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Executive summary

Safety modelling and analysis of organizational processes in air traffic - D6: Model evaluation and improvement

EUROCONTROL CARE Innovative Research III

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Problem area
Safety culture is broadly recognized as important for Air Traffic Management (ATM) safety 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. Previously we developed an agent-based organizational model for safety occurrence reporting at an Air Navigation Service Provider (ANSP) in relation to safety culture indicators.

Description of work
This report presents an evaluation and refinement of an agent-based organizational model of Western and Eastern European ANSPs. The evaluation is based on a sensitivity analysis, which provides insight into the influence of parameters and groups of parameters in the organizational model on the safety culture indicators in various contextual settings. The resulting improved generic model for a Western European ANSP has been combined with information of a specific Western-European ANSP (ANSP-3) to predict values and classes of its safety culture indicators.

Results and conclusions
Results of a model-based sensitivity analysis are presented for various safety culture indicators. On this basis, the organizational model has been updated and predictions of safety culture indicators for a specific ANSP are provided. In a follow-up study, the validity of these model results will be evaluated by comparison with results for ANSP-3 of the Eurocontrol Safety Culture Monitoring Tool (SCMT).

Applicability

This research supports the understanding of the impact of formal and informal organizational processes on safety culture.

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1 Introduction

It is the aim of this section to introduce the context and aim of the research presented in this report (Section 1.1), to provide a summary of previous research and explaining key features of the agent-based organizational model (Section 1.2), and to present the structure of this report (Section 1.3).

1.1 Context and aim

The importance of proper organizational processes to maintain the safety of complex operations is currently well realized. It is generally recognized 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). The recognition of the importance of organizational aspects for operational safety is reflected in the considerable number of publications on organizational and safety culture (e.g., Gordon et al., 2006; Mearns et al., 2008; Choudhry et al., 2007; Hopkins, 2006; Ek et al., 2007), and in plans of Eurocontrol, FAA and CANSO to see more and more ANSPs go through safety culture processes as a prelude to SESAR and NextGen.

The main aspects of organizational culture are clearly reflected in a definition by Uttal (1983): 'Shared values (what is important) and beliefs (how things work) that interact with a company's people, organizational structures and control systems to produce behavioral norms (the way we do things around here).' There exists a large variety of definitions of safety culture (Choudhry et al., 2007), we use the term safety culture as those aspects of organizational culture that may have an effect on safety. As such, the understanding of what is safety culture stems from understanding of the organizational culture and its effect on safety, in line with reasoning of Hopkins (2006).

Various studies have focused on characterization of safety culture and on assessment of safety culture of various organizations, including Air Navigation Service Providers (ANSPs). However, the links of safety culture with organizational structures and processes are not well understood yet and this affects the identification of ways to improve safety culture. As a way forward, the current research project aims 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 may provide a proper basis for understanding the causal relations between organizational processes that influence safety culture, such that robust and flexible policies may be identified to improve and maintain a sufficient level of safety culture in an organization.

As a basis for development and validation we coordinated our research efforts with safety culture research pursued at Eurocontrol Experimental Centre. In an effort to measure and understand safety culture at European ANSPs, Eurocontrol has been developing a Safety Culture Measurement Tool (SCMT) (Gordon et al., 2006; Mearns et al., 2008). The SCMT uses safety culture questionnaires with statements about potential enablers and disablers of safety culture in an ANSP, and employees are asked anonymously to indicate the applicability of these statements to their organization. Based on the aggregated results of the questionnaires, the SCMT uses workshops to analyse the key safety culture issues and to provide solutions for them. The tool has now been applied at several ANSPs.

1.2 Summary of previous research

In (Stroeve et al., 2007a,b,c) we reported about a suitable multi-agent organizational modelling method that was identified by a literature survey and applied in an air traffic case. In the continuation of the research (Sharpanskykh and Stroeve, 2008a,b; Sharpanskykh et al., 2008), the development of the model has been focused on safety occurrence reporting and its relation with safety culture at ANSPs. The agent-based organizational model is aimed to describe the emergence of safety culture vulnerabilities in relation to safety occurrence reporting in ANSPs' organizational contexts. Next, Section 1.2.1 summarizes safety culture issues identified in (Sharpanskykh and Stroeve, 2008a), Section 1.2.2 presents key features of the agent-based organizational model developed in (Sharpanskykh et al., 2008) and Section 1.2.3 presents safety culture indicators that can be observed as output in simulations of the model.

1.2.1 Identification of safety culture issues

To identify safety culture aspects relevant for the occurrence reporting, SCMT results of two ANSP's (ANSP-1, ANSP-2) and safety culture data from the literature have been analysed, and interviews have been conducted with experts at Eurocontrol Head Quarters and at a third ANSP (ANSP-3). As result of this analysis, a categorised set of safety culture issues that impact safety occurrence reporting has been determined (Sharpanskykh and Stroeve, 2008a). Figure 1 shows the categorization of factors that influence occurrence reporting. 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 (e.g. a team of air traffic controllers);
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).

These safety culture issues form a basis for the development of the agent-based organizational model, which is described concisely in the next section.

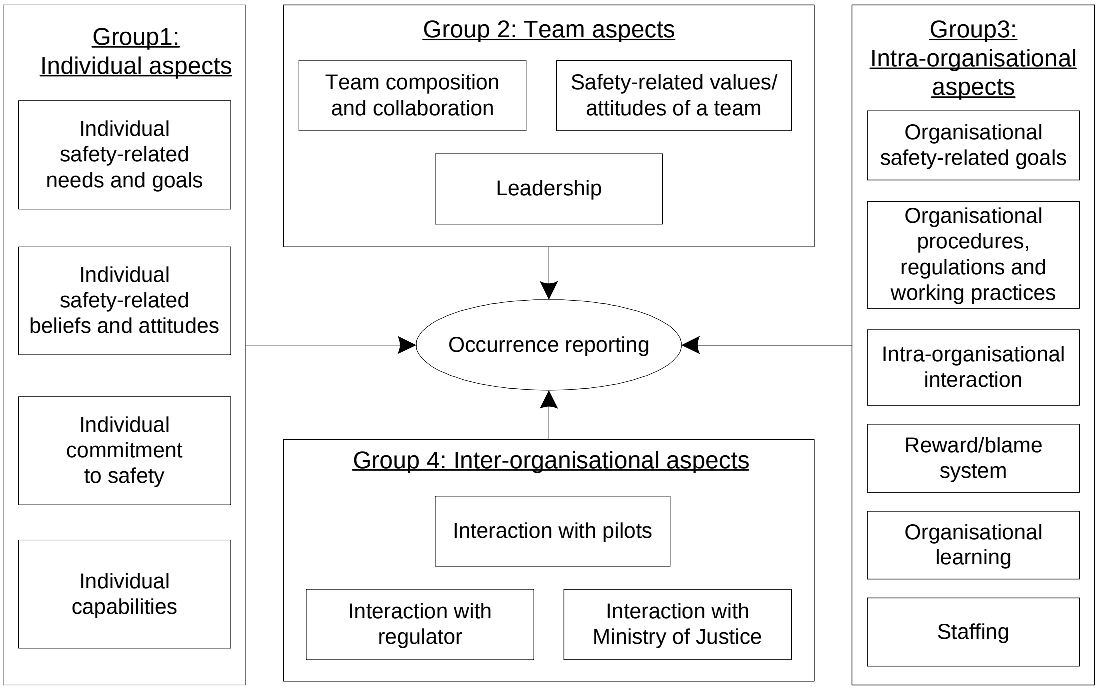


Figure 1: Identified groups of aspects that influence safety occurrence reporting.

1.2.2 Agent-based model for occurrence reporting

The development of the agent-based organizational model has been done in a number of steps for (A) specification of the formal organization and (B) the characteristics and autonomous behaviour of organizational agents. To account for the large variety of organizational and behavioural aspects addressed within these steps, a variety of modelling methods is used within these steps, including graph theory, predicate logic-based modelling and analysis (Sharpanskykh, 2008), constraint-based modelling (Fruhwirth and Abdennadher, 2003), social networks methods (Scott, 2000) and causal networks (Pearl, 2000). Details of the developed model are provided in (Sharpanskykh et al., 2008), the steps in phases (A) and (B) are concisely presented next.

(A) Specification of the formal organization

The formal organization has been specified along the following eight steps.

Step 1. The identification of the organizational roles
A role is a (sub-)set of functionalities of an organization, which are abstracted from specific agents who fulfil them and which can be decomposed at varying aggregation levels. Examples of roles in the model are Safety Investigation Unit, Safety manager, Controller, Supervisor, and Safety Recommendations and Concerns Group.

Step 2. The specification of the interactions between the roles
Relations between roles are represented by interaction and inter-level links at the same and different aggregation levels, respectively.

Step 3. The identification of the requirements for the roles
Requirements on knowledge, skills and personal traits of the agent implementing a role at the lowest aggregation level are identified.

Step 4. The identification of the organizational performance indicators and goals
Goals are objectives that describe a desired state or development of the company, unit or individual. Performance indicators are quantitative or qualitative indicators that reflects the state with respect to a goal.

Step 5. The specification of the resources
Organizational resources such as tools, supplies, components and digital artefacts are defined.

Step 6. The identification of the tasks and relations between the tasks, the resources and the goals
A structured task decomposition is provided for the functions performed in the organization. Each task is linked to the satisfaction of one or more goals.

Step 7. The specification of the authority relations

The following types of authority relations are distinguished: superior-subordinate relations on roles with respect to tasks, responsibility relations, control for resources, and authorization relations. Roles may have different rights and responsibilities with respect to different aspects of task execution, such as execution, passive monitoring, consulting, making technological and managerial decisions.

Step 8. The specification of the workflows

Workflows describe temporal ordering of processes of an organization in particular scenarios. As an example, Figure 2 describes the execution of the formal occurrence reporting initiated by a controller.

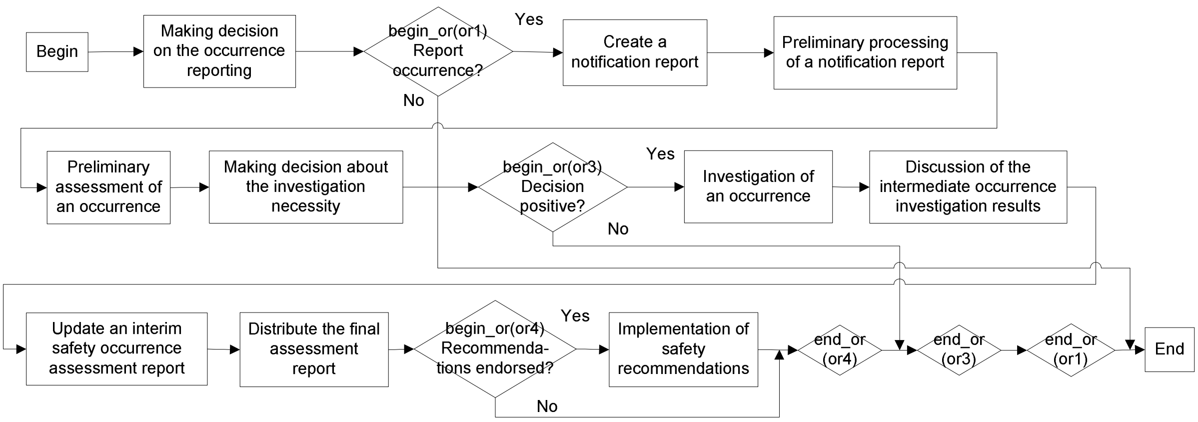


Figure 2: The workflow for formal occurrence reporting.

(B) Specification of Agents

The behaviour of an agent can be considered from external and internal perspectives. From an external perspective, 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). From an internal perspective, the behaviour of the agent is characterized by a specification of causal (temporal) relations between mental (or cognitive) states of the agent, leading to externally observable behavioural patterns. To model internal dynamics of agents, an approach based on causal networks has been used in this study (Pearl, 2000; Sharpanskykh, 2008). Below, some details of the steps for the specification of the agent-based view are presented.

Step 9. Identification of types and characteristics (skills, psychological and cognitive characteristics) of agents

In the model the following agent types have been introduced: controller, supervisor, safety officer, safety investigator, safety manager and occurrence manager. The number of agent instances for these types range from one (e.g. occurrence manager) to 48 (controller). National culture is known to have important influences on agents' priorities of needs, values, attitudes and behaviour (Hofstede, 2005). In the model we use Hofstede's dimensions of a national culture: power distance index, individualism, masculinity, and uncertainty avoidance index.

Step 10. Identification of goals and needs of agents

High level goals of individuals depend on their needs. In the model the following needs of the agent controllers are considered:

(1) Extrinsic needs, which are associated with biological comfort and material rewards;
(2) Social interaction needs, which refer to the desire for social approval and affiliation: the needs for social approval from both his/her own group and from the management;
(3) Intrinsic needs, which concern the desires for self-development and self-actualization.

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 external aspects (e.g., group attitudes, availability of resources) (Pinder, 1998). The identified goals and needs play a role in the decision making model described below in step 15.

Step 11. Identification of commitments, obligations and responsibilities of agents

Commitment to safety of controllers may be influenced by a variety of aspects, such as job description, perceived degree of influence on safety, controller's maturity level (Hersey et al., 2001), as well as the commitment observed by an agent if a group or management (Burt, 1987). As an example, Figure 3 shows the causal network for "Commitment to safety of a controller". For each controller agent a variable e6 is defined, which value reflects the degree of evidence of the state. This agent state depends on other states e_i of the organizational model via weights w_j, which express the strength of the causal relations. These other states may be input variables (rounded boxes) or they may be the result of other causal networks (square boxes). As an example, Figure 4 shows the causal network for e2 'Perception of commitment to safety of management', which is input for the causal network of Figure 3.

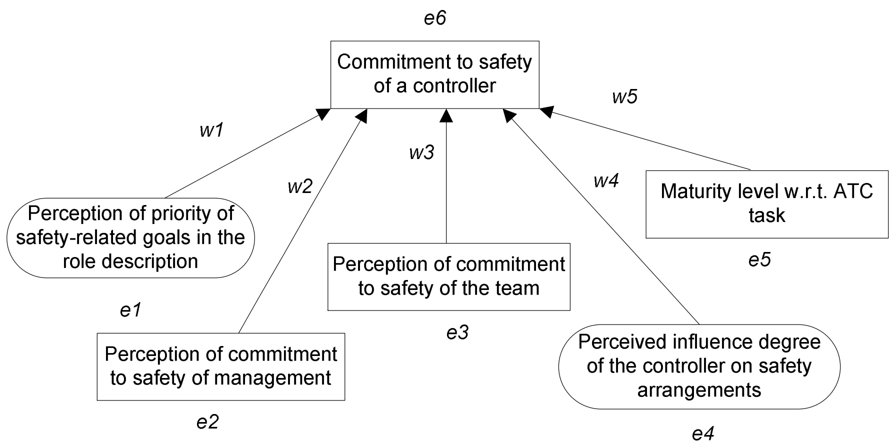


Figure 3: Causal network for commitment to safety of a controller

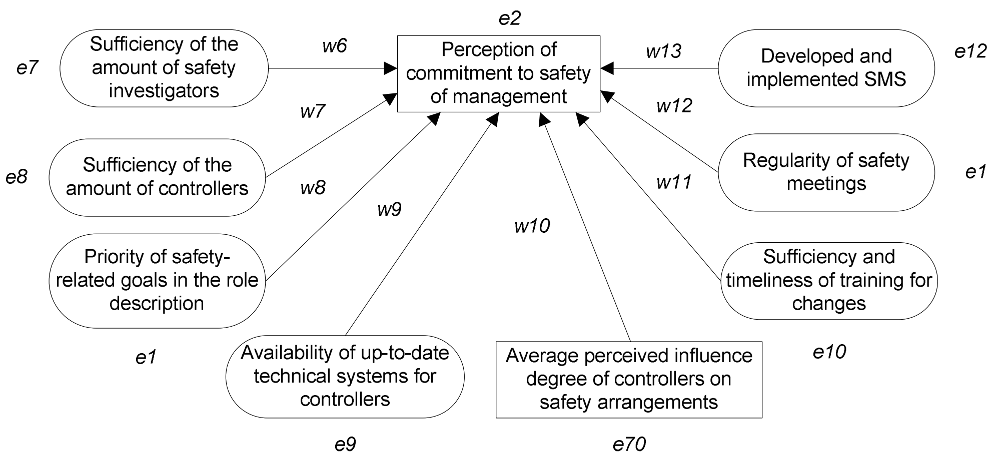


Figure 4: Causal network for perception of commitment to safety of management

Step 12. Identification of attitudes and beliefs of agents

Agents create time-labelled internal representations (beliefs) about their observations, actions and communications. Agents may create beliefs about observed single states (e.g., a notification report is created, an occurrence is reported) and about dependencies between observed states. For example, an agent controller forms the belief about the dependency between providing of a notification report on an occurrence of some type to his/her supervisor and receiving a final assessment report on the occurrence (i.e., feedback) from a safety investigator agent.

Step 13. Identification of relations between agents and informal structures of agents

To model informal interaction relations of controllers the social contagion theory of Burt has been used (Burt, 1987). According to this theory, the intensity of informal communication between the agents is influenced positively by (1) similarity of the communication patterns of the roles of the agents; (2) equality of the statuses of the roles of the agents in the organization; (3) physical possibilities to communicate; (4) degree of acquaintance of the agents with each other. In the model informal interaction relations enhance the knowledge of controllers about safety-related issues and occurrences, and may contribute to the proactive identification of issues by the controllers.

Step 14. Identification of shared beliefs, attitudes, norms and values of (groups of) agents

Teams with intensive informal communication tend to have essential control over attitudes and actions of their members (Burt, 1987). The degree of control depends on the types of national culture and of organizational culture, and on the maturity level of the members w.r.t. their work. To evaluate the degree of a positive attitude to reporting in a team an indirect indicator is used: the average force to report an occurrence calculated over all members of the team over time (see also Step 15 next).

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

The performance variability of occurrence reporting processes is modelled using causal networks quality of a processed notification report, quality of a monthly safety overview report and quality of a final safety occurrence assessment report, and by a controller decision making model. The decision making of an agent controller whether to report an occurrence is modelled on the basis of Vroom's expectancy theory (Pinder, 1998), which involves reasoning about own needs, capabilities and experiences, about the surrounding formal organization and (informal) social structures and processes. According to Vroom's expectancy theory, when an individual evaluates alternative possibilities to act, s/he makes estimations for the following factors: expectancy (E's), instrumentality (I's), and valence (V's) (see Figure 5). Expectancy refers to the individual's belief about the likelihood that a particular act will be followed by a particular outcome. For example, E12 is the expectancy that the act 'report an occurrence' will result in an administrative reprimand. 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. For example, I32 is the instrumentality that own group appreciation of the action will result into own group approval. Valence refers to the strength of the individual's desire for an outcome or state of affairs. For example, V3 is the valence of the controller's management approval needs. In the model, values of expectancies, instrumentalities and valences change over time, and they impact the agents' decisions to report an occurrence.

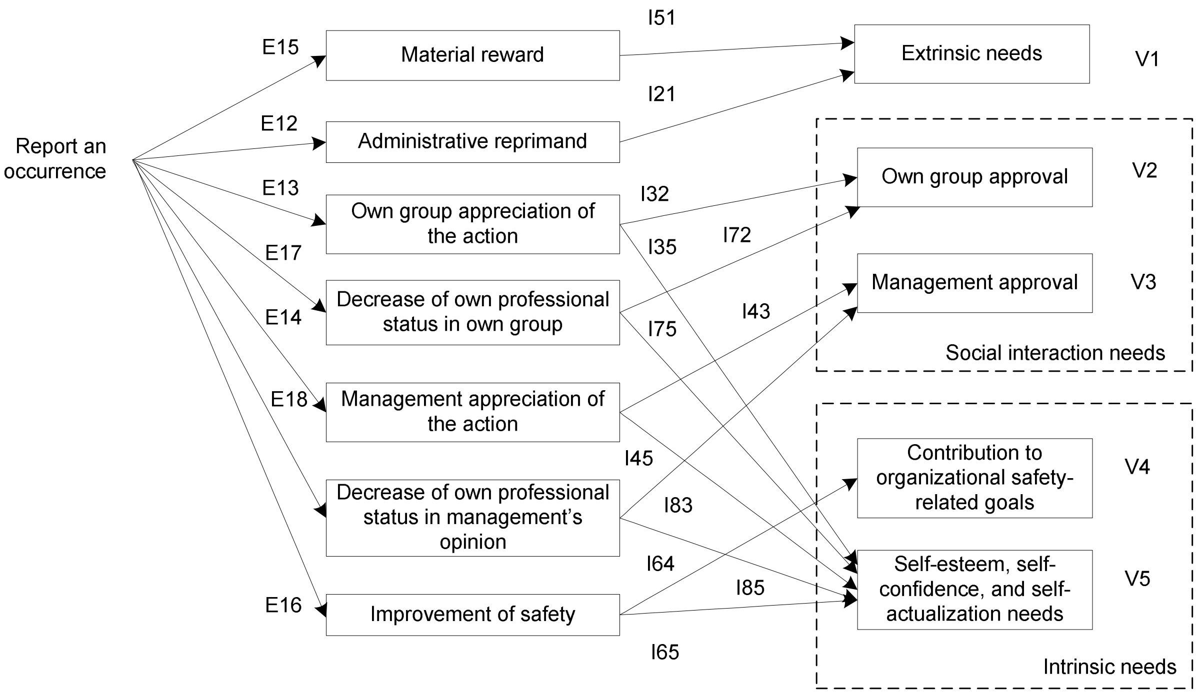


Figure 5: Decision making model for reporting an occurrence by a controller

Step 16. Allocation principles of agents to roles

The agent controllers are assumed to work in 4 shifts, 12 hours per day (12 controllers per shift; 2 per sector). Stable teams of controllers and teams with a variable composition are considered in the simulations. Each shift is managed by a supervisor agent (1 supervisor for 2 shifts).

Step 17. The identification of the generic and domain-specific constraints

Generic constraints ensure internal consistency of an organizational specification. Domain specific constraints restrain behaviour of individuals in a particular organization.

Step 18. Specification of the environmental dynamics

The simulation time is 3 years. The frequencies of different types of occurrences used in the simulation are based on safety occurrence statistics of ANSP-3.

1.2.3 Model output: safety culture indicators

The output of the agent-based organizational model is a number of safety culture indicators listed in Table 1.

Table 1: 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.

1.3 Structure of the report

The research presented in this report aims to use the results of a sensitivity analysis of the agent-based organizational model to arrive at the best possible prediction of safety culture indicators of ANSP-3, which is a Western-European ANSP that has been selected for validation purposes in this project. To address this aim, the report is structured as follows. Section 2 presents the results of a model-based sensitivity analysis for various safety culture indicators. On this basis, the generic organizational model and settings for the validation process are updated in Section 3. Specific settings and the predicted safety culture indicators of ANSP-3 are described in Section 4. In a follow-up study, the validity of these model results will be evaluated by comparison with SCMT results of ANSP-3. Finally, conclusions are provided in Section 5.

2 Sensitivity analysis

The organizational model such as developed in (Sharspankykh et al., 2008) and concisely explained in Section 1.2 contains a large number of parameter values. It is the aim of this section to obtain better insight in the effects of changes in parameter values on the safety culture indicators, in order to promote the understanding of the model and to achieve a list of organizational aspects for which proper knowledge is most important. Next, Section 2.1 presents methods for sensitivity analysis and Section 2.2 presents the results for the organizational model.

2.1 Methods for sensitivity analysis

To perform sensitivity analysis of probabilistic models often methods based on regression coefficients are used, which are relatively simple to calculate (Draper, and Smith, 1981). Such methods are, however, not suitable for non-linear non-monotonic models, such as the developed agent-based organizational model. To determine sensitivities of the input factors (e.g. parameter values) for this type of model, global sensitivity analysis methods can effectively be used (Saltelli et al., 2006, 2008). Such global sensitivity analysis techniques generally have the following advantages:

- the influence of each input factor incorporates its whole domain and the shape of its probability density function;
- they evaluate the effect of an input factor while other factors also vary (perform multidimensional averaging over inputs);
- they are model independent.

Next, we describe the two global sensitivity analysis techniques applied in this study:

1. Monte Carlo filtering, and
2. Factor fixing.

2.1.1 Monte Carlo filtering

Monte-Carlo filtering is often applied if a definition for ‘good’ or ‘acceptable’ model outcome can be given, e.g., through a set of constraints (Young, 1999). In the case of the agent-based organizational model, the acceptable behaviour is defined by a set of safety culture indicators with corresponding ranges of satisfactory values (Sharpanskykh and Stroeve, 2008b). The aim of the Monte

Carlo filtering method is to perform multiple model evaluations with the input factors randomly chosen from suitable ranges and then split the output values into two subsets: those considered as ‘acceptable’ and those considered as ‘unacceptable’, depending on whether they lead to acceptable or unacceptable outputs. The Smirnov test is applied to each input factor to test whether the distributions of the ‘acceptable’ and ‘unacceptable’ values can be regarded as significantly different (Saltelli et al., 2006, 2008). The higher the Smirnov test value for an input factor, the higher its influence on the model output, and hence the higher the sensitivity of output due to changes in the input. In detail, the Monte Carlo filtering method is implemented by the following two steps.

Step 1: MC simulations

A sufficient number of Monte Carlo simulations is performed. For each input factor x_i two sets of values are determined:

- $x_i|B$, containing all values of x_i from the simulations that produced the desired organizational behaviour, and
- $x_i|\underline{B}$, containing all x_i values that did not produce the desired behaviour.

Step 2: Smirnov test

The Smirnov two sample test is performed for each input factor independently. The test statistics are defined by

$$d(x_i) = \sup_Y \| F_B(x_i|B) - F_{\underline{B}}(x_i|\underline{B}) \|,$$

where F_B and $F_{\underline{B}}$ are marginal cumulative probability distribution functions calculated for the sets $x_i|B$ and $x_i|\underline{B}$, respectively, and where Y is the output.

A low level of $d(x_i)$ supports the null-hypothesis H_0: $F_B(x_i|B) = F_{\underline{B}}(x_i|\underline{B})$, meaning that the input factor x_i is not important, whereas a high level of $d(x_i)$ implies the rejection of H_0 meaning that x_i is a key factor.

It is determined at what significance level α, the value of $d(x_i)$ implies the rejection of H_0, where α is the probability of rejecting H_0 when it is true. In the sensitivity analysis, we use the classification High / Medium / Low for the importance of each factor:

- If $\alpha \leq 0.01$, then the importance of the corresponding factor x_i is considered High;
- If $0.01 < \alpha \leq 0.1$, then the importance of the corresponding factor is considered Medium, and
- If $\alpha > 0.1$, then the importance of the corresponding factor is considered Low.

2.1.2 Factor fixing

The Monte Carlo filtering method discussed above provides a measure of the sensitivity of the model output with respect to variations in the input factors. A limitation is that it captures only first-order effects and it does not detect interactions among factors. To solve this problem, variance-based global sensitivity analysis techniques can be used. Such techniques are able to capture interaction (correlation) between input factors by decomposing the variance of the output. One of such techniques – the factor fixing (Saltelli et al., 2008) – is used in this study. By this technique one is able to identify input factors recognized as insignificant by the Monte Carlo filtering approach, but which nevertheless should be considered as significant due to their interaction with other input factors.

Let us consider this technique more specifically. Generally, the output variance V(Y) can be decomposed by conditioning with respect to both x_k and X_{-k}, (where X_{-k} denotes the set of all input factors except for x_k):

$$V(Y) = V(E(Y|\, x_k)) + E(V(Y|\, x_k))$$
$$V(Y) = V(E(Y|\, X_{-k})) + E(V(Y|\, X_{-k}))$$

or, equivalently

$$1= V(E(Y|\, x_k))/\, V(Y) \; + E(V(Y|\, x_k))/\, V(Y)$$
$$1 = V(E(Y|\, X_{-k}))/\, V(Y) + E(V(Y|\, X_{-k}))/\, V(Y)$$

In these equations,

- $E(V(Y|X_{-k}))$ is the expected variance of the output Y obtained if all input factors except x_k are fixed,
- V(Y) is the variance of the output Y,
- $V(E(Y|\, x_k))/\, V(Y)$ is the first-order effect of x_k on Y and
- $E(V(Y|\, X_{-k}))/\, V(Y)$ is the total effect of x_k on Y. The total effect terms give information on the non-additive (interaction) part of the model.

According to (Homma and Saltelli, 1996) a total effect term is equal to the sum of all terms in the variance decomposition that include x_k. For example, if $V(E(Y|\, x_k))/\, V(Y)$ is denoted by S_k and $E(V(Y|\, X_{-k}))/\, V(Y)$ is denoted by S_{Tk}, then for a case of three input factors, the total effect of factor x_1 is

$$S_{T1}= S_1 + S_{12} + S_{13} + S_{123},$$

where

$$S_{12} = V(E(Y|\, x_1, x_2)) \,/\, V(Y) - S_1 - S_2$$
$$S_{13} = V(E(Y|\, x_1, x_3)) \,/\, V(Y) - S_1 - S_3$$
$$S_{23} = V(E(Y|\, x_2, x_3)) \,/\, V(Y) - S_1 – S_2$$
$$S_{123} = V(E(Y|\, x_1, x_2, x_3)) \,/\, V(Y) - S_{12} - S_{23} - S_{13} - S_1 - S_2 – S_3$$

In (Saltelli et al., 2008), factors for which the total effect term S_{Tk} exceeds a threshold value of 0.15, are considered as significant. For the purpose of our study, we use the classification High / Medium / Low for the importance of each factor:

- If $S_{Tk} \geq 0.3$ then the importance of the corresponding factor x_k is considered High;
- If $0.15 < S_{Tk} \leq 0.3$ then the importance of the corresponding factor x_k is considered Medium;
- If $S_{Tk} \leq 0.15$ then the importance of the corresponding factor x_k is considered Low.

2.2 Results

Sensitivity analyses have been performed for the effect on the following safety culture indicators:

1. I1.1: Reporting quality (ratio reported/observed) for the whole organization;
2. I2.1: Average quality of the processed notification reports produced by the whole organization;
3. I3.1: Average quality of the received final safety occurrence assessment reports for the whole organization;
4. I4.1: Average quality of the monthly safety overview reports received by the whole organization;
5. I5.2: Commitment to safety of a team of controllers;
6. I7: Perceived commitment to safety of management.

The sensitivity analyses have been performed for four types of organizational models:

1. Western European ANSP with low personal consequences of occurrences,
2. Western European ANSP with high personal consequences of occurrences,
3. Eastern European ANSP with low personal consequences of occurrences,
4. Eastern European ANSP with high personal consequences of occurrences.

These models were developed and described in (Sharspanskykh et al., 2008). The main settings of the models are presented in Appendix B. The remainder of this section analyses the sensitivity of changes in these safety culture indicators due to variations in the values of evidence input variables e_i and due to variations in the values of the causal network weights w_i.

Evidence input variables
The sensitivity analysis for the evidence input variables e_i has been done both by the Monte Carlo filtering method and by the Factor Fixing method. The combined sensitivity results for these two techniques are presented in Table 2; it lists the highest sensitivity result obtained by either of the two methods . Details of the results of the separate techniques are listed in Appendix A.1. Building forward on the results of Table 2, an overview of the overall importance of each evidence variable is presented in Table 3. For this overall importance, a value of 1 has been attached to each High influence, a value of a 0.5 to a Medium influence, and the sum of the values is listed.

It follows from the results in Table 2 that there is a considerable variety in the importance of the input variables for the various safety culture indicators and for the contextual settings in the model. In particular, it follows from the overall results in Table 3 that some input variables are important for both national cultures and cases of personal consequences (e.g. *e*1 'Priority of safety-related goals in the role description' and *e*4 'Influence degree of controllers on safety arrangements'), other input variables are most important only for one national culture (e.g. *e11* 'Regularity of safety meetings'), while others are mostly not important for either national culture (e.g. *e*36 'Quality of the formal occurrence assessment procedure').

Table 2: Importance of input variables classified by categories High / Medium /Low for four model cases of the model: Western / Eastern European ANSP with low / high personal consequences of occurrences.

Input variables		Case	Safety culture indicators					
			I1.1	I2.1	I3.1	I4.1	I5.2	I7
			Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Safety commitment of team	Perceived safety commitment of management
e1	Priority of safety-related goals in the role description	West-L	H	M	M	L	H	H
		West-H	H	H	M	L	H	H
		East-L	H	H	L	L	H	H
		East-H	M	M	H	L	H	H
e4	Influence degree of controllers on safety arrangements	West-L	H	M	L	L	H	H
		West-H	H	H	H	L	H	H
		East-L	H	H	L	L	H	H

Input variables		Case	Safety culture indicators					
			I1.1	I2.1	I3.1	I4.1	I5.2	I7
			Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Safety commitment of team	Perceived safety commitment of management
		East-H	L	H	M	L	H	H
e7	Sufficiency of number of safety investigators	West-L	H	M	H	H	L	L
		West-H	H	M	H	H	L	H
		East-L	L	L	H	H	H	M
		East-H	L	L	H	H	L	M
e8	Sufficiency of the number of controllers	West-L	M	H	M	H	L	H
		West-H	M	H	L	M	L	H
		East-L	H	H	H	H	L	M
		East-H	L	H	M	H	L	L
e9	Availability of reliable and ergonomic technical systems for controllers	West-L	H	H	M	L	L	H
		West-H	H	H	M	H	M	H
		East-L	H	H	M	L	H	H
		East-H	H	H	M	M	H	H
e10	Sufficiency and timeliness of training for changes	West-L	H	H	M	L	H	H
		West-H	H	H	L	L	M	H
		East-L	M	L	L	L	H	H
		East-H	H	H	M	L	H	H
e11	Regularity of safety meetings	West-L	H	M	M	L	L	H
		West-H	L	L	L	L	L	M
		East-L	M	L	L	L	L	L
		East-H	L	L	L	L	L	M
e12	Developed and implemented SMS	West-L	H	M	M	L	H	H
		West-H	H	H	L	L	M	H
		East-L	H	H	M	L	H	H
		East-H	H	H	L	L	H	H
e14	Level of development of managerial skills	West-L	M	H	M	L	L	H
		West-H	H	H	L	L	L	L
		East-L	M	M	M	L	M	M
		East-H	M	M	M	L	L	M
e19	Self-confidence for ATC task	West-L	L	M	L	L	H	L
		West-H	H	L	L	L	H	L

Input variables		Case	Safety culture indicators					
			I1.1	I2.1	I3.1	I4.1	I5.2	I7
			Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Safety commitment of team	Perceived safety commitment of management
		East-L	M	L	M	L	L	L
		East-H	L	M	L	L	H	L
e20	Commitment to perform ATC task	West-L	L	L	M	L	L	L
		West-H	L	M	L	L	H	L
		East-L	M	L	M	L	L	L
		East-H	L	L	M	L	H	L
e21	Development level of skills for ATC task	West-L	H	H	L	L	H	M
		West-H	L	L	M	L	H	L
		East-L	M	M	L	L	M	L
		East-H	M	H	L	L	M	L
e25	Sufficiency of the number of maintenance personnel	West-L	M	H	M	L	M	M
		West-H	L	H	M	H	L	L
		East-L	M	H	H	L	M	L
		East-H	L	H	M	L	L	L
e26	Quality of formal procedures for system checks and repairs	West-L	M	H	M	L	M	L
		West-H	L	H	L	M	L	M
		East-L	L	L	L	L	L	L
		East-H	L	L	L	M	L	L
e36	Quality of the formal occurrence assessment procedure	West-L	L	M	M	L	L	L
		West-H	L	L	M	M	L	L
		East-L	L	L	M	L	L	M
		East-H	L	L	M	L	L	L
e40	Quality of the communication channel between controllers and safety investigators	West-L	L	L	H	L	M	L
		West-H	L	L	H	L	L	L
		East-L	L	L	H	L	L	L
		East-H	L	L	H	L	L	L
e44	Average commitment to safety of the agents involved in safety analysis	West-L	M	L	M	H	L	L
		West-H	L	L	M	H	M	L
		East-L	L	L	L	H	L	L
		East-H	M	L	H	H	L	L
e71	Formal support for confidentiality of	West-L	H	L	M	L	L	L
		West-H	H	L	L	L	M	M

Input variables		Case	Safety culture indicators					
			I1.1	I2.1	I3.1	I4.1	I5.2	I7
			Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Safety commitment of team	Perceived safety commitment of management
	reporting	East-L	M	M	L	L	L	L
		East-H	M	L	M	H	L	L

Table 3: Overall importance of input variables for the models of Western and Eastern European ANSPs with both low and high personal consequences of occurrences.

		Western Low	Western High	Eastern Low	Eastern High
e1	Priority of safety-related goals in the role description	4	4.5	4	4
e4	Influence degree of controllers on safety arrangements	3.5	5	4	3.5
e7	Sufficiency of number of safety investigators	3.5	4.5	3.5	2.5
e8	Sufficiency of the number of controllers	4	3	4.5	2.5
e9	Availability of reliable and ergonomic technical systems for controllers	3.5	5	4.5	5
e10	Sufficiency and timeliness of training for changes	4.5	3.5	2.5	4.5
e11	Regularity of safety meetings	3	0.5	0.5	0.5
e12	Developed and implemented SMS	4	3.5	4.5	4
e14	Level of development of managerial skills	3	2	2.5	2
e19	Self-confidence for ATC task	1.5	2	1	1.5
e20	Commitment to perform ATC task	0.5	1.5	1	1.5
e21	Development level of skills for ATC task	3.5	1.5	1.5	2
e25	Sufficiency of the number of maintenance personnel	3	2.5	3	1.5
e26	Quality of formal procedures for system checks and repairs	2.5	2	0	0.5
e36	Quality of the formal occurrence assessment procedure	1	1	1	0.5

e40	Quality of the communication channel between controllers and safety investigators	1.5	1	1	1
e44	Average commitment to safety of the agents involved in safety analysis	2	2	1	2.5
e71	Formal support for confidentiality of reporting	1.5	2	1	2

Weights

The sensitivity analysis for the weights w_i has been done by the Monte Carlo filtering method. The ranges of the weights used in the Monte Carlo simulations are presented in Appendix A.2. These ranges have been estimated based on the relative degree of importance of the corresponding causal relation in the model (based on the literature and interviews). The detailed results of the sensitivity analysis for the weights are listed in Appendix A.3. It follows from these results that for particular safety indicators (like I5.2 and I7) many of the weights have a large influence.

3 Generic model and validation settings

The aim of this section is to arrive at more detailed settings of the organizational model and of its validation process. Section 3.1 presents an overview of the settings of the organizational model. Section 3.2 presents Monte Carlo simulation results on the ranges of the safety culture indicators for variations in the evidence input variables and their implications for satisfactory ranges of the indicators as will be applied in the future validation process.

3.1 Model settings

This section specifies the model settings of the organizational model. The structure and mechanisms of the agent-based organizational model are in line with the description in (Sharpanskykh et al., 2008). However, as a result of insights obtained by the sensitivity analysis presented in Section 2 and Appendix A, a number of weights of the models have been adapted. In particular, weights that have been identified as significant by the sensitivity analysis, but that are considered of minor importance based on generic insights from the literature, were decreased. Furthermore, a number of changes have been made to reflect the nuances of the cultural aspects and their consequences for the organization according to Hofstede (2001, 2005), as is described next. A detailed overview of all weights and the changes in weights is provided in Appendix B.3.

In (Sharpanskykh et al., 2008), we described four characteristics of national culture, which have effect on the priority of needs, values, attitudes and behaviour of subjects in an organization:

- *Individualism* (IDV) index refers to the degree to which individuals are not integrated into tight groups. IDV is stronger in Western European culture than in Eastern European culture.
- *Power Distance Index* (PDI) is the extent to which the less powerful members of organizations accept and expect that power is distributed unequally. The PDI in Western European culture is lower than in Eastern European culture.
- *Masculinity* (MAS) refers to typical men's values as very assertive and competitive, as opposite to women's values like modest and caring.

- *Uncertainty Avoidance Index* (UAI) deals with a society's intolerance for uncertainty and ambiguity. It indicates to what extent a culture programs its members to feel uncomfortable in novel, unstructured situations. Uncertainty avoiding cultures try to minimize the possibility of such situations by strict laws and rules, and people are also more emotional. Uncertainty accepting cultures are more tolerant of different and novel opinions, and they try to have as few rules as possible.

Table 4 below shows ways in which these four dimensions of national culture have been found to have influence on the performance within organizations (Hofstede, 2001, 2005).

Table 4: Specification of generic organizational consequences of national culture characteristics, as adapted from (Hofstede,2001, 2005).

Dimension	Low	High
Individualism	– moral involvement with company; – more importance attached to training and use of skills in jobs; – managers aspire to conformity and orderliness; – group decisions are considered better than individual decisions; – managers choose duty, expertness and prestige as life goals; – social relations predetermined in terms of being part of a group (ingroup); – people thought of in terms of ingroups and outgroups; – more road traffic accidents per 1000 vehicles; – managers rate having security in their position as important; – organization has great influence on members' well-being;	– calculative involvement with company; – more importance attaches to freedom and challenge in jobs; – managers rate having autonomy as important; – individual decisions are considered better than group decisions; – fewer road traffic accidents per 1000 vehicles; – policies and practices should allow for individual initiative.

	– promotions on seniority; – policies and practices vary according to relations.	
Power distance	– managers seen as making decisions after consulting with subordinates; – stronger perceived work ethic; – strong disbelief that people dislike work; – managers like seeing themselves as practical and systematic; – people admit a need for support; – employees less afraid of disagreeing with their boss; – employees show more cooperativeness; – mixed feelings about employees' participation in management; – informal employee consultation possible without formal participation; – higher-educated employees hold much less authoritarian values than lower-educated ones; – high qualification of lower strata (people lower in organizational hierarchy).	– managers seen as making decisions autocratically and paternalistically; – close supervision positively evaluated by subordinates; – more frequent belief that people dislike work; – managers more satisfied with directive or persuasive superior; – employees reluctant to trust each other; – managers seen as showing less consideration; – formal employee participation possible without informal consultation; – higher- and lower-educated employees show similar values about authority; – low qualification of lower strata
Masculinity	– interdependence ideal; – lower job stress;	– money and things orientation; – performance and growth are important; – independence ideal
Uncertainty avoidance	– less emotional resistance to change; – lower job stress; – stronger achievement	– higher job stress; – loyalty to employer is seen as a virtue; – greater generation gap;

	motivation; – more risk-taking; – stronger ambition for individual advancement; – preference for manager career over specialist career; a manager need not to be an expert in the field he manages; – preference for broad guidelines; – rules may be broken for pragmatic reasons; – more sympathy for individual and authoritative decisions; – more prepared to compromise with opponents; – managers more willing to make individual and risky decisions; – more ambitious employees; lower satisfaction scores	– managers are selected on the basis of seniority; – less achievement motivation; fear of failure; – lower ambition for individual advancement; – preference for specialist career over manager career; – conflict in organizations is undesirable; – initiative of subordinates should be kept under control; – ideological appeal of consensus and of consultative leadership; – organizations should be as uniform as possible; – managers more involved in details; – managers more task-oriented and consistent in their style; – managers less willing to make individual and risky decisions; – less ambitious employees; higher satisfaction scores.

3.2 Settings for validation process

Due to the changes in weights the range over which the safety culture indicators in the model may vary, may also have changed. Knowledge on these ranges of safety culture indicators is needed to determine appropriate boundaries for discerning classes of high, medium and low values. Such classification will be used in the validation process as explained in (Sharpanskykh and Stroeve, 2008b).

For each setting of both Eastern and Western European ANSP models, 1000 simulation trials of three years each have been performed with random choices of the evidence input variables. Figure 6 to Figure 13 show the histograms of the distribution of the values of the safety culture indicators obtained by these simulations for low personal consequences of occurrences. Comparison of the histograms of the safety indicator results for the modelled Eastern and Western

European ANSPs shows that the distributions for safety culture indicators I3.1, I4.1, I5.1, I5.2, I6 and I7 are similar for both organizations. Differences are manifest for indicators I2.1 and most prominently for indicator I1.1.

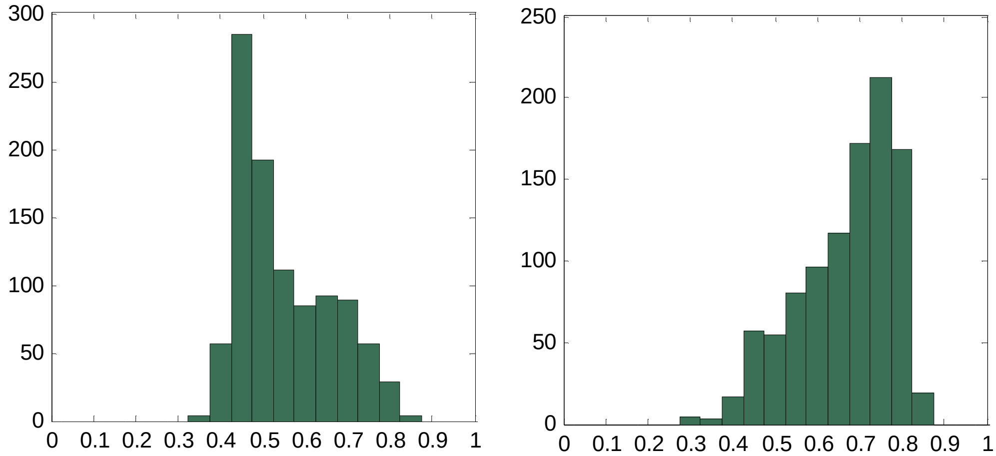


*Figure 6: Distribution of the values of indicator I1.1 (Reporting quality (ratio reported/observed) for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

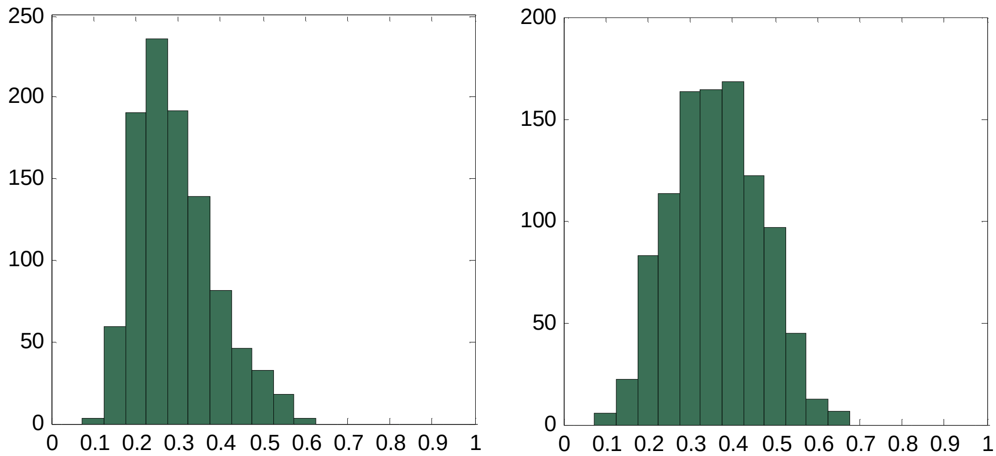
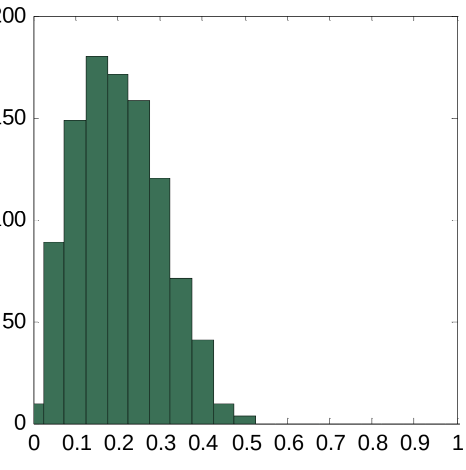


*Figure 7: Distribution of the values of indicator I2.1 (Average quality of the processed notification reports produced by the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*



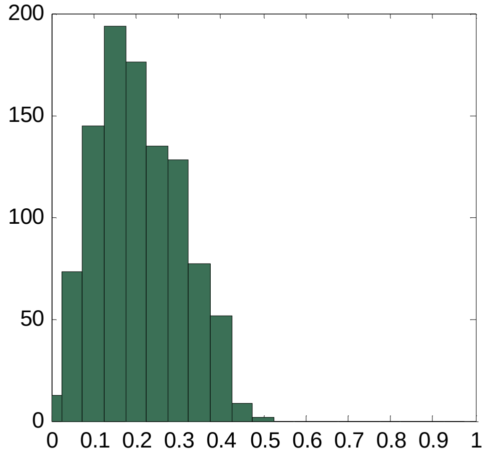


*Figure 8: Distribution of the values of indicator I3.1 (Average quality of the received final safety occurrence assessment reports for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

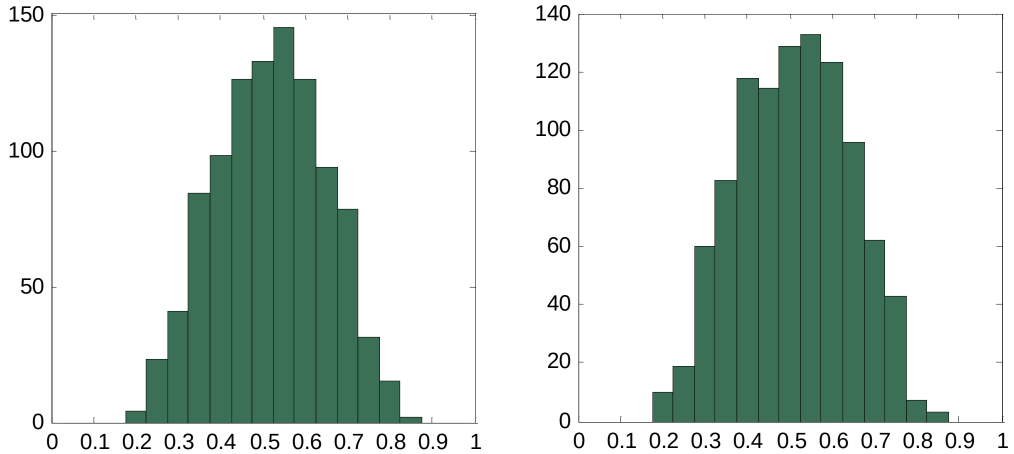


*Figure 9: Distribution of the values of indicator I4.1 (Average quality of the monthly safety overview reports received by the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

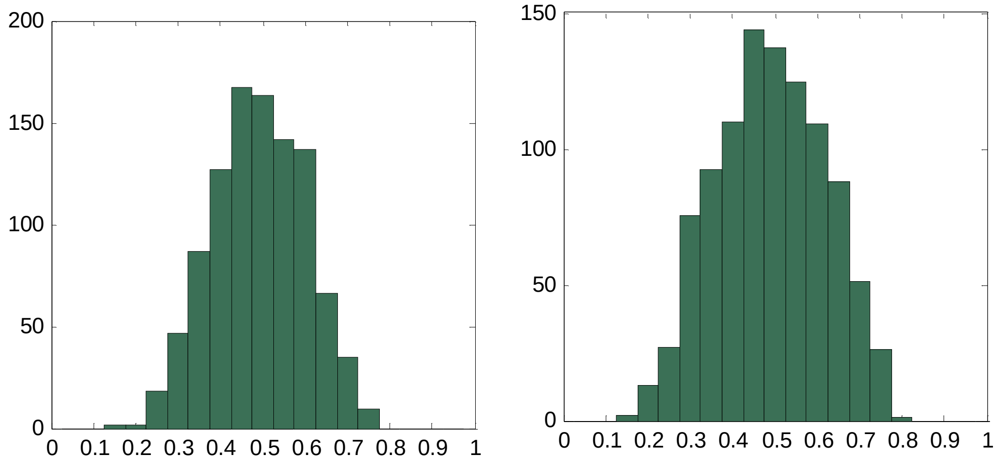


*Figure 10: Distribution of the values of indicator I5.1 (Commitment to safety of a controller) for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

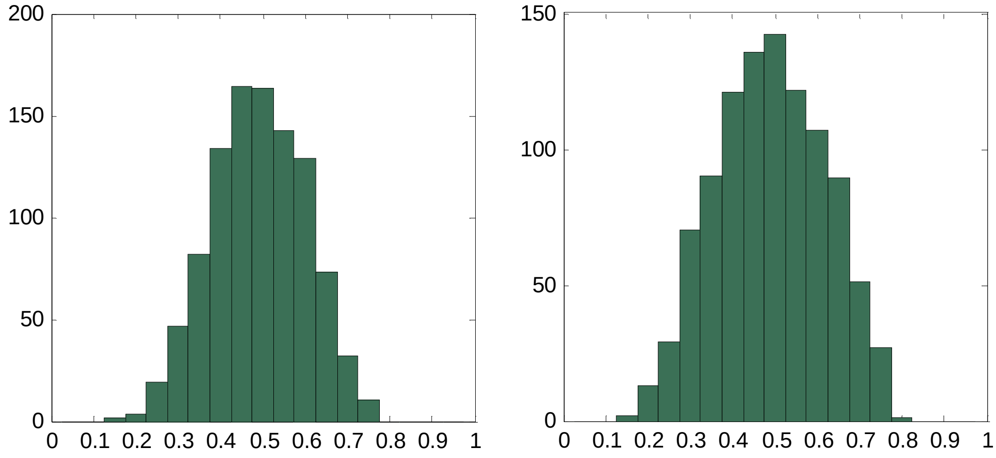


*Figure 11: Distribution of the values of indicator I5.2 (Commitment to safety of a team of controllers) for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

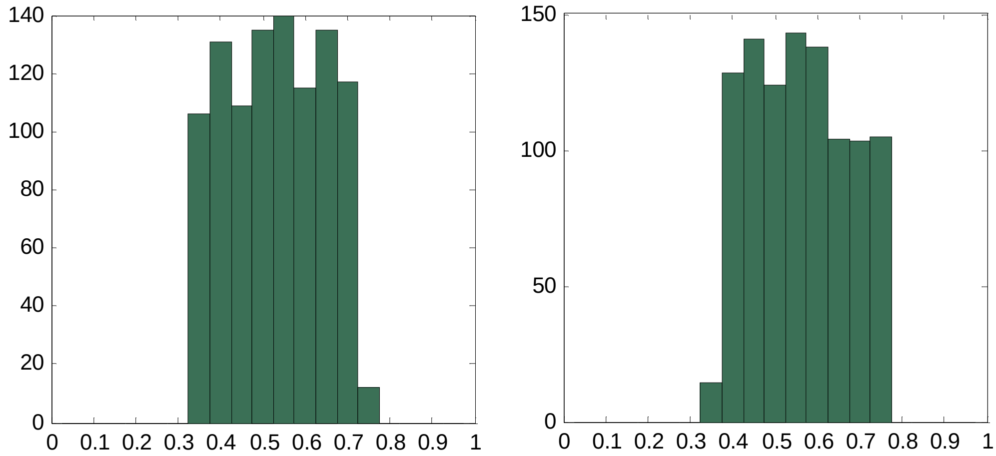


*Figure 12: Distribution of the values of indicator I6 (Perceived commitment to safety of supervisor) for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

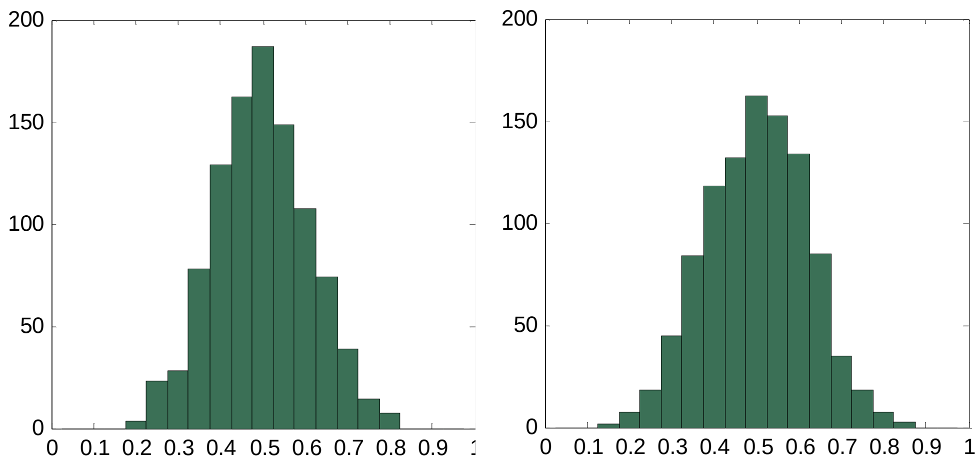


*Figure 13: Distribution of the values of indicator I7 (Perceived commitment to safety of management) for the whole organization) from 1000 simulations based on the model of the Eastern European ANSP (**left**) and the Western European ANSP (**right**).*

In addition to differences in values of safety culture indicators for various contextual settings, histograms like those in Figure 6 to Figure 13 are used to define classes of Low, Medium and High values of the indicators. In particular, above results for both Western and Eastern European culture plus additional (not shown) results for settings with high personal consequences of occurrences for both cultures, are used to define ranges of values for the safety culture indicators in accordance with the relative contributions specified in Table 5. The Low boundary cuts the first 30% of the safety culture indicator values, the following 55% of the values belong to the class Medium and the remaining 15% belongs to the class High. Table 5 also contains a redefinition of the classes with respect to the ranges of average results for the Eurocontrol Safety Culture Monitoring Tool (SCMT) questionnaire. The Low/Medium/High cut-off points and the relation with the ranges of average values in the SCMT questionnaire have been selected to be consistent with available SCMT data of ANSP-2 (different from ANSP-3).

Table 5: Definition of attributes of safety culture indicator value classes.

Class of value of safety culture indicator	Relative contribution	Range of average value in SCMT questionnaire
Low	30%	[0, 3.25]
Medium	55%	(3.25, 4]
High	15%	(4, 5]

The resulting values of the bounds of the safety culture indicators are presented in Table 6. This definition replaces Table 6 of (Sharpanskykh and Stroeve, 2008b). In Table 6 below the focus is on the indicators that can be related to SCMT questions, the values of bounds of the indicators have been changed and the indicator I8.1 ‘Average value of the reprimand constituent in the force to report for controllers in the whole organization’ has been removed.

Table 6: Updated definition of qualitative scales for the safety culture indicators, using the Monte Carlo simulation results depicted in the histograms of Figure 6 to Figure 13. The updated definition replaces Table 6 in (Sharpanskykh and Stroeve, 2008b).

Safety Culture Indicator		High	Medium	Low
I1.1	Reporting quality (ratio reported/observed) for the whole organization	(0.76, 1]	(0.55, 0.76]	[0, 0.55]
I2.1	Average quality of the processed notification reports produced by the	(0.45, 1]	(0.27, 0.45]	[0, 0.27]

	whole organization			
I3.1	Average quality of the received final safety occurrence assessment reports for the whole organization	(0.32, 1]	(0.14, 0.32]	[0, 0.14]
I4.1	Average quality of the monthly safety overview reports received by the whole organization	(0.66, 1]	(0.44, 0.66]	[0, 0.44]
I5.1	Commitment to safety of a controller	(0.63, 1]	(0.43, 0.63]	[0, 0.43]
I5.2	Commitment to safety of a team of controllers	(0.63, 1]	(0.43, 0.63]	[0, 0.43]
I6	Perceived commitment to safety of a supervisor	(0.7, 1]	(0.48, 0.7]	[0, 0.48]
I7	Perceived commitment to safety of management	(0.63, 1]	(0.45, 0.63]	[0, 0.45]

4 Model setting and results for ANSP-3

The aim of this section is to define appropriate values for the input variables of the organizational model in accordance with the information about the Western-European ANSP-3 selected for validation purposes in this study (Section 4.1), and to predict the safety culture indicators for ANSP-3 (Section 4.2).

4.1 Model settings for ANSP-3

The basis of the organizational model for ANSP-3 is the model structure described in (Sharpanskykh et al., 2008) and the updated weights described in Section 3 and Appendix B. The ANSP-3 specific model aspects relate to the fact that it is a Western European organization, the settings of input evidence variables and our assessment of personal consequences of safety occurrences. As a basis for determination of the values of settings in the organizational model for the case of ANSP-3, we had interviews with a safety manager and a safety occurrence investigator at ANSP-3, and we were provided insight in the safety management plan of ANSP-3. Based on this information and on our model knowledge, we determined the values of the input evidence variables shown in Table 7.

Table 7: The values of the input variables for ANSP-3 as considered in the model.

Variable	Description	Value	Explanation
e1	Priority of safety-related goals in the role description	0.9	High priority in SMS and expressed in interviews.
e4	Influence degree of controllers on safety arrangements	0.7	Supported partially by interviews.
e7	Sufficiency of number of safety investigators	0.5	A relatively small safety management department.
e8	Sufficiency of the number of controllers	0.8	Generally sufficient number of controllers; overload conditions have occurred.
e9	Availability of reliable and ergonomic technical systems for controllers	0.9	The controllers operate modern, properly maintained technical systems.

e10	Sufficiency and timeliness of training for changes	0.8	About two training sessions of several days yearly at ANSP-3 with positive feedback.
e11	Regularity of safety meetings	0.8	Meetings at different levels and of different groups are organized regularly.
e12	Developed and implemented SMS	0.8	Well documented safety management system; some parts of SMS still needed to be (re-)implemented.
e14	Level of development of managerial skills	0.9	Skills and competences are tested regularly.
e19	Self-confidence for ATC task	0.8	Controllers typically have a high self-confidence, which may nevertheless decrease as a result of involvement in occurrences.
e20	Commitment to perform ATC task	0.8	Controllers have a high commitment to perform ATC tasks.
e21	Development level of skills for ATC task	0.9	Controllers have a high level of skills to perform ATC tasks; their skills and competences assessed regularly.
e25	Sufficiency of the number of maintenance personnel	0.9	Large maintenance groups at ANSP-3, which work 24 hr/day and are quickly available in case of problems.
e26	Quality of formal procedures for system checks and repairs	0.9	Extensive list of procedures for system checks and repairs. There are about 5 technical problems per year during ATC.
e36	Quality of the formal occurrence assessment procedure	0.9	Clear and specific description of the occurrence assessment procedure of the ANSP-3.
e40	Quality of the communication channel between controllers and safety investigators	0.5	Feedback is not given formally; often oral form is preferred.
e44	Average commitment to safety of the agents	0.9	Based on the organization of safety-related activities,

	involved in safety analysis		initiatives; developed and introduced SMS.
e71	Formal support for confidentiality of reporting	0.7	Although anonymity of reporting is supported, in practice it is often possible to identify the reporter.
Table 21 (page 9)	Personal consequences of occurrences	Medium	It has been stated that there is a non-punitive culture at ANSP-3. The idea of punishment has been abandoned since some years as result of stimulus by management. Some older controllers are still a bit more reluctant to report incidents.

4.2 Safety culture indicator results for ANSP-3

Based on the model developed and its settings for ANSP-3, as presented in (Sharpanskykh et al., 2008) and the previous sections, a thousand simulation trials have been performed, where each simulation trial represents three years of operation. Table 8 below shows the obtained values of the average safety culture indicators and the related classes (as defined in Table 6).

Table 8: Model simulation results for the average safety culture indicators of ANSP-3.

Index	Safety culture indicator	Value	Class
I1.1	Reporting quality (ratio reported/observed) for the whole organization	0.80	High
I2.1	Average quality of the processed notification reports produced by the whole organization	0.65	High
I3.1	Average quality of the received final safety occurrence assessment reports for the whole organization	0.23	Medium
I4.1	Average quality of the monthly safety overview reports received by the whole organization	0.70	High
I5.1	Commitment to safety of a controller	0.72	High
I5.2	Commitment to safety of a team of controllers	0.70	High
I6	Perceived commitment to safety of a supervisor	0.78	High
I7	Perceived commitment to safety of management	0.76	High

It follows from Table 8 that only safety culture indicator I3.1 belongs to the class Medium and all other indicators are classified as High. Lower values of I3.1 may indicate non-regular feedback provision on safety occurrences to air traffic controllers and/or insufficient amount of details in the safety occurrence assessment reports. The values of indicators I1.1 and I4.1 are close to the border of the class Medium, the other High indicators are well away from this border. Note that indicator I1.1 is defined over the occurrences identified and recognized by air traffic controllers; occurrences not identified by the air traffic controllers are not included in I1.1.

The follow-up report D7 will include an analysis of the organizational aspects related to the values of the safety indicators.

5 Conclusions

This report presents the results of the evaluation and refinement of an agent-based organizational model of Western and Eastern European ANSPs. The evaluation is based on a sensitivity analysis, which provides insight into the influence of parameters and groups of parameters in the organizational model on the safety culture indicators in various contextual settings. Based on this additional insight a number of weights in the organizational model have been adapted. The resulting improved generic model for a Western European ANSP has been used to predict values and classes of safety culture indicators for ANSP-3.

The updated model and the predictions for ANSP-3 will be used in a follow-up validation study. Next steps will be in line with the validation plan (Sharpanskykh and Stroeve, 2008b):

- Evaluation of the validity of the model predictions via comparison with ANSP-3 SCMT questionnaire results;
- Updating of model features by additional ANSP-3 SCMT questionnaire results and evaluation of the added model validity;
- Identification of major organizational factors via sensitivity analysis of the updated model of ANSP-3;
- Comparison of identified major organizational factors with results of an ANSP-3 SCMT Workshop and identification of safety culture improvement strategies;
- Evaluation of contributions of organizational modelling for safety culture evaluation and improvement.

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Appendix A SENSITIVITY ANALYSIS DETAILS

A.1 SENSITIVITY ANALYSIS RESULTS FOR EVIDENCE VARIABLES

This appendix describes the results of sensitivity analyses that have been performed for the effect of changes in evidence variables on safety culture indicators using two types of techniques: (1) Monte Carlo filtering and (2) Factor fixing. Table 9 to Table 12 below show the results obtained by these techniques for organizational models of Eastern and Western ANSPs with low and high personal consequences of occurrences. The results are based on 1000 Monte Carlo simulation trials, where each trial represents three years of operation. In the Monte Carlo simulations, the values of the evidence input variables have been chosen from their full possible range of [0,1]. The classes High / Medium / Low for the importance of the input variables are defined in Section 2.1 for the sensitivity analysis techniques.

Table 9: Sensitivity analysis results of Eastern European ANSP model with low personal consequences of occurrences.

Safety culture indicator	Sensitivity Technique	Importance of input variables		
		High	Medium	Low
I1.1	MC filtering	e1, e4, e9, e12	e14, e19, e20, e71	rest
	Factor fixing	e8	e1, e10, e11, e14, e21, e25	rest
I2.1	MC filtering	e1, e4, e8, e9, e12, e25	e14, e21, e71	rest
	Factor fixing	e8	e1, e9, e14, e21	rest
I3.1	MC filtering	e7, e40	e8, e9, e19, e36	rest
	Factor fixing	e7, e8, e25	e12, e14, e20, e36, e40	rest
I4.1	MC filtering	e7, e8, e44	–	rest
	Factor fixing	e7	e44	rest
I5.2	MC filtering	e1, e4, e9, e7, e10, e12	e14, e21	rest
	Factor fixing	e1	–	rest
I7	MC filtering	e1, e4, e9, e10, e12	e8, e14, e36, e7	rest

	Factor fixing	–	e1, e12	rest

Table 10: Sensitivity analysis results of Eastern European ANSP model with high personal consequences of occurrences.

Safety culture indicator	Sensitivity Technique	Importance of input variables		
		High	Medium	Low
I1.1	MC filtering	e12	e1, e9, e14, e71	rest
	Factor fixing	e9, e10	e12, e21,e44	rest
I2.1	MC filtering	e4, e8, e9, e10, e12, e21, e25	e1, e14, e19	rest
	Factor fixing	e8, e9	–	rest
I3.1	MC filtering	e7, e40	e36, e71	rest
	Factor fixing	e1, e7, e40, e44	e4, e8, e10, e14, e20, e25, e36	rest
I4.1	MC filtering	e7, e8, e44, e71	e9, e26	rest
	Factor fixing	e7, e44	–	rest
I5.2	MC filtering	e1, e4, e9, e10, e12, e19, e20	e21	rest
	Factor fixing	e1, e4	e10	rest
I7	MC filtering	e1, e4, e9, e10, e12	e7, e11, e14	rest
	Factor fixing	e9, e12	e10	rest

Table 11: Sensitivity analysis results of Western European ANSP model with low personal consequences of occurrences.

Safety culture indicator	Sensitivity Technique	Importance of input variables		
		High	Medium	Low
I1.1	MC filtering	e1, e4, e9, e10, e12, e71	e8, e14	rest
	Factor fixing	e1, e4, e7, e9, e11, e12, e14, e21, e36	e8, e10, e25, e26, e44	rest
I2.1	MC filtering	e8, e9, e10, e25, e26	e1, e4, e11, e19	rest
	Factor fixing	e9, e14, e21	e1, e4, e7, e10, e12, e36	rest
I3.1	MC filtering	e7, e40	e8, e25, e26	rest

	Factor fixing	e7, e40	e1, e8, e9, e10, e11, e12, e14, e20, e36, e44, e71	rest
I4.1	MC filtering	e7, e8, e44	–	rest
	Factor fixing			rest
I5.2	MC filtering	e1, e4, e10, e12, e19, e21	e25, e26, e40	rest
	Factor fixing	e7, e44	–	rest
I7	MC filtering	e1, e4, e8, e9, e10, e11, e12, e14	e21, e25	rest
	Factor fixing	e9, e12	e1, e8, e11	rest

Table 12: Sensitivity analysis results of Western European ANSP model with high personal consequences of occurrences.

Safety culture indicator	Sensitivity Technique	Importance of input variables		
		High	Medium	Low
I1.1	MC filtering	e1, e4, e7, e9, e10, e12, e14, e71	e8	rest
	Factor fixing	e9, e19	e12, e14	rest
I2.1	MC filtering	e1, e4, e8, e9, e10, e12, e14, e25, e26	e7, e20	rest
	Factor fixing	–	e8, e25	rest
I3.1	MC filtering	e4, e7, e40	e1, e9, e21, e36	rest
	Factor fixing	e7	e1, e4, e25, e40, e44	rest
I4.1	MC filtering	e7, e9, e25, e44	e8, e14, e26, e36	rest
	Factor fixing	e7	e44	rest
I5.2	MC filtering	e1, e4, e19, e20, e21	e9, e10, e12, e44, e71	rest
	Factor fixing	e4	e1	rest
I7	MC filtering	e1, e4, e7, e8, e9, e10, e12	e26, e71	rest
	Factor fixing	–	e1, e9, e11, e12	rest

A.2 Ranges of weights adopted in sensitivity analysis

In the sensitivity analysis, Monte Carlo simulations have been performed with variations of the weights in the organizational model. Table 13 shows the ranges of weights used, which refer to the boundaries of uniform probability distributions. The ranges of the weights have been estimated based on the relative degree of importance of the corresponding causal relation in the model (based on the literature and interviews). It can be observed that for some weights a fixed value rather than a range has been adopted. These weights are related to input evidence variables for which it follows from previous sensitivity analysis results (see Appendix A.1), that their impact on the safety culture indicators is low.

Table 13: Ranges of weight values used in the sensitivity analysis for the models of the Western and Eastern European ANSPs. For some weights it follows from a previous sensitivity analysis of the evidence variables, that they are not relevant for the safety culture indicators. For these weights only a point value is specified; this may depend on the situation with high or low personal consequences of occurrences (HPC / LPC).

Weight	Description	Western European	Eastern European
w1	Contribution of e1 ‘Priority of safety-related goals in the role description’ to e6 ‘Commitment to safety of a controller’	[0.05, 0.2]	[0.1, 0.3]
w2	Contribution of e2 ‘Perception of the commitment to safety of management’ to e6 ‘Commitment to safety of a controller’	[0.1, 0.3]	[0.2, 0.4]
w3	Contribution of e3 ‘Perception of commitment to safety of team’ to e6 ‘Commitment to safety of a controller’	[0.05, 0.2]	[0.2, 0.4]
w4	Contribution of e4 ‘Influence degree of controllers on safety arrangements’ to e6 ‘Commitment to safety of a controller’	[0.2, 0.4]	[0, 0.2]
w5	Contribution of e5 ‘Influence degree of controllers on safety arrangements’ to e6 ‘Commitment to safety of a controller’	[0.2, 0.4]	[0, 0.2]
w6	Contribution of e13 ‘the commitment of the supervisor to safety’ to e3 ‘Perception of commitment to safety of team’	[0.05, 0.3]	0.1
w7	Contribution of e41 ‘Average commitment to safety of team members’ to e3 ‘Perception of commitment to safety of team’	[0.05, 0.2]	[0.01, 0.1]
w8	Contribution of e1 ‘Priority of safety-related goals in the role description’ to e2	[0.05, 0.3]	[0.05, 0.3]

	'Perception of the commitment to safety of management'		
w9	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e2 'Perception of the commitment to safety of management'	[0.1, 0.4]	[0.1, 0.3]
w10	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	[0.01, 0.3]	[0.1, 0.3]
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	[0.1, 0.4]	[0.1, 0.4]
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	LPC: [0.01, 0.1] HPC: 0.05	0.1
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	[0.05, 0.5]	[0.05, 0.5]
w14	Contribution of e14 'Level of development of managerial skills' to e13 'Perception of commitment to safety of the supervisor'	[0.3, 0.6]	[0.3, 0.6]
w15	Contribution of e2 'Perception of commitment to safety of management' to e13 'Perception of commitment to safety of the supervisor'	[0.3, 0.9]	[0.3, 0.9]
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	[0.3, 0.6]	[0.4, 0.8]
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	[0.4, 0.9]	[0.1, 0.6]
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	[0.05, 0.2]	[0.05, 0.2]
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	[0.2, 0.4]	[0.2, 0.4]
w20	Contribution of e7 'Quality of technical systems' to e15 'Quality of a processed notification report'.	[0.2, 0.6]	[0.2, 0.6]
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a	[0.2, 0.6]	[0.2, 0.6]

	processed notification report'.		
w22	Contribution of e19 'Self-confidence for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w23	Contribution of e20 'Commitment to perform ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w24	Contribution of e21 'Development level of skills for ATC task' to e5 'Maturity level w.r.t. ATC task'.	LPC: [0.1, 0.4] HPC: 0.25	0.25
w25	Contribution of e23 'Adequacy of mental models for ATC task' to e5 'Maturity level w.r.t. ATC task'.	LPC: [0.1, 0.4] HPC: 0.25	0.25
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	[0.4, 0.6]	[0.4, 0.6]
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	[0.3, 0.7]	[0.3, 0.7]
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	[0.2, 0.6]	[0.2, 0.6]
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	[0.4, 0.8]	[0.4, 0.8]
w30	Contribution of e25 'Sufficiency of the number of maintenance personnel' to e17 'Quality of technical systems'.	[0.2, 0.6]	LPC: [0.2, 0.6] HPC: 0.4
w31	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	LPC: [0.1, 0.3] HPC: 0.2	0.2
w32	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e17 'Quality of technical systems'.	[0.2, 0.8]	LPC: [0.2, 0.6] HPC: 0.4
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'.	[0.4, 0.8]	[0.2, 0.6]
w34	Contribution of e6 'Commitment to safety of a controller' to e29 'Information contribution by a controller'.	[0.2, 0.4]	[0.2, 0.4]
w35	Contribution of e27 'Amount of knowledge on similar safety-related issues of a controller' to e29 'Information contribution by a controller'.	[0.6, 0.9]	[0.6, 0.9]

w36	Contribution of e30 'Information contribution by the supervisor' to e16 'Information contribution by others'.	[0.3, 0.6]	[0.4, 0.8]
w37	Contribution of e28 'Amount of knowledge on similar safety-related issues of the supervisor' to e30 'Information contribution by the supervisor.	[0.4, 0.9]	[0.4, 0.9]
w38	Contribution of e13 'Perceived commitment to safety of the supervisor' to e30 'Information contribution by the supervisor.	[0.2, 0.4]	[0.2, 0.4]
w39	Contribution of e8 'Sufficiency of the number of controllers' to e18 'Acceptability of the workload level'.	[0.7, 0.9]	[0.7, 0.9]
w40	Contribution of e14 'Level of development of managerial skills' to e18 'Acceptability of the workload level'.	[0.1, 0.3]	[0.1, 0.3]
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview report'.	[0.3, 0.5]	[0.3, 0.5]
w43	Contribution of e32 'Quality of safety analysis' to e33 'Quality of a monthly safety overview report'.	[0.4, 0.8]	[0.4, 0.8]
w44	Contribution of e44 'Average commitment to safety of the agents involved in safety analysis' to e32 'Quality of safety analysis'.	[0.2, 0.5]	[0.2, 0.5]
w45	Contribution of e31 'Quality of input data' to e32 'Quality of safety analysis'.	[0.5, 0.9]	[0.5, 0.9]
w46	Contribution of e45 'Average contribution of informal discussions of controllers in teams' to e31 'Quality of input data'.	[0.1, 0.5]	[0.1, 0.5]
w47	Contribution of e46 'Average quality of processed notification reports' to e31 'Quality of input data'.	[0.3, 0.8]	[0.3, 0.8]
w48	Contribution of e47 'Average quality of previous monthly safety overview reports' to e31 'Quality of input data'.	[0.1, 0.3]	[0.1, 0.3]
w49	Contribution o9f e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	[0.1, 0.4]	[0.1, 0.4]
w50	Contribution of e35 'Intensity of informal interactions in the team of controllers' to	[0.2, 0.5]	[0.2, 0.5]

	e34 'Contribution of informal discussions of controllers in the team'.		
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'.	[0.2, 0.5]	[0.2, 0.5]
w52	Contribution of e49 'Average quality of the received monthly safety overview reports' to e34 'Contribution of informal discussions of controllers in the team'.	[0.1, 0.4]	[0.1, 0.4]
w53	Contribution of e36 'Quality of the formal safety occurrence assessment procedure' to e38 'Quality of the final safety occurrence assessment report'.	0.1	0.1
w54	Contribution of e50 'Average commitment to safety of the participants of the meetings' to e38 'Quality of the final safety occurrence assessment report'.	[0.05, 0.3]	[0.05, 0.3]
w55	Contribution of e7 'Sufficiency of the number of safety investigators' to e38 'Quality of the final safety occurrence assessment report'.	0.15	-
w56	Contribution of e15 'Quality of a processed notification report' to e38 'Quality of the final safety occurrence assessment report'.	[0.1, 0.5]	[0.1, 0.5]
w57	Contribution of e37 'Amount of knowledge on similar safety-related issues in the organization' to e38 'Quality of the final safety occurrence assessment report'.	[0.05, 0.25]	[0.05, 0.25]
w58	Contribution of e55 'Average quality of the monthly safety overview reports' to e38 'Quality of the final safety occurrence assessment report'.	[0.05, 0.25]	[0.05, 0.25]
w59	Contribution of e7 'Sufficiency of the number of safety investigators' to p1 'Probability of the feedback provision'.	[0.2, 0.5]	0.3
w60	Contribution of e39 'Severity of an occurrence' to p1 'Probability of the feedback provision'.	[0.2, 0.7]	0.4
w61	Contribution of e40 'Quality of the communication channel between controllers and safety investigators'	0.3	0.3

A.3 Sensitivity analysis results for weights

This appendix contains the results of the sensitivity of the safety culture indicators for variations in the weights using the Monte Carlo filtering technique. The results are based on 1000 Monte Carlo simulation trials, where each trial represents three years of operation. In the Monte Carlo simulations, the values of the weights are chosen according in the ranges specified in Appendix A.2 The results are presented for four cases in Table 14 to Table 17 below, which consider models of Eastern and Western European ANSPs with low and high personal consequences of occurrences. The classes High / Medium / Low for the importance of the weights are defined in Section 2.1 for the Monte Carlo filtering technique.

Table 14: Results of MC filtering sensitivity analysis: Classification of the importance of weights of the Eastern European ANSP model with low personal consequences of occurrences.

Safety culture indicator	Importance of weights		
	High	Medium	Low
I1.1	-	w26, w27, w51, w53, w55	Rest
I2.1	-	-	Rest
I3.1	w9, w29, w31, w43, w50, w56, w57	w4, w8, w14, w15, w16, w18, w19, w26, w33, w37, w45, w47, w54, w58	Rest
I4.1	w9, w14, w15, w18, w21, w30, w31, w33, w39, w40, w42, w57	w1-w8, w10-w13, w16, w19, w20, w22-w29, w32, w35-w38, w41, w43-w49, w51-w55, w58, w60	Rest
I5.2	w1, w4-w20, w22-w29, w31-w45, w47-w50, w52-w55, w57, w58, w60	w2, w3, w21, w30, w46, w51, w56	Rest
I7	w1, w4-w16, w18-w20, w22-w33, w35-w37, w39-w50, w52-w55, w57, w58, w60	w2, w3, w17, w21, w34, w38, w51, w56	Rest

Table 15: Results of MC filtering sensitivity analysis: Classification of the importance of weights of the Eastern European ANSP model with high personal consequences of occurrences.

Safety culture indicator	Importance of weights		
	High	Medium	Low
I1.1	–	w28, w29, w42, w43	Rest
I2.1	–	w47	Rest
I3.1	–	w2, w17, w46, w48	Rest
I4.1	w8, w15, w36, w42, w44, w49	w2, w4, w11, w18, w19, w26, w29, w35, w48, w53, w55, w57	Rest
I5.2	w1, w2, w4-w19, w21-w43, w45, w47-w49, w52-w58, w60	w3, w20, w44, w46, w50, w51	Rest
I7	w1-w19, w21-w33, w35-w45, w47-w50, w52-w60	w20, w34, w46, w51	Rest

Table 16: Results of MC filtering sensitivity analysis: Classification of the importance of weights of the Western European ANSP model with low personal consequences of occurrences.

Safety culture indicator	Importance of weights		
	High	Medium	Low
I1.1	–	w2, w14, w15, w17, w20, w24	Rest
I2.1	w2, w21	w20, w24, w54	Rest
I3.1	w1-w3, w6-w20, w22, w23, w25-w29, w31-w45, w47-w49, w52-w59	w4, w5, w21, w24, w30, w46, w50, w51, w60	Rest
I4.1	w51, w59	w19, w27, w28, w36, w44, w52	Rest
I5.2	w1-w23, w25-w37, w39-w43, w45-w50, w52-w55, w57-w60	w24, w38, w44, w51, w56	Rest
I7	w1-w3, w6-w9, w15-w18, w20, w21, w27, w28, w33, w35,	w10-w14, w22-w24, w26, w29, w31, w32, w37, w41, w45-w47,	Rest

	w36, w38-w40, w42, w43, w48-w50, w53-w55, w57, w58	w60	

Table 17: Results of MC filtering sensitivity analysis: Classification of the importance of weights of the Western European ANSP model with high personal consequences of occurrences.

Safety culture indicator	Importance of weights		
	High	Medium	Low
I1.1	-	w4, w9, w10, w12, w14, w15, w20, w21, w26, w27, w37, w38	Rest
I2.1	-	w4, w28, w29, w51	Rest
I3.1	w1-w59	-	Rest
I4.1	w42	w1, w9, w26, w31, w44, w45, w52	Rest
I5.2	w1-w4, w6-w55, w57-w60	w5, w38, w56	Rest
I7	w1, w4	w6, w8, w10, w19, w28, w34, w35, w36, w48, w49, w51, w52, w58	Rest

Appendix B ORGANIZATIONAL MODEL DETAILS

This appendix contains selected details of the agent-based organizational model as summarized in Section 1.2.2 and defined in detail in (Sharpanskykh et al., 2008).

B.1 INFLUENCE OF NATIONAL CULTURE

Table 18 shows the ranges of values of the evidence variables in the organizational model that are influenced by national culture based on (Hofstede, 2001). Specific values for individual agents are chosen uniformly within these ranges.

Table 18: Ranges of input variables of the generic agent-based organizational model that are influenced by national culture.

Variable	Description	Western European Culture	Eastern European Culture
e61	Individualism index of a controller	[0.7, 0.9]	[0.2, 0.4]
e62	Power distance index of a controller	[0.3, 0.5]	[0.8, 1]
e63	Masculinity index of a controller	[0.05, 0.25]	[0.32, 0.52]
e64	Uncertainty avoidance index of a controller	[0.4, 0.6]	[0.8, 1]

B.2 PARAMETER VALUES RELATED TO SAFETY OCCURRENCES

Table 19 provides indicative descriptions of four types of occurrences and the yearly number of occurrences, as considered in the model. Table 20 shows the values for probabilities that non-reported occurrences are identified by team members or management, as considered in the model.
Table 21 shows the definition of three classes of personal consequences of occurrences. In particular, it specifies the value of an administrative reprimand *r* as result of numbers of types of occurrences. An administrative reprimand is one of the aspects considered in the decision making model of a controller about reporting of an occurrence, such as presented at a high level in Section 1.2.2 or in detail in (Sharpanskykh et al., 2008). It follows from

Table 21 that in an organization with High personal consequences of occurrences, all types of occurrences may lead to reprimands, whereas in organizations with Medium/Low personal consequences only severe (and rare) occurrences lead to reprimands.

Table 19: Numbers of occurrences of different types per year used in the model. The occurrences are distributed over time following the Poisson probability distribution.

Occurrence type	Indicative description of occurrence type	Modelled yearly number of occurrences
A	Incident with serious inability to provide or maintain safe service, involving a large separation infringement and a high risk of collision.	0
B	Incident with partial inability to provide or maintain safe service, involving a medium separation infringement and a medium risk of collision.	2
C	Incident with ability to provide or maintain safe service, involving a small separation infringement and a low risk of collision.	16
other	Occurrence without a separation infringement, e.g. pilot report of a TCAS Advisory or Prolonged Loss of Communication	168

Table 20: Probabilities of identification of different types of not reported occurrences by a team of controllers (p3) and by the management (p2)

Occurrence type	p2	p3
A	0	0
B	0.1	0
C	0.3	0.2
other	0.7	0.4

Table 21: Definition of three classes for personal consequences of occurrences. Here n is the number of occurrences of a particular type and r is the value of the reprimand. For instance the definition $n = 2 \rightarrow r = 0.2$ means that two occurrences lead to a reprimand with value 0.2.

Occurrence type	Personal consequences of occurrences

	Low	Medium	High
A	$n=1 \rightarrow r=1$	$n=1 \rightarrow r=1$	$n=1 \rightarrow r=1$
B	none	$n=1 \rightarrow r=0.5$	$n=1 \rightarrow r=0.5$
C	none	none	$n=2 \rightarrow r=0.2$
other	none	none	$n=4 \rightarrow r=0.1$

B.3 WEIGHTS

Table 22 lists all weights w_i in the organizational model after the adaptations made in the report. Table 23 and Table 24 list the weights that have changed with respect to the model of (Sharpanskykh et al., 2008) for weights that are dependent or independent on national culture, respectively.

Table 22: Values of the weights used in the models of the Western and Eastern European ANSPs.

Weight	Description	Western European	Eastern European
w1	Contribution of e1 'Priority of safety-related goals in the role description' to e6 'Commitment to safety of a controller'	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
w3	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	0.1	0.3
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	0.1
w6	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.1	0.1
w7	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.1	0.05
w8	Contribution of e1 'Priority of safety-related goals in the role description' to e2 'Perception of the commitment to safety	0.15	0.1

	of management'		
w9	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e2 'Perception of the commitment to safety of management'	0.2	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'	0.05	0.2
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	0.2	0.15
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	0.05	0.1
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	0.15	0.15
w14	Contribution of e14 'Level of development of managerial skills' to e13 'Perception of commitment to safety of the supervisor'	0.4	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	0.6
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
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	0.1	0.1
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	0.3	0.3
w20	Contribution of e7 'Quality of technical systems' to e15 'Quality of a processed notification report'.	0.3	0.3
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a processed notification report'.	0.3	0.3

w22	Contribution of e19 'Self-confidence for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w23	Contribution of e20 'Commitment to perform ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w24	Contribution of e21 'Development level of skills for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w25	Contribution of e23 'Adequacy of mental models for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25	0.25
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	0.5	0.5
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	0.5	0.5
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	0.4	0.4
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	0.6	0.6
w30	Contribution of e25 'Sufficiency of the number of maintenance personnel' to e17 'Quality of technical systems'.	0.4	0.4
w31	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	0.2	0.2
w32	Contribution of e9 'Availability of up-to-date technical systems for controllers' to e17 'Quality of technical systems'.	0.4	0.4
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'.	0.6	0.4
w34	Contribution of e6 'Commitment to safety of a controller' to e29 'Information contribution by a controller'.	0.3	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	0.7
w36	Contribution of e30 'Information	0.4	0.6

	contribution by the supervisor' to e16 'Information contribution by others'.		
w37	Contribution of e28 'Amount of knowledge on similar safety-related issues of the supervisor' to e30 'Information contribution by the supervisor.	0.7	0.7
w38	Contribution of e13 'Perceived commitment to safety of the supervisor' to e30 'Information contribution by the supervisor.	0.3	0.3
w39	Contribution of e8 'Sufficiency of the number of controllers' to e18 'Acceptability of the workload level'.	0.8	0.8
w40	Contribution of e14 'Level of development of managerial skills' to e18 'Acceptability of the workload level'.	0.2	0.2
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview report'.	0.4	0.4
w43	Contribution of e32 'Quality of safety analysis' to e33 'Quality of a monthly safety overview report'.	0.6	0.6
w44	Contribution of e44 'Average commitment to safety of the agents involved in safety analysis' to e32 'Quality of safety analysis'.	0.4	0.4
w45	Contribution of e31 'Quality of input data' to e32 'Quality of safety analysis'.	0.6	0.6
w46	Contribution of e45 'Average contribution of informal discussions of controllers in teams' to e31 'Quality of input data'.	0.3	0.3
w47	Contribution of e46 'Average quality of processed notification reports' to e31 'Quality of input data'.	0.5	0.5
w48	Contribution of e47 'Average quality of previous monthly safety overview reports' to e31 'Quality of input data'.	0.2	0.2
w49	Contribution o9f e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.2	0.2
w50	Contribution of e35 'Intensity of informal interactions in the team of controllers' to e34 'Contribution of informal discussions	0.35	0.35

	of controllers in the team'.		
w51	Contribution of e48 'Average quality of the notification reports produced by the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.3	0.3
w52	Contribution of e49 'Average quality of the received monthly safety overview reports' to e34 'Contribution of informal discussions of controllers in the team'.	0.25	0.25
w53	Contribution of e36 'Quality of the formal safety occurrence assessment procedure' to e38 'Quality of the final safety occurrence assessment report'.	0.1	0.1
w54	Contribution of e50 'Average commitment to safety of the participants of the meetings' to e38 'Quality of the final safety occurrence assessment report'.	0.1	0.1
w55	Contribution of e7 'Sufficiency of the number of safety investigators' to e38 'Quality of the final safety occurrence assessment report'.	0.15	0.15
w56	Contribution of e15 'Quality of a processed notification report' to e38 'Quality of the final safety occurrence assessment report'.	0.25	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	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	0.15
w59	Contribution of e7 'Sufficiency of the number of safety investigators' to p1 'Probability of the feedback provision'.	0.3	0.3
w60	Contribution of e39 'Severity of an occurrence' to p1 'Probability of the feedback provision'.	0.4	0.4
w61	Contribution of e40 'Quality of the communication channel between controllers and safety investigators'	0.3	0.3

Table 23: Overview of weights changed w.r.t. the model in (Sharpanskykh et al., 2008). These weights are considered to be independent of the national culture.

Weight	Description	New value	Old value
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	0.1	0.15
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	0.3	0.2
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a processed notification report'.	0.3	0.35
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	0.5	0.6
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	0.5	0.4
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	0.4	0.5
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	0.6	0.5
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview report'.	0.4	0.35
w43	Contribution of e32 'Quality of safety analysis' to e33 'Quality of a monthly safety overview report'.	0.6	0.65
w44	Contribution of e44 'Average commitment to safety of the agents involved in safety analysis' to e32 'Quality of safety analysis'.	0.4	0.35
w45	Contribution of e31 'Quality of input data' to e32 'Quality of safety analysis'.	0.6	0.65
w47	Contribution of e46 'Average quality of processed notification reports' to e31 'Quality of input data'.	0.5	0.6
w48	Contribution of e47 'Average quality of previous monthly safety overview reports' to	0.2	0.1

	e31 'Quality of input data'.		
w49	Contribution o9f e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.2	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'.	0.35	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'.	0.3	0.25
w60	Contribution of e39 'Severity of an occurrence' to p1 'Probability of the feedback provision'.	0.4	0.3

Table 24: Overview of weights changed w.r.t. the model in (Sharpanskykh et al., 2008). These weights are considered different for Western and Eastern European cultures.

Variable	Description	Western European Culture		Eastern European Culture	
		New	Old	New	Old
w8	Contribution of e1 'Priority of safety-related goals in the role description' to e2 'Perception of the commitment to safety of management'	0.15	0.2	0.1	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'	0.2	0.15	0.15	0.15
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	0.2	0.15	0.15	0.15
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment	0.15	0.2	0.15	0.2

	to safety of management'				
w6	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.1	0.05	0.1	0.05
w7	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.1	0.05	0.05	0.05
w10	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	0.05	0.15	0.2	0.15
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	0.05	0.05	0.1	0.05
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'	0.6	0.7	0.4	0.7
w36	Contribution of e30 'Information contribution by the supervisor' to e16 'Information contribution by others'	0.4	0.3	0.6	0.3