}_{a,t} + E\{2,2\}_{a,t} I\{2,2,5\}_{a,t} V\{5\}_{a,t} + \\ & + E\{2,3\}_{a,t} I\{2,3,2\}_{a,t} V\{2\}_{a,t} + E\{2,3\}_{a,t} I\{2,3,5\}_{a,t} V\{5\}_{a,t} + E\{2,4\}_{a,t} I\{2,4,3\}_{a,t} V\{3\}_{a,t} + \\ & + E\{2,4\}_{a,t} I\{2,4,5\}_{a,t} V\{5\}_{a,t} + E\{2,1\}_{a,t} I\{2,1,3\}_{a,t} V\{3\}_{a,t} + E\{2,1\}_{a,t} I\{2,1,5\}_{a,t} V\{5\}_{a,t} + \\ & + E\{2,5\}_{a,t} I\{2,5,4\}_{a,t} V\{4\}_{a,t} + E\{2,5\}_{a,t} I\{2,5,5\}_{a,t} V\{5\}_{a,t} \end{aligned}$$

Satisfaction of needs

The following rules are specified for an agent controller a :

IF rule (1) fires for occurrence(o , cl , a) AND $F_{1,a,t} > F_{2,a,t}$ THEN

IF has_state(a , communicated_from_to(ag , a , inform, reward_provided))

THEN $sat_curr(n1,t) = sat_curr(v1,t-1) + I\{1,5,1\}$ ENDIF

IF has_state(a, communicated_from_to(ag, a, inform, reprimand_provided)

THEN sat_curr(n1,t) = sat_curr(v1,t-1) + I{1,2,1} ENDIF

sat_curr(n2,t) = sat_curr(v2,t-1) + E{1,3} I{1,3,2} I{1,7} I{1,7,2} I{1,7,2}

sat_curr(n3,t) = sat_curr(v3,t-1) + E{1,4} I{1,4,3} I{1,8} I{1,8,3} I{1,8,3}

sat_curr(n4,t) = sat_curr(v4,t-1) + E{1,6} I{1,6,4} I{1,6,4}

sat_curr(n5,t) = sat_curr(v5,t-1) + E{1,3} I{1,3,5} I{1,7} I{1,7,2} I{1,7,2}

+ E{1,4} I{1,4,5} I{1,8} I{1,8,5} I{1,8,5} + E{1,6} I{1,6,5} I{1,6,5}

ENDIF

ELSE ('Occurrence not reported')

sat_curr(n1,t) = sat_curr(v1,t-1) + I{2,6,1} I{2,6,1}

sat_curr(n2,t) = sat_curr(v2,t-1) + E{2,2} I{2,2,2} I{2,3} I{2,3,2} I{2,3,2}

sat_curr(n3,t) = sat_curr(v3,t-1) + E{2,3} I{2,4,3} I{2,1} I{2,1,3} I{2,1,3}

sat_curr(n4,t) = sat_curr(v4,t-1) + E{2,5} I{2,5,4} I{2,5,4}

sat_curr(n5,t) = sat_curr(v5,t-1) + E{2,2} I{2,2,5} I{2,3} I{2,3,5} I{2,3,5}

+ E{2,4} I{2,4,5} I{2,1} I{2,1,5} I{2,1,5} + E{2,5} I{2,5,5} I{2,5,5}

END

Parameters

Parameter	Explanation	Value
Expectancies & instrumentalities for the reporting options		
dw1	The weight of the perception of the positive attitude to reporting in the team for deciding to report by a controller	0.7
dw2	The weight of the perception of the commitment of management to safety for deciding to report by a controller	0.6

dw3	The weight of the occurrence severity for deciding to report by a controller	0.4
dw4	The weight of the average quality of the final safety occurrence assessment reports for similar occurrences for the expectancy E16	0.3
dw5	The weight of the commitment to safety of the management for the expectancy E16	0.15
dw6	The weight of the perceived amount of the provided award for the instrumentality ri51	0.2
ri32 ₀	Initial value of instrumentality in the decision making model to report	0.1
dw7	a coefficient in the decision making model to report relating e61 _a and ri35 _a	0.1
dw8	a coefficient in the decision making model to report	-0.5
dw9	a coefficient in the decision making model to report	-0.5
ri43	an instrumentation in the decision making model to report	0.1
ri64	an instrumentation in the decision making model to report	1
dw10	a coefficient in the decision making model to report	0.2
dw11	a coefficient in the decision making model to report	-0.5
dw12	a coefficient in the decision making model to report	-0.5
dw13	a coefficient in the decision making model to report	0.2
dw14	a coefficient in the decision making model to report	0.6
dw15	a coefficient in the decision making model to report	0.3
dw16	a coefficient in the decision making model to report	-0.4
α	extra reprimand for not reporting	0.05
dw17	a coefficient in the decision making model to report	-0.2
dw18	a coefficient in the decision making model to report	-0.2
dw19	a coefficient in the decision making model to report	-0.5
dw20	a coefficient in the decision making model to report	-0.5
dw21	a coefficient in the decision making model to report	-0.4
dw22	a coefficient in the decision making model to report	-0.2
dw23	a coefficient in the decision making model to report	-0.5
dw24	a coefficient in the decision making model to report	-0.5
dw25	a coefficient in the decision making model to report	-1
dw26	a coefficient in the decision making model to report	-0.2
occ_A_rep	Number of occurrences of type A that lead to a	1

	reprimand	
occ_B_rep	Number of occurrences of type B that lead to a reprimand	1
occ_C_rep	Number of occurrences of type C that lead to a reprimand	1E9
occ_other_rep	Number of occurrences of type Other that lead to a reprimand	1E9
occ_A_rew	Number of occurrences of type A that lead to a reward	1E9
occ_B_rew	Number of occurrences of type B that lead to a reward	1E9
occ_C_rew	Number of occurrences of type C that lead to a reward	1
occ_other_rew	Number of occurrences of type Other that lead to a reward	1
e4 ₀	Initial value of influence degree of controllers on safety arrangements	0.5
e19 _{min}	Minimum initial value of self-confidence for ATC task	0.9
e19 _{max}	Maximum initial value of self-confidence for ATC task	1.0
e20 ₀	Initial value of commitment to perform ATC task	0.8
e44 ₀	Average commitment to safety of the agents involved in safety analysis	0.65
e21 _{min}	Minimum value of development level of skills for ATC task	0.8
e21 _{max}	Maximum value of development level of skills for ATC task	1.0
e61 _{min}	Minimum value of individualism (IDV) index of a controller	0.7
e61 _{max}	Maximum value of individualism (IDV) index of a controller	0.9
e62 _{min}	Minimum value of power Distance Index (PDI) of a controller	0.3
e62 _{max}	Maximum value of power Distance Index (PDI) of a controller	0.5
e63 _{min}	Minimum value of masculinity (MAS) index of a controller	0.05
e63 _{max}	Maximum value of masculinity (MAS) index of a controller	0.25
e64 _{min}	Minimum value of uncertainty Avoidance Index (UAI) of a controller	0.4
e64 _{max}	Maximum value of uncertainty Avoidance Index	0.6

	(UAI) of a controller	
e66 _{ini}	Initial value of perception of confidentiality of reporting	1
T _{TASK15,min}	Minimum duration of Task 15 “Making decision on the occurrence reporting” by controller	1 min
T _{TASK15,max}	Maximum duration of Task 15 “Making decision on the occurrence reporting” by controller	24 hr
T _{TASK2,min}	Minimum duration of Task 2 “Create a notification report” by controller	3 min
T _{TASK2,max}	Maximum duration of Task 2 “Create a notification report” by controller	24 hr
acq_shifts	Number of shifts sufficient for acquaintance of controllers	7
v1 _{min}	Minimum value of basis valence of need n1 “Extrinsic needs” of a controller	1
v1 _{max}	Maximum value of basis valence of need n1 “Extrinsic needs” of a controller	1
v2 _{min}	Minimum value of basis valence of need n2 “Own group approval” of a controller	0.3
v2 _{max}	Maximum value of basis valence of need n2 “Own group approval” of a controller	0.5
v3 _{min}	Minimum value of basis valence of need n3 “Management approval” of a controller	0.3
v3 _{max}	Maximum value of basis valence of need n3 “Management approval” of a controller	0.5
v4 _{min}	Minimum value of basis valence of need n4 “Contribution to safety-related goals” of a controller	0.4
v4 _{max}	Maximum value of basis valence of need n4 “Contribution to safety-related goals” of a controller	0.6
v5 _{min}	Minimum value of basis valence of need n5 “Self-esteem, self-confidence and self-actualization” of a controller	0.7
v5 _{max}	Maximum value of basis valence of need n5 “Self-esteem, self-confidence and self-actualization” of a controller	1
sat_accept(n1)	Acceptable satisfaction value for need n1 “Extrinsic needs”	1
sat_accept(n2)	Acceptable satisfaction value for need n2 “Own group approval”	0.6
sat_accept(n3)	Acceptable satisfaction value for need n3 “Management approval”	0.7

sat_accept(n4)	Acceptable satisfaction value for need n4 “Contribution to safety-related goals”	0.7
sat_accept(n5)	Acceptable satisfaction value for need n2 “Self-esteem, self-confidence and self-actualization”	0.9
p2 _A	Probability of identification of non-reported occurrence of type A by the management	1
p2 _B	Probability of identification of non-reported occurrence of type B by the management	0.9
p2 _C	Probability of identification of non-reported occurrence of type C by the management	0.7
p2 _{other}	Probability of identification of non-reported occurrence of type Other by the management	0.3
p3 _A	Probability of identification of non-reported occurrence of type A by team of controllers	1
p3 _B	Probability of identification of non-reported occurrence of type B by team of controllers	1
p3 _C	Probability of identification of non-reported occurrence of type C by team of controllers	0.8
p3 _{other}	Probability of identification of non-reported occurrence of type Other by team of controllers	0.6
sufficient_similar_occur	The number of safety-related issues similar to a current occurrence known to an agent to provide sufficient information contribution, when a notification report about the current issue is being created	3
T _{eval_man}	Evaluation period of the performance of a controller by the management	30 days
T _{eval_team}	Evaluation period of the performance of a controller by the controller’s team	60 days
T _{shift}	Duration of a shift of controllers	12 hours
N _{ag,cont}	Number of controller agents	48
s1	Decrease of confidence for an occurrence of type A	0.5
s2	Decrease of confidence for an occurrence of type B	0.3
s3	Decrease of confidence for an occurrence of type C	0.1
w1	Contribution of e1 ‘Priority of safety-related goals in the role description’ to e6 ‘Commitment to safety of a controller’	0.1
w2	Contribution of e2 ‘Perception of the commitment to safety of management’ to e6 ‘Commitment to safety of a controller’	0.2
w3	Contribution of e3 ‘Perception of commitment to safety	0.1

	of team' to e6 'Commitment to safety of a controller'	
w4	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3
w5	Contribution of e5 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3
w6	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.1
w7	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.1
w8	Contribution of e1 'Priority of safety-related goals in the role description' to e2 'Perception of the commitment to safety of management'	0.15
w9	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e2 'Perception of the commitment to safety of management'	0.2
w10	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	0.05
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	0.2
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	0.05
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	0.15
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.4
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.6
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	0.1
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	0.3
w20	Contribution of e7 'Quality of technical systems' to e15	0.3

	‘Quality of a processed notification report’.	
w21	Contribution of e18 ‘Acceptability of the workload level’ to e15 ‘Quality of a processed notification report’.	0.3
w22	Contribution of e19 ‘Self-confidence for ATC task’ to e5 ‘Maturity level w.r.t. ATC task’.	0.25
w23	Contribution of e20 ‘Commitment to perform ATC task’ to e5 ‘Maturity level w.r.t. ATC task’.	0.25
w24	Contribution of e21 ‘Development level of skills for ATC task’ to e5 ‘Maturity level w.r.t. ATC task’.	0.25
w25	Contribution of e23 ‘Adequacy of mental models for ATC task’ to e5 ‘Maturity level w.r.t. ATC task’.	0.25
w26	Contribution of e10 ‘Sufficiency and timeliness of training for changes’ to e23 ‘Adequacy of mental models for ATC task’.	0.5
w27	Contribution of e22 ‘Adequacy of knowledge about safety issues’ to e23 ‘Adequacy of mental models for ATC task’.	0.5
w28	Contribution of e42 ‘Average quality of the received final safety occurrence assessment reports’ to e22 ‘Adequacy of knowledge about safety issues’.	0.4
w29	Contribution of e43 ‘Average quality of the received monthly safety overview reports’ to e22 ‘Adequacy of knowledge about safety issues’.	0.6
w33	Contribution of e29 ‘Information contribution by a controller’ to e16 ‘Information contribution by others’.	0.6
w34	Contribution of e6 ‘Commitment to safety of a controller’ to e29 ‘Information contribution by a controller’.	0.3
w35	Contribution of e27 ‘Amount of knowledge on similar safety-related issues of a controller’ to e29 ‘Information contribution by a controller’.	0.7
w36	Contribution of e30 ‘Information contribution by the supervisor’ to e16 ‘Information contribution by others’.	0.4
w37	Contribution of e28 ‘Amount of knowledge on similar safety-related issues of the supervisor’ to e30 ‘Information contribution by the supervisor’.	0.7
w38	Contribution of e13 ‘Perceived commitment to safety of the supervisor’ to e30 ‘Information contribution by the supervisor’.	0.3
w39	Contribution of e8 ‘Sufficiency of the number of controllers’ to e18 ‘Acceptability of the workload level’.	0.8
w40	Contribution of e14 ‘Level of development of managerial skills’ to e18 ‘Acceptability of the workload level’.	0.2

A.4 Agent Controller team

Input ontology

Information type	Source of information
e3 _{a,G} : Perception of commitment to safety of team	Controller
e4 _a : Influence degree of controllers on safety arrangements	Controller
e6 _a : Commitment of safety of a controller	Controller

Output Ontology

Information type	Destination of information
e34 _G : Contribution of informal discussion of controllers in the team	Controller
e35 _G : Intensity of informal interactions in the team of controllers	Controller
e41 _{a,G} : Average commitment to safety of team members	Controller
e57 _G : Perception of the positive attitude to reporting in a team	Controller
e65 _a : Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the team of the controller	Controller
e70 _a : Average perceived degree of influence of controllers on safety arrangements	Controller

Variables

Variable	State space	Initial value	Explanation

e34 _G	[0,1]	None (dependent)	Contribution of informal discussion of controllers in the team
e35 _{max}	[0,1]	0.65	Maximum intensity of informal interactions in the team of controllers
e41 _{a,G}	[0,1]	None (dependent)	Average commitment to safety of team members
e57 _G	[0,1]	None (dependent)	Perception of the positive attitude to reporting in a team
e65 _a	[0,1]	None (dependent)	Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the team of the controller
e70 _a	[0,1]	None (dependent)	Average perceived degree of influence of controllers on safety arrangements

Internal mappings and dynamics

Organizational tasks

None.

Beliefs

At each time step t the values of the factors are calculated as:

Notation e' means the value of e at the time step $t-1$.

Average perceived degree of influence of controllers on safety arrangements:

$$e70_{a,t} = \sum_{ag \in GR} e4_{ag,t} / |GR|, \text{ where } GR = \{g \mid \text{is_in_team}(g, G) \text{ AND } \text{is_in_team}(ag, G)\}$$

Average commitment to safety of team members:

$$e41_{a,G,t} = \sum_{i \in T} e6_{i,G,t} / |T|,$$

here $T = \{ag \mid \exists ag:AGENT \text{ is_in_team}(ag, G) \text{ AND } a \neq ag \text{ AND } ag \neq s\}$, i.e., the set of all agents from G except s and a ; $e6_{i,G,t-1}$ is the agent's i from team G commitment at time point $t-1$.

To calculate $e35_{G,t}$ a measure of degree of acquaintance (acq) of agents $ag1$ and $ag2$ worked n shifts together is introduced, calculated as follows:

if $n = 0$ and t is the current time point, then $acq(ag1, ag2, t) = 0$;

else if $acq_shifts > n > 0$ and t is the current time point, then $acq(ag1, ag2, t) = e35_{max}/n$

else if $n \geq acq_shifts$ & t is the current time point, then $acq(ag1, ag2, t) = e35_{max}$.

The number of shifts, which agents $ag1$ and $ag2$ have worked together is updated in the beginning of a shift gr :

$begin_shift(gr) \& is_in_team(ag1, gr) \& is_in_team(ag2, gr) \& ag1 \neq ag2 \& shifts_together(ag1, ag2, n)$

$\rightarrow 0, 0, 1, 1 \ shifts_together(ag1, ag2, n+1)$

Then, $e35_{G,t} = \sum acq(ag1, ag2, t) / (|G| * (|G| - 1))$.

Contribution of informal discussion of controllers in the team:

IF rule (35) fires THEN

$$e34_{G,t} = w49 * \sum_{a \in \{ag \mid is_in_team(ag, G)\}} e3_{a,G,t} / \text{number of controllers in a team} + w51 * \sum_{s_i \in S1} s_i / |S1| + w52 * \sum_{s_i \in S2} s_i / |S2| + w50 * e35_{G,t}$$

where

$S1 = \{q \mid \exists t1 \text{ has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a1), q), t1)) \& is_supervisor_of(a, G), \text{holds}\}$,

$S2 = \{q \mid \exists t2 \text{ has_state}(a, \text{belief}(\text{monthly_report}(m, q), t2)) \& is_supervisor_of(a, G) \text{ holds}\}$

Perception of the positive attitude to reporting in a team:

$$e57_{G,t} = \sum_{s_i \in S1} s_i / |S1|,$$

where $S1 = \{v \mid \text{has_state}(ag, \text{belief}(\text{force}(\text{report}(o, cl), v), t)) \& is_in_team(ag, G)\}$

Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the team of the controller:

$$e65_{a,t} = \begin{cases} 1, & \text{if } \sum_{oc_i \in OC} oc_i \geq 1, \\ \sum_{oc_i \in OC} oc_i, & \text{if } \sum_{oc_i \in OC} oc_i < 1 \end{cases}$$

where $OC = \{v2 \mid \text{has_state}(as, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), v), t1))$
 $\& \text{is_supervisor_of}(as, gr) \& \text{is_in_team}(a, gr) \& \text{occurrence_severity}(cl, v2) \& t1 \leq t \& t1 \geq$
 $t - T_{\text{eval,team}} \}$

Decision making

None.

Parameters

Parameter	Explanation	Value
$N_{\text{cont.team}}$	Number of controllers per team	12
$T_{\text{eval,team}}$	Evaluation period by the performance of a controller by the controller's team	60 days
w49	Contribution of e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.2
w50	Contribution of e35 'Intensity of informal interactions in the team of controllers' to e34 'Contribution of informal discussions of controllers in the team'.	0.3
w51	Contribution of e48 'Average quality of the notification reports produced by the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.3
w52	Contribution of e49 'Average quality of the received monthly safety overview reports' to e34 'Contribution of informal discussions of controllers in the team'.	0.2

A.5 Agent Controller supervisor

Number of agent controller supervisors is 2.

Input Ontology

Information type	Source of information
observed(env_occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, sec:SECTOR)	Environment & Technical Systems
notification_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	Controller
monthly_report(m: MONTH, v1: VALUE)	Safety Officer

Output Ontology

Information type	Destination of information
notification_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	Safety Investigator
e13 _a : Commitment to safety of the supervisor	Controller
e14: Level of development of managerial skills of supervisor	Controller
e28 _{o, ot, ag} : Amount of knowledge on similar safety-related issues of the supervisor	Controller

Variables

Variable	State space	Initial value	Explanation

e13 _a	[0,1]	None	Commitment to safety of the supervisor
e14 _a	[0,1]	0.6	Level of development of managerial skills of supervisor
e28 _{o, ot, ag}	[0,1]	None	Amount of knowledge on similar safety-related issues of the supervisor

Internal mappings and dynamics

Organizational tasks

(5) finished_process_of_type_for(TASK2, occurrence(o, cl, a))

→ 0, 0, 1, 1 began_process_of_type_for(TASK3, occurrence(o, cl, a))

(6) began_process_of_type_for(TASK3, occurrence(o, cl, a))

→ (T_{TASK3,min}, T_{TASK3,max}, 1, 1) finished_process_of_type_for(TASK3, occurrence(o, cl, a))

(34) finished_process_of_type_for(TASK3, occurrence(o, cl, a))

→ 0, 0, 1, 1 resource_produced_by(TASK3, notification_report_for(occurrence(o, cl, a),
e15_{o, cl, a}))

resource_produced_by(TASK3, notification_report_for(occurrence(o, cl, a), v))

→ 0, 0, 1, 1 has_state(a, communicated_from_to(a, ag_safety_investigator, inform,
notification_report_for(occurrence(o, cl, a), v))

Beliefs

has_state(a, observed(env_occurrence(o, cl, sec))) & is_in_team(a, gr) &
is_supervisor_of(ag, gr)

→ 0, 0, 1, 1 has_probability(has_state(ag, belief(occurrence(o, cl, a), t)), 1-p3_{cl})

has_state(a, belief(occurrence(o, cl, a1), t))

→ 0, 0, 1, 1 has_state(a, belief(occurrence(o, cl, a1), t))

has_state(a, communicated_from_to(a, as, inform, notification_report_for(occurrence(o,
cl, a), v))

→ 0, 0, 1, 1 has_state(as, communicated_from_to(a, as, inform,
notification_report_for(occurrence(o, cl, a), v))

has_state(ag_safety_officer, communicated_from_to(ag_safety_officer, a, inform,
monthly_report(m, v))

→ 0, 0, 1, 1

has_state(a, communicated_from_to(ag_safety_officer, a, inform, monthly_report(m, v))

The perception of agent *a* of the commitment to safety of the team supervisor *s* is calculated as:

$$e13_{a,t} = w14 * e14_{s,t} + w15 * e2_{a,t-1}$$

where *s* is a notation for the supervisor of the team of *a*: is_in_team(*a*, *G*) ∧
is_supervisor_of(*s*, *G*)

Amount of knowledge on similar safety-related issues of the supervisor:

IF rule (33) fires for any occurrence(*o*, *ot*, *ag*) THEN

$e28_{o, ot, ag, t} = 0$, when $|S| = 0$;

$e28_{o, ot, ag, t} = 1/|S|$, when $|S| > 0$ and $|S| \leq \text{sufficient_similar_occur}$;

$e28_{o, ot, ag, t} = 1$, when $|S| > \text{sufficient_similar_occur}$;

where $S = \{ \text{has_state}(a, \text{belief}(\text{occurrence}(o1, ot, a1))) \mid \text{is_in_team}(ag, gr) \ \& \ \text{is_supervisor_of}(a, gr) \}$

Decision making

None.

Parameters

Parameter	Explanation	Value
$T_{\text{TASK3}, \text{min}}$	Minimum duration of TASK3 “Preliminary processing of a notification report”	120 s
$T_{\text{TASK3}, \text{max}}$	Maximum duration of TASK3 “Preliminary processing of a notification	48 hr

	report”	
p3 _A	Probability of identification of non-reported occurrence of type A by team of controllers	1
p3 _B	Probability of identification of non-reported occurrence of type B by team of controllers	1
p3 _C	Probability of identification of non-reported occurrence of type C by team of controllers	0,8
p3 _{other}	Probability of identification of non-reported occurrence of type Other by team of controllers	0.6
sufficient_similar_occur		3
w14	Contribution of e14 ‘Level of development of managerial skills’ to e13 ‘Perception of commitment to safety of the supervisor’	0.4
w15	Contribution of e2 ‘Perception of commitment to safety of management’ to e13 ‘Perception of commitment to safety of the supervisor’	0.6

A.6 Agent Manager

Introduction

The management is considered as one aggregated agent.

Input Ontology

Information type	Source of information
final_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	agent safety investigator
monthly_report(m: MONTH, v1: VALUE)	agent safety officer
observed(env_occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, sec:SECTOR)	environment

Output Ontology

Information type	Destination of information
e1: Priority of safety-related goals in the role description	Controller _i
e7: Sufficiency of amount of safety investigators	Controller _i
e8: Sufficiency of the amount of controllers	Controller _i
e10: Sufficiency and timeliness of training for changes	Controller _i
e12: Developed and implemented SMS	Controller _i
e36: Quality of the formal occurrence assessment procedure	Safety Investigator

e60 _a : Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the management	Controller _i
reprimand_amount	Controller _i
reward_amount	Controller _i

Variables

Variable	State space	Initial value	Explanation
e1	[0,1]	e1 ₀	Priority of safety-related goals in the role description
e7	[0,1]	e7 ₀	Sufficiency of amount of safety investigators
e8	[0,1]	e8 ₀	Sufficiency of the amount of controllers
e10	[0,1]	e10 ₀	Sufficiency and timeliness of training for changes
e12	[0,1]	e12 ₀	Developed and implemented SMS
e36	[0,1]	e36 ₀	Quality of the formal occurrence assessment procedure
e60 _a	[0,1]	0	Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the management
reprimand_amount	[0,1]	0	Amount of reprimand provided to a controller by a manager
reward_amount	[0,1]	0	Amount of reward provided to a

amount			controller by a manager
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Internal mappings and dynamics

Organizational tasks

(21) finished_process_of_type_for(TASK10, occurrence(o, cl, a))

→→ 0, 0, 1, 1 began_process_of_type_for(TASK16, occurrence(o, cl, a))

(22) began_process_of_type_for(TASK16, occurrence(o, cl, a))

→→ ($T_{TASK16,min}$, $T_{TASK16,max}$, 1, 1) finished_process_of_type_for(TASK16, occurrence(o, cl, a))

(31) finished_process_of_type_for(TASK14, month(m))

→→ 0, 0, 1, 1 began_process_of_type_for(TASK16, month(m))

(32) began_process_of_type_for(TASK16, month(m))

→→ ($T_{TASK16,min}$, $T_{TASK16,max}$, 1, 1) finished_process_of_type_for(TASK16, month(m))

Beliefs

has_state(ag, observed(env_occurrence(o, cl, sec))), t)

→→ 0, 0, 1, 1 has_probability(has_state(ag_management, belief(occurrence(o, cl, ag), t)), 1-p_{2-cl})

has_state(a, belief(occurrence(o, cl, ag), t))

→→ 0, 0, 1, 1 has_state(a, belief(occurrence(o, cl, ag), t))

has_state(ag_safety_investigator,
communicated_from_to(ag_safety_investigator, ag_management, inform,
final_report_for(occurrence(o, cl, a), v))

→→ 0, 0, 1, 1

has_state(ag_management, communicated_from_to(ag_safety_investigator,
ag_management, inform, final_report_for(occurrence(o, cl, a), v))

has_state(ag_safety_officer, communicated_from_to(ag_safety_officer,
ag_management, inform, monthly_report(m, v))

→→ 0, 0, 1, 1

has_state(ag_management, communicated_from_to(ag_safety_officer,
ag_management, inform, monthly_report(m, v))

Total severity of a set of occurrences of the controller occurred during the
evaluation time interval, which are known to the management:

$$e60_{a,t} = \begin{cases} 1, & \text{if } \sum_{oc_i \in OC} oc_i \geq 1, \\ \sum_{oc_i \in OC} oc_i, & \text{if } \sum_{oc_i \in OC} oc_i < 1 \end{cases}$$

where $OC = \{v2 \mid \text{has_state}(\text{ag_management}, \text{belief}(\text{final_report}(\text{occurrence}(o, cl, a), q1))) \& \text{occurrence_severity}(cl, v2) \& t1 \leq t \& t1 \geq t - T_{\text{eval,man}}\}$

Decision making

IF |OCC_A_a| ≥ occ_A_rep THEN rep_A = reprimand_A ENDIF

IF |OCC_B_a| ≥ occ_B_rep THEN rep_B = reprimand_B ENDIF

IF |OCC_C_a| ≥ occ_C_rep THEN rep_C = reprimand_C ENDIF

IF |OCC_Other_a| ≥ occ_other_rep THEN rep_Other = reprimand_Other ENDIF

reprimand_amount = max(rep_A, rep_B, repC, rep_Other)

where

OCC_A_a = {o | has_state(a, belief(notification_report_for(occurrence(o, cl, a), t2),
t1)) & cl=A & t1 ≤ t AND t1 > t - T_{eval,man} }

OCC_B_a = {o | has_state(a, belief(notification_report_for(occurrence(o, cl, a), t2),
t1)) & cl=B & t1 ≤ t AND t1 > t - T_{eval,man} }

$$OCC_C_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl=C \& t1 \leq t \text{ AND } t1 > t - T_{\text{eval,man}} \}$$

$$OCC_OTHER_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl \neq A \& cl \neq B \& cl \neq C \& t1 \leq t \text{ AND } t1 \geq t - T_{\text{eval,man}} \}$$

IF $|OCC_A_a| \geq occ_A_rew$ THEN $rew_A = reward_A$ ENDIF

IF $|OCC_B_a| \geq occ_B_rew$ THEN $rew_B = reward_B$ ENDIF

IF $|OCC_C_a| \geq occ_C_rew$ THEN $rew_C = reward_C$ ENDIF

IF $|OCC_Other_a| \geq occ_other_rew$ THEN $rew_Other = reward_Other$ ENDIF

$reward_amount = \max(rew_A, rew_B, rew_C, rew_Other)$

where

$$OCC_A_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl=A \& t1 \leq t \text{ AND } t1 > t - T_{\text{eval,man}} \}$$

$$OCC_B_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl=B \& t1 \leq t \text{ AND } t1 > t - T_{\text{eval,man}} \}$$

$$OCC_C_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl=C \& t1 \leq t \text{ AND } t1 > t - T_{\text{eval,man}} \}$$

$$OCC_OTHER_a = \{o \mid \text{has_state}(a, \text{belief}(\text{notification_report_for}(\text{occurrence}(o, cl, a), t2), t1)) \& cl \neq A \& cl \neq B \& cl \neq C \& t1 \leq t \text{ AND } t1 \geq t - T_{\text{eval,man}} \}$$

Parameters

Parameter	Explanation	Value
$e1_0$	Initial value for Priority of safety-related goals in the role description	0.7
$e7_0$	Initial value for Sufficiency of amount of safety investigators	0.5
$e8_0$	Initial value for Sufficiency of the amount of controllers	0.6

e_{10_0}	Initial value for Sufficiency and timeliness of training for changes	0.6
e_{12_0}	Initial value for Developed and implemented SMS	0.6
e_{36_0}	Initial value for Quality of the formal occurrence assessment procedure	0.85
$T_{TASK16,min}$	Minimum duration of TASK16 “Implementation of safety recommendations”	360 hr
$T_{TASK16,max}$	Maximum duration of TASK16 “Implementation of safety recommendations”	2160 hr
$T_{eval,man}$	Evaluation period of the performance of a controller by the management	30 days
p_{2A}	Probability of identification of non-reported occurrence of type A by the management	1
p_{2B}	Probability of identification of non-reported occurrence of type B by the management	0.9
p_{2C}	Probability of identification of non-reported occurrence of type C by the management	0.7
p_{2other}	Probability of identification of non-reported occurrence of type Other by the management	0.3
occ_A_rep	Number of occurrences of type A that lead to a reprimand	1
occ_B_rep	Number of occurrences of type B that lead to a reprimand	1

occ_C_rep	Number of occurrences of type C that lead to a reprimand	1E9
occ_other_rep	Number of occurrences of type Other that lead to a reprimand	1E9
reprimand_A	Reprimand amount for type A occurrence(s)	1
reprimand_B	Reprimand amount for type B occurrence(s)	0.5
reprimand_C	Reprimand amount for type C occurrence(s)	0.2
reprimand_Other	Reprimand amount for type Other occurrence(s)	0
occ_A_rew	Number of occurrences of type A that lead to a reward	0
occ_B_rew	Number of occurrences of type B that lead to a reward	0
occ_C_rew	Number of occurrences of type C that lead to a reward	0
occ_other_rew	Number of occurrences of type Other that lead to a reward	0
reward_A	Reward amount for reporting type A occurrence(s)	0
reward_B	Reward amount for reporting type B occurrence(s)	0
reward_C	Reward amount for reporting type C occurrence(s)	0
reward_Other	Reward amount for reporting type Other occurrence(s)	0

A.7 Safety investigator

One safety investigator agent is introduced: ag_safety_investigator.

Input Ontology

Information type	Source of information
notification_report_for(occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	Supervisor
monthly_report(m: MONTH, v1: VALUE)	Safety officer
belief(occurrence(o1, ot, a1))	Manager
e7: Sufficiency of amount of safety investigators	Manager
e15 _{o,ot,a} : Quality of a processed notification report	Supervisor
e36: Quality of the formal occurrence assessment procedure	Manager
e39 _{o,cl} : Severity of an occurrence	Environment & Technical Infrastructure
e50: Average commitment to safety of the participants of the meeting	Safety Recommendations and Concerns Group

Output Ontology

Information type	Recipient of information
final_report_for(occurrence(o:OCCURRENCE,	Controller

cl:OCCURRENCE_TYPE, a:AGENT_CONTROLLER), v:VALUE)	
e38: Quality of the final safety occurrence assessment report	Controller
p1: Probability of feedback provision on a safety occurrence	Controller

Variables

Variable	State space	Initial value	Explanation
e37 _{o, ot, ag}	[0,1]	None (dependent)	Amount of knowledge on similar safety-related issues in the organization
e38	[0,1]	None (dependent)	Quality of the final safety occurrence assessment report
e40	[0,1]	e40 ₀	Quality of the communication channel between controllers and safety investigators
p1	[0,1]	None (dependent)	Probability of feedback provision on a safety occurrence

Internal mappings and dynamics

Organizational tasks

(9) finished_process_of_type_for(TASK4, occurrence(o, cl, a))
→_{0, 0, 1, 1} began_process_of_type_for(TASK5, occurrence(o, cl, a))

(10) began_process_of_type_for(TASK5, occurrence(o, cl, a))
→_(T_{TASK5,min}, T_{TASK5,max,sep}, 1, 1) finished_process_of_type_for(TASK5, occurrence(o, cl, a)) WHEN cl is type A, B or C

→→ (T_{TASK5,min}, T_{TASK5,max,other}, 1, 1) finished_process_of_type_for(TASK5, occurrence(o, cl, a)) WHEN cl is type Other

(11) finished_process_of_type_for(TASK5, occurrence(o, cl, a))

→→ 0, 0, 1, 1 began_process_of_type_for(TASK6, occurrence(o, cl, a))

(12) began_process_of_type_for(TASK6, occurrence(o, cl, a))

→→ (T_{TASK6,min}, T_{TASK6,max}, 1, 1) finished_process_of_type_for(TASK6, occurrence(o, cl, a))

(13) finished_process_of_type_for(TASK6, occurrence(o, cl, a))

→→ 0, 0, 1, 1 began_process_of_type_for(TASK7, occurrence(o, cl, a))

(14) began_process_of_type_for(TASK7, occurrence(o, cl, a))

→→ (T_{TASK7,min}, T_{TASK7,max}, 1, 1) finished_process_of_type_for(TASK7, occurrence(o, cl, a))

(35) finished_process_of_type_for(TASK9, occurrence(o, cl, a))

→→ 0, 0, 1, 1 resource_produced_by(TASK9, final_report_for(occurrence(o, cl, a), e38_{o, cl, a}))

Beliefs

Amount of knowledge on similar safety-related issues in the organization:

IF rule (34) fires:

e37_{o, ot, ag, t} = 0, when |S| = 0;

e37_{o, ot, ag, t} = 1, when |S| > sufficient_similar_occur;

e37_{o, ot, ag, t} = 1/|S|, when |S| > 0 and |S| ≤ sufficient_similar_occur

where S = { has_state(ag_safety_manager, belief(occurrence(o1, ot, a1)))}

has_state(a, communicated_from_to(a, ag_safety_investigator, inform, notification_report_for(occurrence(o, cl, a), v))

→→ 0, 0, 1, 1

has_state(ag_safety_investigator, communicated_from_to(a,
ag_safety_investigator, inform, notification_report_for(occurrence(o, cl, a), v))

resource_produced_by(TASK9, final_report_for(occurrence(o, cl, ag1), v)) &
present_time(t)

→→ 0, 0, 1, 1

has_state(ag_safety_investigator,
communicated_from_to(ag_safety_investigator, a, inform,
final_report_for(occurrence(o, cl, ag1), v)) & has_state(ag_safety_investigator,
belief(final_report_for(occurrence(o, cl, ag1)), t)

has_state(ag_safety_officer, communicated_from_to(ag_safety_officer,
ag_safety_investigator, inform, monthly_report(m, v))

→→ 0, 0, 1, 1

has_state(ag_safety_investigator, communicated_from_to(ag_safety_officer,
ag_safety_investigator, inform, monthly_report(m, v))

Decision making

Quality of the final safety occurrence assessment report:

IF rule (34) fires (*End of preliminary processing of a notification report*):

$$e38_{o, ot, ag, t} = w53 * e36_t + w55 * e7_t + w56 * e15_{o, ot, ag, t-1} + w58 * \sum_{s_i \in S1} s_i / |S1| + w57 * e37_{o, ot, ag, t} + w54 * e50_{t-1}$$

where $S1 = \{q \mid \text{has_state}(ag, \text{belief}(\text{monthly_report}(m, q)) \text{ holds})\}$

Probability of feedback provision on a safety occurrence:

$$p1_{o, cl, t} = w59 * e7_t + w60 * e39_{o, cl, t} + w61 * e40_t$$

Parameters

Parameter	Explanation	Value
$T_{TASK5,min}$	Minimum duration of TASK5 “Preliminary assessment of an occurrence”	24 hr
$T_{TASK5,max,sep}$	Maximum duration of TASK5 “Preliminary assessment of an occurrence” when the occurrence is a separation infringement of type A, B or C	72 hr
$T_{TASK5,max,other}$	Maximum duration of TASK5 “Preliminary assessment of an occurrence” when the occurrence is of type Other	48 hr
$T_{TASK6,min}$	Minimum duration of TASK6 “Making decision about the investigation necessity”	60 s
$T_{TASK6,max}$	Maximum duration of TASK6 “Making decision about the investigation necessity”	1 day
$T_{TASK7,min}$	Minimum duration of TASK7 “Investigation of an occurrence”	36 hr
$T_{TASK7,max}$	Maximum duration of TASK7 “Investigation of an occurrence”	1080 hr
$e40_0$	Initial value of quality of the communication channel between controllers and safety investigators	0.5
$w53$	Contribution of e36 ‘Quality of the formal safety occurrence assessment procedure’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.1
$w54$	Contribution of e50 ‘Average commitment	0.1

	to safety of the participants of the meetings’ to e38 ‘Quality of the final safety occurrence assessment report’.	
w55	Contribution of e7 ‘Sufficiency of the number of safety investigators’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15
w56	Contribution of e15 ‘Quality of a processed notification report’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.25
w57	Contribution of e37 ‘Amount of knowledge on similar safety-related issues in the organization’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15
w58	Contribution of e55 ‘Average quality of the monthly safety overview reports’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15
w59	Contribution of e7 ‘Sufficiency of the number of safety investigators’ to p1 ‘Probability of the feedback provision’.	0.3
w60	Contribution of e39 ‘Severity of an occurrence’ to p1 ‘Probability of the feedback provision’.	0.4
w61	Contribution of e40 ‘Quality of the communication channel between controllers and safety investigators’	0.3
sufficient_ similar_ occur	Maximal amount of knowledge about occurrences of each type, which determines the effect of the controller’s information contribution to proactive identification of safety issues	3

A.8 Safety Officer

One agent of type Safety Officer is introduced: ag_safety_officer

Input Ontology

Information type	Source of information
belief(notification_report_for(occurrence(o, cl, a), q))	Manager
belief(monthly_report(m, q))	Manager
e7: Sufficiency of amount of safety investigators	Manager
e34 _G : Contribution of informal discussion of controllers in the team	Controller Team
e44: Average commitment to safety of the agents involved in safety analysis	Controller

Output Ontology

Information type	Recipient of information
monthly_report(m: MONTH, v1: VALUE)	Safety Investigator, Manager, Controllers Supervisor, Controllers
e33 _m : Quality of a monthly safety overview report	Safety Investigator, Manager, Controllers Supervisor, Controllers

Variables

Variable	State	Initial value	Explanation
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	space		
e31 _m	[0,1]	None (dependent)	Quality of input data for month m
e33 _m	[0,1]	None (dependent)	Quality of a monthly safety overview report

Internal mappings and dynamics

Organizational tasks

(17) finished_process_of_type_for(TASK8, occurrence(o, cl, a))

→→_{0, 0, 1, 1} began_process_of_type_for(TASK9, occurrence(o, cl, a))

(18) began_process_of_type_for(TASK9, occurrence(o, cl, a))

→→ (T_{TASK9,min}, T_{TASK9,max}, 1, 1) finished_process_of_type_for(TASK9, occurrence(o, cl, a))

(19) finished_process_of_type_for(TASK9, occurrence(o, cl, a))

→→_{0, 0, 1, 1} began_process_of_type_for(TASK10, occurrence(o, cl, a))

(20) began_process_of_type_for(TASK10, occurrence(o, cl, a))

→→ (T_{TASK10,min}, T_{TASK10,max}, 1, 1) finished_process_of_type_for(TASK10, occurrence(o, cl, a))

(23) fact: present_time(0) holds for [0, 1]

(24) present_time(t) →→_{0, 0, 1, 1} present_time(t+1)

(25) present_time(t) & mod(t, T_{TASK12,ini}) = 0 →→_{0, 0, 1, 1}

began_process_of_type_for(TASK12, month(t/ T_{TASK12,ini} + 1))

(26) began_process_of_type_for(TASK12, month(m))

→ (T_{TASK12,min}, T_{TASK12,max}, 1, 1) finished_process_of_type_for(TASK12, month(m))

(29) finished_process_of_type_for(TASK13, month(m))

→ 0, 0, 1, 1 began_process_of_type_for(TASK14, month(m))

(30) began_process_of_type_for(TASK14, month(m))

→ (T_{TASK14,min}, T_{TASK14,max}, 1, 1) finished_process_of_type_for(TASK14, month(m))

(36) finished_process_of_type_for(TASK14, month(m))

→ 0, 0, 1, 1 resource_produced_by(TASK14, monthly_report(m, e33_m))

resource_produced_by(TASK14, monthly_report(m, v))

→ 0, 0, 1, 1

∀a:AGENT has_state(ag_safety_officer,
communicated_from_to(ag_safety_officer, a, inform, monthly_report(m, v))

Beliefs

Quality of input data (for monthly safety overview report):

IF rule (35) fires:

$$e31_{m,t} = w47 * \sum_{s_i \in S1} s_i / |S1| + w48 * \sum_{s_i \in S2} s_i / |S2| + w46 * \sum_{gr \in \text{AGENT_CONTROLLER_TEAM}} e34_{G,t} / |\text{AGENT_CONTROLLER_TEAM}|$$

where S1 = {q | has_state(ag_safety_manager,
belief(notification_report_for(occurrence(o, cl, a), q)) holds },

S2 = {q | has_state(ag_safety_manager, belief(monthly_report(m, q)) holds }

Decision making

Quality of a monthly safety overview report:

IF rule (35) fires:

$$e33_{m,t} = w42 * e7_t + w43 * (w44 * e44_{t-1} + w45 * e31_{m,t-1})$$

Parameters

Parameter	Explanation	Value
$T_{TASK9,min}$	Minimum duration of TASK9 “Update an interim safety occurrence assessment report”	24 hr
$T_{TASK9,max}$	Maximum duration of TASK9 “Update an interim safety occurrence assessment report”	120 hr
$T_{TASK10,min}$	Minimum duration of TASK10 “Distribute the final safety occurrence assessment report among all concerned roles”	1 hr
$T_{TASK10,max}$	Maximum duration of TASK10 “Distribute the final safety occurrence assessment report among all concerned roles”	360 hr
$T_{TASK12,min}$	Minimum duration of TASK12 “Safety data collection and pre-processing”	360 hr
$T_{TASK12,max}$	Maximum duration of TASK12 “Safety data collection and pre-processing”	720 hr
$T_{TASK14,min}$	Minimum duration of TASK14 “Preparation and distribution of a monthly safety overview report”	24 hr
$T_{TASK14,max}$	Maximum duration of TASK14 “Preparation and distribution of a monthly safety overview report”	120 hr
w_{42}	Contribution of e7 ‘Sufficiency of the number of safety investigators’ to e33 ‘Quality of a monthly safety overview report’.	0.4
w_{43}	Contribution of e32 ‘Quality of safety analysis’ to e33 ‘Quality of a monthly safety overview report’.	0.6
w_{44}	Contribution of e44 ‘Average commitment to safety of the agents involved in safety analysis’ to e32 ‘Quality of safety analysis’.	0.4
w_{45}	Contribution of e31 ‘Quality of input data’ to e32 ‘Quality	0.6

	of safety analysis’.	
w46	Contribution of e45 ‘Average contribution of informal discussions of controllers in teams’ to e31 ‘Quality of input data’.	0.3
w47	Contribution of e46 ‘Average quality of processed notification reports’ to e31 ‘Quality of input data’.	0.5
w48	Contribution of e47 ‘Average quality of previous monthly safety overview reports’ to e31 ‘Quality of input data’.	0.2

A.9 Environment & Technical infrastructure

The entity Environment & Technical Infrastructure represents the technical systems that support the agents and the safety-related occurrences that exist in the environment.

Input ontology

Information type	Source of information
None	-

Output Ontology

Information type	Destination of information
observed(env_occurrence(o:OCCURRENCE, cl:OCCURRENCE_TYPE, sec:SECTOR))	Controller Controller Team Manager
e17: Quality of technical systems	Controller
e39 _{o,cl} : Severity of an occurrence	Controller Controller Team Manager

Variables

Variable	State space	Initial value	Explanation
e9	[0,1]	e9 ₀	Availability of reliable and ergonomic technical systems for controllers
e25	[0,1]	e25 ₀	Sufficiency of the amount of maintenance personnel

e26	[0,1]	e26 ₀	Quality of formal procedures for system checks and repairs
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Internal mappings and dynamics

Quality of technical systems:

$$e17_t = w30 * e25_t + w31 * e26_t + w32 * e9_t$$

Numbers of occurrences of different types per year are used in the model (see Table below). The occurrences are generated over time following the Poisson probability distribution using the inverse transform algorithm (see [Ross]).

Parameters

Parameter	Explanation	Value
e9 ₀	Initial value of availability of reliable and ergonomic technical systems for controllers	0.75
e25 ₀	Initial value of sufficiency of the amount of maintenance personnel	0.9
e26 ₀	Initial value of quality of formal procedures for system checks and repairs	0.8
n _A	Frequency of occurrences of type A (Incident with serious inability to provide or maintain safe service, involving a large separation infringement and a high risk of collision)	0 / year
n _B	Frequency of occurrences of type B (Incident with partial inability to provide or maintain safe service, involving a medium separation infringement and a medium risk of collision)	2 / year
n _C	Frequency of occurrences of type C (Incident with ability to provide or maintain safe service, involving a small separation infringement and a low risk of collision)	16 / year

n _{Other}	Frequency of occurrences of type Other (Occurrence without a separation infringement, e.g. pilot report of a TCAS Advisory or Prolonged Loss of Communication)	168 / year
w ₃₀	Contribution of e25 'Sufficiency of the number of maintenance personnel' to e17 'Quality of technical systems'.	0.4
w ₃₁	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	0.2
w ₃₂	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e17 'Quality of technical systems'.	0.4

A.10 Safety Recommendations and Concerns Group (SRCG)

Input ontology

Information type	Source of information
e6: Commitment of safety of a controller	Controller

Output Ontology

Information type	Destination of information
e11: Regularity of safety meetings	Controller
e50: Average commitment to safety of the participants of the meeting	Safety Investigator

Variables

Variable	State space	Initial value	Explanation
e11	[0,1]	e11 ₀	Regularity of safety meetings
e50	[01,]	None (dependent)	Average commitment to safety of the participants of the meeting

Internal mappings and dynamics

Organizational tasks

(15) finished_process_of_type_for(TASK7, occurrence(o, cl, a))

→ 0, 0, 1, 1 began_process_of_type_for(TASK8, occurrence(o, cl, a))

(16) began_process_of_type_for(TASK8, occurrence(o, cl, a))
 $\rightarrow (T_{TASK8,min}, T_{TASK8,max}, 1, 1)$ finished_process_of_type_for(TASK8, occurrence(o, cl, a))

Beliefs

Average commitment to safety of the participants of the meeting (on safety occurrences):

IF rule (34) fires:

$$e50_t = (e44_{t-1} + \sum s_i / |S1|) / 2$$

$$s_i \in S1$$

where $S1 = \{e6_{ag, t-1} \mid ag \in AGENT_CONTROLLER\}$

Decision making

None.

Parameters

Parameter	Explanation	Value
$T_{TASK8,min}$	Minimum duration of TASK8 “Discussion of the intermediate occurrence investigation results”	12 hr
$T_{TASK8,max}$	Maximum duration of TASK8 “Discussion of the intermediate occurrence investigation results”	120 hr
$e11_0$	Initial value of regularity of safety meetings	0.8

A.11 Safety Monitoring Group

Input ontology

None.

Output Ontology

None.

Variables

None.

Internal mappings and dynamics

Organizational tasks

(27) finished_process_of_type_for(TASK12, month(m))

→ 0, 0, 1, 1 began_process_of_type_for(TASK13, month(m))

(28) began_process_of_type_for(TASK13, month(m))

→ ($T_{\text{TASK13,min}}$, $T_{\text{TASK13,max}}$, 1, 1) finished_process_of_type_for(TASK13, month(m))

Beliefs

None.

Decision making

None.

Parameters

Parameter	Explanation	Value
$T_{\text{TASK13,min}}$	Minimum duration of TASK13 “Safety data analysis”	24 hr
$T_{\text{TASK13,max}}$	Maximum duration of TASK13 “Safety data analysis”	72 hr

A.12 Model assumptions

Model structural assumptions

Table 13: List of model structural assumptions of the organizational model.

ID	Description
A1	There are four types of occurrences: separation infringements A (most severe), B and C (least severe), and other occurrences, which do not involve a separation infringement (e.g. pilot report of TCAS advisory or prolonged loss of communication).
A2	An occurrence is always and instantaneously identified by the responsible controller.
A3	An occurrence may be identified instantaneously by the team members of the responsible controller with an occurrence-type dependent probability.
A4	A non-reported occurrence may be identified by the management with an occurrence-type dependent probability.
A5	The quality of a processed notification report created by a controller is influenced by the controller's maturity level, the quality of technical systems used for the occurrence identification, the level of controller's workload, and the information contribution by other team members.
A6	The information contribution by other team members comprises the contribution by a controller who possesses the most knowledge on similar occurrences in the team and by the controller team supervisor.
A7	The information contribution by a team member depends on the team member's amount of knowledge on occurrences of the same type and on the team member's commitment to safety (as indication of the willingness to provide this information).
A8	The information contribution by a controller team supervisor depends on the supervisor's amount of knowledge on occurrences of the same type and on the supervisor's commitment to safety (as indication of the

	willingness to provide this information).
A9	The quality of technical systems depends on the sufficiency of maintenance personnel, the availability of up-to-date technical systems and the quality of formal procedures for system repairs and checks.
A10	The maturity of a controller depends on the controller's experience (the development level of skills for the ATC task, adequacy of mental models for ATC task) and the willingness and ability to take responsibility for the ATC task (self-confidence for ATC task, commitment to perform ATC task)
A11	The adequacy of the mental models for the ATC task of a controller is based on training (sufficiency and timeliness of training for changes) and on information obtained on safety issues (adequacy of knowledge about safety issues).
A12	The adequacy of knowledge about safety issues of a controller is based on the received final safety assessment reports on occurrences reported by the controller and on the received monthly safety overview reports.
A13	Monthly safety overview reports are provided to every agent at the end of each month and they are always read by the agents.
A14	The probability of the provision of a final safety occurrence assessment report for a reported occurrence depends on the type of the occurrence, on the sufficiency of the amount of safety investigators, and on the quality of the communication channel between controllers and safety investigators.
A15	The quality of a monthly safety overview report depends on the sufficiency of the amount of safety investigators, on the average commitment to safety of the agents involved in safety analysis and on the quality of input data for analysis.
A16	The input data for safety analysis to generate a monthly safety overview report comprise all notification reports processed previously, previous monthly safety overview reports and informal information contribution of discussions among controllers in their teams.
A17	The contribution of informal discussions among controllers in a team

	depends on the safety-related knowledge possessed by the team (average quality of the notification reports produced by the team and average quality of the received monthly safety overview reports), the intensity of informal interactions in the team and the perceived commitment to safety of the team (as a measure of the willingness to provide this information).
A18	The intensity of informal interaction in a team of controllers is proportional to the number of shifts worked together (as a measure of the degree of acquaintance of the controllers).
A19	The quality of a final safety occurrence assessment report depends on the quality of input for occurrence investigation (the corresponding processed notification report, received monthly safety overview reports, and knowledge on safety-related issues of the same type collected in the organization), the sufficiency of the amount of safety investigators, and the average commitment to safety of the participants of the safety investigation meetings.
A20	The safety manager possesses information about all reported and investigated safety occurrences.
A21	A controller team supervisor is a representative of the management. The supervisor promotes safety policies and attitudes towards safety of the management and sees to that these policies are followed/realized.
A22	The commitment to safety of a controller team supervisor is influenced by the management's commitment to safety and by the level of development of the managerial skills of the supervisor.
A23	Controllers within a team can perceive each others' commitment state without any distortion.
A24	Controllers within a team can perceive each others' attitude towards reporting without any distortion.
A25	The commitment to safety of a controller depends on the management's commitment to safety, the priority of safety-related goals in the controller's role description (i.e., a formal constituent), the perception of the commitment to safety of the team of controllers, the perceived

	influence degree of the controller on safety arrangements, and the maturity level of the controller (as an indication of the ability and willingness of the controller to accept safety-related goals and act accordingly).
A26	The commitment of the management as perceived by controllers depends on the investments of the management in personnel (controllers, safety investigators), in training, and in technical systems, by the formal commitment to safety (the priority of safety-related goals, organization of safety-related activities, the degree of development of implementation of SMS), and by the actual degree of influence of controllers on safety arrangements.
A27	The perception of a controller of the commitment to safety of the controller's team is influenced by the perception of the commitment to safety of the controller team supervisor and by the average commitment to safety of the team members.
A28	Beliefs of agents persist forever.
A29	The priority of satisfied needs decreases.
A30	Organizational reprimand and reward policies are known to and are interpreted correctly by each controller.
A31	The controller's perception of the management's appreciation of a reporting action of a controller is proportional to the commitment of the management to safety and to the perception of the commitment of the supervisor to safety.
A32	The controller's perception of a decrease in the controller's professional status in the controller's team is proportional to the total severity of the controller's occurrences that happened during the team evaluation period, the intensity of the informal interactions in the team and the level of the belief that the confidentiality of reporting is not supported.
A33	The controller's perception of a decrease in the controller's professional status with the management is proportional to the total severity of the controller's occurrences that happened during the management evaluation

	period.
A34	The perceived degree of contribution of a reported occurrence to improvement of safety is dependent on the severity of the occurrence, the commitment to safety of the management, the average quality of the final safety occurrence assessment reports for similar occurrences provided to the controller, and the average quality of the received monthly safety overview reports.
A35	The self-confidence of a controller may decrease as result of occurrences and it cannot increase.

Parameter values

Table 14: List of weights in the organizational model and their values for ANSP-3: nominal values and ranges as used in the sensitivity analysis.

Parameter	Description	Nominal value	Range
<i>w1</i>	Contribution of e1 'Priority of safety-related goals in the role description' to e6 'Commitment to safety of a controller'	0.1	[0.05, 0.2]
<i>w2</i>	Contribution of e2 'Perception of the commitment to safety of management' to e6 'Commitment to safety of a controller'	0.2	[0.1, 0.3]
<i>w3</i>	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	0.1	[0.05, 0.2]
<i>w4</i>	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3	[0.2, 0.4]
<i>w5</i>	Contribution of e5 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3	[0.2, 0.4]
<i>w6</i>	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.1	[0.05, 0.3]
<i>w7</i>	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.1	[0.05, 0.2]
<i>w8</i>	Contribution of e1 'Priority of safety-related goals in the role description' to e2 'Perception of the commitment to safety of management'	0.15	[0.05, 0.3]
<i>w9</i>	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e2 'Perception of the commitment to safety of management'	0.2	[0.1, 0.4]
<i>w10</i>	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	0.05	[0.01, 0.3]
<i>w11</i>	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	0.2	[0.1, 0.4]
<i>w12</i>	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	0.05	0.05
<i>w13</i>	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	0.15	[0.05, 0.5]
<i>w14</i>	Contribution of e14 'Level of development of managerial skills' to e13 'Perception of commitment to safety of the	0.4	[0.3, 0.6]

	supervisor'		
w15	Contribution of e2 'Perception of commitment to safety of management' to e13 'Perception of commitment to safety of the supervisor'	0.6	[0.3, 0.9]
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.4	[0.3, 0.6]
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.6	[0.4, 0.9]
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	0.1	[0.05, 0.2]
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	0.3	[0.2, 0.4]
w20	Contribution of e7 'Quality of technical systems' to e15 'Quality of a processed notification report'.	0.3	[0.2, 0.6]
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a processed notification report'.	0.3	[0.2, 0.6]
w22	Contribution of e19 'Self-confidence for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	[0.25, 0.25]
w23	Contribution of e20 'Commitment to perform ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	[0.25, 0.25]
w24	Contribution of e21 'Development level of skills for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w25	Contribution of e23 'Adequacy of mental models for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	0.5	[0.4, 0.6]
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	0.5	[0.3, 0.7]
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	0.4	[0.2, 0.6]
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	0.6	[0.4, 0.8]
w30	Contribution of e25 'Sufficiency of the number of maintenance personnel' to e17 'Quality of technical systems'.	0.4	[0.2, 0.6]
w31	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	0.2	0.2
w32	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e17 'Quality of technical systems'.	0.4	[0.2, 0.8]
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'.	0.6	[0.4, 0.8]
w34	Contribution of e6 'Commitment to safety of a controller' to e29 'Information contribution by a controller'.	0.3	[0.2, 0.4]
w35	Contribution of e27 'Amount of knowledge on similar safety-related issues of a controller' to e29 'Information contribution by a controller'.	0.7	[0.6, 0.9]
w36	Contribution of e30 'Information contribution by the supervisor' to e16 'Information contribution by others'.	0.4	[0.3, 0.6]
w37	Contribution of e28 'Amount of knowledge on similar safety-related issues of the supervisor' to e30 'Information contribution by the supervisor'.	0.7	[0.4, 0.9]
w38	Contribution of e13 'Perceived commitment to safety of the supervisor' to e30 'Information contribution by the supervisor'.	0.3	[0.2, 0.4]
w39	Contribution of e8 'Sufficiency of the number of controllers' to e18 'Acceptability of the workload level'.	0.8	[0.7, 0.9]
w40	Contribution of e14 'Level of development of managerial skills' to e18 'Acceptability of the workload level'.	0.2	[0.1, 0.3]
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview	0.4	[0.3, 0.5]

	report’.		
w43	Contribution of e32 ‘Quality of safety analysis’ to e33 ‘Quality of a monthly safety overview report’.	0.6	[0.4, 0.8]
w44	Contribution of e44 ‘Average commitment to safety of the agents involved in safety analysis’ to e32 ‘Quality of safety analysis’.	0.4	[0.2, 0.5]
w45	Contribution of e31 ‘Quality of input data’ to e32 ‘Quality of safety analysis’.	0.6	[0.5, 0.9]
w46	Contribution of e45 ‘Average contribution of informal discussions of controllers in teams’ to e31 ‘Quality of input data’.	0.3	[0.1, 0.5]
w47	Contribution of e46 ‘Average quality of processed notification reports’ to e31 ‘Quality of input data’.	0.5	[0.3, 0.8]
w48	Contribution of e47 ‘Average quality of previous monthly safety overview reports’ to e31 ‘Quality of input data’.	0.2	[0.1, 0.3]
w49	Contribution of e3 ‘Perceived commitment to safety of the team’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.2	[0.1, 0.4]
w50	Contribution of e35 ‘Intensity of informal interactions in the team of controllers’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.35	[0.2, 0.5]
w51	Contribution of e48 ‘Average quality of the notification reports produced by the team’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.3	[0.2, 0.5]
w52	Contribution of e49 ‘Average quality of the received monthly safety overview reports’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.25	[0.1, 0.4]
w53	Contribution of e36 ‘Quality of the formal safety occurrence assessment procedure’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.1	[0.1, 0.1]
w54	Contribution of e50 ‘Average commitment to safety of the participants of the meetings’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.1	[0.05, 0.3]
w55	Contribution of e7 ‘Sufficiency of the number of safety investigators’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15	[0.15, 0.15]
w56	Contribution of e15 ‘Quality of a processed notification report’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.25	[0.1, 0.5]
w57	Contribution of e37 ‘Amount of knowledge on similar safety-related issues in the organization’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15	[0.05, 0.25]
w58	Contribution of e55 ‘Average quality of the monthly safety overview reports’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.15	[0.05, 0.25]
w59	Contribution of e7 ‘Sufficiency of the number of safety investigators’ to p1 ‘Probability of the feedback provision’.	0.3	[0.2, 0.5]
w60	Contribution of e39 ‘Severity of an occurrence’ to p1 ‘Probability of the feedback provision’.	0.4	[0.2, 0.7]
w61	Contribution of e40 ‘Quality of the communication channel between controllers and safety investigators’ to p1 ‘Probability of the feedback provision’.	0.3	[0.3, 0.3]

Table 15: Values of input evidence variables of the organizational model, using safety culture survey questionnaire data of ANSP-3: nominal value and lower and upper bounds of a credibility interval used in sensitivity analysis.

Variable	Description	Value		
		Nominal	Low	High
e1	Priority of safety-related goals in the role description	0.60	0.50	0.70
e4	Influence of a controller on safety activities	0.50	0.40	0.60

e7	Sufficiency of the amount of safety investigators	0.50	0.40	0.60
e8	Sufficiency of the amount of controllers	0.60	0.40	0.80
e9	Availability of reliable and ergonomic technical systems for controllers	0.75	0.65	0.85
e10	Sufficiency and timeliness of training for changes	0.60	0.45	0.75
e11	regularity of safety meetings	0.75	0.60	0.90
e12	Developed and implemented SMS	0.60	0.40	0.80
e14	Level of development of managerial skills	0.60	0.40	0.80
e19	Self-confidence for ATC task	0.85	0.75	0.95
e20	Commitment to perform ATC task	0.80	0.70	0.90
e21	Development level of skills for ATC task	0.80	0.70	0.90
e25	Sufficiency of the number of maintenance personal	0.75	0.60	0.90
e26	Quality of formal procedures for system checks and repairs	0.75	0.60	0.90
e35	Intensity of informal interactions in the team of controllers	0.65	0.50	0.80
e36	Quality of the formal safety occurrence assessment procedure	0.85	0.75	0.95
e40	Quality of the communication channel between controllers and safety investigators	0.50	0.30	0.70
e44	Average commitment of the agents involved in the safety analysis	0.65	0.50	0.80
e71	Formal support for confidentiality of reporting	0.65	0.55	0.75