Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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EUROCONTROL CARE Innovative Research III

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A. Sharpanskykh[1], S.H. Stroeve and R. van Lambalgen[1]

[1] Vrije Universiteit Amsterdam

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Summary

Safety culture is broadly recognized as important for ATM and various studies have addressed its characterization and assessment. However, relations between safety culture and formal and informal organizational structures and processes are yet not well understood. This impedes structured improvement of safety culture. In this Eurocontrol CARE Innovative III project we aim to improve the understanding of these relations by agent-based organizational modelling. This report presents the development and initial results of an agent-based organizational model for safety occurrence reporting at an ANSP in relation to the ANSP's safety culture. The model development is supported by data of Eurocontrol's Safety Culture Measurement Tool.

Contents

1 Introduction

In complex and distributed organizations like the air traffic industry, safe operations are the result of interactions between many entities of various types at multiple locations. The importance of proper organizational processes for the safety of complex operations is currently well realised. It is generally acknowledged that the level of safety achieved in an organization depends on the constraints and resources set by people working at the blunt end (e.g. managers, regulators), which determine the working conditions of practitioners who are directly controlling hazardous processes at the sharp end (e.g. pilots, controllers, maintenance operators).

As a way forward for description of organizational structures and processes and inclusion thereof in air traffic safety assessment methods, NLR and Vrije Universiteit Amsterdam collaborate in a Eurocontrol CARE Innovative Research III project. It is the objective of this research project to enhance safety analysis of organizational processes in air traffic by development of formal approaches for modelling, simulation and analysis of organizational relationships and processes. These models should describe the organization at different aggregation levels and should lead to emergent safety issues as result of performance variability and interactions of organizational entities.

The first phase of this research project in 2007 consisted of (1) a literature survey on safety modelling and analysis of organizational processes, and (2) a first application of identified methods to a safety-relevant organizational process in air traffic. The literature survey is reported in (Stroeve et al., 2007a) and it follows that the organizational modelling framework proposed by Popova and Sharpanskykh (2007e) presents the widest repertoire of multi-agent organizational modelling features of the methods considered. This framework has been chosen to study the possibilities of organizational modelling in an air traffic case on safety occurrence reporting (Stroeve et al., 2007b, 2007c).

The continuation of the agent-based organizational modelling research in 2008/2009 focuses on strengthening the relations between air traffic organization, safety culture and the development of incidents in air traffic operations. To support development and validation of the model, ANSP safety culture survey data is used that has been and will be gathered in safety culture research at EUROCONTROL Experimental Centre (EEC). The agent-based organizational model is aimed to describe the emergence of safety culture vulnerabilities in ANSPs' organizational contexts, as well as the development of incidents as a result of ANSPs' safety culture vulnerabilities. Such a model may be used as a tool to select and prioritize policies to improve safety culture, and strengthen the general awareness of the link between safety culture and the development of incidents.

The development of the model is focused on the reporting of safety occurrences and its role within the Safety Management System as a facilitator for optimization of organizational processes (i.e. organizational learning). Occurrence reporting is an important aspect of safety management in an ANSP and it has a range of connections with safety culture. As a basis for the development of an agent-based model for safety occurrence reporting, methods and requirements have been identified in (Sharpanskykh and Stroeve, 2008). Figure 1 shows the categorization of factors that influence occurrence reporting, such as identified in (Sharpanskykh and Stroeve, 2008). It discerns four aggregation levels for the organization of safety occurrence reporting at an ANSP:

1. The level of an individual in the organisation (e.g. a controller, a supervisor, a manager);
2. The level of a team (in particular, a team of air traffic controllers is considered for this study);
3. The level of an organisation (i.e. intra-organisational structures, as departments in an ANSP);
4. The level of inter-organisational interaction (i.e. influences from other organisations on an ANSP).

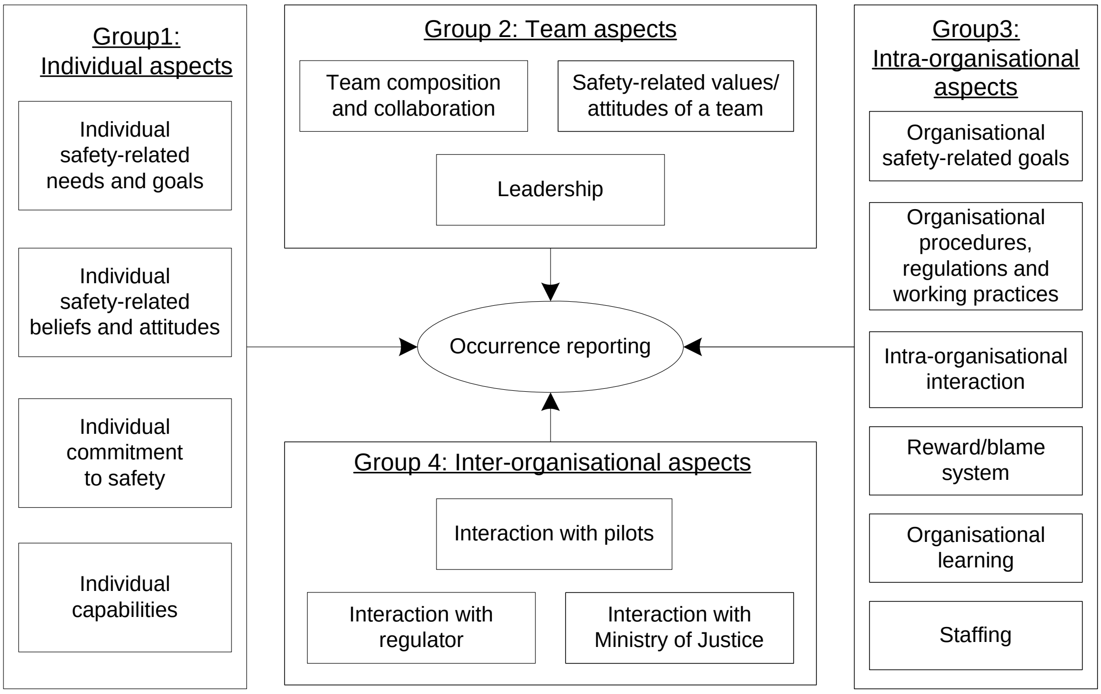

Figure 1: The groups of aspects that influence safety occurrence reporting (Sharpanskykh and Stroeve, 2008).

The aim of the work described in the current report is the development of an agent-based organizational model that relates safety culture aspects and the organization of safety occurrence reporting, as well as the achievement of first simulation results for the model. The model development is based on the methods and requirements of (Sharpanskykh and Stroeve, 2008) and on earlier models of (Stroeve et al., 2007b,c).

The report is structured as follows. Section 2 describes the development of the agent-based organizational model for occurrence reporting. Section 3 provides initial simulation results of the developed model. Section 4 provides concluding remarks.

2 Agent-based organizational model of occurrence reporting

2.1 Model development steps

The model development is performed along the formal framework for organization modelling and analysis of (Popova and Sharpanskykh 2007e). This framework uses four interrelated views on organizations:

- The *organization-oriented view* describes organizational roles, their authority, responsibility and power relations;
- The *performance-oriented view* describes organizational goal structures, performance indicators structures, and relations between them;
- The *process-oriented view* describes organizational functions and processes, how they are related, ordered and synchronized and the resources they use and produce;
- The *agent-oriented view* describes agents' types with their capabilities, models of agent behaviour based on social theories, and principles of allocating agents to roles.

The first three views are used to describe the formal organization, i.e. the organization as it is prescribed in formal organizational documents (e.g. organizational charts, job descriptions, procedures, regulations). The last view is used to specify informal structures and processes of organizational agents.

In line with previous model development (Stroeve et al., 2007b,c), the modelling steps presented in Table 1 are followed for the model development in this report. The modelling methodology presented in (Stroeve et al., 2007b,c) focused primary on the process of development of a model for the formal organization. The modelling approach presented in this report extends the methodology from (Stroeve et al., 2007b,c) in particular in respect of modelling of divergent behaviour of agents and their informal (social) structures. To this end, the set of modelling steps from (Stroeve et al., 2007b,c) (steps 1-8 and 17 in Table 1) is expended with steps dedicated for modelling of divergent behaviour of agents (steps 9-16).

Table 1: Overview of steps in organizational modelling and their relation with the views considered.

Step	Name	View			
		Organization	Performance	Process	Agent
1	Identification of organizational roles	x			
2	Identification of interactions between roles and with the environment	x			
3	Identification of requirements for roles	x			x
4	Identification of organizational performance indicators and goals		x		
5	Identification of resources			x	
6	Identification of organizational tasks and relations between tasks, resources and goals		x	x	
7	Identification of authority relations	x		x	
8	Identification of flows of control			x	
9	Identification of characteristics (skills, psychological and cognitive characteristics) of agents		x		x
10	Identification of goals and needs of agents				x
11	Identification of commitments, obligations and responsibilities of agents				x
12	Identification of attitudes and beliefs of agents				x
13	Identification of relations between agents (e.g., interaction, trust and informal power relations) and informal structures of agents	x			x
14	Identification of shared beliefs, attitudes, norms and values of (groups of) agents				x
15	Identification of performance variability in formal and informal flows of control			x	x
16	Allocation principles of agents to organizational roles				x
17	Identification of organizational constraints	x	x	x	x
18	Specification of the environmental dynamics				x

Via steps 1-8 and 17 in Table 1 the formal organisation is specified. In contrast, steps 9-16 aim at the identification of possible (realistic) variations and deviations of/from the prescribed organizational structure and behaviour that may be attributed to agents allocated to the organizational roles. In particular, steps 9-12 concern the level of an individual agent, steps 13 and 14 concern the level of a group of agents, steps 15 and 16 consider influences of agents on organizational structures and processes. Steps 9-12 identify behavioural aspects of an agent and its characteristics, which are often distinguished in the literature on agent organizations (cf. Weiss (1999); Dignum (2008)). At the level of agent groups the aspects has been identified, which are often recognized as important to describe the group structure and dynamics (cf. social network analysis (Scott, 2000); multi-agent systems (Weiss, 1999); social science (Scott, 1981)).

Previously, in the report D3 a number of aspects have been identified that were evaluated as relevant for modelling of safety culture issues in relation to safety occurrence reporting. These aspects have been elaborated at corresponding organization modelling steps (see Table 2). Note that some of the modelling aspects are elaborated at more than one step. For example, team composition is considered at step 2 by specifying interaction relations between team members, while the allocation of agents to the team's roles is considered at step 16.

Table 2: Steps in organizational modelling and their relation with the modelling aspects identified in the report D3.

Step	Name	Modelling aspects
1	Identification of organizational roles	Roles involved (directly or indirectly) in the reporting process
2	Identification of interactions between roles and with the environment	Team composition Intra-organisational interaction. Safety-related information provided from/to a regulator Interaction between pilots and controllers
3	Identification of requirements for roles	Imposed safety-related goals and responsibilities of an individual.
4	Identification of organizational performance indicators and goals	Priority of safety-related goals in the organisation.
5	Identification of resources	Resources involved (directly or indirectly) in the reporting process
6	Identification of organizational tasks and relations between tasks, resources and goals	Highly quality safety-related training.
7	Identification of authority relations	Influence of an individual on organisational processes.

Step	Name	Modelling aspects
8	Identification of flows of control	Workload.
9	Identification of characteristics (skills, psychological and cognitive characteristics) of agents	Adequate situation awareness Professional capabilities and limitations Cognitive and psychological characteristics
10	Identification of goals and needs of agents	Individual needs and goals
11	Identification of commitments, obligations and responsibilities of agents	Individual commitment to safety Commitment to safety of the management
12	Identification of attitudes and beliefs of agents	Trust in the confidentiality of reporting Trust in the effectiveness of reporting Adequate situation awareness Perception of the commitment to safety of the management Perception of the importance level of an occurrence
13	Identification of relations between agents (e.g., interaction, trust and informal power relations) and informal structures of agents	Influence of an informal/formal leader in a team Influence of an individual on organisational processes. Trust to a peer
14	Identification of shared beliefs, attitudes, norms and values of (groups of) agents	Team values and norms
15	Identification of performance variability in formal and informal flows of control	Consequences of actions undertaken by Ministry of Justice for occurrence reporting
16	Allocation principles of agents to organizational roles	Team composition
17	Identification of organizational constraints	Reward/blame system.
18	Specification of the environmental dynamics	Perception of the severity of an occurrence

In the next section an overview of the developed model is provided with a special attention for the modelling aspects from Table 2.

2.2 Model of the formal organization

The developed model extends the model of an air traffic organization from (Stroeve et al., 2007b,c) by incorporating the safety culture aspects related to safety occurrence reporting identified in the report D3. In the following an overview of the modelling steps is provided.

2.2.1 Step 1: Identification of organizational roles

In the considered organization roles can be represented at three aggregation levels. For example, at the aggregation level 1 the Air Navigation Service Provider is considered as one composite role. The subroles of the Air Navigation Service Provider (e.g., the Control Unit) are described at the aggregation level 2, and so forth. . A special role type is the environment (env). In Table 3 all the generic roles of the considered organization with their subroles are listed. Note that based on the introduced generic roles role instances may be defined for particular applications (e.g., in simulations). Since the role Air Navigation Service Provider plays an important role for modelling of the aspects identified in Table 2, it is refined up to the aggregation level 3. More specifically, within the role Air Navigation Service Provider two subroles - the Safety Investigation Unit (has similarities with the Safety Department of ANSP-3) and Air Traffic Control Unit - are the most relevant roles for this study, thus these roles have been further refined into more specific subroles. The role Safety Recommendations and Concerns Group (has similarities with the Recommendations from Incidents and Safety Concerns (RISC) Group of ANSP-3) is also involved in the safety occurrence assessment and has impact on the organizational learning based on reporting in general. The processes within this role have been modelled at a rather general level by defining quality indicators (described at step 16) associated with some of the processes performed by this role. The same holds for the role Safety Monitoring Group, responsible for the identification of safety trends, hazards and problems, based on collected data (e.g., occurrence reports, values of safety performance indicators).

Furthermore, the internal structure and processes of such roles as Crew, Regulator and Ministry of Justice are out of scope for this study, thus these roles have been considered at the aggregation level 1 only.

Table 3: Identified organizational roles at three aggregation levels.

Level 1	Level 2	Level 3
Air Navigation Service Provider	Operation Management Team	-
	Maintenance Team	-
	Occurrence Manager	-
	Safety Officer	-
	Safety Recommendations and Concerns Group	-
	Safety Monitoring Group	-
	Safety Investigation Unit	Safety Investigator
		Safety Manager
	Air Traffic Control Unit	Controller
		Controllers Supervisor
		Env
Crew	-	-
Regulator	-	-
Ministry of Justice	-	-
Env	-	-

2.2.2 Step 2: Identification of interactions between roles and with the environment

Interaction relations between roles can be depicted at different aggregation levels. In particular, the interaction relations between the roles at the aggregation level 1 of the air traffic organization are depicted in Figure 2. An interaction link denotes a possibility to interact (e.g., by communication). The interaction links have been identified by considering formal regulations of the organization.

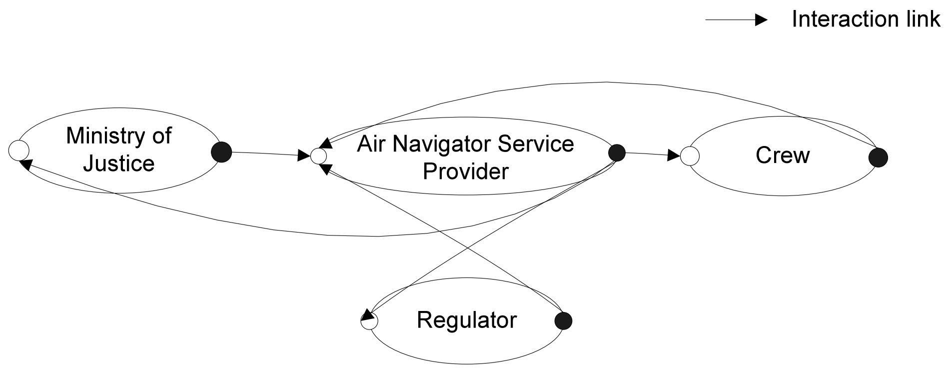

Figure 2: The interaction relations between the generic roles at the aggregation level 1.

The subroles of the role ANSP are depicted at the aggregation level 2 in Figure 3 below. Among these roles is Occurrence Manager, who is responsible for assignment of safety occurrence reports to the corresponding roles. Another subrole of ANSP - Safety Officer – supports the process of safety monitoring and analysis of collected data.

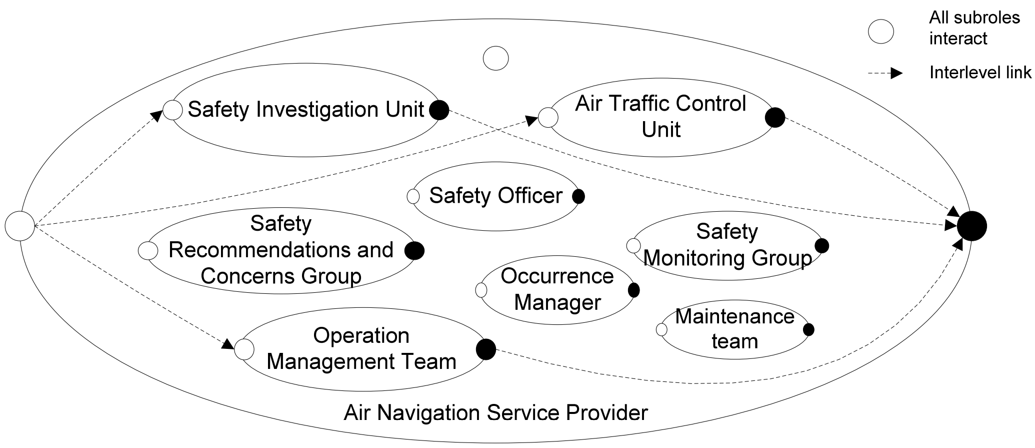

Figure 3: The interaction relations between the subroles of the role Air Nativation Service Provider at the aggregation level 2

The subroles of the roles of the ANSP at the level 2 are depicted at the level 3 below in Figure 4.

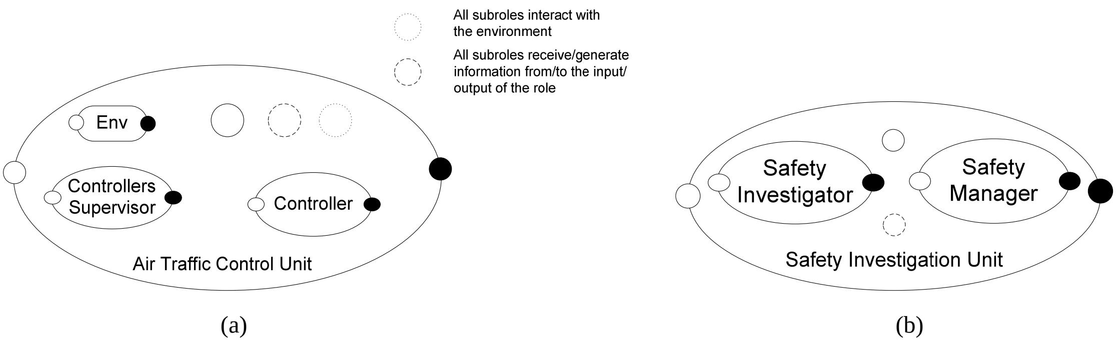

Figure 4: The interaction relations between the subroles of the role Air Traffic Control Unit (a) and of the role Safety Investigation Unit (b) at the aggregation level 3

Ontologies

For each role three types of ontologies are specified: an input ontology, an output ontology and an internal ontology. Input and output ontologies are often referred to as interface ontologies, which are used to describe interactions with other roles. An internal ontology is used to specify internal states of agents allocated to roles.

For specifying communications the interface ontologies for all roles include the following predicate:

communication_from_to: ROLE x ROLE x MSG_TYPE x CONTENT

Here the first argument denoted the role-source of information, the second – the role-recipient of information, the third argument denoted the types of the communication (which may be one of the following {observe, inform, request, decision, readback}) and the fourth – the content of the communication. The sort ROLE is a composite sort that comprises all subsorts of the roles of particular types (e.g., CONTROLLER). The sort CONTENT is also the composite sort that comprises all names of terms that are used as the communication content. Such terms are constructed from sorted constants, variables and functions in the standard predicate logic way.

To specify beliefs of agents allocated to roles the following predicate is used:

belief: BEL_TYPE x ROLE x CONTENT

Here the first argument specifies the belief type from the set {observed, requested, requested_by, informed, informed_by, decision_provided, decision_provided_by}, the second argument specifies the role that initiated the belief creation, and the third argument specifies the content of the belief.

Ontologies of all other roles are constructed in a similar way.

2.2.3 Step 3: Identification of the requirements for the roles

At this step an example of the requirements for the air traffic controller role (of any type) all of which are capabilities (i.e., knowledge or skills) is given:

(1). Passed a rigid medical examination.

(2) 2 or 4 year college degree before initiation of ATC training.

(3) Thorough knowledge of the air traffic management system and the flight regulations.

(4) Computer training.

(5) Air traffic control training.

(6) Excellent listening and communication skills.

(7) Quick decision-making skills.

(8) Ability to stand stress.

(9) Good short-term memory capabilities.

For an incident investigator assigned responsible for investigation of an occurrence the following requirements have been identified extracted from the safety occurrence assessment procedure of ANSP-3:

(1) a minimum of ten years operational experience as a controller;

(2) completed an ATM Occurrences Investigation course;

(3) demonstrable knowledge of the following:

- ICAO Annex 13;
- all national regulations applicable to safety occurrences;

- all EUROCONTROL regulations applicable to safety occurrences;
- all ANSP-3 Operations Division procedures that specify the activities in the Operations Room.

(4) willing to testify as to his actions and reports in relation to safety occurrence assessment to any legal authority or other external body, if so required.

The following requirements have been identified for the Recommendations and Concerns Group (based on the requirements for the RISC group of ANSP-3):

(1) shall include from each sector group at least one controller with a minimum of five years operational experience;
(2) the members should have completed a course of instruction in analysis the causes of safety occurrences using a dedicated methodology.

Note that the measure of the level of development may be associated with (some) capabilities. For example, controllers may differ in the amount of hours that they spent for air traffic control training. This may be expressed by assigning corresponding development levels of this capability to the controllers.

2.2.4 Step 4: Identification of organizational performance indicators and goals

In this step, organizational goals, performance indicators and relations between them and organizational roles are identified.

- *A goal* describes a desired state or development that is aimed to be achieved by a role or an agent. A goal is characterized by the following aspects: (1) name; (2) priority; (3) horizon; (4) ownership; (5) perspective; (6) hardness; and (7) negotiability. More details on goals and performance indicators are provided in (Stroeve et al., 2007).
- *Performance indicators* are quantitative or qualitative indicator that reflects the state/progress of the company, unit or individual. A performance indicator can be soft or hard. A soft performance indicator is difficult to measure directly and usually specified by a qualitative expression, e.g. customer's satisfaction, company's reputation, employees' motivation. A hard performance indicator is well measurable and usually expressed quantitatively, e.g., number of customers, number of landing aircraft, or average time to cross an active runway. The set of performance indicators that can be defined for one organization can be very large and it is often not feasible to monitor all of them. Therefore the companies select a subset of indicators, called key performance indicators, that can give a representative picture of the performance and the costs of measuring and monitoring are reasonable.

Some of the goals and performance indicators relevant for the study are listed in Table 4.

Table 4: Examples of goals and performance indicators of the air traffic organizational model.

#	Goal	Performance indicator
10	It is required to maintain a high level of safety of execution of tasks related to the air traffic management	Level of safety of execution of tasks related to the air traffic management
10.1	It is required to maintain a high level of conformance of all roles involved into the air traffic management to the formal norms and regulations defined for their tasks	Level of conformance of all roles involved into the air traffic management to the formal norms and regulations defined for their tasks.
10.2	It is required to maintain a high (sufficient) level of proficiency of pilots	Level of proficiency of pilots
10.2.1	It is required to maintain a high (sufficient) level of proficiency of pilots operating in regular conditions	Level of proficiency of pilots operating in regular conditions
10.2.2	It is required to maintain a high (sufficient) level of proficiency of pilots operating in non-stationary (hazardous) conditions	Level of proficiency of pilots operating in non-stationary (hazardous) conditions
10.3	It is required to maintain a high (sufficient) level of proficiency of controllers	Level of proficiency of controllers
10.3.1	It is required to maintain a high (sufficient) level of proficiency of controllers operating in regular conditions	Level of proficiency of controllers operating in regular conditions
10.3.2	It is required to maintain a high (sufficient) level of proficiency of controllers operating in non-stationary (hazardous) conditions	Level of proficiency of controllers operating in non-stationary (hazardous) conditions
10.4	It is required to maintain the high quality and reliability of communication lines between roles that are supposed to communicate during the execution of the tasks related to the air traffic management	Quality and reliability of communication lines between roles that are supposed to communicate during the execution of the tasks related to the air traffic management
10.5	It is required to maintain the high quality and reliability of communication lines between the roles involved into the air traffic management and the environment	Quality and reliability of communication lines between the roles involved into the air traffic management and the environment
10.6	It is required to maintain the high quality and reliability of the hardware used in the air traffic control management	Quality and reliability of the hardware used in the air traffic control management
11	It is required to maintain an up-to-date set norms and regulations that ensure the safe execution of the air traffic management tasks	Set norms and regulations that ensure the safe execution of the air traffic management tasks
11.1	It is required to maintain a sufficient proficiency level of regulators and other norm- and regulation-makers	Proficiency level of regulators and other norm- and regulation-makers
11.2	It is required to maintain the regular monitoring of flight data to identify potential hazards and to improve the safety	Regularity of the monitoring of flight data to identify potential hazards and to improve the safety
11.3	It is required to maintain the regular investigation of potential safety hazards	Investigation of potential safety hazards
11.4	It is required to maintain the regular performance of risk assessment of operations.	Performance of risk assessment of operations
11.5	It is required to maintain a timely update of norms and regulations based on investigation reports	Timeliness of update of norms and regulations based on investigation reports

#	Goal	Performance indicator
12	It is required to maintain a consistent set of norms and regulations for the execution of the air traffic control management tasks	Consistency of a set of norms and regulations for the execution of the air traffic control management tasks
13	It is required to maintain a high level of effectiveness and efficiency of the work organization within the Air Traffic Control Unit	Level of effectiveness and efficiency of the work organization within the Air Traffic Control Unit
13.1	It is required to maintain effective coordination of the task execution within the Air Traffic Control Unit	Coordination of the task execution within the Air Traffic Control Unit
13.2	It is required to maintain high flexibility of the task allocation to the controllers within the Air Traffic Control Unit	Flexibility of the task allocation to the controllers within the Air Traffic Control Unit
13.3	It is required to maintain a high level of collaboration within the Air Traffic Control Unit	Level of collaboration within the Air Traffic Control Unit
14	It is required to maintain a high level of effectiveness and efficiency of the work organization of the crew of an aircraft	Level of effectiveness and efficiency of the work organization of the crew of an aircraft
14.1	It is required to maintain a high flexibility of the task distribution between the pilots of a crew	Flexibility of the task distribution between the pilots of a crew
14.2	It is required to maintain a high level of collaboration between the pilots of the crew	Level of collaboration between the pilots of the crew
14.3	It is required to maintain a high level of collaboration during decision making in the crew	Level of collaboration during decision making in the crew
15	It is required to maintain the timely execution of the processes of the air traffic management	Timeliness of the execution of the processes of the air traffic management
16	It is required to maintain a high level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks	Level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks
16.1	It is required to maintain a high level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks in standard conditions	Level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks in standard conditions
16.2	It is required to maintain a high level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks in non-stationary (exceptional) conditions	Level of robustness and unambiguousness of the control (coordination) structure for the execution of tasks in non-stationary (exceptional) conditions
17	It is required to maintain timely reporting of incidents/hazards	Timeliness of reporting of incidents/hazards
18	It is required to maintain timeliness and a high quality of the incident investigation	Timeliness and quality of the incident investigation
18.1	It is required to maintain a high proficiency level of incident investigators	Proficiency level of incident investigators
18.2	It is required to maintain a sufficient level of details of (incident/hazard) notification reports	Level of details of (incident/hazard) notification reports
18.3	It is required to maintain the timely investigation of an incident/hazard	Timeliness of the investigation of an incident/hazard
18.4	It is required to maintain a high level of thoroughness of the incident investigation	Level of thoroughness of the incident investigation

#	Goal	Performance indicator
19	It is required to maintain a high level of recognition of actual incidents/hazards from the potential ones	Level of recognition of actual incidents/hazards from the potential ones
20	It is required to maintain a sufficient level of autonomy of decision making and the operation execution for the roles involved into the air traffic management	Level of autonomy of decision making and the operation execution for the roles involved into the air traffic management
21	It is required to maintain unambiguousness, consistency, correctness and timeliness of information exchanged between agents	Unambiguousness, consistency, correctness and timeliness of information exchanged between agents
21.1	It is required to maintain a high level of unambiguousness and consistency of information exchanged between agents	Unambiguousness and consistency of information exchanged between agents
21.2	It is required to maintain the timely provision of information to all agents that require this information	Timeliness of the provision of information to all agents that require this information
21.3	It is required to maintain the high correctness of information exchanged between agents	Correctness of information exchanged between agents
22	It is required to achieve a highly expeditious flow of air traffic at an airport	Flow of air traffic at an airport
22.1	It is required to maintain a high level of efficiency of scheduling of the aircrafts (for taxiing, departures, arrivals) at an airport	Level of efficiency of scheduling of the aircrafts (for taxiing, departures, arrivals) at an airport

2.2.5 Step 5: Specification of resources

Some of the resource types used in the case study are given in Table 5. The expiration durations for different types of reports are specified in accordance with the Safety Occurrence Assessment Procedure of ANSP-3.

Table 5: Some of the resource types used in the case study

Name	Category	Measurement unit	Expiration duration
Notification report	Discrete	Item	10 years
Preliminary Safety Occurrence Assessment Report	Discrete	Item	10 year
Interim Safety Occurrence Assessment Report	Discrete	Item	10 year
Final Occurrence Assessment Report	Discrete	Item	10 years
Safety Assessment Methodology	Discrete	Item	Not defined
Monitoring report	Discrete	Item	5 years (subjective estimation)
Monthly safety overview report	Discrete	Item	5 years (subjective estimation)
The incident classification database	Discrete	Item	Not defined
The occurrence database	Discrete	Item	Not defined

2.2.6 Step 6: Identification of organizational tasks and their relations

In Table 6 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 6: 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 (subjective estimation)
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 (subjective estimation)
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 (subjective estimation)
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 investigator should notify the Regulator role.	For severe occurrences: Max: 48 hours For less severe occurrences: Max: 72 hours (according to the Safety Occurrence Assessment Procedure)
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 (subjective estimation)

#	Task name	Short description	Durations
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 (subjective estimation, influenced by the interviews at ANSP-3)
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 (subjective estimation)
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 (subjective estimation)
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 (subjective estimation)
Goal: 21.2, 21.3, 21.1			
11	Safety Monitoring	Aims at the identification of safety hazards, problems and trends based on the collected notification reports and the occurrence investigation results.	Continuously 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 (subjective estimation)
13	Safety data analysis	Identification of hazards, safety problems and trends based on the collected data.	Min: 1 day Max: 3 days (subjective estimation)
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 (subjective estimation)
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 5 the decompositions of the identified composite tasks are depicted.

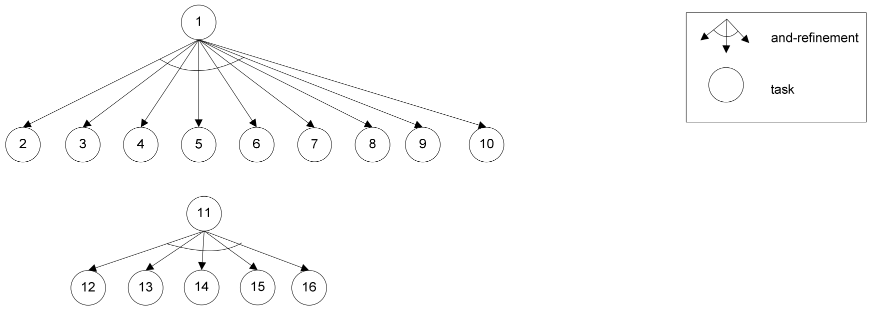

Figure 5: The refinement of composite tasks into subtasks

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 7: 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)	-

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

2.2.7 Step 7: Specification of authority relations

The *responsibility relations* of the roles on different aspects of the identified tasks are given in Table 8. 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 8: The responsibility relations of the roles on different aspects of the identified tasks

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

In Table 9 the superior-subordinate relations on the identified roles with respect to the tasks are specified.

Table 9: 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

2.2.8 Step 8: Specification of the 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 Figure 6. 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.

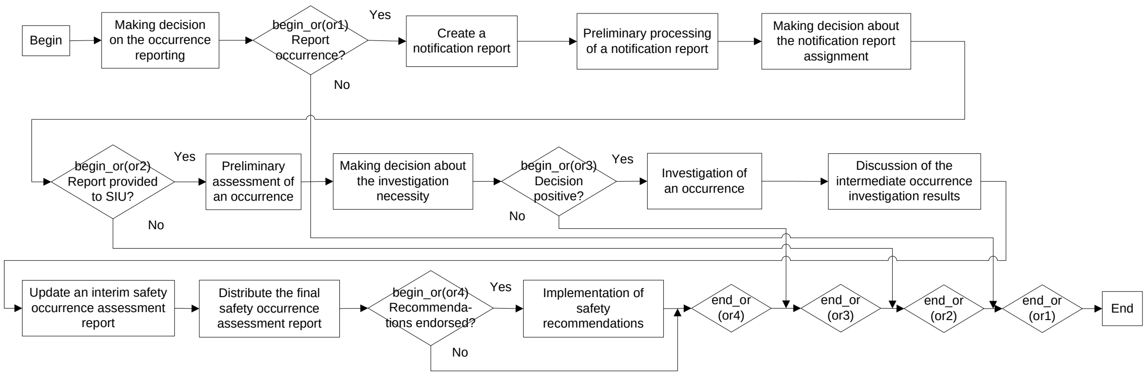

Figure 6: The workflow that defines the execution of the safety occurrence reporting and the report handling task initiated by a controller

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 Figure 6. The estimation of the quality of these data is considered at step 15.

A workflow for the safety monitoring task is depicted in Figure 7. 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.

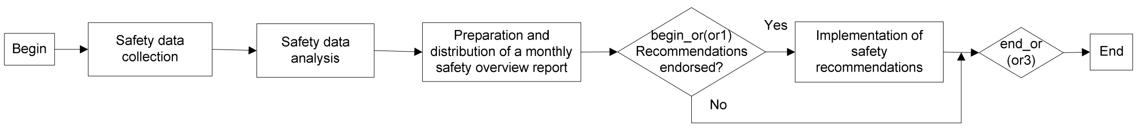

Figure 7: The workflow that defines the execution of the safety monitoring task

2.3 Agent-based organizational model

2.3.1 Modelling techniques

The behaviour of an agent can be considered from both external and internal perspectives. From the external perspective, behaviour of the agent can be described by correlations of a certain complexity between its input and output states over time, expressed in some (temporal) language, without any reference to internal or mental states of the agent. An agent perceives information by (passive or active) observations and generates output in the form of communication (at the mental level) or in the form of actions (at the physical level). Such descriptions can be successfully used for modelling relatively simple types of behaviour (e.g., stimulus-response behaviour (Skinner, 1935)). For less simple types of behaviour (e.g., adaptive or learning behaviour) an external behavioural specification often consists of more complex temporal relations that can not be directly used for simulations.

From the internal perspective the behaviour of the agent can be characterized by a specification of more direct causal (temporal) relations between mental (or cognitive) states of the agent, based on which an externally observable behavioural pattern is generated (see). Figure 8 provides a graphical representation of a cognitive model of an agent. Such types of models are called sometimes causal networks (see for example, (Pearl, 2000)).

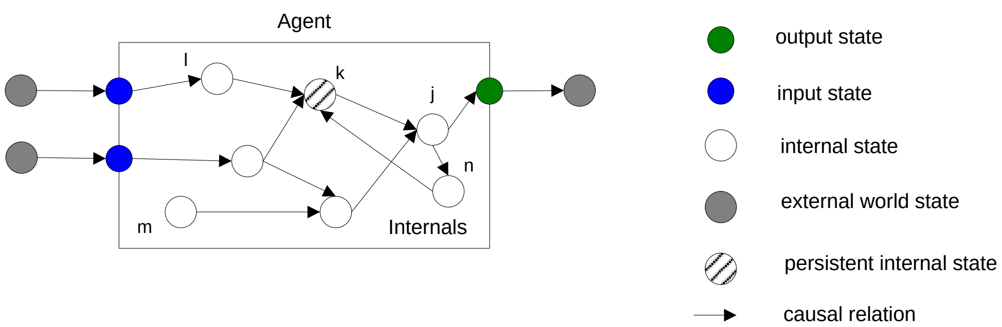

Figure 8: A graphical representation of a general causal model that describes the internal dynamics of an agent

An internal state may be created or changed in one of the following ways:

- directly based on a sequence of input states (state l in Figure 8);
- indirectly based on a sequence of input states through other internal states (state k in Figure 8);
- independently of input (may be dependent on other internal states of this type) (state m in Figure 8).

Qualitative labels may be associated with states in a causal network (such as ‘high’, ‘average’, ‘low’); e.g., different degrees of a desire or commitment can be considered. Furthermore, qualitative labels may be also defined for causal relations (such as '+', '-', '++', '--'), indicating the sign and strength of the relation (i.e., the degree of (positive or negative) influence of one state on another one). For example, if some belief state is related by a strong causal relation (e.g., by '++') to a qualified desire state, then the presence of the belief ensures the 'high' value of the desire. Qualitative causal networks are intuitive and can easily be used in computational analysis. Although qualitative causal networks may be used successfully for modelling relatively simple systems and processes, they are not sufficient for modelling more complex systems. States in complex systems often have multiple causal relations (distributed in time) from other states. To represent combined influences of such relations plausibly, more refined measures are needed (e.g., quantified labels). Furthermore, often complex systems contain loops (or cycles) (e.g., j-k-n in Figure 8). Qualitative labels are not suitable for propagation of causal relations in a loop, for this purpose more fine-grained quantities should be associated with both states and causal relations. In the general case, the numerical value of the degree of influence on a state by other states can be represented by a function of the quantities associated with the influencing states and with the causal links. In the study this function is weighted average. More specifically, with each state in the model, a variable is defined, which value reflects the degree of evidence of the state (denoted by *ei*). Furthermore, the strength of a causal relation between two states is expressed by a weight (denoted by *wi*). Note that the sum of the weights of all causal relations to a state is equal to 1. Further in this report in the graphical causal models rectangles with rounded corners represent states associated with independent variables, which values are determined based on the knowledge over the organization collected during interviews sessions and based on the organizational documentation. The ordinary rectangles represent states with dependent variables. In Figure 9 the degree of evidence *e4* is calculated as: $e4 = \sum_{i=1..3} wi \cdot ei$, where $\sum_{i=1..3} wi = 1$

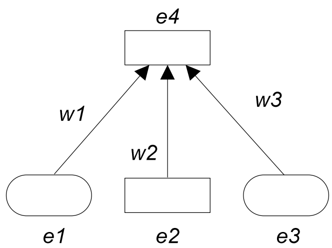

Figure 9: A state with multiple causal relations

Note that sometimes in Cognitive Science joint cognitive states are attributed to a group of agents (e.g., joint commitments, joint desires and goals). In this study aggregated cognitive states of groups have been used as well. Precise estimations of evidences for such states are given below, where these states are discussed.

Executability is an important advantage of causal network specifications. By means of executable specifications it is possible to perform automated simulations of different scenarios of the agent's behaviour.

In Cognitive Science and in Artificial Intelligence many frameworks for modelling internal dynamics of (human and artificial) agents have been developed (Sun, 2008; Kim, 1996; Van der Hoek, W. et. *al*., 1998; Bratman, 1999; Anderson, 1993). Although some of these frameworks gained popularity (e.g., BDI framework (Bratman, 1999); ACT-R (Anderson, 1993)), none of them became an accepted standard for cognitive modelling due to wide variety of aspects and processes modelled in this area. Usually the choice of particular cognitive states of agents depends on the problem being modelled. For this study the relevant cognitive states of an agent have been identified based on the information about safety culture issues (refer to the report 3) identified in the safety culture questionnaires and in the literature, and collected during the interviews.

2.3.2 Step 9: Identification of types and characteristics of agents

In the model the following simple (not composite) agent types have been introduced:

- at-controller,
- at-controller supervisor,
- at-safety officer,
- at-safety investigator,
- at-safety manager,
- at-occurrence manager.

Furthermore, a number of composite agents (holons) (Schillo, 2003) have been defined, whose behaviour is modelled at a rather abstract level:

- at-safety monitoring group,
- at-maintenance team,
- at-safety recommendations and concerns group,
- at-operation management team,
- at-regulator,
- at-crew,
- at-ministry of justice.

The characteristics and their possible values for most of the identified agent types are provided in Table 10. Furthermore, Table 10 lists the instances of the agent types used in the simulation. Studies have shown (Arvidsson, 2006) that due to a strict selection procedure, which ensures that right people with appropriate skills and characteristics are chosen, and similarity of training programs, a team of controllers has a high degree of homogeneity in terms of the skills and characteristics possessed by the controllers.

Table 10: Types of agents and potential values of their characteristics in the air traffic organizational model

Agent Type	Agent Instances	Characteristic	Possible values
at-controller	cag1 – cag48	decision-making skills	{bad, good, excellent}
		passed a rigid medical examination	{yes, no}
		the number of years of college education before initiation of ATC training	[2, 4]
		knowledge of the air traffic management system and the flight regulations	{bad, good, excellent}
		number of hours of computer training	any number
		number of hours of air traffic control training	any number
		listening and communication skills	{bad, good, excellent}
		ability to stand stress	{yes, no}
		short-term memory capabilities	{bad, good, excellent}
		perceived locus of control	{internal, external}
		perceived self-efficacy	{high, medium, low}
		development level of skills for ATC task	[0, 1]
at-controller supervisor	sag1, sag2	the same charactistics as for the controller type	
		level of development of management skills	overall development level: [0, 1]
at-crew	crew-ag	control of aircraft	development level: [1, 4]
		decision-making skills	{bad, good, excellent}
		passed a rigid medical examination	{yes, no}
		knowledge of the flight regulations	{bad, good, excellent}
		number of hours of computer training	any number
		listening and communication skills	{bad, good, excellent}
		short-term memory capabilities	{bad, good, excellent}
at-regulator	regulator-ag	knowledge of general safety standards, requirements and regulations for the execution of flight operations	{bad, good, excellent}
		level of proficiency of use of a safety assessment framework	{no, low, high}
		listening and communication skills	{bad, good, excellent}

Agent Type	Agent Instances	Characteristic	Possible values
at-safety investigator	investigator-ag	decision-making skills	{bad, good, excellent}
		knowledge of general safety standards, requirements and regulations applicable to safety occurrences	{bad, good, excellent}
		analytic skills	{bad, good, excellent}
		level of proficiency of use of a safety assessment framework	{no, low, high}
		listening and communication skills	{bad, good, excellent}
		operational experience as a controller	any number
		completed an ATM Occurrences Investigation course	{yes, no}
at-safety manager	safety manager-ag	the same as for the safety investigator	
		safety investigators management skills	overall development level: [1, 4]
at-operation management team	management-ag	decision-making skills	{bad, good, excellent}
		employee management skills	{bad, good, excellent}
		listening and communication skills	{bad, good, excellent}
		ability to stand stress	{yes, no}
at-safety officer	safety officer-ag	decision-making skills	{bad, good, excellent}
		knowledge of the air traffic management system and the flight regulations	{bad, good, excellent}
		number of hours of air traffic control training	any number
		listening and communication skills	{bad, good, excellent}
		ability to stand stress	{yes, no}
		short-term memory capabilities	{bad, good, excellent}
at-occurrence manager	occurrence manager-ag	decision-making skills	{bad, good, excellent}
		listening and communication skills	{bad, good, excellent}
		ability to stand stress	{yes, no}
		knowledge of the air traffic management system and the flight regulations	{bad, good, excellent}
at-safety monitoring group	smg-ag	decision-making skills	{bad, good, excellent}
		listening and communication skills	{bad, good, excellent}
		knowledge of the air traffic management system and the flight	{bad, good, excellent}

Agent Type	Agent Instances	Characteristic	Possible values
		regulations	
at-safety recommendations and concerns group	sracg-ag	knowledge of techniques for analysis of causes of safety occurrences using a dedicated methodology	{bad, good, excellent}
		decision-making skills	{bad, good, excellent}
		listening and communication skills	{bad, good, excellent}
For all agent types	-	IDV	[1, 100]
		PDI	[1, 100]
		MAS	[1, 100]
		UAI	[1, 100]

Rule-/peer-dependent decision making

In his book about safety ethics Patankar (2005) uses Kohlberg's theory of moral development at three levels:

- Level 1 – Self interest: decisions ate motivated by self-interest of preventing pain, e.g. from legal prosecution or supervisor's punitive treatment. This may lead to strict rule following;
- Level 2 – Conformity to one's society: decisions are motivated by the drive to fit in the perceived demands from the society, e.g. by strongly depending on the opinion of peers;
- Level 3 – The principle of respect: decision are based on high moral standards and respect for others.

In the agent-based model we use agents with decision making standards at levels 1 and 2, and apply them in the model as either rule-dependent or peer-dependent.

Personality traits

Two personality traits, which can affect a controller's decision process to report, are self-efficacy and locus of control.

- *Perceived self-efficacy* is a person's judgment on expected performance (Bandura, 1991). Since self-efficacy influences (positively) the self-confidence of an air traffic controller to perform ATC task, it is a personality trait which affects the maturity of the air traffic controller (described in step 15).
- *Locus of control* refers to an individual's perception about the underlying main causes of events in his/her life. .People with an internal locus of control believe that their behaviour is guided by their personal decisions and efforts and people with an external locus of control believe that their behaviour is guided by fate, luck, or other external circumstances (Spector & Connor, 1994). For air traffic control, this would affect the controller's perceived degree of influence on safety arrangements, which eventually influences the commitment of the controller to safety.

National culture

A number of studies have identified an important role of the national culture of an agent, which influences the agent’s priority of needs, values, attitudes and behaviour (Hofstede, 1997). In particular, Hofstede distinguishes the following dimensions of a national culture:

- *Power Distance Index* (PDI) that is the extent to which the less powerful members of organizations accept and expect that power is distributed unequally. This represents inequality (more versus less), but defined from below, not from above. It suggests that a society's level of inequality is endorsed by the followers as much as by the leaders.
- *Individualism* (IDV) on the one side versus its opposite, collectivism, that is the degree to which individuals are integrated into groups. On the individualist side are societies in which the ties between individuals are loose. On the collectivist side are societies in which people from birth onwards are integrated into strong, cohesive in-groups, which continue protecting them in exchange for unquestioning loyalty.
- *Masculinity* (MAS) versus its opposite, femininity, refers to the distribution of roles between the genders which is another fundamental issue for any society to which a range of solutions are found. The study from (Hofstede, 1997) revealed that (a) women's values differ less among societies than men's values; (b) men's values from one country to another contain a dimension from very assertive and competitive and maximally different from women's values on the one side, to modest and caring and similar to women's values on the other. The assertive pole has been called 'masculine' and the modest, caring pole 'feminine'.
- *Uncertainty Avoidance Index* (UAI) deals with a society's tolerance for uncertainty and ambiguity. It indicates to what extent a culture programs its members to feel either uncomfortable or comfortable in unstructured situations. Unstructured situations are novel, unknown, surprising, different from usual. Uncertainty avoiding cultures try to minimize the possibility of such situations by strict laws and rules. People in uncertainty avoiding countries are also more emotional. The opposite type, uncertainty accepting cultures, are more tolerant of opinions different from what they are used to; they try to have as few rules as possible, and on the philosophical and religious level they are relativist and allow many currents to flow side by side.

In Table 11 the indexes along each of the national culture dimensions for three example countries from the Hofstede’s study are shown.

Helmreich and his colleagues (Helmreich, 2000) developed measures of culture that incorporated Hofstede’s survey and administered them to more than 8,000 pilots in 26 countries. The survey contained items that are directly related to the aviation domain, that are conceptually related to Hofstede's dimensions, and have been validated as predictors of pilot performance. The results of this study demonstrated the enduring importance of national culture.

Table 11: National culture indexes for three example countries (Hofstede, 1997).

Country	PDI	IDV	MAS	UAI
the Netherlands	38	80	14	53
Romania	90	30	42	90
China	80	20	66	30

Characteristics of modelled agents

In this study an Eastern and a Western European ANSP are considered. For the Eastern European ANSP the Romanian cultural indexes have been used, and for the Western European ANSP the Dutch cultural indexes have been used (see Table 12). Furthermore, it is assumed in the current study that the types of people identified in (Patankar, 2005) determine variations of the national culture indexes as shown in Table 12 . For example, a rule-dependent controller has UAI higher than average. Similarly, a peer dependent controller (on the team's opinion) has a lower IDV and a peer dependent controller (on the management's opinion) has a higher PDI than average.

Table 12: National culture indexes for the controllers considered in the simulation, with r denoting a random variable uniformly distributed in the interval (0, 1).

Variable	Description	Western European Culture	Eastern European Culture
e61	IDV index of a controller	0.7+0.2*r	0.2+0.2*r
e62	PDI of a controller	0.3+0.2*r	0.8+0.2*r
e63	MAS index of a controller	0.05+0.2*r	0.32+0.2*r
e64	UAI of a controller	0.4+0.2*r	0.8+0.2*r

2.3.3 Step 10: Identification of goals and needs of agents

In modern social science behaviour of individuals is considered as goal-driven. A goal is defined as an objective to be satisfied describing a desired state or development of the individual. It is recognized that high level goals of individuals are largely dependent on their needs. These needs are to a great extent determined by the individual behavioural and biological history (i.e., biological and social background). Currently the following division of needs is identified in social science:

- Extrinsic needs associated with biological comfort and material rewards;
- Social interaction needs that refer to the desire for social approval, affiliation and companionship;
- Intrinsic needs that concern the desires for self-development, self-actualization, mastery and challenge.

Such a categorization has some similarities with the hierarchy of needs proposed by Maslow (Pinder, 1998).

In line with above categorization in the model the following needs of the agents controllers are considered:

(1) Extrinsic needs;

(2) Social interaction needs: the needs for social approval from both his/her own group and from the management;

(3) Intrinsic needs: contribution to organisational safety-related goals, self-confidence, self-esteem and self-actualisation needs.

The priority of the needs and goals of an agent depend on his/her personal characteristics, the current degree of satisfaction of the needs and goals, diverse environmental aspects (e.g., group attitudes, availability of resources) (Pinder, 1998). As shown in (Pinder, 1998) the priorities of needs indicated in the Maslow‘s hierarchy are not always valid. For example, peer-dependent controllers (following the classification from step 9) attach a higher priority to social interaction needs, whereas the safety fundamentalists give a higher priority to intrinsic needs, more specifically to the contribution to organisational safety-related goals.

The contribution of the national culture dimensions for the priorities of goals considered in this study are the following:

- The lower the IDV index , the higher is the importance of the social interaction needs (more specifically, the own group approval needs); on the contrary, a high IDV index favours individualistic (intrinsic and extrinsic) needs.
- A high PDI index favours a high priority of management approval needs.
- A high MAS index favours a high level of self-esteem, self-confidence and self-actualization needs.
- The UAI index is interpreted as the degree of adherence to existing formal procedures, norms and regulations. This index has a positive influence on the priority of organizational safety-related goals.

2.3.4 Step 11: Identification of commitments, obligations and responsibilities of agents

The most prominent commitments of agents, which have been identified in the safety culture questionnaires used as sources for this study, are those about the commitment to safety. The commitment to safety of a controller is important in the controllers decision to report. If the controller is not committed to contribute to safety, the motivation of the controller to report is low. Several factors influence this commitment, such as job description, perceived degree of influence on safety and controller’s maturity level (Figure 10). The values of the weights of the relations from the causal network of Figure 10 and from all other ones introduced below are given in Table 31 in Appendix A.

In (Griffin and Bateman, 1986) two important aspects of organizational commitment of an agent are distinguished: (a) belief and acceptance of the values and goals of the organization (safety-related goals in this case; the acceptance of the organizational goals is influenced by the maturity degree w.r.t. ATC task, see step 15 for more explanation for maturity); (b) a willingness to exert effort on behalf of the organization (which is an element of the maturity w.r.t. ATC task in this case). Thus, the priority of safety-related goals in the role description and the maturity level w.r.t. ATC task are the primary constituents of the commitment. According to (Griffin and Bateman, 1986) the commitment increases when an agent has influence on decisions related to the object of commitment. Furthermore, also the environment (own group, management) influences commitment (Burt, 1987). The more cohesive the group, the more influence it has on the agent. Similarly, the more control and monitoring the management exerts, the higher its influence on the agent. The commitment to safety of a team is modelled in step 14.

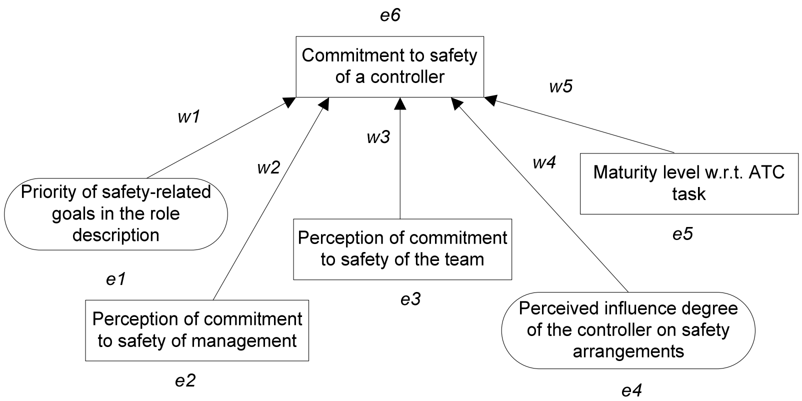

Figure 10: Commitment to safety of a controller with the contributing factors

The dimensions of the national culture influence the values of the weights from Figure 10; contributors, which increase the values of the weights, are shown in Table 13.

Table 13: The weights from Figure 10 for Western and Eastern European cultures

Variable	Description	Western European Culture	Eastern European Culture
w1	Contribution of e1 ‘Priority of safety-related goals in the role description’ to e6 ‘Commitment to safety of a controller’ (European)	0.1	0.2
w2	Contribution of e2 ‘Perception of the commitment to safety of management’ to e6 ‘Commitment to safety of a controller’	0.2	0.3

Variable	Description	Western European Culture	Eastern European Culture
w3	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	0.1	0.2
w4	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3	0.1
w5	Contribution of e5 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3	0.2
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.4	0.65
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.6	0.35

An agent evaluates the management's commitment to safety by considering factors that reflect the effort of the management in contribution to safety (externally observable actions, arrangements). The perception of commitment to safety of management is outlined in Figure 11. An agent controller perceives the claimed commitment to safety by management and real evidences that support this claim. In particular, by assigning a high priority to safety-related goals the management claims its commitment to safety. Strong evidences to support this claim are well-organized safety management, (substantial) financial investments in safety and organization of diverse safety-related activities, in which all roles concerned with safety are involved. These groups of evidences are reflected in Figure 11. The evidence *e70* is calculated over all agent controllers cag1-cag24. The most significant contribution weights have been chosen as w8, w11, w10, w13.

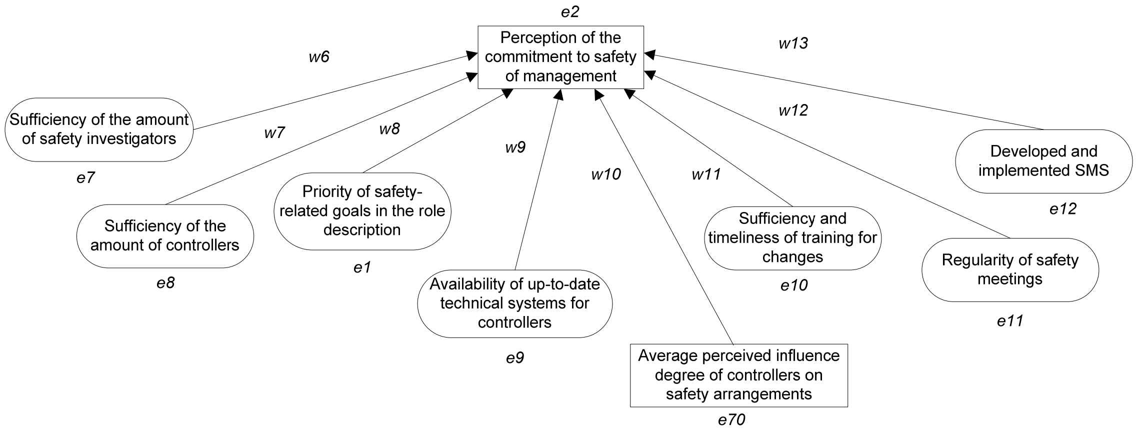

Figure 11: Commitment to safety of management with the contributing factors

2.3.5 Step 12: Identification of attitudes, beliefs and knowledge of agents

In the model, an agent-controller creates the following range of beliefs:

1. Belief about an observed occurrence;
2. Belief about a created notification report;
3. Belief about a received final safety assessment report for a reported occurrence (a feedback);
4. Belief about arrangements that followed a feedback;
5. Belief about degree of acquaintance with another controller;
6. Belief about perceived own influence level on safety arrangements in the organization;
7. Belief about about the quality of notification reports and safety occurrence assessment reports, which reflects the correctness and completeness of knowledge w.r.t. actual state of affairs in the world;
8. Belief that a material reward has been received for reporting;
9. Belief that a material reward has not been received for reporting;
10. Belief that a material reward will follow after reporting;
11. Belief that a material reward will result into partial satisfaction of extrinsic needs;
12. Belief that an administrative reprimand followed after a (sequence of) occurrence(s);
13. Belief that no administrative reprimand followed after a (sequence of) occurrence(s);
14. Belief that an administrative reprimand will follow after a (sequence of) occurrence(s);
15. Belief about severity of an occurrence;
16. Belief that no other agent observed the occurrence;
17. Belief that other agents observed the occurrence will not report;
18. Belief that own professional status in the management' s opinion will decrease after reporting;
19. Belief that own professional status in the management' s opinion will decrease after not reporting;
20. Belief that own professional status in the group will decrease after not reporting;
21. Belief that own professional status in the group will decrease after reporting;
22. Belief that the report will be treated in a depersonalised way.

Beliefs 8 to 22 are used during decision making by a controller whether to report an occurrence as outlined in Section 2.3.8.

2.3.6 Step 13: Identification of relations between agents

According to (Arvidsson, 2006) and the conducted interviews, teams of controllers in the Western European culture do not have evident informal leaders. The role of the leader is performed by the controller's supervisor. In the simulation, a team of controllers is considered to be a shift. The composition of shifts may change over time.

To model informal interaction relations of controllers the Burt's social contagion theory has been used (Burt, 1987). According to this theory, the intensity of informal communication between the roles is influenced positively by the following factors:

1. Similarity of the communication patterns of the roles;
2. Equality of the statuses of the roles in the organization;
3. Physical possibilities to communicate;
4. Degree of acquaintance of the roles with each other.

For a team of controllers the factors 1-3 have a degree of evidence, whereas factor 4 depends on the team composition (stable versus variable). Thus, generally a group of controllers should have intensive interaction relations, which is also confirmed by the interviews. Such relations may enhance the knowledge of controllers about safety-related issues and occurrences, and may contribute to the proactive identification of issues by the controllers.

In the simulation, controllers work in shifts. A shift consists of three sessions. The duration of each session is 1 hour. After each session the obligatory break follows, which lasts for 1 hour. During a break the controllers are physically located in the same space, which enables their informal discussions of occurrences observed and other safety issues.

2.3.7 Step 14: Identification of shared beliefs, attitudes, norms and values of agents

Teams with intensive informal communication tend to have essential control over attitudes and actions of their members (Burt, 1987). The control degree depends on the types of national culture and of organizational culture, and on the maturity level of the members w.r.t. their work (see step 15). To evaluate the degree of a positive attitude to reporting in a team an indirect indicator (i.e., an indicator that cannot be measured directly can be evaluated by an alternative indicator) is used: the average force to report an occurrence calculated over all members of the team over time (see step 15) (parameter *e57*).

The perception of a controller of the commitment to safety of a team is outlined in Figure 12. It involves commitment to safety of the supervisor, as well as commitment to safety of the team members (the average is calculated over the commitment degrees of the controllers within the team). The formal team leader (controllers supervisor) is responsible for realizing goals and strategies of the management in his/her team. Thus, the commitment to safety of the leader depends on the commitment of the management, as well as, on the leader's level of development of the managerial skills. In the model considered $w15 > w14$. The values of *w16* and *w17* depend on the type of the national culture. More specifically, a high PDI index favours $w16 > w17$ and a low IDV index favours $w16 < w17$.

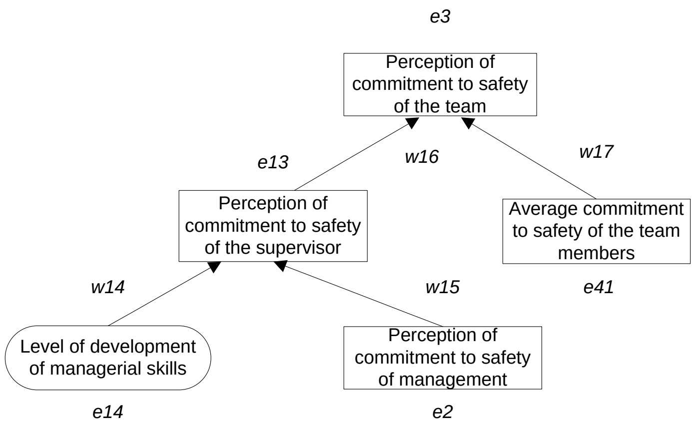

Figure 12: Commitment to safety of a team with the contributing factors

2.3.8 Step 15. Identification of agent performance variability in formal and informal flows of control

The performance of agents is variable and this has effect on safety occurrence reporting. Next we discuss a range of aspects that influence the following key quality indicators of safety occurrence reporting:

- Quality of a processed notification report;
- Quality of a monthly safety overview report;
- Quality of a final safety occurrence assessment report;
- Provision of feedback on occurrence reporting;
- Deciding to report an occurrence.

Quality of a processed notification report

Although precise modelling of ATC operations is out of scope of this study, the factors that influence the quality of a notification report produced based on an observed occurrence, and on which occurrence investigation is based, are considered. These factors are shown in Figure 13.

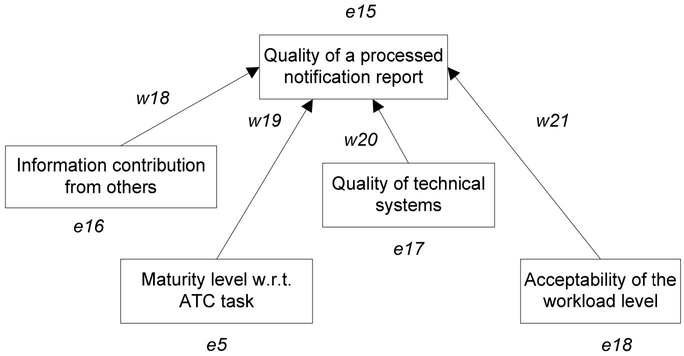

Figure 13: Quality of a notification report with the contributing factors

The quality of a notification report is influenced by the quality of perception and comprehension of a situation by a controller in the context of execution of an air traffic control task. The perception and comprehension of a controller are dependent on:

- The quality of technical systems which ensures (timely) provision of the required data and minimal distortion of these data (see Figure 16);
- Information contribution provided by other agents involved in the execution of an air traffic control task (e.g., controllers, pilots, controllers supervisor) (considered in Figure 17);
- Maturity level w.r.t. ATC task, which among others indicates the level of development of skills related to memory, perception, analytic thinking and concentration of a controller (considered in Figure 14).

Generally, quality of perception and comprehension of a controller degrades when his/her workload level increases above some threshold (an acceptable level). Positive contributors for maintaining the workload level within acceptable bounds are shown in Figure 18. In the model the weights *w20* and *w21* are greater than *w18* and *w19*.
In the following the factors contributing to the quality of a notification report are discussed in more detail.

Maturity level w.r.t. ATC task
In the theory of Situational Leadership (Hersey, P., Blanchard, K.H., Johnson, D.E., 2001) the maturity of a team member with respect to a task is defined as an aggregate of the member's experience, willingness and ability to take responsibility for the task. The ability of an agent to perform a task is determined by his/her knowledge and (the development degree of) his/her skills required for the task execution. The willingness of an agent to perform a task is determined by the agent's confidence and commitment, which are necessary for the task execution. In the theory of Situational Leadership four stages of the maturity of a team member are distinguished:

1. Agents who are both unable and either unwilling or too insecure to take responsibility to perform a task. They are neither competent nor confident (low maturity level).
2. Agents who have less skill level, but willing to perform a task. They are motivated but lack the appropriate skills (average maturity level).
3. Agents who are able but unwilling or too apprehensive to perform a task (average maturity level).
4. Agents who are both able and willing to take responsibility to perform a task (high maturity level).

The contributing factors to the maturity level w.r.t. an ATC task are presented in Figure 14.
For the model considered it is assumed that both constituents of the maturity have the same weight, i.e., $w22=w23 = w24 = w25$, and that $w26 > w27$.

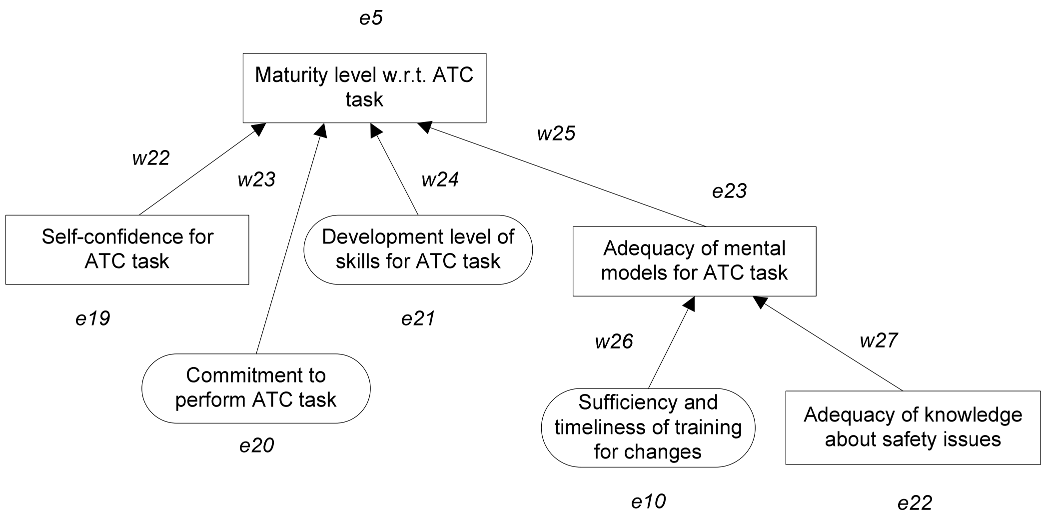

Figure 14: Maturity level w.r.t. ATC task with the contributing factors

According to the interviews and literature, the procedure for selection of controllers ensures that controllers with the high commitment and self-confidence to perform the ATC tasks, and with a high development level of the skills required for the ATC tasks are chosen. However, the level of self-confidence may change over time; the dynamics of self-confidence is considered below in the section on decision making.

The knowledge of a controller w.r.t. the ATC task is dependent on the adequacy of the mental models for the ATC tasks. A mental model is a set of beliefs of an agent about a situation that provides a framework for thinking and helps to rationalise and predict (Manktelow and Jones 1987). The adequacy of mental models of a controller for the ATC task depends on the sufficiency and timeliness of training provided to the controller and the adequacy of knowledge about safety-related issues.

The causal network for the adequacy of knowledge about safety issues is shown in Figure 15. This knowledge is required for a more profound comprehension of events and making more informed decisions (taking into consideration information about safety-related issues) during the execution of ATC tasks. Such knowledge is contained in reports resulted from safety-related activities (final safety occurrence assessment reports and monthly safety overview reports are considered in this study). Thus, the adequacy of knowledge about safety issues in the organization depends to a great extent on the quality of these reports. Note the evidence *e42* is calculated over the final safety assessment reports received by the controller and *e43* is calculated over the monthly safety overview reports received by the controller. In the model it is assumed that *w28* = *w29*. At the beginning of simulation, no reports have been collected and no safety issues have been identified, thus the adequacy of knowledge about safety issues equals 0.

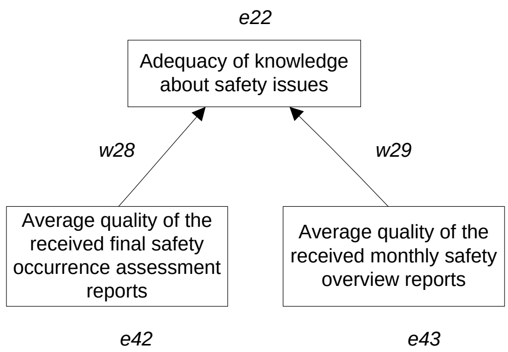

Figure 15: Adequacy of knowledge about safety issues in the organization

Quality of technical systems

The quality of technical systems (Figure 16) depends on:

- The availability of technical systems (resources), required for the effective and efficient execution of air traffic control tasks;
- The quality of maintenance of technical systems, which value is determined by a number of constituents. Among these constituents are qualities of the formal procedures for system checks and for repairs. The quality of these procedures is dependent on the clarity of identification of role responsibilities, on the frequency of system checks and on scheduling and timely performance of system repairs;
- The sufficiency of the amount of qualified maintenance personnel, which is dependent on the number of technical systems that need to be maintained and on the degree of exploitation of these systems by controllers (e.g., dependent on the air traffic amount).

In the model it is assumed that *w30* > *w31* and *w32* > *w31*.

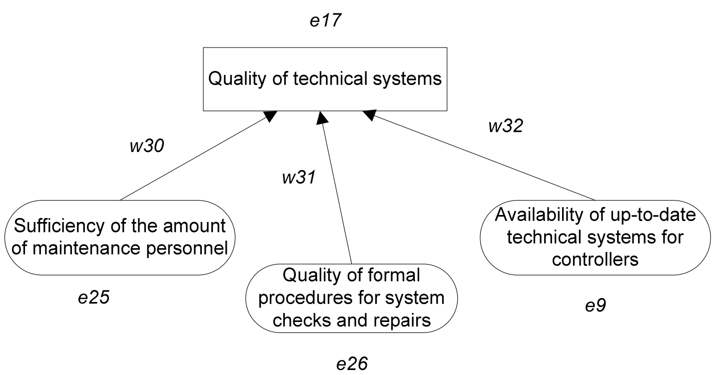

Figure 16: Quality of technical systems with the contributing factors

Information contribution provided by other agents

Other agents may also provide useful information to a controller, which may enhance his/her comprehension of a situation in the context of an air traffic control task (see Figure 17). Among these agents are controller(s) assigned to the same sector, controllers of the adjacent sectors, and the controllers supervisor. To provide information useful for the occurrence recognition, the controller-information provider should possess knowledge relevant to the occurrence (e.g., knowledge about similar observed occurrences). The more knowledge related to the occurrence the controller possesses, the higher the effect of his/her information contribution. In this model it is assumed that the knowledge about three or more similar occurrences is the maximal amount of knowledge (*e27* = *e28* = 1). Such knowledge is stored in the form of beliefs about observed occurrences. Furthermore, the motivation to provide this knowledge depends on the commitment of the controller to safety. Similarly, the information contribution by the controllers supervisor depends on the amount of knowledge about safety-related issues, and on his/her commitment to safety.

In the model it is assumed that *w33* > *w36*, since the controllers which work on the same task have better awareness about the details of this task. Furthermore, *w35* > *w34* and *w37* > *w38*, since the possessed knowledge determines largely the usefulness of the information contribution.

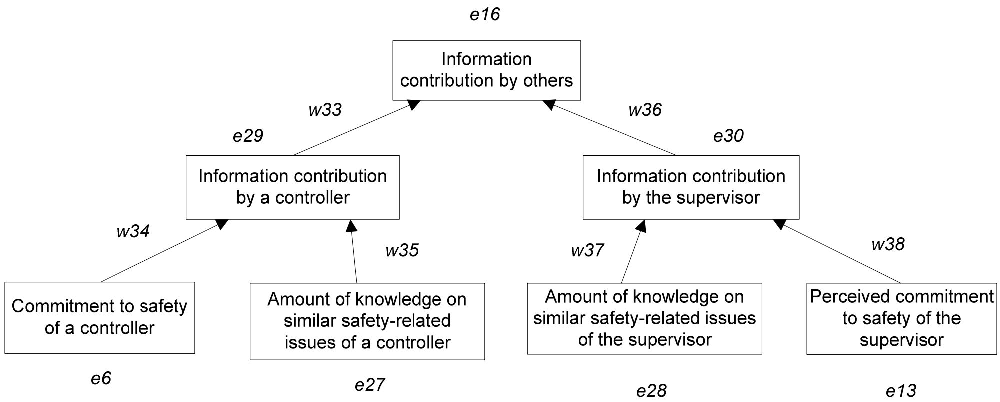

Figure 17: Information contribution by others with the contributing factors

Acceptability of the workload level

The acceptability of the workload level (see Figure 18) depends on:

- Sufficiency of the number of air traffic controllers. Evaluated by determining if the number of controllers in each sector is sufficient to handle the traffic in the sector;
- Level of development of managerial skills. (Highly) developed management skills of the supervisor contribute to a work distribution under which each team member has an acceptable for him/her workload level.

In the model it is assumed that *w39* > *w40*.

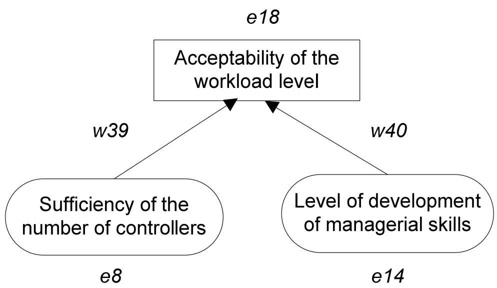

Figure 18: Acceptability of the workload level with the contributing factors

Quality of a monthly safety overview report

To identify safety issues in the organization proactively different activities are organized, among them is safety monitoring. Usually, these activities are organized by members of the Safety department (safety investigators and safety manager). Thus, it is important to ensure the sufficiency of the amount of professional safety investigators in the Safety department. The quality of safety analysis performed during the execution of the safety monitoring task is determined by:

- Average commitment to safety of the agents involved in safety analysis.
- Quality of input data for analysis (i.e., collected occurrence notification reports, previous monthly safety overview reports, and ideas of the participants triggered by available safety-related information).

In the model it is assumed that *w43* > *w42* and *w45* > *w44*.

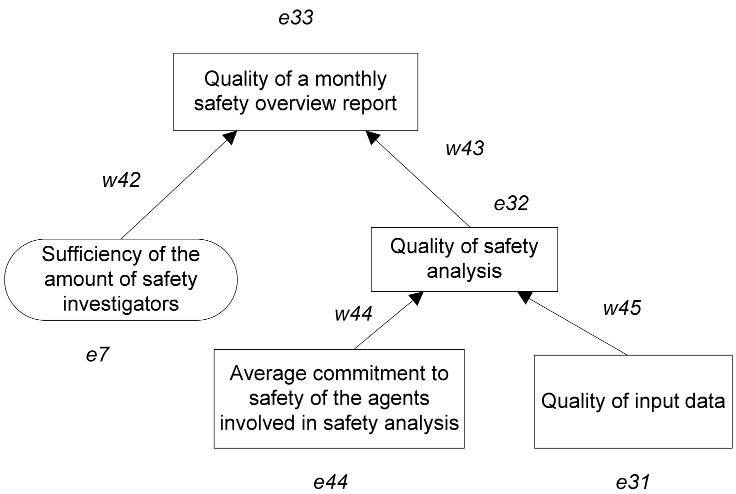

Figure 19: Quality of a monthly safety overview report

The quality of input data (Figure 20) for safety analysis depends on:

- The average quality of the notification reports collected so far; the quality of the report for an occurrence, which has not been reported, is estimated as 0;

- The average quality of previous monthly safety overview reports;
- Average contribution of informal discussions in teams of controllers.

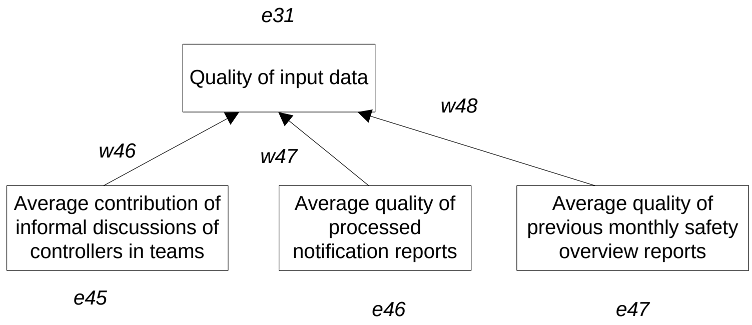

Figure 20: Quality of input data for safety analysis

The causal network for the contribution of informal discussions in teams of controllers is shown in Figure 21. According to the interviews and literature air traffic controllers feel very enthusiastic and passionate about their job and discuss job-related events and issues also in their free time. Therefore, according to the social contagion theory, the intensity of informal interactions in the team of controllers is high. Furthermore, the commitment to safety of the team of controllers stimulates discussions of safety-related issues in the organization. The notification reports created by the controllers of the team, as well as the knowledge about safety issues in the organization (through monthly safety overview reports) serve as background knowledge for these discussions. To calculate the intensity of informal interactions in the team of controllers the measure of acquaintance of controllers c1 and c2 has been introduced acq(c1, c2): acq(c1, c2) = 1 if the number of shifts, in which c1 and c2 worked together (joint shifts) is ≥ 7, and if the number is less than 7, then acq(c1, c2) = number of joint shifts / 7. Then *e35* is calculated as the average of the averages of the acquaintance degrees of each controller with each other controller in the team. Then, the evidence *e45* is calculated as average over the contributions of all teams of controllers in the organization (*e34*). The evidence *e46* is calculated over all processed notification reports. The evidence *e47* is calculated over all previous monthly overview reports. In the model *w47 > w48*; furthermore, *w49 = w50 = w51*, *w51 > w52*.

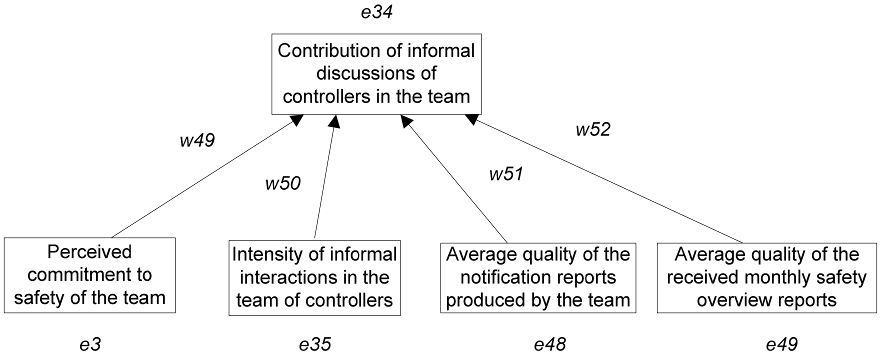

Figure 21: Contribution of informal discussions of controllers in the team to identification of safety-related problems.

Quality of the final safety occurrence assessment report

The quality of the final safety assessment report for an occurrence (see Figure 22) depends on:

- The quality of a processed notification report on the occurrence provided by a controller (supervisor);
- The quality of the formal safety assessment procedure, which defines a sequence of steps for the investigation of a reported occurrence. The quality is dependent on the clarity of identification of investigation steps, responsible roles and time constraints;
- Sufficiency of the amount of safety investigators;
- Background knowledge used during the occurrence investigation represented by the knowledge on similar safety-related issues in the organization (e.g., stored in the database, written in safety reports) and the knowledge about safety issues in the organization (obtained through monthly safety overview reports). The amount of knowledge on similar safety-related issues in the organization is maximal if at least three similar occurrences are known;
- The quality of the meetings during the occurrence investigation is influenced by the commitment to safety of the participants of the meetings, which ensures their willingness to perform a high quality occurrence investigation.

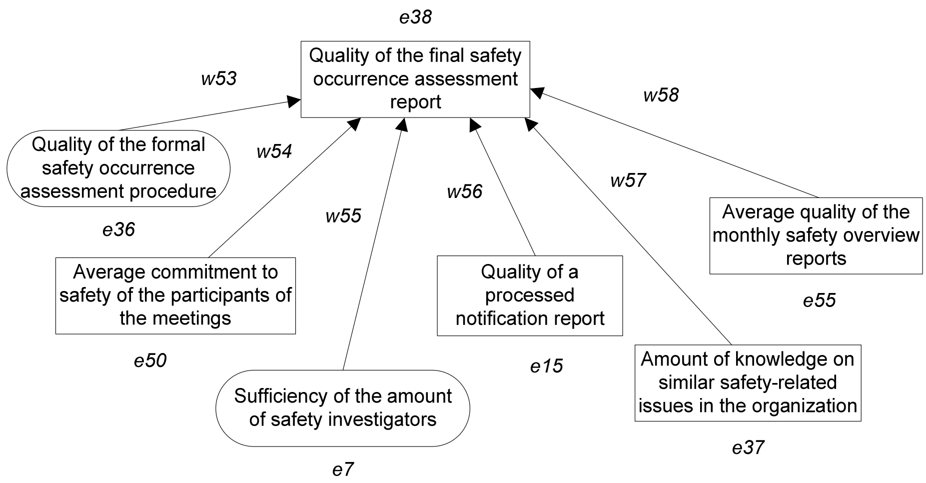

Figure 22: Quality of the final safety occurrence assessment report

Provision of feedback on occurrence reporting

Provision of feedback on notification reports based on final safety occurrence assessment reports, and of generalized monthly safety overview reports is an important aspect of organizational learning. Whereas monthly safety overview reports are often provided in written (printed) form, a feedback on a safety occurrence may be provided both orally and in written form. In the model, provision of the feedback is modelled as a stochastic process. The probability of the feedback provision is used for generating the value of a discrete random variable *FP* (indicating the feedback provision in the simulation) with the sample space is {0, 1}. Here *0* indicates that a feedback has not been provided, whereas *1* indicates the feedback provision.

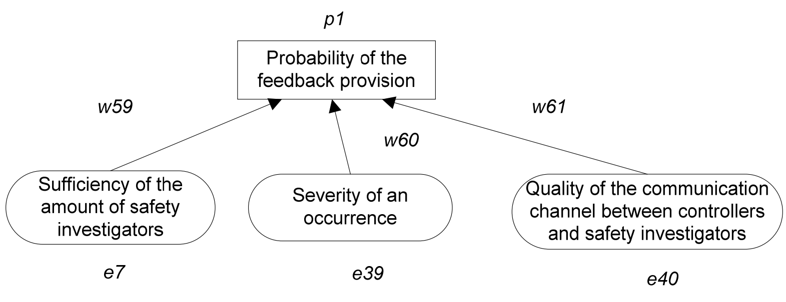

Figure 23: Probability of the feedback provision on a safety occurrence.

For a monthly safety overview report it is assumed that it is always provided to controllers.

Deciding to report an occurrence

When an agent-controller decides whether to report an occurrence s/he reasons about two alternatives: report and not report. For formalize the decision making process the expectancy theory (the version of Vroom) (Pinder, 1998), which has received good empirical support has been used. According to this theory, when an individual evaluates alternative possibilities to act, s/he explicitly or implicitly makes estimations for the following factors: *expectancy*, *instrumentality*, and *valence* (see Figure 24).

- Expectancy refers to the individual's belief about the likelihood that a particular act will be followed by a particular outcome (called a first-level outcome).
- Instrumentality is a belief concerning the likelihood of a first level outcome resulting into a particular second level outcome; its value varies between -1 and +1. A second level outcome represents a desired (or avoided) by an agent state of affairs that is reflected in the agent's goals and needs. Although the notion of instrumentality can be perceived as probability, in contrast to the latter instrumentality may take negative values, in case a second-level outcome does not follow a particular first-level outcome.
- Valence refers to the strength of the individual's desire for an outcome or state of affairs. While second level outcomes are directly related to the agent's needs, the valence values associated with these outcomes refer to priorities of these needs. The values of valence change over time (e.g., depending on the satisfaction of needs).

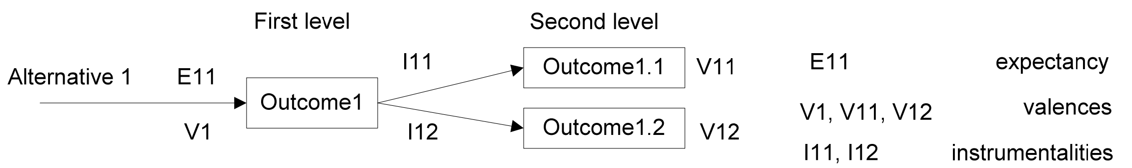

Figure 24: An example of the motivation model by Vroom (Pinder, 1998)

In the Vroom model *the force on an individual to perform an act is a monotonically increasing function of the algebraic sum of the products of the valences of all outcomes and the strength of his expectancies that the act will be followed by the attainment of these outcomes* (Pinder, 1998). Hence, the force to perform act i can be calculated as:

$$F_i = \sum_{j=1}^{n} E_{ij} \cdot \sum_{k=1}^{m} V_k \times I_{jk}$$

Here E_{ij} is the strength of the expectancy that act i will be followed by outcome j; V_j is valence of first-level outcome j; I_{jk} is perceived instrumentality of outcome j for the attainment of outcome k. Thus, in this study the controller's process of decision making whether to report an occurrence consists in calculating the forces of both actions alternatives: reporting (F_1) and not reporting (F_2) an occurrence. If $F_1 \geq F_2$ the controller will report an occurrence, otherwise not.

The decision making model to report an occurrence is shown in Figure 25. In Table 16 the model variables are described. For calculation of the variables of the decision making model the notion of an observed occurrence pattern of a controller is used. An *observed occurrence pattern* of a controller c is a set of the pairs (o_i, t_i) for each occurrence o_i observed by c at the time point t_i. To obtain the set of all occurrences from an occurrence pattern observed by a controller c between time points t1 and t2, the functor obs_occurrences_by_between(c, t1, t2) is used. Moreover, the following more specific sets of occurrences may be distinguished: a set of occurrences reported by the controller (reported_occurrences_by_between(c, t1, t2)), a set of occurrences of the controller known to management (known_management_occurrences_for_between(c, t1, t2)), and a set of occurrences of the controller known to his/her team (known_team_occurrences_for_between(c, t1, t2)). In the decision making models the occurrence sets are calculated for an evaluation period, established by the management (e.g., a month or a quarter). In the end of each evaluation period the controller's performance is judged by the management, and reprimands, as well as rewards may be provided. Furthermore, the total severity measure may be calculated for an occurrence set as the sum of all severities of the occurrences from the set:

$$total\_severity(OC) = \begin{cases} 1, & if \sum_{oc_i \in OC} oc_i \geq 1, \\ \sum_{oc_i \in OC} oc_i, & if \sum_{oc_i \in OC} oc_i < 1 \end{cases}$$

The severities of different types of occurrences are given in Table 14.

Table 14: Severities of different types of occurrences

Occurrence type	***Severity***
A	0.9
B	0.6
C	0.3
E	0.05

For some occurrence patterns of a controller known to the management reprimands may be provided to the controller, which is taken into consideration in the decision making models below. Additional evidences of the states not considered in the parts of the model discussed before, but which are used in the decision making models, are provided in Table 15.

Table 15: Additional evidences of the states of a controller

Evidence of a state	***State description***
e59	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)

Evidence of a state	*State description*
e60	Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the management
e65	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
e66	Perception of the confidentiality of reporting. If a formal regulation exists ensuring the confidentiality of reporting, then *e66* > 0.7. The probability that nobody has observed the occurrence (*p3*) has a positive effect on *e66*.
e67	Perceived severity of the provided reprimand
e68	Perceived amount of the provided reward

Table 16: The decision making model to report an occurrence

Model variable	**Description**
	Expectancies
E12(c, t_{curr}, t_{eval}, o_{curr}), here t_{curr} is the current time point; t_{eval} is the period for the evaluation of the controller, o_{curr} is the current occurrence, over which the decision is evaluated	0.5*(f1(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) $\cup$ {o_{curr}}) + f2(t_{curr}, known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) $\cup$ {o_{curr}})), where f1 is a formal constituent; f1(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) $\cup$ {o_{curr}}) = 1, when a formal reprimand regulation exists for the pattern known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) $\cup$ {o_{curr}} expressed using the function repr: VALUE x OCCURRENCE_TYPE $\rightarrow$ VALUE, otherwise f1(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) $\cup$ {o_{curr}}) = 0. f2 is an experience constituent; initially (t = 0), f2(0, OC_i) = 0, for each occurrence set OC_i. If it has been observed that a reprimand has been provided for the set of occurrences OC_i at the time point t', then f2(t'+1, OC_i)= f2(t', OC_i) + 0.1; on the contrary, if it has not been observed that a reprimand has been provided for the set of occurrences OC_i during the evaluation period, then f2(t''+1, OC_i)= f2(t'', OC_i) - 0.2, here t'' is the end time point of the evaluation period. If 0.5*(f1(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) $\cup$ {o_{curr}}) + f2(known_management_occurrences_for_between(c,

Model variable	Description
	$t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}})) > 1, then E12(c, t_{curr}, t_{eval}, o_{curr})= 1. If 0.5*(f1(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}}) + f2(known_management_occurrences_for_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}}) < 0, then E12(c, t_{curr}, t_{eval}, o_{curr}) = 0.
E13	(1 – *e66*)*(0.7**e57* + 0.3**e3*), where *e57* is the perception of the positive attitude to reporting in the team, *e3* the perception of commitment to safety of the team, and *e66* is the perception of the confidentiality of reporting.
E14	0.6**e2* + 0.4**e13*, where *e2* is the perception of the commitment of management to safety and *e13* is the perception of the commitment of the supervisor to safety.
E15(c, t_{curr}, t_{eval}, o_{curr}), here t_{curr} is the current time point; t_{eval} is the period for the evaluation of controller, o_{curr} is the current occurrence, over which the decision is evaluated	0.5*(f3(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}}) + f4(t_{curr}, reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}})), where f3 is a formal constituent; f3(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}}) = 1, when a formal reward regulation exists for the set of occurrences reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}} expressed using the function rew: VALUE x OCCURRENCE_TYPE → VALUE, otherwise f3(reported_occurrences_by_between (c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}}) = 0. f4 is an experience constituent; initially (t = 0), f4(0, OC_i) = 0, for each occurrence set. If it has been observed that a reward has been provided for the reported set of occurrences OC_i at the time point t' during the evaluation, then f2(t'+1, OC_i)= f2(t', OC_i) + 0.1; on the contrary, if it has not been observed that a reward has been provided for the reported set of occurrences OC_i during the evaluation period, then f2(t''+1, OC_i)= f2(t'', OC_i) - 0.2, where t'' is the end of the evaluation period. If 0.5*(f3(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}}) + f4(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr} -1) ∪ {o_{curr}})) > 1, then E15(c, t_{curr}, t_{eval}, o_{curr}) = 1. If 0.5*(f3(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}}) + f4(reported_occurrences_by_between(c, $t_{curr} – t_{eval}$, t_{curr}-1) ∪ {o_{curr}}) < 0, then E15(c, t_{curr}, t_{eval}, o_{curr}) = 0.

Model variable	Description
E16	0.4* *e39* + 0.3**e59* + 0.15**e2* + 0.15**e43*, where *e39* is the occurrence severity; *e59* is the average quality of the final safety occurrence assessment reports for similar occurrences provided to the controller (when the average is calculated, the quality of not received feedback = 0); *e2* is the commitment to safety of management, and *e43* is the average quality of the received monthly safety overview reports.
E17(c, t_{curr}, t_{eval}, o_{curr})	(1 – *e66*) * *e65* * *e35*, where *e65* is the total severity of the set of occurrences known_team_occurrences_for_between(c, t_{curr} – 2*t_{eval}, t_{curr}-1) ∪ {o_{curr}}, *e35* reflects the intensity of informal interactions in the team of controllers, *e66* is the perception of the confidentiality of reporting.
E18(c, t_{curr}, t_{eval}, o_{curr}), here t_{curr} is the current time point; t_{eval} is the period for the evaluation of controller, o_{curr} is the current occurrence, over which the decision is evaluated	*e60*, where *e60* is the total severity of the set of occurrences known_management_occurrences_for_between(c, t_{curr} – t_{eval}, t_{curr}-1) ∪ {o_{curr}}
Instrumentalities	
I21	-0.3* *e67*, where *e67* is the perceived severity of the provided reprimand.
I51	0.2 * *e68*, where *e68* is the perceived amount of the provided reward.
I32	0.1
I35	*e61*/5. where *e61* is the IDV index value of the controller
I72(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e35** *e65*, where *e35* reflects the intensity of informal interactions in the team of controllers, and *e65* is the total severity of the set of occurrences known_team_occurrences_for_between(c, t_{curr} – 2*t_{eval}, t_{curr}-1) ∪ {o_{curr}}.
I75(c, t_{curr}, t_{eval}, o_{curr})	- 0.5 * *e61* * *e35* * *e65*, where *e35* reflects the intensity of informal interactions in the

Model variable	Description
	team of controllers and *e65* is the total severity of the set of occurrences, known_team_occurrences_for_between(c, t_{curr} – 2*t_{eval}, t_{curr}-1) ∪ {o_{curr}}, *e61* is the IDV index of the controller.
I43	0.1
I45	*e62*/5, where *e62* is the PDI value of the controller
I83(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e60*, where *e60* is the total severity of the set of occurrences known_management_occurrences_for_between(c, t_{curr} – t_{eval}, t_{curr}-1) ∪ {o_{curr}}
I85(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e62* * *e60* , where *e60* is the total severity of the set of occurrences, known_management_occurrences_for_between(c, t_{curr} – t_{eval}, t_{curr}-1) ∪ {o_{curr}} and *e62* is the PDI value of the controller
I64	1
I65	0.2**e6*, where *e6* is the commitment to safety of the controller

Furthermore, for each type of needs basis valences have been specified, which reflect the degree of importance of particular needs taken alone (e.g., without considering other needs). When different types of needs are considered simultaneously, the agent makes the estimation of current degrees of importance of the needs (i.e., determines current valence values). During such estimation s/he takes into account: (1) basis valences of the needs; (2) current degrees of satisfaction of the needs. More specifically, the valence value for the need is evaluated as:

$$v(need, c) = \begin{cases} v_{basis}(need, c) \cdot \dfrac{sat\_accept(need)}{sat\_curr(need)}, & sat\_curr(need) \geq sat\_accept(need) \\ v_{basis}(need, c) + v_{basis}(need, c) \cdot \dfrac{sat\_accept(need) - sat\_curr(need)}{sat\_accept(need)}, & sat\_curr(need) < sat\_accept(need) \end{cases}$$

Here v_{basis}(need) is a function that assigns a basis valence value for a need; sat_accept(need) is a function that assigns an acceptable satisfaction value for a need; sat_curr(need) is a function that assigns a current satisfaction value for a need. The basis valences of the needs used in the simulation are provided in Table 17. The acceptable satisfaction values for the needs used in the simulation are provided in Table 18.

Table 17: Basis valences of the needs of the agent controllers

Controller	ATC skills	Basic valences of the needs				
		$v1_b$	$v2_b$	$v3_b$	$v4_b$	$v5_b$
from Eastern culture	0.7 + 0.3·a*	1	0.8 -0.2·b	0.8 + 0.2·c	0.8 + 0.2·d	0.5 + 0.1·e
from Western culture			0.3 -0.2·f	0.3 + 0.2·g	0.4+ 0.2·h	0.7+ 0.3·k

* a, b, c, d, e, f, g, h, k are random variable uniformly distributed in the interval (0, 1)

Table 18: Acceptable satisfaction values for needs

Need	Eastern European Culture	Western European Culture
Extrinsic needs	1	1
Own group approval	0.8	0.6
Management approval	1	0.7
Contribution to safety-related goals	0.7	0.7
Self-esteem, self-confidence and self-actualization	0.6	0.9

After a reporting act the satisfaction of the needs of the agent changes as shown in Table 19.

Table 19: Change of the satisfaction of the needs, when an occurrence is reported

Need	Value change
Extrinsic needs	if a reward is provided: I51 if a reprimand is provided: I21
Own group approval	E13*I32 + E17*I72
Management approval	E14*I43 + E18*I83
Contribution to safety-related goals	E16*I64
Self-esteem, self-confidence and self-actualization	E13*I35 + E17*I75 + E14*I45 + E18*I85 + E16*I65

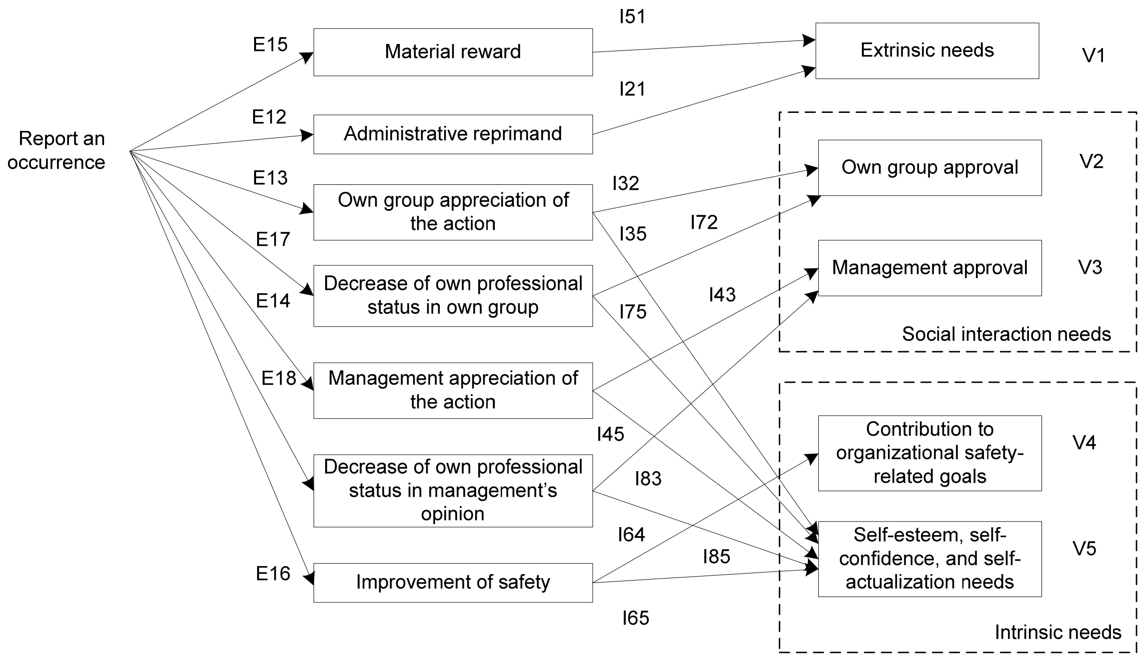

Figure 25: Decision making model for reporting an occurrence by a controller

The decision making model to not report an occurrence is shown in Figure 26. In Table 21 the model parameters are described. After not reporting an occurrence the satisfaction of the needs of the agent changes (the exact types of changes used in the simulation are provided in Table 20.

Table 20: Change of the satisfaction of the needs, when an occurrence is not reported

Need	Value change
Extrinsic needs	I61
Own group approval	E13*I32 + E17*I72
Management approval	E14*I43 + E18*I83
Contribution to safety-related goals	E16*I64
Self-esteem, self-confidence and self-actualization	E13*I35 + E17*I75 + E14*I45 + E18*I85 + E16*I65

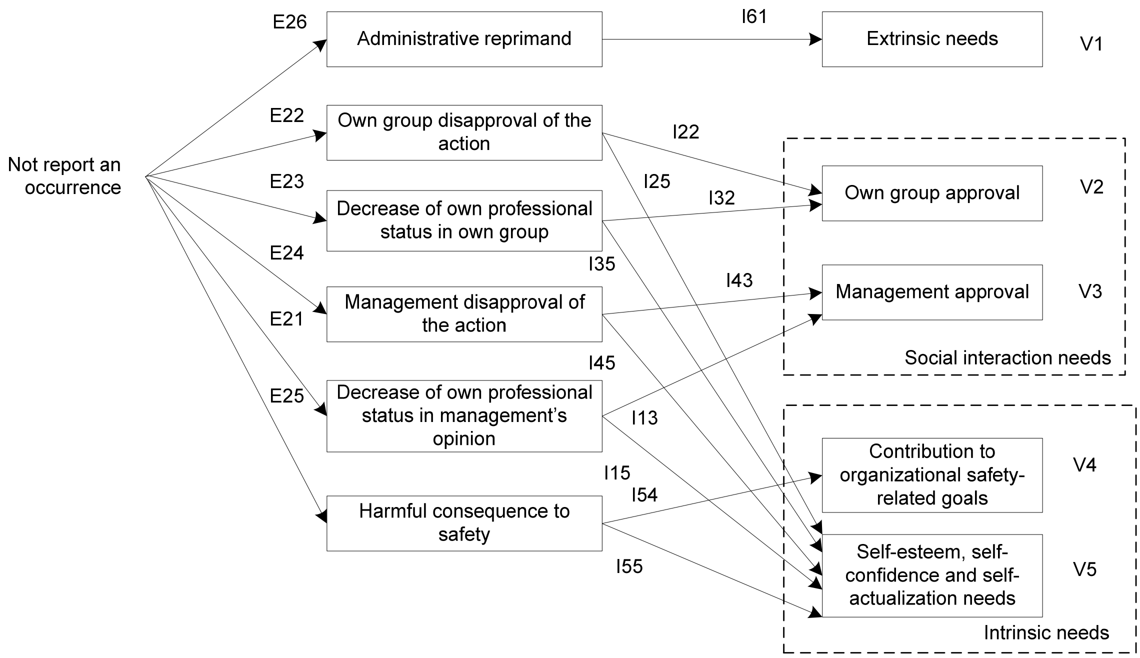

Figure 26: Decision making model for not reporting an occurrence by a controller

Table 21: The decision making model for not reporting an occurrence

Model variable	Description
	Expectancies
E26 (c, t_{curr}, t_{eval}, o_{curr}), here t_{curr} is the current time point; t_{eval} is the period for the evaluation of the controller, o_{curr} is the current occurrence, over which the decision is evaluated	(1 – p2)* 0.5*(f1(occurrence pattern) + f2(occurrence pattern) + τ) – p2, where p2 is the probability that the unreported occurrence will not be discovered by the management; f1 and f2 are defined as for E12 and τ is in [0, 0.1] reflects an extra reprimand for not reporting.
E22	(1 – p3)* (0.7**e57* + 0.3**e3*) – p3, where p3 is the probability that nobody from the team has observed the occurrence, *e57* is the perception of the positive attitude to reporting in the team and *e3* is the perception of commitment to safety of the team.
E24	(1-p2)*(0.6**e2* + 0.4**e13*) – p2, where p2 is the probability that the unreported occurrence will not be discovered by the management, *e2* is the commitment of management to safety and *e13* is the commitment of the supervisor to safety.
E23(c, t_{curr}, t_{eval}, o_{curr})	(1-p3)* *e35* **e65* – p3, where p3 is the probability that nobody from the team has observed the occurrence, where *e65* is the total severity of the set of occurrences known_team_occurrences_for_between(c, $t_{curr} - 2 t_{eval}$, $t_{curr}-1$) ∪ {o_{curr}}, *e35* reflects the intensity of informal interactions in the team of controllers.

Model variable	Description
E21(c, t_{curr}, t_{eval}, o_{curr})	(1-p2) * *e60* – p2, where p2 is the probability that the unreported occurrence will not be discovered by the management, *e60* is the total severity of the set of occurrences known_management_occurrences_for_between(c, $t_{curr} - t_{eval}$, t_{curr}-1) $\cup$ {o_{curr}}
E25	0.6* *e39* + 0.3**e59* + 0.1**e43*, where *e39* is the occurrence severity; *e59* is the average quality of the final safety occurrence assessment reports for similar occurrences provided to the controller (when the average is calculated, the quality of not received feedback = 0); and *e43* is the average quality of the received monthly safety overview reports.
Instrumentalities	
I61	-0.3 * *e67* + α, where α is an extra reprimand for not reporting.
I22	-0.2* *e39*, where *e39* is the occurrence severity.
I25	-*e61*/5 where *e61* is the IDV index value of the controller [-0.2, 0].
I32(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e35* *e65*, where *e35* reflects the intensity of informal interactions in the team of controllers, and *e65* is the total severity of the set of occurrences known_team_occurrences_for_between(c, t_{curr} – 2*t_{eval}, t_{curr}-1) $\cup$ {o_{curr}}.
I35(c, t_{curr}, t_{eval}, o_{curr})	- *e61* * *e35* * *e65/2*, where *e35* reflects the intensity of informal interactions in the team of controllers and *e65* is the total severity of the set of occurrences, known_team_occurrences_for_between(c, t_{curr} – 2*t_{eval}, t_{curr}-1) $\cup$ {o_{curr}}, *e61* is the IDV index of the controller.
I43	-0.4* *e39*, where *e39* is the occurrence severity.
I45	- *e62*/5, where *e62 is* the PDI value of the controller.
I13(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e60*, where *e60* is the total severity of the set of occurrences known_management_occurrences_for_between(c, $t_{curr} - t_{eval}$, t_{curr}-1) $\cup$ {o_{curr}}
I15(c, t_{curr}, t_{eval}, o_{curr})	- 0.5* *e62* * *e60*, where *e60* is the total severity of the set of occurrences, known_management_occurrences_for_between(c, $t_{curr} - t_{eval}$, t_{curr}-1) $\cup$ {o_{curr}} and *e62* is the PDI value of the controller
I54	-1
I55	-0.2**e6*, where e6 is the commitment to safety of the controller

Table 22: Probabilities of identification of different types of not reported occurrences by a team of controllers (p3) and by the management (p2)

Type of occurrence	p2	p3
A	0	0
B	0.1	0
C	0.3	0.2
E	0.7	0.4

Informal flows of control

If an occurrence of a controller has been also observed by another agent (e.g., by another controller or by the controllers supervisor) and afterwards no reporting by the controller followed, then

(1) A discussion between the agents observed the occurrence will follow and the first controller will re-evaluate his/her decision whether to report the occurrence, or

(2) The occurrence will be reported anonymously by the second controller, or

(3) No actions will be undertaken by the second controller.

If the controllers have a high maturity level w.r.t. ATC task, then the case (3) has a very low probability. Furthermore, according to the interviews the case (2) occurs rarely in teams of controllers. Thus, only the case (1) is considered in simulation. The informal flow of the case (1) occurs directly after the negative decision made on the reporting of an occurrence (i.e., after the process 'Making decision on the occurrence reporting').

In Figure 27 a part of the formal workflow that defines the execution of the safety occurrence reporting and the report handling task initiated by a controller extended with the informal flow of control of the case (1) is given. In the process of informal discussion of controllers at least two agents participate: the controller agent, in whose sector the occurrence happened and the agent, who also observed the occurrence (it can be a controller of an adjacent sector and/or a controller workmate (in a pair)). The duration of the informal discussion of controller task are defined as follows (subjective estimation): min: 2 min; max: 2 hours.

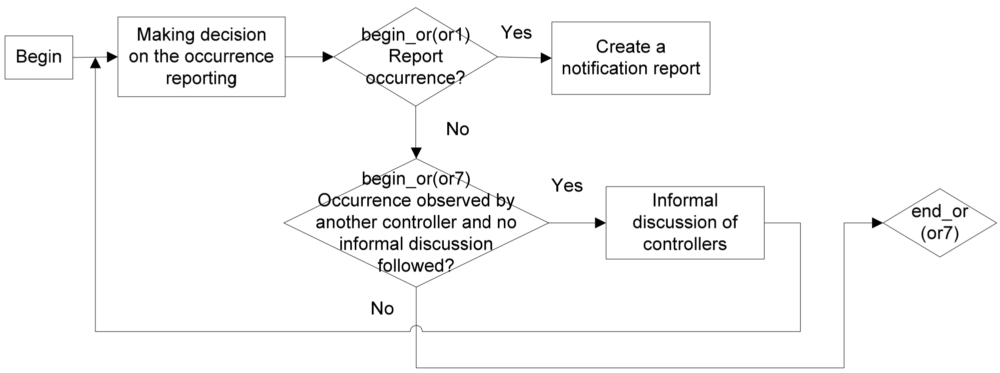

Figure 27: A part of the formal workflow that defines the execution of the safety occurrence reporting and the report handling task initiated by a controller extended with the informal flow of control of the case (1)

2.3.9 Step 16: Allocation principles of agents to organizational roles

Stable teams of controllers and teams with a variable composition will be considered in simulation. It is assumed that agents allocated to the roles in the organizational model possess all the necessary skills, however have variations in psychological characteristics.

2.3.10 Step 17: Identification of organizational constraints

For the purpose of this study the identification of organizational constraints is focused on safety culture. The constraints on a number of safety culture indicators have been identified (see Table 23) based on the list of safety culture issues (Sharpanskykh and Stroeve, 2008). Three aggregation levels for constraints are distinguished: the level of an individual controller, the level of a team of controllers, and the level of the whole organization. If the value of a safety culture indicator is evaluated as unsatisfactory (e.g., low), then more specific model parameters underlying this value can be identified using model-based reasoning techniques (e.g., backward propagation) based on the model. A satisfactory value for a safety culture indicator depends on the importance of the indicator for purpose of modelling, on the type of organization, on the specific organizational requirements. The satisfactory values for the safety indicators used in the simulations are defined in (Sharpanskykh and Stroeve, 2008b).

Table 23: Safety culture indicators monitored in simulations

Index	Safety Culture Indicator
I1.1/ I1.2/ I1.3	Reporting quality (ratio reported/observed) for controller (I1.1) / team (I1.2) / the whole organization (I1.3).
I2.1/ I2.2/ I2.3	Average quality of the processed notification reports produced by a controller (I2.1) / team of controllers (I2.2) / the whole organization (I2.3). By quality the correctness and completeness of information about the reported occurrence is understood.
I3.1/ I3.2/ I3.3	Average quality of the received final safety occurrence assessment reports for controller (I3.1) / team (I3.2) / the whole organization (I3.3). By quality of a received final safety occurrence assessment report the completeness of the occurrence report with respect to the identification of actual causes of the occurrence is understood. If no final safety occurrence assessment report for a reported occurrence has been received by a controller, then the quality of the received report is equal to 0.
I4.1 / I4.2/ I4.3	Average quality of the monthly safety overview reports received by a controller (I4.1) / team of controllers (I4.2) / the whole organization (I4.3). By quality of a monthly safety overview report the completeness of the report with respect to the identification of actual safety trends in the organization is understood. If some monthly safety overview report has been received by a controller, then the quality of the received monthly safety overview report for that month equals to 0.
I5.1 / I5.2	Commitment to safety of a controller (I5.1) / perceived commitment to safety of a team of controllers (I5.2).
I6	Perceived commitment to safety of supervisor.
I7	Perceived commitment to safety of management.
I8.1/ I8.2/ I8.3	Average value of the reprimand constituent in the force to report for a controller (I8.1) / team of controllers (I8.2) / the whole organization (I8.3). The reprimand constituent forms a part of the formula for the force to report an occurrence. It determines the degree by which the reporting force of a controller is reduced due to the disciplinary measures expected as a result of reporting.

The identified safety culture indicators can be used to detect safety culture vulnerabilities formulated as aggregates over the safety culture issues described in the report (Sharpahnskykh and Stroeve, 2008), as shown in Table 24. When one or more safety culture indicator(s) related to a safety culture vulnerability has a unsatisfactory value(s), then the likelihood of the vulnerability increases.

Table 24: Relations between safety culture indicators and safety culture vulnerabilities

Safety Culture Indicators	Safety culture vulnerability	Safety culture issues from the report D3
I3.1, I3.2, I3.3	Lack of feedback on reported occurrences decreases the controller’s motivation for further reporting	S1.2 Actors are not motivated to report their safety concerns because of the lack of feedback and interest experienced in the organisation. S1.6 The influence of occurrence reporting on the improvement of safety is not clear to individual human operators. S3.16 No feedback on reporting is received
I4.1, I4.2, I4.3, I3.1, I3.2, I3.3	Controllers lack knowledge about safety-related issues in the ANSP	S3.17 Feedback / lessons learned from incidents comes too late or not at all
I8.1, I8.2, I8.3	Disciplinary measures influence negatively occurrence reporting	S1.3 During analysis of more severe occurrences, the license of involved controller(s) may be temporarily retracted. S1.4 Fear of prosecution may lead to some reservation to formal (written) occurrence reporting and a preference for informal (oral) reporting. S2.4 Actors avoid informal discussion of problems with their peers, since it may lead to (unfavourable) consequences. S3.19 Lack of consistency about disciplinary measures for incidents. S3.20 In some countries controllers may get a financial penalty if they are involved in a safety occurrence. S3.21 Controllers do not receive acknowledgement for reporting. S4.11 The Ministry of Justice may decide to investigate (severe) occurrences and decide to prosecute involved organisations or human operators. In investigation and prosecution, occurrence reports may be used.
I5.1	Mediocre commitment to safety of a controller	S1.14 Not all organisational actors recognize their responsibility for safety.
I5.2	A group has a negative influence on reporting of a controller	S1.5 In some exceptional cases, it may be that shame and peer pressure is a reason for not reporting. S2.2 Fixed teams may have a negative effect on reporting (peer loyalty).
I5.2	A group has a negative influence on attitude to safety of a controller	S2.8 Safe behaviour is not encouraged (e.g., neutral attitude) by a team.

Safety Culture Indicators	Safety culture vulnerability	Safety culture issues from the report D3
I7	Commitment to safety of management is not trusted by a controller	S1.8 Actors do not report some minor occurrences because they consider that there is no enough staff to process these reports. S1.15 Organisational actors may question the safety commitment or safety improvement strategy of managers (not known, outward appearance of the commitment).
I1.1, I1.2, I1.3 (for insignificant occurrences)	Low motivation to report insignificant occurrences	S1.10 Actors do not recognize minor occurrences as important to report. S1.11 Actors consider that they are not supposed to report minor occurrences.
I1.1, I1.2, I1.3 (for significant occurrences)	Low motivation to report significant occurrences	S1.13 Older controllers are less disposed towards safety occurrence reporting than younger ones.
I1.1, I1.2, I1.3, I2.1, I2.1, I2.1	The organizational learning is impaired due to mediocre occurrence reporting	S4.13 Union has information about incidents, but does not want to share.
I6	Controllers supervisor does not reinforce safety culture	S2.9 Supervisors may not effectively reinforce safety culture

2.3.11 Step 18: Specification of environmental dynamics

In the simulation 6 sectors are considered, for each of which two controllers roles are allocated. In the simulation, as in reality, controllers work in shifts. A shift consists of three sessions. The duration of each session is 1 hour. After each session the obligatory break follows, which lasts for 1 hour. During a break the controllers are physically located in the same space, which enables their informal discussions of occurrences observed and other safety issues. The simulation time is 3 years (12 operational hours per day). The overall number of controllers agents is 48. Two team settings are considered: (1) stable teams of controllers (within a shift); (2) varying teams of controllers (within a shift). It will be investigated how the setting of a team influences the values of the identified safety performance indicators.

The frequencies (or probabilities) of different types of occurrences used in the simulation are specified based on the Annual Safety Report 2007 of ANSP-3.

3 Initial simulation results

3.1 Specification of organizational settings

To investigate the properties of the developed model, the following nine types of organizations have been defined:

- *Setting 1*: Organization, which formally makes an appearance of a highly committed to safety organization, however the actual commitment is lower. Organization performs average control over activities of controllers and reprimands for occurrences.
- *Setting 2*: Organization, which formally makes an appearance of a highly committed to safety organization, however the actual commitment is lower. The control over activities of controllers is low and reprimands are given only for serious occurrences. Rewards are provided for reporting series of less severe occurrences.
- *Setting 3*: Formally committed organization, which puts substantial investments in safety. No reprimands are provided for occurrences, except for the class A.
- *Setting 4*: Formally committed organization, which puts substantial investments in safety. However, the quality of management of safety activities is low. No reprimands are provided for occurrences, except for the class A.
- *Setting 5*: Formally committed organization which puts substantial investments in safety. Organization performs close control over activities of controllers and reprimands for occurrences.
- *Setting 5a*: Formally committed organization which puts substantial investments in safety. Organization performs close control over activities of controllers and reprimands for occurrences. Influence of controllers on safety arrangements is high.
- *Setting 6*: Organization, which formally makes an appearance of a committed to safety organization, however the actual commitment is much lower. Organization performs close control over activities of controllers and reprimands for occurrences.
- *Setting 6a*: Organization has low commitment to safety and makes low investment in safety. Organization performs close control over activities of controllers and reprimands for occurrences.
- *Setting 7*: Organization has low commitment to safety and makes low investment in safety. No reprimands are provided for occurrences, except for the class A, and control over the activities of controllers is not strict.

Table 25 shows a number of organizational aspects, which are characterized by qualitative labels (i.e., ‘high’, ‘average’, ‘low’). Table 30 in Appendix A shows the specific settings of the model for these qualitative labels.

Table 25: Organizational types used in simulations

Organizational aspect	*Setting 1*	*Setting 2*	*Setting 3*	*Setting 4*	*Setting 5*	*Setting 5a*	*Setting 6*	*Setting 6a*	*Setting 7*
Formal commitment to safety	high	high	high	high	high	high	average	low	low
Investment in personnel	average	average	high	high	high	high	low	low	low
Quality of technical systems	average	average	high	high	high	high	average	average	average
Formal support for confidentiality of reporting	average	average	high	high	high	high	low	low	low
Quality of management of safety activities	low	low	high	low	high	high	low	low	low
Personal consequences of occurrences	high	average	low	low	high	high	high	high	low
Personal rewards for reporting	none	high	none	none	none	none	none	none	none
Influence of a controller on organizational safety arrangements	low	low	high	high	average	high	low	low	low
Quality of identification of occurrences	average	low	low	low	high	high	high	high	low

3.2 Simulation results for organizational settings

In this series of experiments relatively homogeneous sets of controllers agents are used in the contexts of an Eastern European ANSP and of a Western European ANSP. Furthermore, the supervisors of different shifts of the ANSPs implement goals and norms of the organization in the same way. The aim of this study is to investigate different aspects of the safety reporting culture at the organizational level in both cultural contexts. For such analysis the identified set of organizational safety culture indicators is used.

Table 26 and Table 27 show the simulation results for the safety culture indicators in the variety of organizational settings defined in Section 3.1 for an Eastern and Western European ANSP, respectively. For three organizational settings variable as well as stable shift compositions are evaluated, for the remainder stable shifts are used. Next we discuss the main results.

It follows from the simulation results that the formal reward/reprimand system of an ANSP has a noticeable impact on reporting. In particular, the results for setting 5a versus setting 3 show that the introduction of reprimands and of a close control over activities of controllers in the ANSP's that are committed to safety, causes a notable decrease in the reporting quality (ratio of reported versus observed occurrences) in both cultures. On the contrary, it follows from a comparison of the results of setting 6a versus setting 7, that in organizations with little commitment to and investments in safety there is a significant increase in reporting quality as results of reprimands and a close control over controller agents. In such organizations these measures thus could be considered as instruments to make controller agents report (forcedly).

It can be observed in Table 26 and Table 27 that in general, the controllers in the Eastern European ANSP are more sensible to changes of the organizational settings than the controllers in the Western European ANSP. This is reflected in greater deviations of the reporting quality among different organizational settings in the Eastern European case. It may be explained by a higher dependence of the Eastern European controller agents on the behaviour and values of their peers within a shift and in relation to the management.

The quality of the processed notification reports produced depends greatly in both cultures on the quality of technical systems used by controllers and on investment in personnel. Furthermore, in the Western European ANSP the degree of influence of controllers on organizational safety arrangements has a notable impact on the quality of the processed notification reports (settings 1, 2, 5). Moreover, in both cultures the controllers tend to decrease the quality of notification reports (e.g., by holding back from informing some relevant details) in the conditions of high personal consequences of occurrences. The lowest quality of notification reports occurs in simulations of an Eastern European ANSP with a low commitment to and investment in safety and in personnel.

The quality of the feedback (received final safety occurrence assessment report) is almost the same for both cultures. Furthermore, according to the simulation, the quality of the feedback is not a determining factor for the controller's decision to report; this factor has an effect when it is combined with other factors (for example, as in settings 6 and 7).

The quality of the received monthly safety overview reports depends in both cultures mostly on the investment in personnel and on the quality of management of safety activities. Also, a positive correlation between the reporting quality and the quality of the received monthly safety overview reports can be observed in the simulation results.

As can be seen from the simulation results, the controller's commitment to safety in both cultures is influenced greatly by the perceived actual organizational commitment to safety. Furthermore, quality of management of safety activities has a little impact on the controller's commitment in both cultures. The controller's commitment to safety in the Western European culture is influenced notably by the perceived controller's influence on organizational safety arrangements (for example, see setting 3). The commitment of controllers in the Eastern European ANSP is influenced by the ANSP's reward/reprimand system and by the quality of identification of occurrences (for example, see setting 2) (a similar dependence has not been confirmed for the Western European ANSP). The organizational commitment to safety has a greater impact on the safety commitment of controllers in the Eastern European culture than in the Western European culture. The perceived commitment to safety of management is almost the same for the controllers in both cultural contexts.

It has been established that varying shift composition has almost no effect on the values of safety culture indicators in ANSPs committed to safety (settings 1-5). This can be explained partially by a high homogeneity of the controllers agents used in the simulations. However, in Eastern European organizations with low commitment and low investments to/in safety, a positive effect of the varying shift composition on reporting is more visible (settings 6 and 7). A possible explanation is that the shift influence (e.g., negative attitude to reporting) on a controller in the varying setting is lower in comparison with the stable setting. Almost no effect of the varying shift composition on the controllers in the Western European ANSPs has been observed.

Table 26: The values of the safety culture indicators (means) for an ANSP from the Eastern European culture

	Setting 1		*Setting 2*	*Setting 3*	*Setting 4*	*Setting 5*	*Setting 5a*	*Setting 6a*	*Setting 6*		*Setting 7*	
Stability of shifts of controllers	stable	var.	stable	stable	stable	stable	stable	stable	stable	var.	stable	var.
Safety culture indicator												
Reporting quality (ratio reported/observed)	0.67	0.66	0.82	0.86	0.85	0.77	0.77	0.45	0.46	0.51	0.20	0.26
Average quality of the produced processed notification reports	0.44	0.43	0.53	0.73	0.72	0.67	0.67	0.24	0.26	0.27	0.11	0.13
Average quality of the feedback (received final safety occurrence assessment reports)	0.19	0.19	0.18	0.5	0.33	0.51	0.5	0.07	0.07	0.07	0.07	0.07
Average quality of the received monthly safety overview reports	0.48	0.48	0.49	0.86	0.69	0.86	0.86	0.33	0.33	0.34	0.32	0.33
Average commitment to safety	0.60	0.60	0.65	0.74	0.72	0.7	0.73	0.37	0.48	0.49	0.36	0.37
Average perceived commitment to safety of management	0.54	0.55	0.55	0.79	0.73	0.74	0.77	0.25	0.38	0.38	0.25	0.25
Average value of the reprimand constituent in the force to report	0.14	0.14	0.11	0.07	0.07	0.14	0.14	0.14	0.14	0.14	0.07	0.07

Table 27: The values of the safety culture indicators (means) for an ANSP from the Western European culture

	Setting 1		*Setting 2*	*Setting 3*	*Setting 4*	*Setting 5*	*Setting 5a*	*Setting 6a*	*Setting 6*		*Setting 7*	
Stability of shifts of controllers	stable	var.	stable	stable	stable	stable	stable	stable	stable	var.	stable	var.
Safety culture indicator												
Reporting quality (ratio reported/observed)	0.77	0.77	0.87	0.9	0.9	0.77	0.78	0.43	0.49	0.5	0.37	0.36
Average quality of the produced processed notification reports	0.5	0.5	0.56	0.77	0.76	0.67	0.68	0.23	0.27	0.28	0.20	0.19
Average quality of the feedback (received final safety occurrence assessment reports)	0.18	0.18	0.19	0.5	0.34	0.5	0.5	0.07	0.08	0.08	0.07	0.07
Average quality of the received monthly safety overview reports	0.48	0.48	0.48	0.86	0.69	0.86	0.86	0.33	0.34	0.34	0.33	0.33
Average commitment to safety	0.5	0.5	0.5	0.68	0.67	0.61	0.68	0.37	0.43	0.43	0.37	0.37
Average perceived commitment to safety of management	0.55	0.55	0.54	0.77	0.73	0.74	0.77	0.25	0.39	0.39	0.25	0.25
Average value of the reprimand constituent in the force to report	0.14	0.14	0.11	0.07	0.07	0.14	0.14	0.14	0.14	0.14	0.07	0.07

3.3 Simulation of effect of stringency of supervisor

According to (Ek et al., 2007) and the interviews, supervisors differ in the realization of organizational goals and policies. The implementation of organizational norms and rules within shifts of controllers by supervisors and its influence on the reporting behaviour of controllers is considered in this experiment series. The simulations have been performed using setting 1. Within this setting, the supervisor agent 1 for shifts 1 and 2 performs a stricter control over the activities of controllers and initiates reprimands for both serious occurrences and for series of insignificant occurrences (the factor 'Personal consequences of occurrences' from Table 30 is high), whereas the supervisor agent 2 for shifts 3 and 4 is less strict in control and initiates reprimands for serious occurrences only (the factor 'Personal consequences of occurrences' from Table 30 is average). For each cultural context 100 simulation trials have been performed. The reporting of insignificant safety occurrences is investigated in more detail, since reporting of such type of occurrences is often neglected in reality (according to interviews).

As can be seen in Figure 28 and Figure 29, the force to report fluctuates less after the first month in the Eastern ANSP. To some degree this can be seen as an effect of the strongly pronounced collectivity of this culture. Further, in both cultures with stable shifts a stricter control and reprimands (shift 1) result in a better reporting (see Table 31), although the force is more negative than in the less strict case (shift 4) (see Figure 28 and Figure 29). Note that the difference in the quality of reporting is greater for the Eastern culture (0.13).

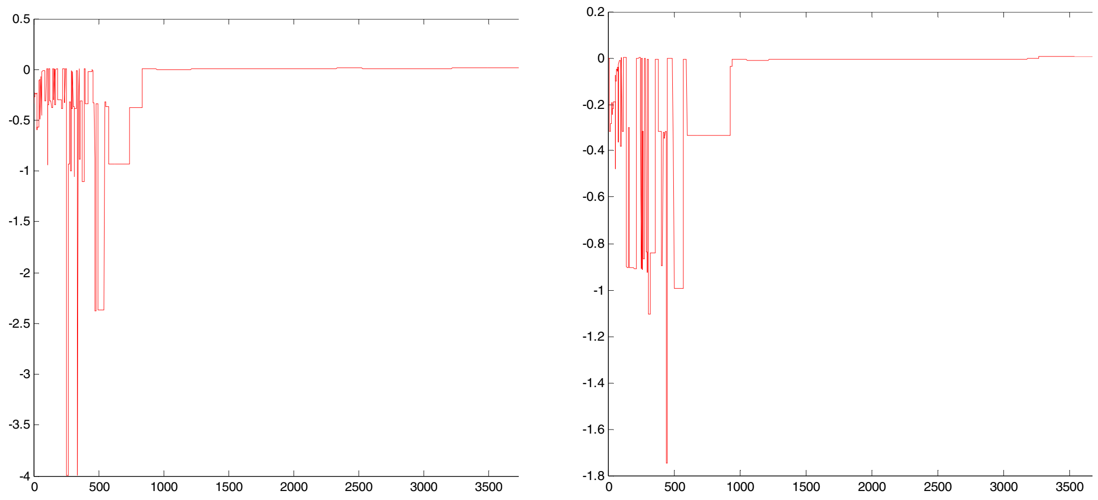

Figure 28: Force as function of time (hr) to report insignificant occurrence in a shift with a strict supervisor (left) and a shift with a loose supervisor (right) of an Eastern European ANSP.

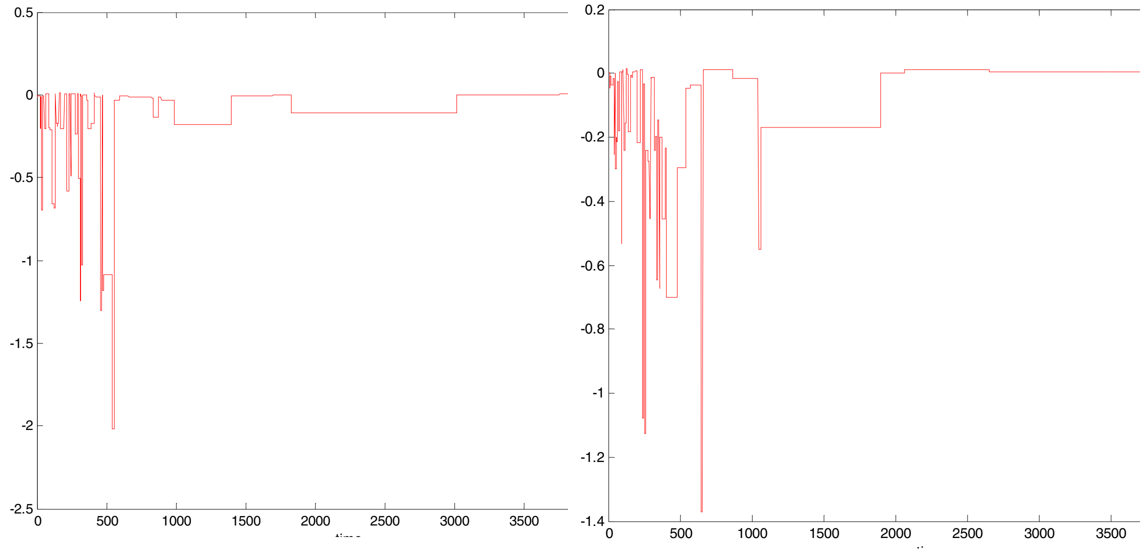

Figure 29: Force as function of time (hr) to report insignificant occurrence in a shift with a strict supervisor (left) and a shift with a loose supervisor (right) of a Western European ANSP.

In the setting with variable shifts (new agent allocation every day) no significant difference of the reporting quality among the shifts has been identified. However, the overall reporting quality in the Eastern European ANSP drops by 5% compared to the stable shifts situation (1.5% decrease in the Western European ANSP). From this a high sensitivity of the reporting quality in Eastern European ANSPs to the shift composition can be presumed.

Table 28: Reporting quality (mean) for insignificant occurrences in stable or varying shifts with strict or loose supervisors in the Eastern and Western European cultures.

ANSP's context	*Stable shifts*		*Varying shifts*	
	Strict supervisor	*Loose supervisor*	*Strict supervisor*	*Loose supervisor*
Eastern European culture	0.56	0.43	0.46	0.45
Western European culture	0.61	0.56	0.58	0.56

4 Concluding remarks

James Reason once said that ‘safety culture has the definitional precision of a cloud.’ Although currently a considerable amount of work has been done to characterize safety culture via survey studies, the causal relations with organizational processes and their effect on risk are in general still vague. We have shown in this reports that it is possible to systematically develop models that account for a large variety of organizational aspects, thus providing a different and structured view on safety culture from the perspective of the formal organization in relation with the variable behaviour of agents in it. Such modelling provides the opportunity of new understandings of organizational effects on operational safety and the structured development of policies for improvement of safety culture. The development of the model has been done on the basis of data from Eurocontrol’s SCMT as well as specific organizational data of ANSP-3. Preliminary model results provide remarkable insights in potential relations between the quality of occurrence reporting and organizational factors at an ANSP. In a separate report a validation plan for the model has been developed (Sharpanskykh and Stroeve, 2008b). The planned validation study will show whether these types of results can be substantiated by the SCMT data of ANSP-3.

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Appendix A Model details

Table 29: Overview of variables in the agent-based organizational model.

Variable	Description	Type	Value
e1	Priority of safety-related goals in the role description	Input	Table 30
e2	Perception of the commitment to safety of management	State	-
e3	Perception of commitment to safety of team	State	-
e4	Influence degree of controllers on safety arrangements	Input	Table 30
e5	Maturity level w.r.t. ATC task	State	-
e6	Commitment of safety of a controller	State	-
e7	Sufficiency of amount of safety investigators	Input	Table 30
e8	Sufficiency of the amount of controllers	Input	Table 30
e9	Availability of reliable and ergonomic technical systems for controllers	Input	Table 30
e10	Sufficiency and timeliness of training for changes	Input	Table 30
e11	Regularity of safety meetings	Input	Table 30
e12	Developed and implemented SMS	Input	Table 30
e13	Commitment to safety of the supervisor	State	-
e14	Level of development of managerial skills	Input	Table 30
e15	Quality of a processed notification report	State	-
e16	Information contribution from others	State	-
e17	Quality of technical systems	State	-
e18	Acceptability of the workload level	State	-
e19	Self-confidence for ATC task	State	-
e20	Commitment to perform ATC task	Input	Table 10
e21	Development level of skills for ATC task	Input	Table 10
e22	Adequacy of knowledge about safety issues	State	-
e23	Adequacy of mental models for ATC task	State	-
e25	Sufficiency of the amount of maintenance personnel	Input	Table 30
e26	Quality of formal procedures for system checks and repairs	Input	Table 30
e27	Amount of knowledge on similar safety-related issues of a controller	State	-
e28	Amount of knowledge on similar safety-related issues of the supervisor	State	-
e29	Information contribution by a controller	State	-
e30	Information contribution by the supervisor	State	-
e31	Quality of input data	State	-
e32	Quality of safety analysis	State	-
e33	Quality of a monthly safety overview report	State	-
e34	Contribution of informal discussion of controllers in the team	State	-
e35	Intensity of informal interactions in the team of controllers	State	-
e36	Quality of the formal occurrence assessment procedure	Input	Table 30
e37	Amount of knowledge on similar safety-related issues in the organization	State	-
e38	Quality of the final safety occurrence assessment report	State	-
e39	Severity of an occurrence	Input	Table 14
e40	Quality of the communication channel between controllers and safety investigators	Input	Table 30
e41	Average commitment to safety of team members	State	-
e42	Average quality of the received final safety occurrence assessment reports	State	-

Variable	Description	Type	Value
e43	Average quality of the received monthly safety overview reports	State	-
e44	Average commitment to safety of the agents involved in safety analysis	State	-
e45	Average contribution of informal discussions of controllers in team	State	-
e46	Average quality of processed notification reports	State	-
e47	Average quality of previous monthly overview reports	State	-
e48	Average quality of the notification reports produced by the team	State	
e49	Average quality of the received monthly safety overview reports	State	-
e50	Average commitment to safety of the participants of the meeting	State	-
e51-e56	Not defined		
e57	Perception of the positive attitude to reporting in a team	State	-
e59	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)	State	-
e60	Total severity of a set of occurrences of the controller occurred during the evaluation time interval, which are known to the management	State	-
e61	Individualism (IDV) index of a controller	Input	Table 12
e62	Power Distance Index (PDI) of a controller	Input	Table 12
e63	Masculinity (MAS) index of a controller	Input	Table 12
e64	Uncertainty Avoidance Index (UAI) of a controller	Input	Table 12
e65	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	State	-
e66	Perception of the confidentiality of reporting	State	-
e67	Perceived severity of the provided reprimand	State	-
e68	Perceived amount of the provided reward	State	-
e69	not defined		
e70	Average perceived degree of influence of controllers on safety arrangements	State	-

Table 30: Relations between the qualitative labels used for specifying the organizational types and corresponding numerical values

	Organizational aspect	low	average	high
O.1	Formal commitment to safety	$e1 \in [0, 0.4)$ $e36 \in [0, 0.3)$ $e12 \in [0, 0.4)$	$e1 \in [0.4, 0.8)$ $e36 \in [0.3, 0.7)$ $e12 \in [0.4, 0.8)$	$e1 \in [0.8, 1]$ $e36 \in [0.7, 1]$ $e12 \in [0.8, 1]$
O.2	Investment in personnel	$e7 \in [0, 0.3)$ $e10 \in [0, 0.3)$ $e8 \in [0, 0.4)$	$e7 \in [0.3, 0.8)$ $e10 \in [0.3, 0.7)$ $e8 \in [0.4, 0.8)$	$e7 \in [0.8, 1]$ $e10 \in [0.7, 1]$ $e8 \in [0.8, 1]$

	Organizational aspect	low	average	high
O.3	Quality of technical systems	e9 ∈ [0, 0.3) e26 ∈ [0, 0.4) e25 ∈ [0, 0.3)	e9 ∈ [0.3, 0.7) e26 ∈ [0.4, 0.8) e25 ∈ [0.3, 0.8)	e9 ∈ [0.7, 1] e26 ∈ [0.8, 1] e25 ∈ [0.8, 1]
O.4	Formal support for confidentiality of reporting	e71 ∈ [0, 0.4)	e71 ∈ [0.4, 0.8)	e71 ∈ [0.8, 1]
O.5	Quality of management of safety activities	e11 ∈ [0, 0.2) e44 ∈ [0, 0.4) e40 ∈ [0, 0.4)	e11 ∈ [0.2, 0.6) e44 ∈ [0.4, 0.8) e40 ∈ [0.4, 0.8)	e11 ∈ [0.6, 1] e44 ∈ [0.8, 1] e40 ∈ [0.8, 1]
O.6	Influence of a controller on organizational safety arrangements	e4 ∈ [0, 0.3)	e4 ∈ [0.3, 0.7)	e4 ∈ [0.7, 1]
O.7	Quality of identification of occurrences	*for type B:* p2 ∈ [0.2, 0.3) p3 ∈ [0.2, 0.3) *for type C:* p2 ∈ [0.5, 0.6) p3 ∈ [0.4, 0.5) *for others:* p2 ∈ [0.8, 1] p3 ∈ [0.7, 1]	*for type B:* p2 ∈ [0.1, 0.2) p3 ∈ [0.1, 0.2) *for type C:* p2 ∈ [0.3, 0.5) p3 ∈ [0.2, 0.4) *for others:* p2 ∈ [0.5 ,0.8] p3 ∈ [0.4, 0.7]	*for type B:* p2 = 0 p3 = 0 *for type C:* p2 ∈ [0.1, 0.3) p3 ∈ [0.1, 0.2) *for others:* p2 ∈ [0.2 ,0.5] p3 ∈ [0.1, 0.4]
O.8	Personal consequences of occurrences	*for type A:* repr(1, A)=1	*for type A:* repr(1, A)=1 *for type B:* repr(1, B)=0.5	*for type A:* repr(1, A)=1 *for type B:* repr(1, B)=0.5 *for type C:* repr(2, C)=0.2 *for other:* repr(4, other)=0.1
O.9	Personal rewards for reporting	None	NA	*for type C:* rew(1, C)=0.1 *for other:* rew(1, other)=0.01
O.10	Stability of shifts of controllers	Varying shifts	NA	Stable shifts

Table 31: Standard values of the weights of the causal relations in the model.

Weight	Description	Value
w1	Contribution of e1 'Priority of safety-related goals in the role description' to e6 'Commitment to safety of a controller'	Table 13
w2	Contribution of e2 'Perception of the commitment to safety of management' to e6 'Commitment to safety of a controller'	Table 13
w3	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	Table 13
w4	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	Table 13

Weight	Description	Value
w5	Contribution of e5 ‘Influence degree of controllers on safety arrangements’ to e6 ‘Commitment to safety of a controller’	Table 13
w6	Contribution of e13 ‘the commitment of the supervisor to safety’ to e3 ‘Perception of commitment to safety of team’	0.05
w7	Contribution of e41 ‘Average commitment to safety of team members’ to e3 ‘Perception of commitment to safety of team’	0.05
w8	Contribution of e1 ‘Priority of safety-related goals in the role description’ to e2 ‘Perception of the commitment to safety of management’	0.2
w9	Contribution of e9 ‘Availability of up-to-date technical systems for controllers’ to e2 ‘Perception of the commitment to safety of management’	0.15
w10	Contribution of e70 ‘Average perceived influence degree of controllers on safety arrangements’ to e2 ‘Perception of the commitment to safety of management’	0.15
w11	Contribution of e10 ‘Sufficiency and timeliness of training for changes’ to e2 ‘Perception of the commitment to safety of management’	0.15
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’	0.2
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
w16	Contribution of e13 ‘the commitment of the supervisor to safety’ to e3 ‘Perception of commitment to safety of team’	Table 13
w17	Contribution of e41 ‘Average commitment to safety of team members’ to e3 ‘Perception of commitment to safety of team’	Table 13
w18	Contribution of e16 ‘Information contribution from others’ to e15 ‘Quality of a processed notification report’.	0.15
w19	Contribution of e5 ‘Maturity level w.r.t. ATC task’ to e15 ‘Quality of a processed notification report’.	0.2
w20	Contribution of e7 ‘Quality of technical systems’ to e15 ‘Quality of a processed notification report’.	0.3
w21	Contribution of e18 ‘Acceptability of the workload level’ to e15 ‘Quality of a processed notification report’.	0.35
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’.	0.6
w27	Contribution of e22 ‘Adequacy of knowledge about safety issues’ to e23 ‘Adequacy of mental models for ATC task’.	0.4
w28	Contribution of e42 ‘Average quality of the received final safety occurrence assessment reports’ to e22 ‘Adequacy of knowledge about safety issues’.	0.5

Weight	Description	Value
w29	Contribution of e43 ‘Average quality of the received monthly safety overview reports’ to e22 ‘Adequacy of knowledge about safety issues’.	0.5
w30	Contribution of e25 ‘Sufficiency of the amount of maintenance personnel’ to e17 ‘Quality of technical systems’.	0.4
w31	Contribution of e26 ‘Quality of formal procedures for system checks and repairs’ to e17 ‘Quality of technical systems’.	0.2
w32	Contribution of e9 ‘Availability of up-to-date technical systems for controllers’ to e17 ‘Quality of technical systems’.	0.4
w33	Contribution of e29 ‘Information contribution by a controller’ to e16 ‘Information contribution by others’.	0.7
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’.	0.3
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 iof 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
w41	not defined	
w42	Contribution of e7 ‘Sufficiency of the amount of safety investigators’ to e33 ‘Quality of a monthly safety overview report’.	0.35
w43	Contribution of e32 ‘Quality of safety analysis’ to e33 ‘Quality of a monthly safety overview report’.	0.65
w44	Contribution of e44 ‘Average commitment to safety of the agents involved in safety analysis’ to e32 ‘Quality of safety analysis’.	0.35
w45	Contribution of e31 ‘Quality of input data’ to e32 ‘Quality of safety analysis’.	0.65
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’.	0.6
w48	Contribution of e47 ‘Average quality of previous monthly safety overview reports’ to e31 ‘Quality of input data’.	0.1
w49	Contribution o9f e3 ‘Perceived commitment to safety of the team’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.25
w50	Contribution of e35 ‘Intensity of informal interactions in the team of controllers’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.25
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’.	0.25
w52	Contribution of e49 ‘Average quality of the received monthly safety overview reports’ to e34 ‘Contribution of informal discussions of controllers in the team’.	0.15

Weight	Description	Value
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 to safety of the participants of the meetings’ to e38 ‘Quality of the final safety occurrence assessment report’.	0.1
w55	Contribution of e7 ‘Sufficiency of the amount 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 amount of safey investigators’ to p1 ‘Probability of the feedback provision’.	0.4
w60	Contribution of e39 ‘Severity of an occurrence’ to p1 ‘Probability of the feedback provision’.	0.3
w61	Contribution of e40 ‘Quality of the communication channel between controllers and safety investigators’	0.3