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Safety modelling and analysis of organizational processes in air traffic - D7: Validation

EUROCONTROL CARE Innovative Research III

S.H. Stroeve
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Executive summary

SAFETY MODELLING AND ANALYSIS OF ORGANIZATIONAL PROCESSES IN AIR TRAFFIC - D7: VALIDATION

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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 the results of the organizational model as well as a validation of these results. In the validation study we compared the model results for a particular ANSP-3 with the results of a EUROCONTROL safety culture survey study of ANSP-3 in three phases:
-*Phase 1*- Comparison of model-based and survey-based safety culture indicators, where the input values of the model were completely based on organizational information available prior to the survey questionnaire results;
-*Phase 2*- Comparison of model-based and survey-based safety culture indicators, where the input values of the model used organizational information in combination with survey questionnaire results;
-*Phase 3*- Comparison of major organizational factors affecting the safety culture indicators and related organizational improvement options, which were inferred from a sensitivity analysis of the organizational model, with key issues and recommendations stemming from safety culture survey workshop results.

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Organization
Modelling

Results and conclusions
The following validation results were obtained in these three phases:
-Phase 1- The model predicted safety culture indicators which were mostly higher than the survey questionnaire results. In particular, for six out of the seven relevant indicators a higher class was predicted by the model.
-Phase 2- The model predicted safety culture indicators which were mostly equal to the survey questionnaire results. In particular, for six out of seven indicators the same class was predicted by the model.
-Phase 3- The major organizational factors and organizational improvement options identified by the model-based sensitivity study were largely consistent with the safety culture issues and the recommendations arrived at via the workshops in the survey study. The survey results included more details of the organizational context and revealed some aspects that were out of the scope of the organizational model.

In conclusion, to achieve valid predictions of the safety culture indicators by the model, we needed input data from the safety culture survey questionnaire, and on this basis the sensitivity analysis provided valid results for important organizational factors influencing the safety culture indicators and related recommendations.

The major added advantage of agent-based organizational modelling is that it provides a structured, formally-grounded means for analysis and improvement of safety culture. It defines explicit formal relations between safety culture indicators and organizational processes and structures, thus enabling identification of important organizational aspects impacting safety culture by sensitivity analysis techniques. Insights in relations between safety culture indicators and organizational structures and processes may be used to further enhance safety culture questionnaires and prepare safety culture survey workshops.

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

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Contents

1 INTRODUCTION

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 (Gordon et al., 2006; Mearns et al., 2008; Choudhry et al., 2007; Hopkins, 2006; Ek et al., 2007). Safety culture aims to keep the collective mind of an organization, through its entirety of individual minds, continually focused on safety (EUROCONTROL/FAA AP15 Safety, 2008). As a prelude to systemic changes in ATM via SESAR in Europe and NextGen in the USA, Eurocontrol, FAA and CANSO plan to see more and more Air Navigation Service Providers (ANSPs) go through safety culture measurement and improvement processes.

The main aspects of organizational culture are 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 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, in line with reasoning of Hopkins (2006).

Various studies have focused on characterization and assessment of safety culture (e.g., Mearns et al., 2008; Ek et al., 2007). However, the links of safety culture with organizational structures and processes are yet not well understood and this affects the determination 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 aim to 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. To this end, a suitable multi-agent organizational modelling method was identified in a literature survey and applied to a first air traffic case in (Stroeve et al., 2007a,b,c). The development of the model has been focused on safety occurrence reporting at an ANSP and its relation with safety culture in (Sharpanskykh and Stroeve, 2008a,b, 2009a,b; Sharpanskykh et al., 2008, Stroeve et al., 2008). The purpose of the current report is to present the model results and their validation.

As a basis for the validation we coordinated our research efforts with safety culture research pursued by EUROCONTROL. In an effort to measure and understand safety culture at European ANSPs, EUROCONTROL has been developing a safety culture survey approach (Gordon et al., 2006; Mearns et al., 2008; EUROCONTROL/FAA AP15 Safety, 2008). This survey approach 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, workshops are used to analyse the key safety culture issues and to provide solutions for them. The survey has now been applied at several ANSPs.

1.2 Structure of study and report

The developed model was used to predict the safety culture performance of a particular West-European ANSP, referred to as ANSP-3. The model results were compared with the results of a EUROCONTROL safety culture survey study of ANSP-3. The modelling and validation study was done in the following three phases:

- Phase 1: Comparison of model-based and survey-based safety culture indicators, where the input values of the model were completely based on organizational information available prior to the survey questionnaire results;
- Phase 2: Comparison of model-based and survey-based safety culture indicators, where the input values of the model used organizational information in combination with survey questionnaire results;
- Phase 3: Comparison of major organizational factors affecting the safety culture indicators and related organizational improvement options, which were inferred from a sensitivity analysis of the organizational model, with key issues and recommendations stemming from the safety culture survey workshop results.

The organizational model is presented in Section 2. The results of Phases 1, 2 and 3 are presented in Sections 3, 4 and 5, respectively. A discussion and conclusions are provided in Section 6.

2 SUMMARY OF ORGANIZATIONAL MODEL

For modelling the safety occurrence reporting in an ANSP the modelling framework and methodology from (Sharpanskykh, 2008) was used, which comprises a sequence of organization design steps. This framework allows modelling institutional (prescriptive) aspects of the formal organization, as well as the social behaviour of organizational actors (agents). This section provides an overview of the developed agent-based organization model, where Section 2.1 focuses on the formal organization, Section 2.2 describes the performance of agents in the organization and Section 2.3 gives an overview of the types of model parameters and the model outputs. A detailed description of the model can be found in associated reports (Sharpanskykh et al., 2008; Sharpanskykh and Stroeve, 2009a).

2.1 SPECIFICATION OF THE FORMAL ORGANIZATION

A specification of the formal organization is provided along three interrelated views: organization-oriented view, performance-oriented view and process-oriented view. The methodology for the model development along these views includes various steps, which can be read in (Sharpanskykh, 2008; Stroeve et al., 2007c, 2008) and associated reports.

The *organization-oriented view* describes a functional decomposition of an organization by a composite structure of the roles at various aggregation levels. These roles are abstracted from particular agents that may fulfil them, e.g. business unit, department, manager or operator. The organization-oriented view describes interactions between roles and specifies the authority relations in an organization: superior-subordinate relations on roles with respect to tasks, responsibility relations, authorization relations and control for resources. An example of interactions between roles is illustrated in Figure 1.

The *performance-oriented view* describes the goals of the organizational roles in a goal structure of generic and specific goals. It uses performance indicators as measures of goal achievement for organizational roles.

The *process-oriented view* describes tasks and processes in the organization. It specifies static and dynamic relations between processes, e.g. decomposition, ordering and synchronization, and the resources used and produced.

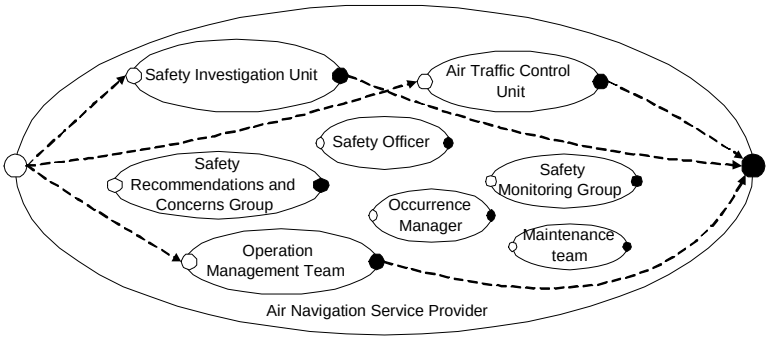

Figure 1: Example of organization-oriented view: roles considered in Air Navigation Service Provider (at aggregation level 2) and links to roles at other levels. Details are in (Sharpanskykh et al., 2008; Sharpanskykh and Stroeve, 2009a).

Safety occurrence reporting is a key process in the organizational model and the workflow for its tasks is shown in Figure 2 as an example. The workflow describes the actions for the reporting of occurrences and the processing of reported occurrences, starting with deciding by a controller to report an occurrence, up to assessment of occurrences and implementation of policies to prevent similar occurrences. The workflow is a product of the process-oriented view and it has interactions with both the organization- and performance oriented views. In relation with the organization-oriented view, the responsibilities of the roles for the tasks in the workflow are defined, e.g., the Controller role is responsible for execution of and decision making with respect to the task 'Create a notification report', the Controller Supervisor is responsible for monitoring and consulting for this task. In relation with the performance-oriented view, goals that are pursued by tasks in a workflow are addressed, e.g. goals to achieve particular reporting quality levels.

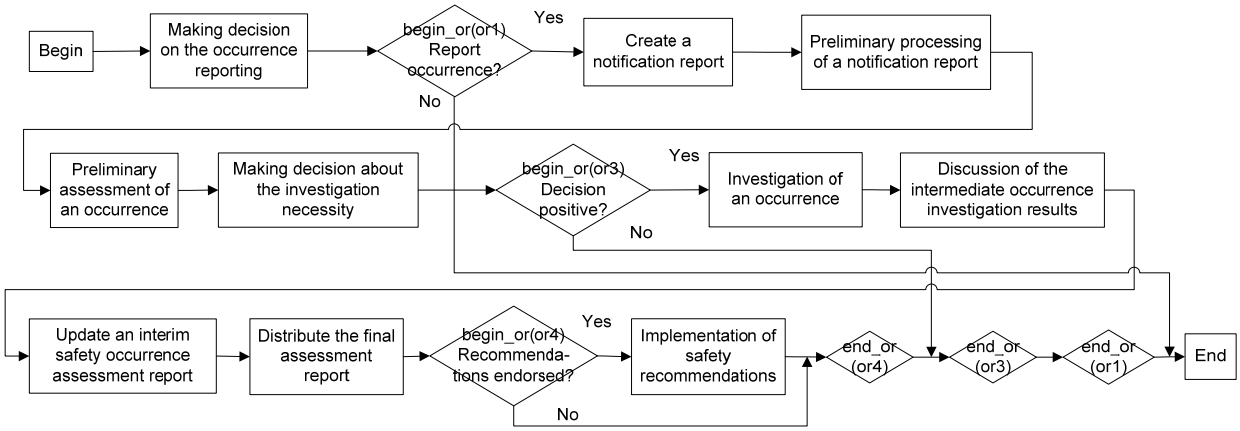

Figure 2: Workflow example: occurrence reporting

2.2 SPECIFICATION OF AGENTS

An agent is an entity that is able to perceive and act upon its environment. The behaviour of an agent can be considered from external and internal perspectives.

From the *external perspective* the behaviour can be specified by dynamic relations between agent's input and output states, corresponding to interaction with other agents and with the environment in a multi-agent organization (Figure 3). An agent perceives information by observation or communication and generates output in the form of communication or actions.

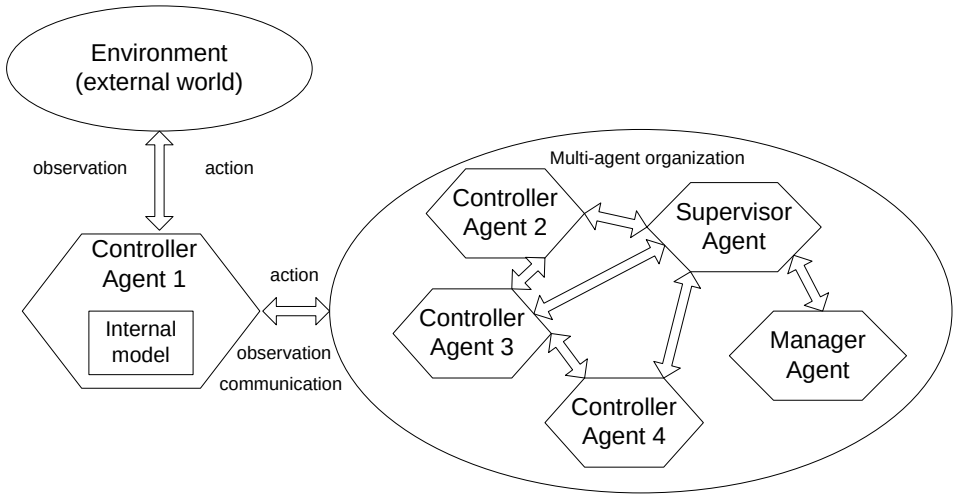

Figure 3: External perspective of an agent in a multi-agent organization

From the *internal perspective* the behaviour of an agent is characterized by causal relations between internal states of the agent, based on which externally observable behavioural patterns are generated (Figure 4). The internal states of an agent include *information attitudes* (e.g. belief, knowledge) and *pro-attitudes* (e.g. desire, intention, obligation, commitment) (Wooldridge and Jennings, 1995). Agents are considered as goal-driven, where pro-attitudes are based on *needs*. The externally observable behaviour based on the internal states is determined by the *decision making process*. The way in which these aspects of agent are represented in this study is discussed next.

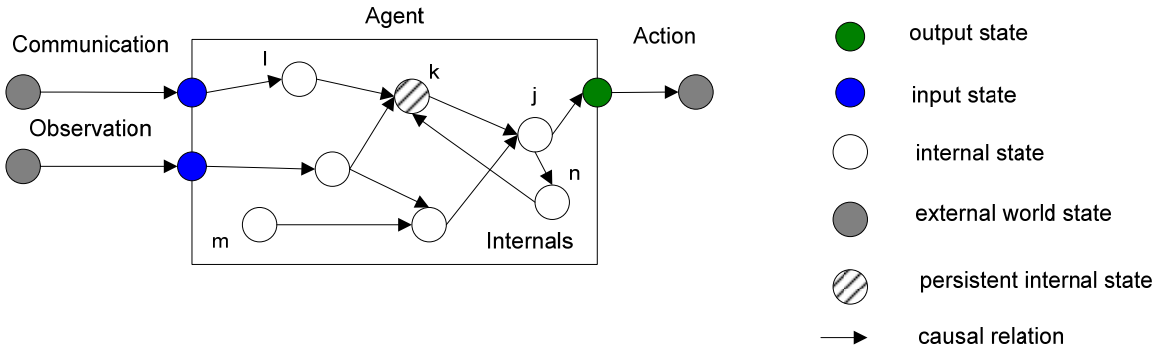

Figure 4: Internal perspective of an agent

Agent's information attitudes and pro-attitudes

Agents create time-labelled internal representations (beliefs) about their input and output states, which may persist over time. Besides beliefs about single states, an agent forms beliefs about dependencies between its own states, observed states of the environment, and observed states of other agents.

In the developed model we use the Temporal Trace Language (TTL) to represent temporal relations between state properties (Sharpanskykh, 2008). For example, the property that for all time points if an agent ag believes that action a is rewarded with r, then ag will after 30 time units perform a, is formalized in TTL as:

$$\forall t{:}TIME\ [\ at(internal(ag, belief(reward\_for\_action(r, a))), t) \rightarrow at(output(ag, performed\_action(a)), t+30)\ ]$$

In our study relations between agent's states are mostly modelled by causal networks (Pearl, 2000), which describe weighted static mappings between 'evidence variables', which take on values in the range from 0 to 1. As an example Figure 5 shows the causal network for the commitment to safety of a controller. According to this causal network, a controller agent's commitment to safety is influenced by the perceived commitment to safety of team members and the management, by the priority of safety-related goals in the role description, by the influence of the controller on safety activities and by the maturity level of the controller (Burt, 1987; Griffin and Bateman, 1986). The rounded boxes in Figure 5 refer to evidence variables that are considered as input of the organizational model and the rectangular boxes refer to evidence variables that depend on other evidence variables in the model. For instance, an agent evaluates the management's commitment to safety by considering factors that reflect the management's effort in contributing to safety, such as investment in personnel and technical systems, training and safety arrangements. As another example, the maturity level of a controller depends on aspects as the self-confidence, the

commitment to perform the ATC task, the level of skill and the level of training of the agent and the quality of feedback on occurrence reporting received by the agent. By interconnection of causal networks feedback loops exist in the model.

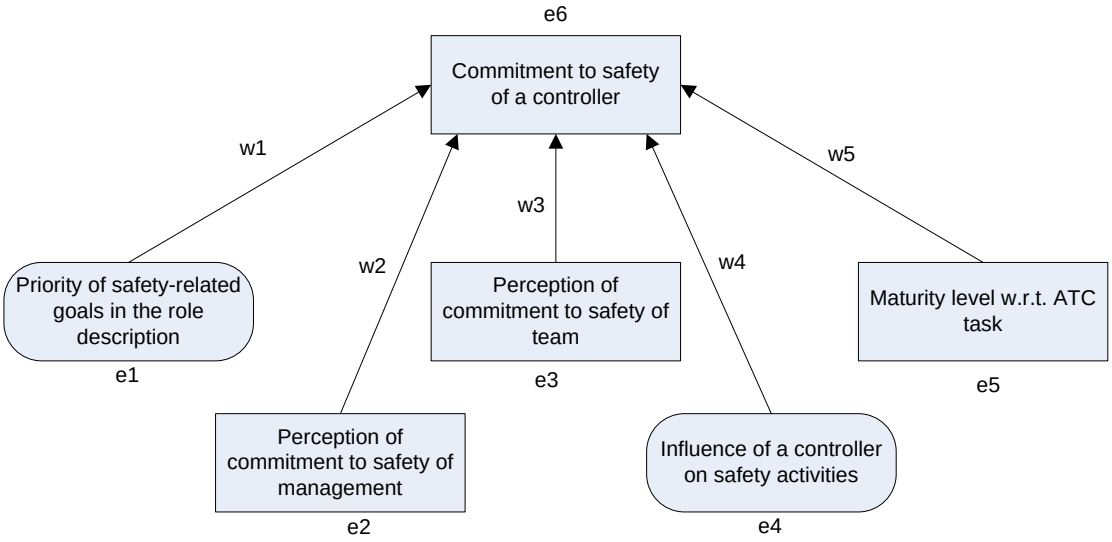

Figure 5: Causal network for 'Commitment to safety of a controller'

Agent's needs

Social science considers behaviour of individuals as goal-driven, where the individual goals are based on needs. Three types of needs are distinguished: (1) extrinsic needs associated with biological comfort and material rewards; (2) social interaction needs that refer to the desire for social approval and affiliation, e.g. own group approval and management approval; (3) intrinsic needs that concern the desires for self-development and self-actualization, e.g. contribution to safety-related goals, self-esteem and self-confidence. Different needs have different priorities and minimal acceptable satisfaction levels for individuals in different cultures. In this study we use the cultural classification framework of Hofstede (2005), which considers three indices: individualism index reflects the degree to which individuals are not integrated into groups; power distance index is the extent to which the less powerful members of an organization accept and expect that power is distributed unequally; and uncertainty avoidance index deals with individual's tolerance for uncertainty and ambiguity. The model uses values for these indices that are suitable for Western European culture (Hofstede, 2005). The model has internal states that represent to what extent the agent's needs are satisfied as result of external events, the behaviour of other agents and decisions made. The level of satisfaction of agent's needs influences the decision making process.

Agent's decision making process

The decision making model of agents is based on the expectancy theory by Vroom (Pinder, 1998) and it is illustrated in Figure 6. According to Vroom's theory, when a human evaluates alternative possibilities to act, the following factors are explicitly or implicitly taken into account: valence, expectancy and instrumentality.

- *Expectancy* refers to the individual's belief about the likelihood that a particular act will be followed by a particular outcome (called a first-level outcome). For example in Figure 6, the expectancy E12 refers to the agent's belief of the likelihood that reporting of an occurrence will be followed by an administrative reprimand.
- *Instrumentality* is a belief concerning the likelihood that a first level outcome results into a second level outcome, which represents a (un)desirable state as reflected by the agent's needs. For example in Figure 6, the instrumentality I32 refers to the belief about the likelihood that own group appreciation of the action results in own group approval.
- *Valence* refers to the strength of the individual's desire for an outcome or state of affairs. The values of valences depend on the degree of satisfaction of the agent's need: the more a need is satisfied, the less is its valence.

In Vroom's model the force F_i on an individual to perform an act is defined as:

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

Here E_{ij} is the strength of the expectancy that act i will be followed by outcome j; V_k is the valence of the second level outcome k; I_{jk} is perceived instrumentality of outcome j for the attainment of outcome k. The agent's decision making model considers two forces for reporting or not reporting; the alternative with the greatest force is performed.

Expectancies, instrumentalities and valences are dynamic variables that change over time due to individual and organizational learning. In particular, in the model their values depend on the occurrence of events and on related evidence variables. For example in Figure 6, the agent's expectancies E12 and E15 change depending on the reprimands and rewards for occurrences reported by the agent or another agent in its shift (instrumentalist/social learning); and E16 is adjusted based on the feedback from the safety investigator agent on previously reported occurrences and the observed implementation of safety recommendations for previous reports (instrumentalist learning), as well as safety information informally provided by other controllers during breaks (social learning).

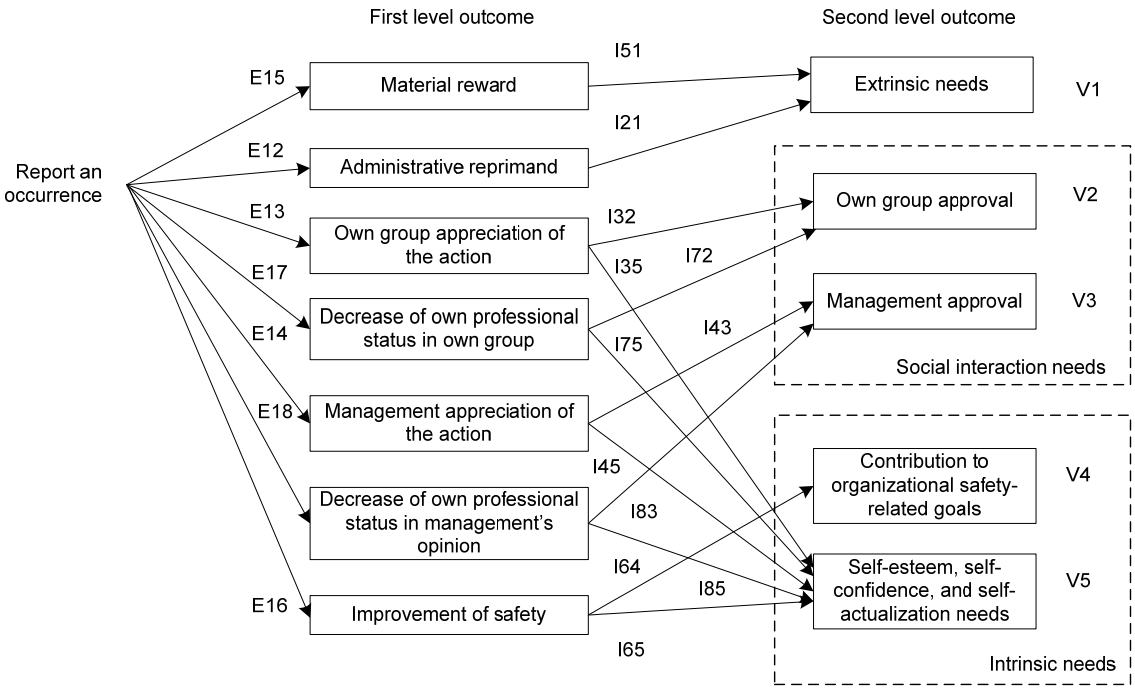

Figure 6: Decision making model for reporting an occurrence (E's are expectancies, I's are instrumentalities and V's are valences)

2.3 Model parameters and outputs

The dynamics of the agent-based organizational model depend on the model structure such as outlined in the previous sections and on a range of parameter values. We distinguish the following types of parameters:

- Evidence input variables, which are the independent inputs of the causal networks in the model (Table 1 provides a list of all 22 evidence input variables);
- Weights, which reflect the importance of mappings between the evidence variables in the causal networks (the model contains 60 weights);
- Task durations, which refer to the (limits of) task durations in workflows (the model contains upper and lower bounds for 16 tasks);
- Decision making, which are related to Vroom's decision making model presented in Section 2.2 (28 parameters);
- Other (55 parameters).

In this study we used two sets of parameter values, which will be presented in Sections 3 and 4.

Table 1: Model input evidence variables

Variable	Description
e1	Priority of safety-related goals in the role description
e4	Influence of a controller on safety activities
e7	Sufficiency of the number of safety investigators
e8	Sufficiency of the number of controllers
e9	Availability of reliable and ergonomic technical systems for controllers
e10	Sufficiency and timeliness of training for changes
e11	Regularity of safety meetings
e12	Developed and implemented safety management system (SMS)
e14	Level of development of managerial skills
e19	Self-confidence for ATC task
e20	Commitment to perform ATC task
e21	Development level of skills for ATC task
e25	Sufficiency of the number of maintenance personnel
e26	Quality of formal procedures for system checks and repairs
e35	Intensity of informal interactions in the team of controllers
e36	Quality of the formal safety occurrence assessment procedure
e40	Quality of the communication channel between controllers and safety investigators
e44	Average commitment of the agents involved in the safety analysis
e61	Individualism index of a controller
e62	Power distance index of a controller
e63	Masculinity index of a controller
e64	Uncertainty avoidance index of a controller
e71	Formal support for confidentiality of reporting

Based on a broad list of safety culture issues related to occurrence reporting that we identified in (Sharpanskyk and Stroeve, 2008a), Table 2 shows the eight safety culture indicators that are observable in the agent-based organizational model; these are the model outputs.

Table 2: Model output safety culture indicators

Index	Safety Culture Indicator
I1.1	Average reporting quality of controllers. It refers to the ratio of reported versus observed occurrences.
I2.1	Average quality of the processed notification reports. It refers to the correctness and completeness of information about the reported occurrences.
I3.1	Average quality of the final safety occurrence assessment reports. It refers to the completeness of the occurrence report with respect to the causes of the occurrence.
I4.1	Average quality of the monthly safety overview reports received by controllers. It refers to the completeness of the report with respect to the safety trends.

Index	Safety Culture Indicator
I5.1	Average commitment to safety of controllers.
I5.2	Average commitment to safety of a team as perceived by controllers.
I6	Average commitment to safety of a supervisor as perceived by controllers.
I7	Average commitment to safety of management as perceived by controllers.

3 MODEL & VALIDATION PHASE I

This section presents a comparison of the results of the organizational model of ANSP-3 with questionnaire results of the EUROCONTROL safety culture survey study of ANSP-3. Section 3.1 presents the results for the safety culture indicators as inferred from the survey questionnaire data. In line with the validation plan (Sharpanskykh and Stroeve, 2008b) these survey questionnaire-based safety culture indicators are compared with two sets of model results. Section 3.2 presents the comparison of an original set of model results as presented previously in (Sharspansykh and Stroeve, 2009a).

3.1 SURVEY QUESTIONNAIRE-BASED SAFETY CULTURE INDICATORS

In the validation plan (Sharpanskykh and Stroeve, 2008b) we defined a relation between safety culture indicators and particular questions in the safety culture survey questionnaire. Table 3 shows the resulting safety culture indicators using weighted averages of the survey questionnaire results.

Table 3: Relation of safety culture indicators to specific questions from the safety culture survey questionnaire for ANSP-3, as defined in (Sharpanskykh and Stroeve, 2008)

Safety Culture Indicator		Related safety culture survey questions	Weight	Survey result	Total
No.	**Description**				
I1.1	Reporting quality (ratio reported/observed) in the whole organization.	A.24 People understand the need to report incidents in order to identify trends and make changes to the system if required	0.5	3.7	3.7
		A.31. If I see an unsafe practice by a colleague I am able to report it in a way that we all learn lessons from it.	0.3	3.3	
		A.32. If I do something unsafe I am aware that I may be asked to explain myself	0.2	4.1	
I2.1	Average quality of the processed notification reports produced by a controller in the whole organization.	No related question identified.	-	-	-

Safety Culture Indicator		Related safety culture survey questions	Weight	Survey result	Total
No.	Description				
I3.1	Average quality of the received final safety occurrence assessment reports by controllers in the whole organization.	A.22 Appropriate responses are made after an incident to address why the incident occurred.	1	3.7	3.7
I4.1	Average quality of the monthly safety overview reports received by controllers in the whole organization.	A.24 People understand the need to report incidents in order to identify trends and make changes to the system if required	0.4	3.7	3.5
		A.29 Lessons learned from incidents are published in a de-identified manner in a newsletter or similar document	0.6	3.3	
I5.1	Commitment to safety of a controller	B.10 Controllers would never compromise their responsibility to safety.	1	3.8	3.8
I5.2	Perceived commitment to safety of a team of controllers	A.4 My colleagues are committed to safety.	0.7	4.0	3.9
		A.11 Everyone at my Unit/Team feels that safety is their personal responsibility.	0.3	3.8	
I6	Perceived commitment to safety of supervisor.	B.16 My concern about safety would be acted on if I expressed them to my supervisor	1	3.0	3.0
I7	Perceived commitment to safety of management.	A.7 My management is committed to safety	1	3.4	3.4

Different types of results are obtained by the safety culture survey questionnaires and the agent-based organizational model. The questionnaire results include mean scores for the level of agreement to statements on a scale from 1 (“fully disagree”) to 5 (“fully agree”). The model results for safety culture indicators range on scales from 0 to 1. Since the questionnaire and model scales are different and the results for neither of them can be expected to be uniformly distributed along the full scales, we introduce three classes for the values of the indicators: Low / Medium / High. Table 4 shows our definition of these classes for the questionnaire result scales. It follows from an analysis of survey questionnaire results of a particular ANSP-2 (different from ANSP-3) that for this ANSP 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 4: Definition of attributes of safety culture indicator value classes

Class of value of safety culture indicator	Range of average value in survey questionnaire	Relative contribution ANSP-2
Low	[1, 3.25]	30%
Medium	(3.25, 4]	55%
High	(4, 5]	15%

These results are mapped to classes Low/Medium/High according to Table 4 as defined earlier in (Sharpanskykh and Stroeve, 2009a). The resulting classes of the safety culture indicators are shown in Table 5. It can be observed that as result of these methods, the safety culture indicators are Medium, with exception of a class Low for indicator I6 'Perceived commitment to safety of supervisor'.

Table 5: Summary of safety culture indicators obtained via questionnaire data of ANSP-3

Index	Safety culture indicator	Value	Class
I1.1	Average reporting quality of controllers	3.7	Medium
I2.1	Average quality of the processed notification reports	-	-
I3.1	Average quality of the final safety occurrence assessment reports	3.7	Medium
I4.1	Average quality of the monthly safety overview reports received by controllers	3.5	Medium
I5.1	Average commitment to safety of controllers	3.8	Medium
I5.2	Average commitment to safety of a team as perceived by controllers	3.9	Medium
I6	Average commitment to safety of a supervisor as perceived by controllers	3.0	Low
I7	Average commitment to safety of management as perceived by controllers	3.4	Medium

3.2 Comparison of model and survey results

In (Sharpanskykh and Stroeve, 2009a) we presented a first set of model results. The model input data for these results are based on interview results with a safety manager and safety investigator of ANSP-3 and some safety management documentation of ANSP-3. The model results are shown in Table 6.

Table 6: Model simulation results for the average safety culture indicators of ANSP-3 (Sharpanskykh and Stroeve, 2009a)

Index	Safety culture indicator	Value	Class
I1.1	Average reporting quality of controllers	0.80	High
I2.1	Average quality of the processed notification reports	0.65	High
I3.1	Average quality of the final safety occurrence assessment reports	0.23	Medium
I4.1	Average quality of the monthly safety overview reports received by controllers	0.70	High
I5.1	Average commitment to safety of controllers	0.72	High
I5.2	Average commitment to safety of a team as perceived by controllers	0.70	High
I6	Average commitment to safety of a supervisor as perceived by controllers	0.78	High
I7	Average commitment to safety of management as perceived by controllers	0.76	High

The class labels (Low/Medium/High) attached to these results are based on a definition provided earlier in (Sharpanskykh and Stroeve, 2009a). This definition is based on Monte Carlo simulations that revealed the probability densities of safety culture indicator values for variations in the settings of the evidence input variables. In particular, all evidence input variables listed in Table 1 were varied over their full range, except the national culture variables (e61-e64) which were associated with Western European culture. Figure 7 provides examples of histograms for the Monte Carlo simulations results for two safety culture indicators. Next, on the basis of these Monte Carlo simulation results, we associated ranges of values for each safety culture indicator to the classes High / Medium /Low: the upper 15% is High, the middle 55% is Medium and the lower 30% is Low, in line with the relative contributions of ANSP-2. Table 7 shows the resulting boundaries of the model results for the class definitions.

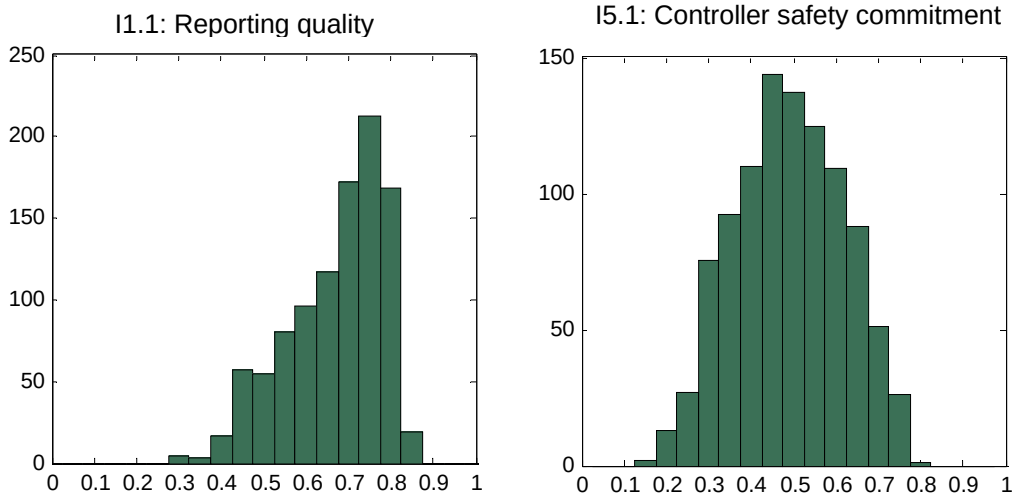

Figure 7: Examples of distributions of safety culture indicators (Monte Carlo simulation results)

Table 7: Class definitions for the model output values (Sharpanskykh and Stroeve, 2009a)

Safety Culture Indicator		Low	Medium	High
I1.1	Average reporting quality of controllers	[0, 0.55]	(0.55, 0.76]	(0.76, 1]
I2.1	Average quality of the processed notification reports	[0, 0.27]	(0.27, 0.45]	(0.45, 1]
I3.1	Average quality of the final safety occurrence assessment reports	[0, 0.14]	(0.14, 0.32]	(0.32, 1]
I4.1	Average quality of the monthly safety overview reports received by controllers	[0, 0.44]	(0.44, 0.66]	(0.66, 1]
I5.1	Average commitment to safety of controllers	[0, 0.43]	(0.43, 0.63]	(0.63, 1]
I5.2	Average commitment to safety of a team as perceived by controllers	[0, 0.43]	(0.43, 0.63]	(0.63, 1]
I6	Average commitment to safety of a supervisor as perceived by controllers	[0, 0.48]	(0.48, 0.7]	(0.7, 1]
I7	Average commitment to safety of management as perceived by controllers	[0, 0.45]	(0.45, 0.63]	(0.63, 1]

For easy comparison, Table 8 shows the classes of the safety culture indicators for both the organizational model results and the safety culture survey questionnaire data. It follows from this table that according to the model all safety culture indicators except I3.1 are High. The Medium value of I3.1 indicates sub-optimal feedback provision on safety occurrences to air traffic controllers and/or insufficient amount of details in the safety occurrence assessment reports. The model 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.

Table 8 shows that the safety culture indicators based on the survey questionnaire results are all Medium, except for indicator I6, which is Low. The questionnaire-based scores are not close to the class borders. Comparing the survey and model results, it is clear that the model results are consistently higher than the survey results, except for indicator I3.1.

Table 8: Comparison of the classes of the safety culture indicators obtained by the organizational model and the survey questionnaire data

Index	Safety culture indicator	Model	Survey
I1.1	Average reporting quality of controllers	High	Medium
I2.1	Average quality of the processed notification reports	High	-
I3.1	Average quality of the final safety occurrence assessment reports	Medium	Medium
I4.1	Average quality of the monthly safety overview reports received by controllers	High	Medium
I5.1	Average commitment to safety of controllers	High	Medium
I5.2	Average commitment to safety of a team as perceived by controllers	High	Medium
I6	Average commitment to safety of a supervisor as perceived by controllers	High	Low
I7	Average commitment to safety of management as perceived by controllers	High	Medium

4 Model & Validation Phase 2

This section presents an updated set of model results, using unused survey questionnaire data as input for the organizational model (Section 4.1), and it compares those model results with the survey questionnaire-based safety culture indicators (Section 4.2).

4.1 Update of model input

As planned in (Sharpanskykh and Stroeve, 2008b) we updated the input variables of the organizational model in line using data of yet unused questions in the safety culture survey questionnaire of ANSP-3. Table 9 shows the input variables, related survey questions and the ANSP-3 results for these questions. Using a linear mapping from the range [1,5] of the survey data to the range [0,1] of the organizational model data, Table 9 shows the values of the input variable of the organizational model based on the means of the survey results (column 'Value of variable: Survey'). For example, the mean of the survey results for questions related to *e1* is 3.4 and the linear mapping results in a value of 0.6. We simply used a linear mapping, since we did not have knowledge of the particular distributions of answers to the questions. The update of the model input (column: 'Value of variable: New') is based on the survey data in combination with the previous information stemming from the interviews and the SMS documentation of ANSP-3. This combination of information sources was weighted by our impression of the quality of the previous information and our judgement of the relevance of the survey questions for the evidence input variable considered. For example, for variable *e1* we considered that the related questions provide a good indication but not a precise reflection of its content, and therefore we downgraded its value from its original one, but not all the way to the survey result. It can be observed in Table 9 that as a result of the updating process, almost all values of the evidence input variables have been decreased.

Table 9: Updated model input variables, including safety culture survey questionnaire results

Variable	Description	Related safety culture survey questions	Survey result	Value of variable		
				Old	Survey	New
e1	Priority of safety-related goals in the role description	A.1. Balancing safety against the other requirements of my job is a challenge	3.5	0.90	0.60	0.70
		A.5. Safety is a responsibility shared throughout the organization	3.7			
		A.12. The other people in the organization do not understand the safety roles we fulfil	3.0			
e4	Influence of a controller on safety activities	B.2 Our opinion and input into safety assessments are actively sought after.	2.8	0.70	0.49	0.50
		B.12 We are consulted about changes to the technical/engineering system that impact on the way we do our work	3.2			
		B.15 I have the opportunity to provide input in the ATC systems development or acquisition process.	2.9			
e7	Sufficiency of the number of safety investigators	None	-	0.50	-	0.50
e8	Sufficiency of the number of controllers	A.14 Sometimes you have to break the safety rules to cope with the workload	2.9	0.80	0.48	0.60
e9	Availability of reliable and ergonomic technical systems for controllers	B.8 I trust the ATC equipment that I use in my job.	3.9	0.90	0.73	0.75
e10	Sufficiency and timeliness of training for changes	A.28. Information about changes to procedures or the system is easily accessible	3.4	0.80	0.58	0.60
		A.26 There are so many changes that it is hard to keep track of the current situation	2.8			
		A.30. I am kept informed of changes that have been made to procedures or systems	3.7			
e11	regularity of safety meetings	A.20 Team meetings are used to communicate concern and collect ideas for improvement	3.1	0.80	0.53	0.75
e12	Developed and implemented SMS	A.6. Management takes action on safety issues that we raise	3.1	0.80	0.56	0.60
		A.12. The other people in the organization do not understand the safety roles we fulfil	3.0			

Variable	Description	Related safety culture survey questions	Survey result	Value of variable		
				Old	Survey	New
		A.21. Voicing concerns about safety is actively encouraged.	3.2			
		D.18. Safety is well-integrated into our business management approach.	3.6			
e14	Level of development of managerial skills	D.14 I have attended at least one safety related training course within the last year.	3.4	0.90	0.60	0.60
e19	Self-confidence for ATC task	A.3 I have confidence in the people that I interact with in my normal working situation	4.10	0.80	0.78	0.85
e20	Commitment to perform ATC task	None	-	0.80	-	0.80
e21	Development level of skills for ATC task	B.18 Someone with operational knowledge (supervisor/mentor/ other) sits with me to check my performance at least once a year	4.00	0.90	0.75	0.80
e25	Sufficiency of the number of maintenance personnel	None	-	0.90	-	0.75
e26	Quality of formal procedures for system checks and repairs	B.6 Maintenance staff perform sufficient system checks	3.8	0.9	0.70	0.75
e35	Intensity of informal interactions in the team of controllers	A.3. I have confidence in the people that I interact with in my normal working situation	4.1	0.9	0.64	0.65
		A.19. People in this organization share information in order to keep the organization working properly.	3.2			
		B.9 We openly discuss incidents in an attempt to learn from them	3.4			
e36	Quality of the formal safety occurrence assessment procedure	None	-	0.90	0.90	0.85
e40	Quality of the communication channel between controllers and safety investigators	None	-	0.5	-	0.50
e44	Average commitment of the agents involved in the safety analysis	A.6. Management takes action on safety issues that we raise	3.1	0.9	0.65	0.65
		A.9. Management is interested in the safety issues that we raise	3.3			
		A.10. My manager would always support me if I had a safety concern.	3.4			
		A.23. People do not get involved in safety because their opinions	3.3			

Variable	Description	Related safety culture survey questions	Survey result	Value of variable		
				Old	Sur vey	New
		are not listened to.				
		D.12 I take a personal involvement in major safety initiatives.	4.1			
		D.19 I clearly show that safety is one of my core personal values.	4.4			
e71	Formal support for confidentiality of reporting	A.25. I trust the confidentiality of the reporting and investigation process.	3.7	0.7	0.68	0.65

4.2 COMPARISON OF MODEL AND SURVEY RESULTS

Table 10 shows the simulation results using the update of the model input and their corresponding classes. Table 11 shows the comparison of the safety culture indicator classes for the survey questionnaire data and the updated model results. All safety culture indicators for the updated model are now in the class Medium, except for indicator I2.1. Indicators I1.1 and I7 are close to the class border with High, all other indicators are well off from a class border. It follows from a comparison of the original model results in Table 8 and the updated model results in Table 11 that all indicators transferred to a lower class, except for indicators I2.1 and I3.1. Comparison of the model and survey results in Table 11 shows that the results are consistent for six out of seven indicators, only the result for indicator I6 is lower in the survey than in the model. As a result of the input updating the consistency between the model and the survey-based results for the safety culture indicators has thus increased considerably.

Table 10: Model simulation results for the safety culture indicators using the updated model input

Index	Safety culture indicator	Value	Class
I1.1	Average reporting quality of controllers	0.74	Medium
I2.1	Average quality of the processed notification reports	0.54	High
I3.1	Average quality of the final safety occurrence assessment reports	0.2	Medium
I4.1	Average quality of the monthly safety overview reports received by controllers	0.58	Medium
I5.1	Average commitment to safety of controllers	0.56	Medium
I5.2	Average commitment to safety of a team as perceived by controllers	0.55	Medium
I6	Average commitment to safety of a supervisor as perceived by controllers	0.6	Medium
I7	Average commitment to safety of management as perceived by controllers	0.61	Medium

Table 11: Comparison of the safety culture indicator classes for the survey questionnaire data and for the organizational model with updated model input values

Index	Safety culture indicator	Model	Survey
I1.1	Average reporting quality of controllers	Medium	Medium
I2.1	Average quality of the processed notification reports	High	-
I3.1	Average quality of the final safety occurrence assessment reports	Medium	Medium
I4.1	Average quality of the monthly safety overview reports received by controllers	Medium	Medium
I5.1	Average commitment to safety of controllers	Medium	Medium
I5.2	Average commitment to safety of a team as perceived by controllers	Medium	Medium
I6	Average commitment to safety of a supervisor as perceived by controllers	Medium	Low
I7	Average commitment to safety of management as perceived by controllers	Medium	Medium

5 Model & Validation Phase 3

In Model and Validation Phase 3, we perform a sensitivity analysis for the organizational model (Section 5.1), from this sensitivity analysis we infer major organizational factors affecting the safety culture indicators and related organizational improvement options (Section 5.2) and we compare these results with key issues and recommendations stemming from the safety culture survey workshop results (Section 5.3). An evaluation of the success of the validation is presented along six success criteria in Section 5.4.

5.1 Sensitivity analysis

In Sections 3 and 4 we compared the safety culture indicator results of the organizational model with related results of the survey questionnaire of ANSP-3 for two input settings of the model. For the updated input model setting we found the best agreement between the model and the survey questionnaire results. It is the aim of this section to evaluate the sensitivity of the safety culture indicators for variations in the parameter values of the organizational model with the updated model input setting. Section 5.1.1presents the sensitivity analysis method. Section 5.1.2 presents the results of the sensitivity analysis.

5.1.1 Sensitivity analysis method

The sensitivity analysis method used in this report is Monte Carlo filtering. Monte-Carlo filtering is often applied if a definition for ‘good’ or ‘acceptable’ model outcome can be given (Young, 1999). In the case of the agent-based organizational model, the desired behaviour is defined by the set of safety culture indicators with corresponding ranges of High values as defined in Table 7. 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 to split the output values into two subsets: High versus Low/Medium safety culture indicators. The Smirnov test is applied to each input factor to test whether these two distributions 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 a High safety culture indicator (as defined in Table 7), and
- $x_i|\underline{B}$, containing all x_i values that produced a Low or Medium safety culture indicator (as defined in Table 7).

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

A total safety culture sensitivity index is defined by firstly setting a value 0 for Low sensitivity, a value 0.5 for Medium sensitivity and a value 1 for High sensitivity, and subsequently summing those values over all safety culture indicators for a particular factor.

5.1.2 Sensitivity analysis results

The reproducibility of the sensitivity analysis results is tested on two series of simulations. For each simulation series it is identified for each safety culture indicator which model factors belong to the class High (set S_H) and which

belong to the class Medium (set S_M). Then the similarity of the obtained sets is evaluated by the following reproducibility indices:

1. $\rho(S_H^1, S_H^2) = \left|S_H^1 \cap S_H^2\right| / \left|S_H^1 \cup S_H^2\right|$,
2. $\rho(S_M^1, S_M^2) = \left|S_M^1 \cap S_M^2\right| / \left|S_M^1 \cup S_M^2\right|$,
3. $\rho(S_H^1, S_M^1, S_H^2, S_M^2) = \left|(S_H^1 \cup S_M^1) \cap (S_H^2 \cup S_M^2)\right| / \left|(S_H^1 \cup S_M^1) \cup (S_H^2 \cup S_M^2)\right|$,

where the superscript denotes the simulation series. Table 12 shows the results of these reproducibility indices for the sensitivity analysis results of ANSP-3 as function of the number of simulations. For the two simulation series, complete agreement of the results was found to be obtained in 8000 simulations. Appendix A shows the results of the sensitivity analysis as obtained in 8000 simulations.

Table 12: Overview of the reproducibility indices for the sensitivity analysis results of ANSP-3 as function of the number of simulations, based on the results of two simulation series

Reproducibility index	**Number of simulations**			
	2000	4000	6000	8000
$\rho(S_H^1, S_H^2)$	0.81	0.88	0.96	1
$\rho(S_M^1, S_M^2)$	0.63	0.72	0.93	1
$\rho(S_H^1, S_M^1, S_H^2, S_M^2)$	0.83	0.86	0.97	1

Table 13 shows all evidence input variables, their nominal values and the credibility interval ranges used in the sensitivity analysis, and their total safety culture sensitivity indices based on above mapping procedure. All evidence input variables with values larger or equal to four are marked. There are eight evidence input variables that have such important effect on the safety culture indicators.

Table 13: Total safety culture sensitivity index for the evidence input variables of the ANSP-3 model

Input evidence variable		Value	Total SC sensitivity index
e1	Priority of safety-related goals in the role description	0.60 [0.50, 0.70]	5.5
e4	Influence of a controller on safety activities	0.50 [0.40, 0.60]	5
e7	Sufficiency of the number of safety investigators	0.50 [0.40, 0.60]	6.5

Input evidence variable		Value	Total SC sensitivity index
e8	Sufficiency of the number of controllers	0.60 [0.40, 0.80]	8
e9	Availability of reliable and ergonomic technical systems for controllers	0.75 [0.65, 0.85]	5.5
e10	Sufficiency and timeliness of training for changes	0.60 [0.45, 0.75]	4
e11	regularity of safety meetings	0.75 [0.60, 0.90]	2.5
e12	Developed and implemented SMS	0.60 [0.40, 0.80]	5
e14	Level of development of managerial skills	0.60 [0.40, 0.80]	7
e19	Self-confidence for ATC task	0.85 [0.75, 0.95]	3.5
e20	Commitment to perform ATC task	0.80 [0.70, 0.90]	3
e21	Development level of skills for ATC task	0.80 [0.70, 0.90]	1
e25	Sufficiency of the number of maintenance personnel	0.75 [0.60, 0.90]	3.5
e26	Quality of formal procedures for system checks and repairs	0.75 [0.60, 0.90]	0.5
e35	Intensity of informal interactions in the team of controllers	0.65 [0.50, 0.80]	0
e36	Quality of the formal safety occurrence assessment procedure	0.85 [0.75, 0.95]	0
e40	Quality of the communication channel between controllers and safety investigators	0.50 [0.30, 0.70]	1
e44	Average commitment of the agents involved in the safety analysis	0.65 [0.50, 0.80]	1.5
e61	Individualism index of a controller	0.8 [0.7, 0.9]	0
e62	Power distance index of a controller	0.4 [0.3, 0.5]	0
e63	Masculinity index of a controller	0.15 [0.05, 0.25]	0
e64	Uncertainty avoidance index of a controller	0.5 [0.4, 0.6]	0
e71	Formal support for confidentiality of reporting	0.65 [0.55, 0.75]	0

For other types of parameters in the model the same sensitivity analysis was performed and the results are provided in Appendix A. Overall, the importance of the other parameters for the total set of safety culture indicators is more modest than the importance of the input evidence variables. Only for one weight *w6*, which describes the relation between the commitment of a supervisor to safety

and the perception of the commitment to safety in a team, a total safety culture index of 4 is achieved in the sensitivity analysis. All other parameters are less important.

5.2 Sensitivity analysis-based conclusions

The sensitivity analysis presented in Section 5.1 forms the basis for identification of major organizational factors that impact the safety culture indicators in Section 5.2.1 and a list of propositions to improve the safety culture of ANSP-3 in Section 5.2.2. The factors and improvement strategy that are presented in this section were proposed prior to disclosure of the results of the safety culture survey workshop at ANSP-3.

5.2.1 Identification of Major Organizational Factors

Based on the sensitivity analysis results the following major organizational factors (MOF) are hypothesized for ANSP-3. These MOFs will be validated in Section 5.3.1.

MOF-1: Sufficiency of the number of controllers
It follows from the sensitivity analysis that the evidence input variable *e8* 'Sufficiency of the number of controllers' has a high effect on all safety culture indicators. The value of the input variable is *e8 = 0.6±0.2*, based on a single indirectly related survey question (A.14 in Table 9, page 24) and interview feedback of a safety manager at ANSP-3.

MOF-2: Level of development of managerial skills of supervisors
It follows from the sensitivity analysis that the input evidence variable *e14* 'Level of development of managerial skills' (of the supervisor) has a high effect on all safety culture indicators, except on the controllers' perception of the safety commitment of the management. The value of the input variable is *e14=0.6±0.2*, based on a single indirectly related survey question (Table 9). The large sensitivity for weight *w6* shows that the level of development of managerial skills of the supervisor has a large effect on all commitment related safety culture indicators.

MOF-3: Sufficiency of the number of safety investigators

The sensitivity analysis shows that the input evidence variable *e7* 'Sufficiency of the number of safety investigators' has a high effect on the quality of the occurrence assessment, the quality of the monthly safety overview report and all commitment related safety culture indicators. The value of the input variable is *e7 = 0.5±0.1*, based on an interview with the safety investigator at ANSP-3.

MOF-4: Priority of safety-related goals in the role description

The sensitivity analysis shows that the input evidence variable *e1* 'Priority of safety-related goals in the role description' has a high effect on all commitment-related safety culture indicators. The value of the input variable is *e1 = 0.6±0.1*, based on the results of three related survey questions (Table 9).

MOF-5: Availability of reliable and ergonomic technical systems for controllers

The sensitivity analysis shows that the input evidence variable *e9* 'Availability of reliable and ergonomic technical systems for controllers' has a high effect on the commitment-related safety culture indicators and on the quality of the notification report. The value of the input variable is *e9 = 0.75±0.1*, based on the result of a related survey question (Table 9) and interview results. Although the value of this variable is already reasonably high, the model indicates that further increase would still have a considerable effect on commitment-related safety culture indicators.

MOF-6: Influence of a controller on safety activities

It follows from the sensitivity analysis that the input evidence variable *e4* 'Influence degree of controllers on safety arrangements' has a high effect on the commitment-related safety culture indicators and the number of notification reports. The value of the variable is *e4 = 0.5±0.1*, based on medium scores on three directly related survey questions (Table 9).

MOF-7: Developed and implemented Safety Management System (SMS)

The sensitivity analysis shows that the input evidence variable *e12* 'Developed and implemented SMS' has a high effect on the commitment-related safety culture indicators, and a medium effect on the number of reported occurrences and the quality of the notification reports. The value of the input variable is *e12 = 0.6±0.2*, based on the results of four survey questions that reflect aspects of the implemented SMS (see Table 9) as well as insight in parts of the SMS documentation.

MOF-8: Sufficiency and timeliness of training for changes
The sensitivity analysis shows that the input evidence variable *e10* 'Sufficiency and timeliness of training for changes' has a high effect on the commitment-related safety culture indicators. The value of the input variable is *e10 = 0.6±0.2*, based on three related survey questions (see Table 9).

5.2.2 Identification of organizational improvement options

The major organizational factors, which have a strong effect on the safety culture indicators, have provided the basis for the proposition of the following five organizational improvement options. Next, the details and related major organizational factor are presented for each organizational improvement option (OIO).

OIO-1: More involvement of controllers in safety assessment for development of new systems and procedures

Organizational improvement option in detail
(a) Controllers should be more involved in safety assessments for development of new systems and procedures.
(b) These safety assessments should have a sufficiently broad scope such that the variability in the working context of the controllers is addressed in a way that is well recognized and understood by the controllers involved in the assessment.
(c) The assessment should explicitly address the consideration of capacity versus safety in nominal and non-nominal conditions.

Relation with major organizational factors
It follows from MOF-6 that the influence of controllers on safety activities has a considerable effect on the safety culture indicators and that the controllers expressed to be involved in safety activities only to a medium level. It follows from MOF-5 that the availability of reliable and ergonomic systems is important for commitment-related safety culture indicators; overall the trust in the ATC equipment is good at ANSP-3. It follows from MOF-4 that priority of safety-related goals in the role description is important for commitment-related safety culture indicators; the safety roles and balancing safety with other requirements is not always clear at ANSP-3.
OIO-1 directly addresses MOF-6. OIO-1 supports improvement of MOF-5, since it should lead to systems that are better accepted by the controllers. OIO-1

supports improvement of MOF-4, since it should lead to clearer well-accepted procedures for balancing safety and capacity in nominal and non-nominal conditions.

OIO-2: Improve workload of controllers by developing explicit rules for balancing safety and capacity in nominal and non-nominal conditions

Organizational improvement option in detail

(a) The workload of controllers should be improved by explicit guidelines that support the supervisors and the controllers in balancing safety and capacity.
(b) These guidelines should be determined in a safety assessment as indicated in OIO-1 with involvement of controllers.
(c) A result of these guidelines may be that the number of controllers should increase.

Relation with major organizational factors

It follows from MOF-1 that the sufficiency of the number of controllers has a high effect on all safety culture indicators. In relation, the possibilities of the controllers to cope with the workload in nominal and non-nominal conditions are important for the safety culture. In relation, MOF-4 stresses the importance of clear safety guidelines in the role descriptions of controllers.
OIO-2 supports the reduction of workload as considered in MOF-1. OIO-2 furthermore supports MOF-4, as expressed for the anticipated result of OIO-1.

OIO-3: Improve the quality of management by supervisors

Organizational improvement option in detail

(a) The quality of the management by supervisors should be improved.
(b) The quality of management may be improved by further development of the managerial skills and techniques of supervisors.
(c) The quality of management may be improved by developing clear guidelines that support supervisors in their decisions for dealing with capacity-safety issues in nominal and non-nominal conditions. The development of such guidelines may be achieved in coordination with OIO-1 and OIO-2.

Relation with major organizational factors

It follows from MOF-2 that the quality of the management by the supervisors has a considerable effect on the safety culture indicators.
OIO-3 supports the improvement of the quality of management by supervisors as expressed in MOF-2.

OIO-4: Improve coherence and communication in the safety management system

Organizational improvement option in detail

(a) The coherence and communication in the safety management system should be improved.
(b) Improvement of the coherence means that safety assessment (prior to operation) and safety monitoring (during operation) should be more consistent, such that safety indicators and safety requirements formulated in the safety assessment are well captured in the safety monitoring phase.
(c) Improvement of the communication means, on the one hand, that voicing about safety issues is encouraged, and on the other hand, that there should be a structured way to always provide feedback on the safety issues raised (either prior to or during operation). Therefore, OIO-4 should be addressed in good coordination with OIO-1.

Relation with major organizational factors

It follows from MOF-7 that the developed and implemented SMS has a considerable effect on the safety culture indicators. Related safety culture survey questionnaire results indicate only medium responses for voicing about safety issues and the management response to such issues. In relation, MOF-3 indicates that having a sufficient number of safety investigators has a high effect on many safety culture indicators. The number of safety investigators at ANSP-3 is quite low.

OIO-4 supports the improvement of the SMS as expressed in MOF-7. Improvement of the coherence and communication in the SMS requires the monitoring of more safety indicators and more structured communication. As such it is likely that more safety investigators are needed for this purpose, as expressed in MOF-3.

OIO-5: Improve the communication about and training for changes

Organizational improvement option in detail

(a) The communication about changes to systems, procedures or working conditions should be improved.
(b) Appropriate training should be considered for changes to systems, procedures or working conditions.

(c) In such communication and training there should be reference to the conclusions of the safety assessments conducted in line with OIO-1, explaining the reasons for the change and its assessed impact.

Relation with major organizational factors
It follows from MOF-8 that sufficiency and timeliness of training have a high effect on the commitment-related safety culture indicators.
OIO-5 supports the improvement of MOF-8 and it may thereby increase the commitment of the controllers.

5.3 Validation of sensitivity analysis-based conclusions

In Section 5.2 we identified Major Organizational Factors affecting safety culture based on the sensitivity analysis of the model for ANSP-3, as well as Organizational Improvement Options as recommendations to enhance these factors. In the safety culture survey of ANSP-3 performed by EUROCONTROL, a range of safety culture issues became clear from the results of the questionnaire and the safety culture workshops. In coordination with EUROCONTROL personnel that performed the safety culture survey at ANSP-3, we compared the results of the survey with the model-based assessment in a safety culture model workshop. Section 5.3.1 presents the comparison of the identified safety culture issues. Section 5.3.2 presents the comparison of the identified recommendations.

5.3.1 Comparison of Major Organizational Factors

In Section 5.2.1 we identified eight Major Organizational Factors affecting safety culture. In the safety culture model workshop, we identified for each Major Organizational Factor the range of related results of the safety culture survey, and we reached a conclusion about the agreement between the results of the model and the safety culture survey.

MOF-1: Sufficiency of the number of controllers

Related issues in the safety culture survey study
- Currently, there is a reduction in traffic volume and as such there is no shortage of controller resources.
- In contingency situations, there may be insufficient controller resources.
- It is recognized that the balance between safety and capacity may be a problem.
- There is a lack of confidence regarding the long term planning of resources.

Conclusion

There is some agreement between the model and survey results, but it is not an important issue according to the safety culture survey. In particular, due to the present reduction in traffic volume there is no shortage of controllers but the long term planning is viewed as problematic.

MOF-2: Level of development of managerial skills of supervisors

Related issues in the safety culture survey study

- There is a lack of leadership role for the supervisor to brief and motivate people.
- There is a lack of authority of supervisors.
- Not all supervisors encourage feedback on safety events.
- The competence profile of supervisors is based on old role profiles, which do not reflect the current organization.
- The selection process of supervisors is not defined according to an appropriate profile.
- There is a lack of managerial skills of supervisors regarding interaction with their peer supervisors and the management.

Conclusion

Similar results have been obtained by the SC survey and the organizational model. The SC survey results provide additional and more detailed insights in the lack of managerial skills of supervisors.

MOF-3: Sufficiency of the number of safety investigators

Related issues in the safety culture survey study

- More resources on the investigation side and safety assessments side are required.
- People in the organization do not well know how they can effectively contribute to the investigation process.

Conclusion

The model and the survey identified the same key factors that need to be addressed.

MOF-4: Priority of safety-related goals in the role description

Related issues in the safety culture survey study

- People in the organisation believe that pressure and conflicting goals are obstacles that force management to set priorities that are not always in favour of safety.
- Safety messages are not always well processed by the middle management, for instance the severity of messages may get diluted.

Conclusion

There is some agreement between the model and survey results. The survey identified in detail which roles are not appropriately understood.

MOF-5: Availability of reliable and ergonomic technical systems for controllers

Related issues in the safety culture survey study

- The implementation of a new system was perceived as being rushed.
- During the development of a new system the safety argument was felt to be misused.
- The prevailing culture that 'change is good' is questionable.

Conclusion

This factor became important quite recently in the safety culture survey (after the questionnaire phase). The model well detected the issue as a key factor.

MOF-6: Influence of a controller on safety activities

Related issues in the safety culture survey study

- Controllers do not feel they are consulted enough about major changes affecting safety of operations.
- The impression that controllers' opinions are not listened to is due to the fact they do not see actions deriving from the concerns they raise and adequate feedback about these concerns is not provided.

Conclusion

The results of the model and the survey are compliant.

MOF-7: Developed and implemented Safety Management System (SMS)

Related issues in the safety culture survey study

- The SMS is seen as an asset and at an advanced level.
- The transmission of safety concerns upwards in the organization does not appear to be working, nor is the top-down communication being effectively translated through the levels.

Conclusion

There is good agreement between the survey and the model results.

MOF-8: Sufficiency and timeliness of training for changes

Related issues in the safety culture survey study

- On-Job-Training is not optimally organized.
- Controllers receive adequate ATC training, although the high number of students has meant that some of them are controlling together on the same sector.
- Training issues related to changes may be underestimated. More realistic assessments of training requirements should be put in place. This is the major point in relation to training.

Conclusion

The survey study and the model agree. It follows from the safety culture survey that overall it is not a very important issue.

5.3.2 Comparison of recommendations

In Section 5.2.2 we presented five Organizational Improvement Options, which address the Major Organizational Factors identified by the model. In the safety culture model workshop we compared these recommendations with those of the Eurocontrol safety culture survey study of ANSP-3.

OIO-1: More involvement of controllers in safety assessment for development of new systems and procedures

Organizational improvement option in detail

(a) Controllers should be more involved in safety assessments for development of new systems and procedures.

(b) These safety assessments should have a sufficiently broad scope such that the variability in the working context of the controllers is addressed in a way that is well recognized and understood by the controllers involved in the assessment.
(c) The assessment should explicitly address the consideration of capacity versus safety in nominal and non-nominal conditions.

Related recommendations in safety culture survey study

- In the survey study it was recognized as a problem that only a specific small team is consulted in development of new tools. The views of this team are not always representative for the majority of controllers. There is an implicit recommendation to improve the communication between the team and the other controllers.

Conclusion

There is agreement on the recognition of the importance of the safety-capacity balance. The survey results are more specific on the processes in place, in particular with regard to a specific team that is consulted for the development of new tools.

OIO-2: Improve workload of controllers by developing explicit rules for balancing safety and capacity in nominal and non-nominal conditions

Organizational improvement option in detail

(a) The workload of controllers should be improved by explicit guidelines that support the supervisors and the controllers in balancing safety and capacity.
(b) These guidelines should be determined in a safety assessment as indicated in OIO-1 with involvement of controllers.
(c) A result of these guidelines may be that the number of controllers should increase.

Related recommendations in safety culture survey study

- The erosion of safety buffers should be investigated.
- There is an implicit recommendation to involve operational staff in the definition of traffic levels.

Conclusion

The recommendations of both studies are similar.

OIO-3: Improve the quality of management by supervisors

Organizational improvement option in detail

(a) The quality of the management by supervisors should be improved.
(b) The quality of management may be improved by further development of the managerial skills and techniques of supervisors.
(c) The quality of management may be improved by developing clear guidelines that support supervisors in their decisions for dealing with capacity-safety issues in nominal and non-nominal conditions. The development of such guidelines may be achieved in coordination with OIO-1 and OIO-2.

Related recommendations in safety culture survey study

- Provide management training to supervisors for enhancing teamwork and transmission of safety messages.
- Enhance the supervisory role in safety and determine the required competencies and training.

Conclusion

The recommendations of both studies are fully aligned.

OIO-4: Improve coherence and communication in the safety management system

Organizational improvement option in detail

(a) The coherence and communication in the safety management system should be improved.
(b) Improvement of the coherence means that safety assessment (prior operation) and safety monitoring (during operation) should be more consistent, such that safety indicators and safety requirements formulated in the safety assessment are well captured in the safety monitoring phase.
(c) Improvement of the communication means, on the one hand, that voicing about safety issues is encouraged, and on the other hand, that there should be a structured way to always provide feedback on the safety issues raised (either prior or during operation). Therefore, OIO-4 should be addressed in good coordination with OIO-1.

Related recommendations in safety culture survey study

- The top-down communication should be improved.
- There should be better support for upward transmission of safety concerns.

- The learning from incidents should be enhanced by team resource management.
- There should be more resources for safety investigation.

Conclusion
There is good agreement between the recommendations of both studies.

OIO-5: Improve the communication about and training for changes

Organizational improvement option in detail
(a) The communication about changes to systems, procedures or working conditions should be improved.
(b) Appropriate training should be considered for changes to systems, procedures or working conditions.
(c) In such communication and training there should be reference to the conclusions of the safety assessments conducted in line with OIO-1, explaining the reasons for the change and its assessed impact.

Related recommendations in safety culture survey study
- Improvement of the top-down communication.
- Particular safety training for various functions.

Conclusion
The recommendations of both studies are well aligned.

Recommendations uniquely identified in the survey study
The safety culture survey identified several recommendations which are not explicitly addressed in the model-based study. Below, a list is provided of these recommendations and the way it is partly or not addressed in the model-based assessment.

- *Survey:* Learning from incidents should be enhanced by team-training focusing on the effects of lessons learned on daily practice.
  Model: Although some methods for learning from incidents are in the model, specific team-training measures are not covered.
- *Survey:* Self-briefing should be complemented by supervisors' support.
  Model: Although OIO-3 at a general level considers the quality of management by supervisors, it does not explicitly include the supervisors' support for self-briefings.

- *Survey:* OJTI standards should reconsider how to ensure safety during heavy traffic periods.
  Model: On-the-job-training is not in the scope of the developed model.
- *Survey:* The Engineering department should consider putting in place a tailored learning process.
  Model: Learning processes for the Engineering department are not in the scope of the developed model.
- *Survey:* It is recommended to build teamwork by promoting informal social interaction, which may be facilitated by social areas, a gym, a new canteen, etc. This recommendation follows from a perceived lack of social interaction between personnel, which is in part due to a new rostering scheme.
  Model: The organizational model represents social interaction between controllers during breaks, but the new rostering scheme is not considered in the model. As a result the lack of informal interaction was not identified as a key factor in the model.
- *Survey:* There should be more focus on the priority of safety in decision making by the management.
  Model: In general, OIO-4 recommends improvement of the safety management system, but specific recommendations on changes in the management structure as provided in the safety culture survey are lacking in the model-based study. A reason is that the management is represented in the model as a single role rather than at a more detailed organizational structure view.
- *Survey:* The interaction with the regulatory authorities should be improved.
  Model: Interaction with regulatory authorities is not in the scope of the developed model.
- *Survey:* The safety training should be improved for various functions in the organization, addressing particular traffic situations and controllers' role in the safety management system.
  Model: OIO-5, which addresses training for changes, and OIO-4, which addresses communication in the safety management system, are related, but the recommendation in the survey study is more specific.

5.4 Conclusions

In the validation plan (Sharpanskykh and Stroeve, 2008b) we formulated six success criteria for the validation by the comparison with results of the safety culture survey results. Next we present the evaluation of each criterion.

Cr1. The number of safety culture indicators for which the qualitative scales are equal for the results of the organizational model and the survey questionnaire-based results.
In Phase 1, one safety culture indicator has an equal class and six indicators have different classes. Except for one indicator, the model results are consistently higher than the survey results.

Cr2. The number of safety culture indicators for which the qualitative scales are equal for the results of the updated organizational model and the survey questionnaire-based results.
In Phase 2, six safety culture indicators have equal classes and one indicator has a different class. The inconsistent indicator considers the perceived commitment of the supervisor, which is Medium according to the model and Low in the survey-based evaluation. The results in Phase 2 show that given appropriate model inputs, mostly valid model output results for the safety culture indicators have been obtained.

Cr3. The increase in the number of valid safety culture indicators from Cr1 to Cr2. This is a measure of the internal consistency of the model.
An increase of five equal safety culture indicator classes in the predictions in Phase 2 compared to Phase 1. This difference is due to the differences in the values of the input evidence variables of the model.

Cr4. The number of similar safety culture organizational vulnerabilities as identified in the survey workshop at ANSP-3 and by the organizational model.
It follows from the comparison of the eight Major Organizational Factors identified using the organizational model with issues identified by the Eurocontrol safety culture survey at ANSP-3, that there is good agreement for six factors and some agreement for the remaining two factors (MOF-1, MOF-4). In general, the issues identified by the survey study provide more detailed information about the organizational context of the safety culture issues. This detailed information was mainly obtained in the workshops phase of the safety culture survey, where the personnel was asked to discuss particular safety culture issues with low scores in the safety culture questionnaire. Since the safety culture survey report for ANSP-3 did not include an explicit list of safety culture issues, we did not analyse which safety culture issues were identified in the survey study but were not found by the organizational model.

Cr5. The number of safety culture improvement strategies identified by the organizational model in comparison with those identified by the survey workshop at ANSP-3.

The comparison of the Organizational Improvement Options of the model-based study with the recommendations of the survey study shows that the identified OIOs are consistent with the survey recommendations. The recommendations of the survey study tend to reflect the larger detail in the organizational context as has emerged in the survey workshops at ANSP-3. In addition to the list of consistent recommendations, the survey study identified a number of recommendations that are not or only partly addressed in the model-based study. Recommendations that were not addressed reflect aspects that are out of the scope of the model, e.g. OJTI or learning processes of the Engineering department. Recommendations that were only partly addressed mostly reflect aspects for which the organizational context is known in more detail via the workshops at ANSP-3.

Cr6. The number and quality of ways of interaction between the safety culture survey and organizational agent-based modelling that may support understanding and improvement of safety culture.

The major added advantage of agent-based organizational modelling is that it provides a structured, formally-grounded means for analysis and improvement of safety culture. It defines explicit formal relations between safety culture indicators and organizational processes and structures, thus enabling identification of important organizational aspects impacting safety culture by sensitivity analysis techniques. Insights in relations between safety culture indicators and organizational structures and processes may be used to further enhance safety culture questionnaires and prepare safety culture survey workshops.

6 DISCUSSION AND CONCLUSIONS

In this report we presented the results of the validation study of an agent-based organizational model for occurrence reporting at an air navigation service provider. In the validation study we compared the model results for a particular ANSP-3 with the results of a Eurocontrol safety culture survey study of ANSP-3.

In summary, the following results were obtained in the three phases of this model and validation study:

- In Phase 1, the input values of the model were completely based on organizational information available prior to the survey questionnaire results. The model predicted safety culture indicators which were mostly higher than the survey questionnaire results. In particular, for six out of the seven relevant indicators a higher class was predicted by the model.
- In Phase 2, the input values of the model were based on a combination of organizational information and survey questionnaire results. The model predicted safety culture indicators which were mostly equal to the survey questionnaire results. In particular, for six out of seven indicators the same class was predicted by the model.
- In Phase 3, major organizational factors affecting the safety culture indicators and related organizational improvement options were inferred from a sensitivity analysis of the organizational model. Next these results were compared with safety culture issues and recommendations stemming from safety culture survey workshops. The major organizational factors and organizational improvement options identified by the model-based sensitivity study were largely consistent with the safety culture issues and the recommendations arrived at via the workshops in the survey study. The survey results included more details of the organizational context and revealed some aspects that were out of the scope in the organizational model.

Comparing the results of Phases 1 and 2, there is a clear difference in the attained consistency between the survey questionnaire and model results. This difference is due to the differences in the values of the input evidence variables of the model. The overall higher values used in Phase 1 led to safety culture indicator classes that were mostly higher in Phase 1 than in Phase 2, and that were mostly inconsistent with the survey questionnaire results in Phase 1 and mostly consistent in Phase 2. The values of the evidence input variables in Phase 1 were based on organizational information stemming from interviews with a

safety manager and a safety investigator at ANSP-3, and from the SMS of ANSP-3. It follows from the survey questionnaire results that the thus determined values for these variables were too optimistic. The survey questionnaire results provided an overview of the opinions of a large number of employees with a variety of roles, as such they give a considerably broader basis for the evaluation of the evidence input variables than what can be achieved by interviews.

The results in Phase 2 show that given appropriate model inputs, mostly valid model output results for the safety culture indicators have been obtained. This shows that the model structure and other parameters are such that the model can well predict the safety culture indicators for appropriate input evidence variables. A limitation of the validation exercise in Phase 2 is that both the reference outputs and the evidence input values were based on the survey questionnaire results. Although different questions were used for these two classes, the responses to groups of questions reflect similar tendencies in safety culture dimensions at ANSP-3, and as such the values for the inputs and reference outputs may have been correlated. Moreover, we know from the sensitivity analysis that there are various input evidence variables that have a strong effect on the output safety culture indicators. All in all, the consistent prediction in Phase 2 is a positive indication that a valid model has been developed, but due to the same basis for input and reference output not a strong proof though.

The assessment of the model validity in Phases 1 and 2 was based on a comparison of the model results for safety culture indicators with a mapping of the mean answers to selected survey questions. Since the development of the agent-based model of ANSP3 was done independently from the development of the safety culture survey questionnaire, not all safety culture indicators from the model match well with questions from the questionnaire, as can be observed in Table 3 on page 17. For example, a more direct question related to indicator I1.1 would be 'If I observe an unsafe situation (occurrence), I will always report about it'. In general, if the semantic distance between the safety culture indicator and the related questions is larger, the validity of the reference for the safety culture indicator used in the validation process is more questionable. A similar argument can be made with respect to the evaluation of the input evidence variables based on the survey questionnaire data (Table 9, page 24). Furthermore, only a subset (rather than all) of the questions is coupled to the model. As a way forward, the consistency between the survey questionnaire and the model inputs and outputs may be enhanced by adding more consistent questions to the survey and/or by reformulating the model such that the inputs and outputs would be more in line with survey questions. A drawback of the first option is that by adding new

questions, the integrity, consistency and balance of the questionnaire may be disturbed. A limitation of the second option is the effort and the potential lack of data for modelling the remaining safety culture issues; this would require further research.

The results in Phase 3 show that the outcomes based on the sensitivity analysis of the model are mostly consistent with the results of the safety culture survey workshops. Both the model and the workshop used results of the survey questionnaire as input, but the processes for achieving their results were completely different and independent. As such, the consistency in their results is a good indication of the model's validity. The limitation in the detail of the organizational context and the scope of the model results is, on the one hand, a fundamental modelling issue, in the sense that a model is always an abstraction of reality and it focuses on selected aspects. On the other hand, the range of organizational aspects that are considered in detail in the model may be enhanced. In the current study, the model development was focused on the occurrence reporting cycle and other processes such as management actions, engineering activities and traffic management actions by controllers were modelled at a high (abstract) level. In the model of the occurrence reporting cycle, various ways of learning from incidents in the organization could be further elaborated, by addressing, e.g. training effects, prerequisites for individual and social learning, and differences in individual learning styles. The level of modelling detail of other organizational processes (like management, engineering, air traffic control) may be enhanced, thus enabling more specific results for these organizational layers and the air traffic control operations. Addressing more in detail the effect of safety culture on the air traffic control operations might make it possible to provide an explicit link between safety culture and safety of operations.

In conclusion, to achieve valid predictions of the safety culture indicators by the model, we needed input data from the safety culture survey questionnaire, and on this basis the sensitivity analysis provided valid results for important organizational factors influencing the safety culture indicators and related recommendations. In general, the developed model has a range of input variables that reflect attitudes and opinions of people in the organization, and a safety culture survey questionnaire is a suitable tool to obtain an overview for these. As such, the agent-based organizational modelling approach may be used in addition to safety culture questionnaires and workshops.

The major added advantage of agent-based organizational modelling is that it provides a structured, formally-grounded means for analysis and improvement of safety culture. It defines explicit formal relations between safety

culture indicators and organizational processes and structures, thus enabling identification of important organizational aspects impacting safety culture by sensitivity analysis techniques. Using such information, specific causes and consequences of particular safety culture problems can be determined. Furthermore, strategies of improvement of safety culture can be formulated, as was demonstrated in this report. Insights in relations between safety culture indicators and organizational structures and processes may be used to further enhance safety culture questionnaires and prepare safety culture survey workshops.

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Appendix A SENSITIVITY ANALYSIS DETAILS

This appendix contains detailed results of the sensitivity analysis of the organizational model of ANSP-3 according to the sensitivity analysis methods presented in Section 5.1.1:

- Table 14 shows the sensitivity of the safety culture indicators for the evidence input variables, according to the classes Low/Medium/High;
- Table 15 provides a summary of Table 14 by showing the total safety culture sensitivity index for the evidence input variables, as well as the values of these parameters;
- Table 16 shows the sensitivity of the safety culture indicators for the weights;
- Table 17 provides a summary of Table 16 by showing the total safety culture sensitivity index for the weights, as well as the values of these parameters;
- Table 18 shows the sensitivity of the safety culture indicators for task times;
- Table 19 provides a summary of Table 18 by showing the total safety culture sensitivity index for task times, as well as the values of the task times;
- Table 20 shows the sensitivity of the safety culture indicators for aspects of dealing with occurrences by management;
- Table 21 provides a summary of Table 20 by showing the total safety culture sensitivity index for the occurrence management-related parameters, as well as the values of these parameters.

Table 14: Importance of evidence input variables classified by categories High / Medium / Low for the ANSP3 model

Input variables		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Commitment to safety of a controller	Safety commitment of team	Perceived safety commitment of supervisor	Perceived safety commitment of management
e1	Priority of safety-related goals in the role description	M	M	L	M	H	H	H	H
e4	Influence degree of controllers on safety arrangements	H	L	L	L	H	H	H	H

Input variables		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Commitment to safety of a controller	Safety commitment of team	Perceived safety commitment of supervisor	Perceived safety commitment of management
e7	Sufficiency of number of safety investigators	M	L	H	H	H	H	H	H
e8	Sufficiency of the number of controllers	H	H	H	H	H	H	H	H
e9	Availability of reliable and ergonomic technical systems for controllers	M	H	L	L	H	H	H	H
e10	Sufficiency and timeliness of training for changes	L	L	L	L	H	H	H	H
e11	Regularity of safety meetings	L	L	L	L	M	L	H	H
e12	Developed and implemented SMS	M	M	L	L	H	H	H	H
e14	Level of development of managerial skills	H	H	H	H	H	H	H	L
e19	Self-confidence for ATC task	L	M	M	M	H	H	L	L
e20	Commitment to perform ATC task	M	M	L	L	H	H	L	L
e21	Development level of skills for ATC task	L	L	M	L	L	L	L	M
e25	Sufficiency of the number of maintenance personnel	L	M	H	H	M	L	L	M
e26	Quality of formal procedures for system checks and repairs	L	M	L	L	L	L	L	L
e35	Intensity of informal interactions in the team of controllers	L	L	L	L	L	L	L	L
e36	Quality of the formal occurrence assessment procedure	L	L	L	L	L	L	L	L
e40	Quality of the communication channel between controllers and safety investigators	L	L	H	L	L	L	L	L

Input variables		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting quality	Quality of notification reports	Quality of occurrence assessment	Quality of monthly safety overview	Commitment to safety of a controller	Safety commitment of team	Perceived safety commitment of supervisor	Perceived safety commitment of management
e44	Average commitment to safety of the agents involved in safety analysis	L	L	L	H	M	L	L	L
e61	Individualism index of a controller	L	L	L	L	L	L	L	L
e62	Power distance index of a controller	L	L	L	L	L	L	L	L
e63	Masculinity index of a controller	L	L	L	L	L	L	L	L
e64	Uncertainty avoidance index of a controller	L	L	L	L	L	L	L	L
e71	Formal support for confidentiality of reporting	L	L	L	L	L	L	L	L

Table 15: Nominal values and credibility intervals for the evidence input variables of the model and their total safety culture sensitivity indices resulting from the sensitivity analysis

Input evidence variable		Value	Total SC sensitivity index
e1	Priority of safety-related goals in the role description	0.60 [0.50, 0.70]	5.5
e4	Influence of a controller on safety activities	0.50 [0.40, 0.60]	5
e7	Sufficiency of the number of safety investigators	0.50 [0.40, 0.60]	6.5
e8	Sufficiency of the number of controllers	0.60 [0.40, 0.80]	8
e9	Availability of reliable and ergonomic technical systems for controllers	0.75 [0.65, 0.85]	5.5
e10	Sufficiency and timeliness of training for changes	0.60 [0.45, 0.75]	4
e11	regularity of safety meetings	0.75 [0.60, 0.90]	2.5
e12	Developed and implemented SMS	0.60 [0.40, 0.80]	5
e14	Level of development of managerial skills	0.60 [0.40, 0.80]	7
e19	Self-confidence for ATC task	0.85 [0.75, 0.95]	3.5

Input evidence variable		Value	Total SC sensitivity index
e20	Commitment to perform ATC task	0.80 [0.70, 0.90]	3
e21	Development level of skills for ATC task	0.80 [0.70, 0.90]	1
e25	Sufficiency of the number of maintenance personnel	0.75 [0.60, 0.90]	3.5
e26	Quality of formal procedures for system checks and repairs	0.75 [0.60, 0.90]	0.5
e35	Intensity of informal interactions in the team of controllers	0.65 [0.50, 0.80]	0
e36	Quality of the formal safety occurrence assessment procedure	0.85 [0.75, 0.95]	0
e40	Quality of the communication channel between controllers and safety investigators	0.50 [0.30, 0.70]	1
e44	Average commitment of the agents involved in the safety analysis	0.65 [0.50, 0.80]	1.5
e61	Individualism index of a controller	0.8 [0.7, 0.9]	0
e62	Power distance index of a controller	0.4 [0.3, 0.5]	0
e63	Masculinity index of a controller	0.15 [0.05, 0.25]	0
e64	Uncertainty avoidance index of a controller	0.5 [0.4, 0.6]	0
e71	Formal support for confidentiality of reporting	0.65 [0.55, 0.75]	0

Table 16: Importance of weights classified by categories High / Medium /Low for the ANSP3 model

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w1	Contribution of e1 'Priority of safety-related goals in the role description' to e6 'Commitment to safety of a controller'	L	L	M	L	M	M	L	L
w2	Contribution of e2 'Perception of the commitment to safety of management' to e6 'Commitment to safety of a controller'	L	L	L	L	L	M	L	L
w3	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	L	L	L	L	M	L	L	L

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w4	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	L	L	M	L	H	H	L	L
w5	Contribution of e5 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	L	L	L	L	H	H	L	L
w6	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	L	L	L	L	H	H	H	H
w7	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	L	L	L	H	M	M	L	L
w8	Contribution of e1 'Priority of safety-related goals in the role description' to e2 'Perception of the commitment to safety of management'	L	M	L	L	L	L	L	L
w9	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e2 'Perception of the commitment to safety of management'	L	L	L	L	M	H	M	H
w10	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	L	L	L	L	L	H	M	H
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	L	L	L	L	L	L	L	L
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	L	L	L	L	L	L	L	H
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	L	L	L	L	L	L	M	H

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w14	Contribution of e14 'Level of development of managerial skills' to e13 'Perception of commitment to safety of the supervisor'	L	L	L	L	L	L	L	L
w15	Contribution of e2 'Perception of commitment to safety of management' to e13 'Perception of commitment to safety of the supervisor'	L	L	L	L	L	L	H	L
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	M	L	L	L	L	L	L	L
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	M	L	L	L	L	L	M	L
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	L	L	L	M	L	L	L	L
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	L	M	L	L	L	L	L	L
w20	Contribution of e17 'Quality of technical systems' to e15 'Quality of a processed notification report'.	L	M	L	L	M	L	L	M
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a processed notification report'.	L	H	L	L	L	L	L	L
w22	Contribution of e19 'Self-confidence for ATC task' to e5 'Maturity level w.r.t. ATC task'.	L	L	L	L	L	L	L	L
w23	Contribution of e20 'Commitment to perform ATC task' to e5 'Maturity level w.r.t. ATC task'.	L	L	L	L	L	L	L	L
w24	Contribution of e21 'Development level of skills for ATC task' to e5 'Maturity level w.r.t. ATC task'.	L	L	L	L	L	L	L	L
w25	Contribution of e23 'Adequacy of mental models for ATC task' to e5 'Maturity level w.r.t. ATC task'.	L	L	L	L	L	L	L	L
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	L	L	L	L	L	M	L	L

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	L	L	L	L	L	M	L	L
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	L	L	L	L	M	M	L	L
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	L	L	L	L	M	M	L	L
w30	Contribution of e25 'Sufficiency of the number of maintenance personnel' to e17 'Quality of technical systems'.	L	L	L	L	L	L	L	L
w31	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	M	L	L	L	L	L	L	L
w32	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e17 'Quality of technical systems'.	L	L	L	L	L	L	L	L
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'.	L	L	L	L	L	M	L	L
w34	Contribution of e6 'Commitment to safety of a controller' to e29 'Information contribution by a controller'.	L	L	L	L	L	L	L	L
w35	Contribution of e27 'Amount of knowledge on similar safety-related issues of a controller' to e29 'Information contribution by a controller'.	L	L	L	L	L	L	L	L
w36	Contribution of e30 'Information contribution by the supervisor' to e16 'Information contribution by others'.	L	L	L	L	L	M	L	L

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w37	Contribution of e28 'Amount of knowledge on similar safety-related issues of the supervisor' to e30 'Information contribution by the supervisor.	L	L	L	M	L	L	L	L
w38	Contribution of e13 'Perceived commitment to safety of the supervisor' to e30 'Information contribution by the supervisor.	L	L	L	M	L	L	L	L
w39	Contribution of e8 'Sufficiency iof the number of controllers' to e18 'Acceptability of the workload level'.	M	M	L	L	L	L	L	L
w40	Contribution of e14 'Level of development of managerial skills' to e18 'Acceptability of the workload level'.	M	M	L	L	L	L	L	L
w41	not defined	-	-	-	-	-	-	-	-
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview report'.	L	L	L	H	L	L	L	L
w43	Contribution of e32 'Quality of safety analysis' to e33 'Quality of a monthly safety overview report'.	L	L	L	H	L	L	L	L
w44	Contribution of e44 'Average commitment to safety of the agents involved in safety analysis' to e32 'Quality of safety analysis'.	L	L	L	H	L	L	L	M
w45	Contribution of e31 'Quality of input data' to e32 'Quality of safety analysis'.	L	L	L	H	L	L	L	M
w46	Contribution of e45 'Average contribution of informal discussions of controllers in teams' to e31 'Quality of input data'.	M	L	L	H	L	L	M	L
w47	Contribution of e46 'Average quality of processed notification reports' to e31 'Quality of input data'.	L	L	L	H	L	L	L	L
w48	Contribution of e47 'Average quality of previous monthly safety overview reports' to e31 'Quality of input data'.	L	L	L	H	L	L	L	L

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w49	Contribution of e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	L	L	L	L	L	L	M	M
w50	Contribution of e35 'Intensity of informal interactions in the team of controllers' to e34 'Contribution of informal discussions of controllers in the team'.	L	L	L	M	L	L	L	L
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'.	L	L	L	L	L	L	L	L
w52	Contribution of e49 'Average quality of the received monthly safety overview reports' to e34 'Contribution of informal discussions of controllers in the team'.	L	L	L	L	L	M	L	L
w53	Contribution of e36 'Quality of the formal safety occurrence assessment procedure' to e38 'Quality of the final safety occurrence assessment report'.	L	L	L	M	L	L	L	L
w54	Contribution of e50 'Average commitment to safety of the participants of the meetings' to e38 'Quality of the final safety occurrence assessment report'.	L	L	H	L	L	L	L	L
w55	Contribution of e7 'Sufficiency of the number of safety investigators' to e38 'Quality of the final safety occurrence assessment report'.	L	L	L	M	L	L	L	L
w56	Contribution of e15 'Quality of a processed notification report' to e38 'Quality of the final safety occurrence assessment report'.	L	L	L	L	L	L	L	L
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'.	L	L	H	L	L	L	M	L

Weights		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
w58	Contribution of e55 'Average quality of the monthly safety overview reports' to e38 'Quality of the final safety occurrence assessment report'.	L	L	M	L	M	L	M	L
w59	Contribution of e7 'Sufficiency of the number of safety investigators' to p1 'Probability of the feedback provision'.	L	L	H	L	L	L	L	L
w60	Contribution of e39 'Severity of an occurrence' to p1 'Probability of the feedback provision'.	L	L	H	L	L	L	L	L
w61	Contribution of e40 'Quality of the communication channel between controllers and safety investigators'	L	L	L	L	L	L	L	L

Table 17: Nominal values and credibility intervals for the weights of the model as applied in the sensitivity analysis, and the resulting total safety culture sensitivity indices

Weights		Value	Total SC sensitivity index
w1	Contribution of e1 'Priority of safety-related goals in the role description' to e6 'Commitment to safety of a controller'	0.1 [0.05, 0.2]	1.5
w2	Contribution of e2 'Perception of the commitment to safety of management' to e6 'Commitment to safety of a controller'	0.2 [0.1, 0.3]	0.5
w3	Contribution of e3 'Perception of commitment to safety of team' to e6 'Commitment to safety of a controller'	0.1 [0.05, 0.2]	0.5
w4	Contribution of e4 'Influence degree of controllers on safety arrangements' to e6 'Commitment to safety of a controller'	0.3 [0.2, 0.4]	2.5
w5	Contribution of e5 'Maturity level w.r.t. ATC task' to e6 'Commitment to safety of a controller'	0.3 [0.2, 0.4]	2
w6	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.1 [0.05, 0.3]	4
w7	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.1 [0.05, 0.2]	2
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 [0.05, 0.3]	0.5

Weights		Value	Total SC sensitivity index
w9	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e2 'Perception of the commitment to safety of management'	0.2 [0.1, 0.4]	3
w10	Contribution of e70 'Average perceived influence degree of controllers on safety arrangements' to e2 'Perception of the commitment to safety of management'	0.05 [0.01, 0.3]	2.5
w11	Contribution of e10 'Sufficiency and timeliness of training for changes' to e2 'Perception of the commitment to safety of management'	0.2 [0.1, 0.4]	0
w12	Contribution of e11 'Regularity of safety meetings' to e2 'Perception of the commitment to safety of management'	0.05 [0.05, 0.05]	1
w13	Contribution of e12 'Developed and implemented SMS' to e2 'Perception of the commitment to safety of management'	0.15 [0.05, 0.5]	15
w14	Contribution of e14 'Level of development of managerial skills' to e13 'Perception of commitment to safety of the supervisor'	0.4 [0.3, 0.6]	0
w15	Contribution of e2 'Perception of commitment to safety of management' to e13 'Perception of commitment to safety of the supervisor'	0.6 [0.3, 0.9]	1
w16	Contribution of e13 'the commitment of the supervisor to safety' to e3 'Perception of commitment to safety of team'	0.4 [0.3, 0.6]	0.5
w17	Contribution of e41 'Average commitment to safety of team members' to e3 'Perception of commitment to safety of team'	0.6 [0.4, 0.9]	1
w18	Contribution of e16 'Information contribution from others' to e15 'Quality of a processed notification report'.	0.1 [0.05, 0.2]	0.5
w19	Contribution of e5 'Maturity level w.r.t. ATC task' to e15 'Quality of a processed notification report'.	0.3 [0.2, 0.4]	0.5
w20	Contribution of e17 'Quality of technical systems' to e15 'Quality of a processed notification report'.	0.3 [0.2, 0.6]	1.5
w21	Contribution of e18 'Acceptability of the workload level' to e15 'Quality of a processed notification report'.	0.3 [0.2, 0.6]	1
w22	Contribution of e19 'Self-confidence for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25 [0.25, 0.25]	0
w23	Contribution of e20 'Commitment to perform ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25 [0.25, 0.25]	0
w24	Contribution of e21 'Development level of skills for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25 [0.25, 0.25]	0
w25	Contribution of e23 'Adequacy of mental models for ATC task' to e5 'Maturity level w.r.t. ATC task'.	0.25 [0.25, 0.25]	0
w26	Contribution of e10 'Sufficiency and timeliness of training for changes' to e23 'Adequacy of mental models for ATC task'.	0.5 [0.4, 0.6]	0.5
w27	Contribution of e22 'Adequacy of knowledge about safety issues' to e23 'Adequacy of mental models for ATC task'.	0.5 [0.3, 0.7]	0.5

Weights		Value	Total SC sensitivity index
w28	Contribution of e42 'Average quality of the received final safety occurrence assessment reports' to e22 'Adequacy of knowledge about safety issues'.	0.4 [0.2, 0.6]	1
w29	Contribution of e43 'Average quality of the received monthly safety overview reports' to e22 'Adequacy of knowledge about safety issues'.	0.6 [0.4, 0.8]	1
w30	Contribution of e25 'Sufficiency of the amount of maintenance personnel' to e17 'Quality of technical systems'.	0.4 [0.2, 0.6]	0
w31	Contribution of e26 'Quality of formal procedures for system checks and repairs' to e17 'Quality of technical systems'.	0.2 0.25, 0.25]	0.5
w32	Contribution of e9 'Availability of reliable and ergonomic technical systems for controllers' to e17 'Quality of technical systems'.	0.4 [0.2, 0.8]	0
w33	Contribution of e29 'Information contribution by a controller' to e16 'Information contribution by others'.	0.6 [0.4, 0.8]	0.5
w34	Contribution of e6 'Commitment to safety of a controller' to e29 'Information contribution by a controller'.	0.3 [0.2, 0.4]	0
w35	Contribution of e27 'Amount of knowledge on similar safety-related issues of a controller' to e29 'Information contribution by a controller'.	0.7 [0.6, 0.9]	0
w36	Contribution of e30 'Information contribution by the supervisor' to e16 'Information contribution by others'.	0.4 [0.3, 0.6]	0.5
w37	Contribution of e28 'Amount of knowledge on similar safety-related issues of the supervisor' to e30 'Information contribution by the supervisor.	0.7 [0.4, 0.9]	0.5
w38	Contribution of e13 'Perceived commitment to safety of the supervisor' to e30 'Information contribution by the supervisor.	0.3 [0.2, 0.4]	0.5
w39	Contribution of e8 'Sufficiency iof the number of controllers' to e18 'Acceptability of the workload level'.	0.8 [0.7, 0.9]	1
w40	Contribution of e14 'Level of development of managerial skills' to e18 'Acceptability of the workload level'.	0.2 [0.1, 0.3]	1
w42	Contribution of e7 'Sufficiency of the number of safety investigators' to e33 'Quality of a monthly safety overview report'.	0.4 [0.3, 0.5]	1
w43	Contribution of e32 'Quality of safety analysis' to e33 'Quality of a monthly safety overview report'.	0.6 [0.4, 0.8]	1
w44	Contribution of e44 'Average commitment to safety of the agents involved in safety analysis' to e32 'Quality of safety analysis'.	0.4 [0.2, 0.5]	1.5
w45	Contribution of e31 'Quality of input data' to e32 'Quality of safety analysis'.	0.6 [0.5, 0.9]	1.5
w46	Contribution of e45 'Average contribution of informal discussions of controllers in teams' to e31 'Quality of input data'.	0.3 [0.1, 0.5]	2
w47	Contribution of e46 'Average quality of processed notification reports' to e31 'Quality of input data'.	0.5 [0.3, 0.8]	1

Weights		Value	Total SC sensitivity index
w48	Contribution of e47 'Average quality of previous monthly safety overview reports' to e31 'Quality of input data'.	0.2 [0.1, 0.3]	1
w49	Contribution of e3 'Perceived commitment to safety of the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.2 [0.1, 0.4]	1
w50	Contribution of e35 'Intensity of informal interactions in the team of controllers' to e34 'Contribution of informal discussions of controllers in the team'.	0.35 [0.2, 0.5]	0.5
w51	Contribution of e48 'Average quality of the notification reports produced by the team' to e34 'Contribution of informal discussions of controllers in the team'.	0.3 [0.2, 0.5]	0
w52	Contribution of e49 'Average quality of the received monthly safety overview reports' to e34 'Contribution of informal discussions of controllers in the team'.	0.25 [0.1, 0.4]	0.5
w53	Contribution of e36 'Quality of the formal safety occurrence assessment procedure' to e38 'Quality of the final safety occurrence assessment report'.	0.1 [0.1, 0.1]	0.5
w54	Contribution of e50 'Average commitment to safety of the participants of the meetings' to e38 'Quality of the final safety occurrence assessment report'.	0.1 [0.05, 0.3]	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, 0.15]	0.5
w56	Contribution of e15 'Quality of a processed notification report' to e38 'Quality of the final safety occurrence assessment report'.	0.25 [0.1, 0.5]	0
w57	Contribution of e37 'Amount of knowledge on similar safety-related issues in the organization' to e38 'Quality of the final safety occurrence assessment report'.	0.15 [0.05, 0.25]	1.5
w58	Contribution of e55 'Average quality of the monthly safety overview reports' to e38 'Quality of the final safety occurrence assessment report'.	0.15 [0.05, 0.25]	1.5
w59	Contribution of e7 'Sufficiency of the number of safety investigators' to p1 'Probability of the feedback provision'.	0.3 [0.2, 0.5]	1
w60	Contribution of e39 'Severity of an occurrence' to p1 'Probability of the feedback provision'.	0.4 [0.2, 0.7]	1
w61	Contribution of e40 'Quality of the communication channel between controllers and safety investigators' to p1 'Probability of the feedback provision'.	0.3 [0.3, 0.3]	0

Table 18: Importance of task times classified by categories High / Medium / Low for the ANSP3 model

Task times		Safety Culture Indicators							
		I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
		Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
1	Safety occurrence reporting and the report handling	L	L	L	L	L	L	L	L
2	Create a notification report	L	L	M	L	L	L	L	L
3	Preliminary processing of a notification report	L	L	L	L	L	L	L	L
4	Making decision about the notification report assignment	L	L	L	L	L	M	L	L
5	Preliminary assessment of an occurrence	L	L	L	L	L	L	L	L
6	Making decision about the investigation necessity	L	L	L	L	L	L	M	L
7	Investigation of an occurrence	L	L	H	L	L	L	L	L
8	Discussion of the intermediate occurrence investigation results	L	L	L	L	L	L	L	L
9	Update an interim safety occurrence assessment report	M	M	L	L	L	L	L	L
10	Distribute the final safety occurrence assessment report among all concerned roles	L	L	L	L	L	L	L	L
11	Safety Monitoring	L	L	L	L	L	L	L	L
12	Safety data collection and pre-processing	L	L	L	L	L	L	L	L
13	Safety data analysis	L	L	L	L	L	L	L	L
14	Preparation and distribution of a monthly safety overview report	L	L	L	L	L	L	L	L
15	Making decision on the occurrence reporting	L	L	L	L	L	L	L	L
16	Implementation of safety recommendations	L	L	L	L	L	L	L	L

Table 19: Ranges for the task times in the model and their total safety culture sensitivity indices resulting from the sensitivity analysis

Task		Time	Total SC sensitivity index
1	Safety occurrence reporting and the report handling	Depends on the duration of the subtasks	0
2	Create a notification report	[0.05 h, 12 h]	0.5
3	Preliminary processing of a notification report	[0.03 h, 24 h]	0

Task		Time	Total SC sensitivity index
4	Making decision about the notification report assignment	[0.03 h, 12 h]	0.5
5	Preliminary assessment of an occurrence	[24 h, 36 h]	0
6	Making decision about the investigation necessity	[0.017 h, 12 h]	0.5
7	Investigation of an occurrence	[36 h, 1080 h]	1
8	Discussion of the intermediate occurrence investigation results	[12 h, 120 h]	0
9	Update an interim safety occurrence assessment report	[12 h, 60 h]	1
10	Distribute the final safety occurrence assessment report among all concerned roles	[1 h, 180 h]	0
11	Safety Monitoring	[204 h, 456 h]	0
12	Safety data collection and pre-processing	[180 h, 360 h]	0
13	Safety data analysis	[12 h, 36 h]	0
14	Preparation and distribution of a monthly safety overview report	[12 h, 60 h]	0
15	Making decision on the occurrence reporting	[0.017 h, 12 h]	0
16	Implementation of safety recommendations	[360 h, 2160 h]	0

Table 20: Importance of aspects of dealing with occurrences by management, classified by categories High / Medium / Low for the ANSP3 model

Management occurrence policy	Safety Culture Indicators							
	I1.1	I2.1	I3.1	I4.1	I5.1	I5.2	I6	I7
	Reporting	Notification reports	Occurrence assessment	Monthly safety overview	Commitment of controller	Commitment of team	Perceived comm of supervisor	Perceived comm of management
Reprimand amount for type A occurrence(s)	L	L	L	L	L	L	L	L
Reprimand amount for type B occurrence(s)	M	M	M	L	L	L	L	L
Reprimand amount for type C occurrence(s)	L	L	L	L	L	L	L	L
Reprimand amount for type Other occurrence(s)	H	H	L	L	L	M	L	L
Reward amount for reporting type C occurrence(s)	L	L	L	L	L	L	L	L
Reward amount for reporting type Other occurrence(s)	H	H	L	L	L	L	L	L
Evaluation period of the performance of a controller by the management	M	L	L	L	L	L	L	L
Probability non-reported occurrence of type B is identified by management	H	H	M	L	L	L	M	L
Probability non-reported occurrence of type C is identified by management	L	L	L	L	L	L	L	L
Probability non-reported occurrence of type Other is identified by management	H	H	L	L	L	L	L	L

Table 21: Nominal values and credibility intervals for management occurrence policy parameters of the model and their total safety culture sensitivity indices resulting from the sensitivity analysis

Management occurrence policy parameter	Value	Total SC sensitivity index
Reprimand amount for type A occurrence(s)	0.9 [0.8, 1]	0
Reprimand amount for type B occurrence(s)	0.5 [0.3, 0.7]	1.5
Reprimand amount for type C occurrence(s)	0.2 [0, 0.4]	0
Reprimand amount for type Other occurrence(s)	0.1 [0, 0.2]	2.5
Reward amount for reporting type C occurrence(s)	0.1 [0, 0.2]	0
Reward amount for reporting type Other occurrence(s)	0.1 [0, 0.2]	2
Evaluation period of the performance of a controller by the management	45 days [30 d, 60 d]	0.5
Probability non-reported occurrence of type B is identified by management	0.9 [0.8, 1]	3
Probability non-reported occurrence of type C is identified by management	0.7 [0.6, 0.8]	0
Probability non-reported occurrence of type Other is identified by management	0.3 [0.2, 0.4]	2