Risk Observatory design and early prototype

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Short abstract: Future Sky Safety is a Joint Research Programmed (JRP) on Safety, initiated by EREA, the association of European Research Establishments in Aeronautics. The Programmed contains two streams of activities: 1) coordination of the safety research programmers of the EREA institutes and 2) collaborative research projects on European safety priorities.

This deliverable is produced by the Project P4 “Total system risk assessment of Future Sky Safety. The main objective of the work documented in this report is the definition and evaluation of an early prototype of the Risk Observatory

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Acronyms

Acronym	Definition
A/C	Aircraft
ADREP	Accident/Incident Data Reporting
ANSP	Air Navigation Service Provider
ARC	Abnormal Runway Contact
ARMS	Airline Risk Management Solutions
ASIAS	Aviation Safety Information Analysis and Sharing
BRQ	Business requirement
CAA	Civil Aviation Authority
EASA	European Aviation Safety Agency
EC	European Commission
EU	European Union
FDM	Flight Data Monitoring
FOQA	Flight Operations Quality Assurance
GUI	Graphical User Interface
IATA	International Air Transport Association
RAT	Risk Analysis Tool
RO	Risk Observatory
SIRA	Safety Issue Risk Assessment
SPI	Safety Performance Indicator

Glossary of terms

Safety data	Facts or figures derived from safety management sources such as occurrence reports and Flight Data Monitoring (FDM) programmes. For example, the number of unstabilised approaches or loss of separation events in a period. Safety data is rarely useful by itself until it is processed and organized in a specific context, which then becomes safety information.
Safety information	Safety data organized and processed in a specific context, allowing the recipient of the information to make decisions on future actions. Example: “there is no significant reduction in the rate of unstabilised approaches for runway 99 at XYZ despite the Crew Memo issued 12 months ago reminding crews about the established Standard Operating Procedure.”
Safety intelligence	Knowledge and comprehension of the Aviation System, generated from investigation and reflection over safety information and safety data. Safety intelligence is necessary to assist aviation safety practitioners to effectively manage safety. Example: “The published NDB approach for runway 99 at XYZ is offset from the runway centre line, inducing low level manoeuvres which are in conflict with the stable approach criteria. Feedback from crews involved in these events suggest they are aware of the SOP conflict but decide to continue the approach due to the low perceived risk for the aircraft.”

EXECUTIVE SUMMARY

Problem Area

The Future Sky Safety (FSS) Project P4 "Total system risk assessment" develops a Risk Observatory prototype as a support tool for safety management. In previous work, the project team identified business, system and user requirements for the Risk Observatory. The objective of this task within the project is to develop an early prototype and to demonstrate and evaluate this early prototype with stakeholders. The purpose of the evaluation sessions with stakeholders is to collect feedback using the early prototype as a mock-up of the Risk Observatory's functionalities and design to validate and, if necessary, update the identified requirements.

Description of Work

The development of the early prototype was conducted in four steps.

First, the business, system and user requirements defined FSS P4 were reviewed to identify the functionalities and design aspects that would be considered in the early prototype development. This review led to the development of five main functionalities of the early prototype: the homepage, the occurrences dashboard, the risk dashboard, the search dashboard and the what-if analysis dashboard.

In the next step, two use cases were defined to be able to demonstrate the functionalities of the early prototype with existing risk models and data.

The third step involved the implementation of the early prototype design in a software tool to be able to demonstrate functionalities and potential outputs of the Risk Observatory. As part of this step, a few data visualization tools were evaluated for implementation of the prototype. The software application Balsamiq was selected to implement the early prototype. The early prototype is available in the form of a mock-up of a webpage-format that can be shared as PDF file. A video demonstrating the functionalities of the prototype was also developed.

Finally, demonstration and evaluation sessions were organized with stakeholders to demonstrate the early prototype and to receive feedback on the prototype's functionalities and design. The following stakeholders were interviewed: five aircraft/helicopter operators, one authority/regulator, and two ANSPs.

Results & Conclusions

The project team received a positive response on the demonstrated functionalities and design of the early prototype. The most interesting features according to the interviewed stakeholders are the risk dashboard, the search dashboard and the what-if analysis dashboard. The general opinion on the occurrences dashboard is that this sort of analysis is already done by most organisations. The possibility to benchmark safety performance in the occurrences and risk dashboards received mixed feedback. Some

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stakeholders appreciate this feature, whereas others are more reluctant to compare safety performance and question the feasibility and added value of benchmarking their operations. During the feedback sessions, concerns were raised on different topics, including accessibility of data, reliability and validation of risk models, lack of standardisation and criteria, and lack of context information to understand the occurrence and associated risk.

The early prototype is an excellent method to validate the identified business, system and user requirements with stakeholders. The feedback received during the demonstration of the early prototype to stakeholders will help the project team to further refine identified requirements and development of the prototype.

During the development and evaluation of the early prototype Risk Observatory with stakeholders, the stakeholders provided 23 recommendations. In addition, recommendations are defined by the authors. Two of these recommendations are generic, while the rest are intended to mitigate the concerns raised by the stakeholders during the evaluation sessions. All recommendations are allocated to the FSS P4 project team. The recommendations include:

- Develop a strategy to interact with, complement and strengthen similar data sharing activities like the EASA big data programme for aviation safety (Data4Safety)
- Develop an approach to build trust in the risk models and their output used in the Risk Observatory. Therefore, the project team is recommended to address the validation and verification of the risk models applied in the Risk Observatory, especially the risk models that generate results for the risk dashboard and what-if analysis dashboards.
- Identify software applications on the market for implementation of the Risk Observatory prototype, and assess the need and feasibility to develop specific software applications for the implementation of (specific aspects of) the Risk Observatory prototype's functionalities and design.
- Consider a method to ensure that contextual information can be maintained during data fusion and made available in the Risk Observatory's dashboards. It is recommended to demonstrate in the Risk Observatory prototype (e.g. through use cases) the way in which contextual information will be available to the end user.
- Address data collection to populate the Risk Observatory prototype as soon as possible to ensure that the project has timely access to data needed for further development of the Risk Observatory prototype, including the demonstration of use cases.

Applicability

This document provides recommendations to FSS P4 project team that can be considered during the further development of the Risk Observatory prototype. Furthermore, concerns raised during the evaluation sessions should be addressed by the FSS P4 project team to improve the value proposition and feasibility of the Risk Observatory.

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1 INTRODUCTION

1.1. The Programme

The European Commission (EC) Flight Path 2050 vision aims to achieve the highest levels of safety to ensure that passengers and freight as well as the air transport system and its infrastructure are protected. However, trends in safety performance over the last decade indicate that the ACARE Vision 2020 safety goal of an 80% reduction of the accident rate is not being achieved. A stronger focus on safety is required. Therefore a Joint Research Programme (JRP) on Aviation Safety – Future Sky Safety (FSS) – has been started in the beginning of 2015, aiming for Coordinated Safety Research as well as Safety Research Coordination. Future Sky Safety has the goal to coordinate research and identify innovation actions targeting the highest levels of safety for European aviation [1].

1.2. Project context

In the FSS project P4 "Total System Risk Assessment", a working and practical prototype Risk Observatory (RO) is developed as a support tool for safety management. The Risk Observatory will acquire, fuse and structure safety data and translate them to actionable safety information: output that helps the user to distil safety intelligence to allow the implementation of appropriate measures to positively influence safety, i.e. reducing the serious incident and accident probability. The core of the Risk Observatory is formed by a risk assessment framework that integrates risk assessment models specifically developed to represent a certain domain. The framework is fed by different safety data inputs: e.g. normal operational data from the aircraft operator domain (e.g. originating from Flight Data Monitoring (FDM)) and Air Navigation Service Providers (ANSP) domain, but also occurrence and incident data. The Risk Observatory will offer important insights in safety performance to both senior management and at a more detailed working level, safety analysts, which can be used in the risk assessment of new aircraft and systems and in safety assurance by identifying safety trends, key risk areas, and efficient mitigation measures. The Risk Observatory's scope includes the EASA Member States and the operations performed by service providers within the EASA Member States.

1.3. Research objectives

In the FSS Project P4 "Total system risk assessment", an early prototype is developed for assuring that the needs and wishes of end-users are covered appropriately. The early prototype can be regarded as the concept demonstrator for the functionalities of the Risk Observatory prototype, which is the eventual output of the project P4. The early prototype aims to validate the identified business, user and system requirements in an early stage of the Risk Observatory prototype development.

The feedback received during the demonstration of the early prototype to stakeholders will help the project team to further refine identified requirements and development of the prototype.

1.4. Approach

The development of the early prototype was conducted in four steps:

1. First, the business, user and system requirements defined in work package 4.1 “Risk observatory requirements” were reviewed to identify the functionalities and design aspects that would be considered in the early prototype development. This review led to the development of five main functionalities – or pages – of the early prototype: the homepage, the occurrences dashboard, the risk dashboard, the search dashboard and the what-if analysis dashboard.
2. In the next step two use cases were defined to be able to demonstrate the functionalities of the early prototype with existing risk models and data. The use cases, “unstable approach” and “loss of separation”, helped with “story-telling” in the demonstration of the early prototype to possible future end-users.
3. The third step involved the implementation of the early prototype design in a software tool to be able to demonstrate functionalities and potential outputs of the Risk Observatory. As part of this step, multiple data visualization tools were considered for implementation of the prototype. The software application Balsamiq was selected to implement the early prototype. The early prototype is available in the form of a mock-up of a webpage-format that can be shared as PDF file. A video demonstrating the functionalities of the prototype was also developed.
4. Finally, demonstration and evaluation sessions were organized with stakeholders to demonstrate the early prototype and to receive feedback on the prototype’s functionalities and design.

1.5. Structure of the document

The structure of the document is as follows:

- Chapter 2 describes in more detail the development of the early prototype. It addresses the review of business, system and user requirements for the development of the prototype. The chapter also explains the considerations in the design and implementation of the two use cases.
- Chapter 3 describes the approach in the demonstration and evaluation of the early prototype with stakeholders. It summarises the results from the feedback sessions with stakeholders and presents recommendations for further development of the prototype.
- Chapter 4 presents the conclusions and recommendations.
- Appendix A shows the review of requirements, showing the grouping of requirements resulting in the five dashboards of the early prototype dashboard.
- Appendix B provides a guide for the demonstration of the early prototype with the runway excursion use case (the airline version of the prototype).
- Appendix C provides a guide for the demonstration of the early prototype with the mid-air collision use case (the ANSP version of the prototype).
- Appendix D describes success criteria for evaluation of a prototype.
- Appendix E contains an evaluation form for the prototype.

2 EARLY PROTOTYPE DEVELOPMENT

2.1. Review of requirements

In previous FSS P4 activities, the business, and respectively, user and system requirements were developed after consultation with stakeholders. Stakeholders were interviewed to collect their experience with current safety management practices and suggestions for the future needs of the organizations. The results of those interviews were used to derive the business, user and system requirements for the Risk Observatory. The business requirements are used to define the value proposition of the Risk Observatory, while the user and system requirements specify the needs of the Risk Observatory's user that will be considered in the prototype's functionalities and design.

The project team reviewed all requirements defined in D4.1 [2] to identify potential groups of similar or related functionalities that could be implemented on a single dashboard. During the review the project team determined which requirements could be implemented in the early prototype based on the definition of the requirement, the available resources and expected maturity level and scope of the early prototype. From reviewing the requirements the team derived the following main dashboards for the early prototype:

- Homepage
- Occurrences dashboard
- Risk dashboard
- Search dashboard
- What-if analysis dashboard

Appendix A shows the allocation of business, user and system requirements to the five dashboards and provides an explanation of the implementation of the requirements in the early prototype. The appendix also shows visually the allocation of requirements to the early prototype dashboards.

A few requirements could not be assigned to one of the five dashboards or were considered out of scope for the early prototype development. The relevance for the early prototype is determined by the objectives of the early prototype and the fact that the prototype should cover the basic high level functionalities related to safety risk management, safety assurance and safety promotion/communication. Therefore, requirements for the Risk Observatory referring to a generic feature, an advanced feature, or one of an organisational nature were classified as "other (dashboard)" or "not relevant for early prototype".

After the development and implementation of the early prototype the list of requirements was reviewed again to describe the particular implementation of the requirement in the prototype and to assess the level of implementation. The latter aspect represents a maturity level of the early prototype's functionalities and design. Three levels were used: the requirement is implemented, partly implemented, or not relevant for the (early) prototype. A colour code (green, yellow, grey) in the tables in Appendix A indicates the implementation level of each requirement. The level of implementation was directed by

focussing on the functionalities that were considered most important for the value of the Risk Observatory by the stakeholders and project team, the availability of data, and available resources.

Table 1 shows the results of the allocation of requirements to the dashboards in the early prototype, and the corresponding level of implementation. About half of the requirements are (partly) implemented in the early prototype, while about half of the requirements are at this stage of development considered to be not relevant for the early prototype.

Table 1: Results of requirements mapping and implementation in early prototype.

Requirement	Business requirement	User requirements	System requirements
Total number of requirements	23	47	68
Implemented in early prototype	5	23	20
Partly implemented in early prototype	1	7	15
Not relevant for early prototype	17	17	33
Distribution of requirements over dashboards			
Homepage	0	1	6
Occurrences dashboard	1*	9	11
Risk dashboard	3*	11	6
Search dashboard	2	0	6
What-if analysis dashboard	0	4	3
Other	1	5	3
* BRQ50 is implemented in two dashboards.			

2.2. Definition of use cases

The objective of the use cases is to demonstrate the early prototype functionalities and design with existing (risk) models and data. The use cases were selected so that they address two of the six accident types mentioned in the user requirements, specifically runway excursion and mid-air collision (refer to URQ_070 in Appendix A.2). Both accident types are interesting for multiple stakeholders. The safety performance indicators associated with the two uses cases can be monitored and analysed with different types of data, so that the use cases also demonstrate the data fusion aspects of the Risk Observatory. The two use cases are:

- The safety performance indicator (SPI) “Unstable Approach”, associated with the accident type “Runway Excursion”.
- The SPI “Loss of Separation”, related to the accident type “Mid Air Collision”.

For the implementation of functionalities and design of the dashboards in the early prototype existing risk models were used, i.e. the Causal Model for Air Transport Safety CATS [3] and bow-tie model elements from the CAA UK significant seven bow-ties [4]. These models were chosen because of their availability. The usage of these risk models does not suggest that they will be part of the Risk Observatory risk model inventory. WP4.2 and WP4.3 of project P4 are devoted to develop this risk model inventory.

The data for populating the risk models and early prototype dashboards were used for illustration purposes only. Data are partly obtained from actually quantified risk models (e.g. for the risk dashboard and risk picture), complemented with fictitious data. Hence, conclusions cannot be drawn from the results and information shown on the early prototype's dashboards.

2.3. Implementation of the early prototype design

The design of the early prototype was conducted iteratively and incrementally by the project team. The early prototype has five main dashboards and a Login page:

- Login page
- Homepage
- Occurrences dashboard
- Risk dashboard
- Search dashboard
- What-if analysis dashboard

Two versions of the early prototype were developed, one for airlines and one for air navigation service providers. It was decided to develop these two versions to show a representative version of the early prototype to the stakeholders that were involved in the evaluation of the early prototype. It is important to highlight that the different versions of the early prototype shall not impede the total aviation system approach. The Risk Observatory shall enable each stakeholder to analyse risks in whole aviation domain, and provide access to safety information from all domains. Safety risk management and safety performance monitoring from a systemic perspective, not from the perspective of a single organisation or single domain, is namely a key functionality. Appendix B shows the "airline" version of the early prototype with the use case "runway excursion". Appendix C shows the "ANSP" version with the use case "mid-air collision".

Several commercial software packages for visualisation of data and building dashboards were qualitatively evaluated for implementing the early prototype (e.g. Tableau, Pentaho, SiSense, Qlik, MicroStrategy, TIBCO Spotfire, YellowFin, Balsamiq). They were evaluated based on ease of use, flexible data access, functionalities (e.g. customisable visualisations, interactive analysis, embedding, sharing, security etc.) and licence costs. In the end, it was decided by the project team to use the software tool Balsamiq (Version 3.2.4, 22-10-2015) to implement the early prototype in the form of a mock-up of web-based dashboards. Balsamiq enables one to build website wireframes, or screen blueprints, which presents the visual aspects and possible interaction of a user with a website. Based on the ease of use, licence costs and results that could be achieved with Balsamiq, this tool was considered the best solution in the current phase of project. The resulting prototype is available as a .pdf document and a video.

A portion of the Risk Observatory's required features can be developed using existing, commercial software applications. The development of an occurrence dashboard can for example be easily performed

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using Tableau. Note that FAA's ASIAS is also using Tableau for presenting data and safety information on its dashboards. On the other hand, the Risk Observatory has some innovative functionalities (e.g. risk models, a risk picture, the what-if analysis) which are most likely not available in current software applications, and will require dedicated software development.

The following figures show screenshots of the early prototype dashboards.

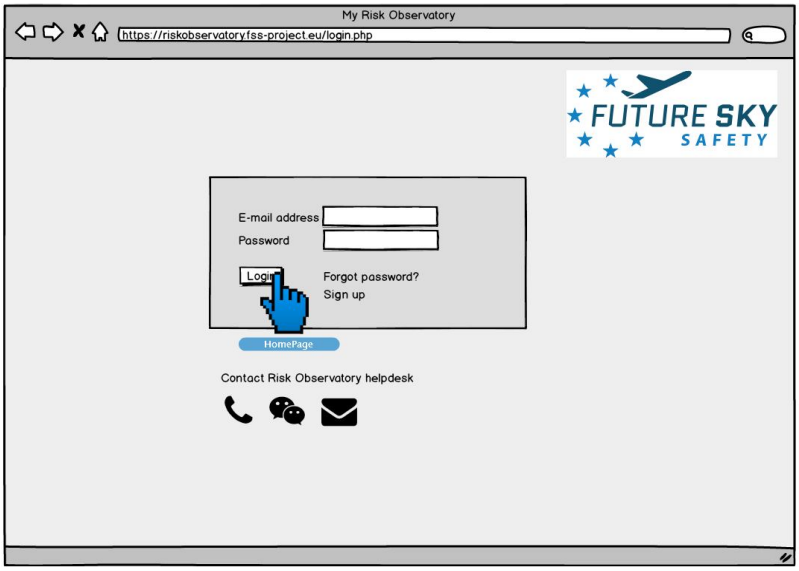

Figure 1: Login page.

Figure 1 shows the log in page for the user to enter the Risk Observatory. Depending on the authorisation or user profile, the user will enter a Homepage (dashboard) that is tailored to the specific user's domain with relevant safety performance indicators (SPIs) and associated risks. Figure 2 shows a screenshot of the homepage which shows the trends in SPIs and risks (traffic light "arrows" indicators). By clicking on the indicator or accident type the user can directly drill down into the underlying safety data and trend analysis. The homepage also provides access to the search dashboard and what-if analysis dashboard.

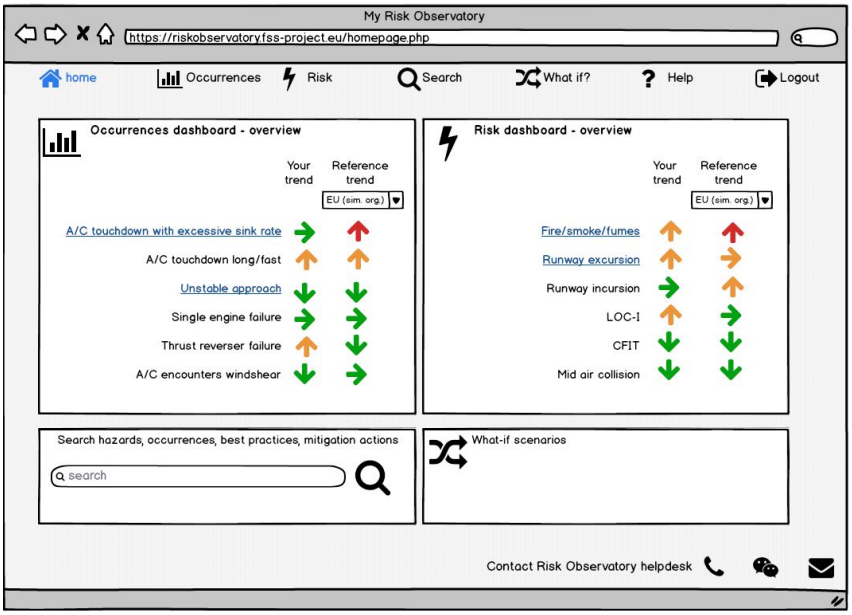

Figure 2: Homepage.

Figure 3 shows a view of the occurrence dashboard, where the user can monitor the number or frequency of a particular safety performance indicator or precursors (e.g. unstable approach). The user has a few functionalities available, for example filtering settings, ability to access the underlying data (records) or link to the risk dashboard to view the risk associated with the occurrence type. The occurrences dashboard presents data from actual reported occurrences, observations, measured events etc.

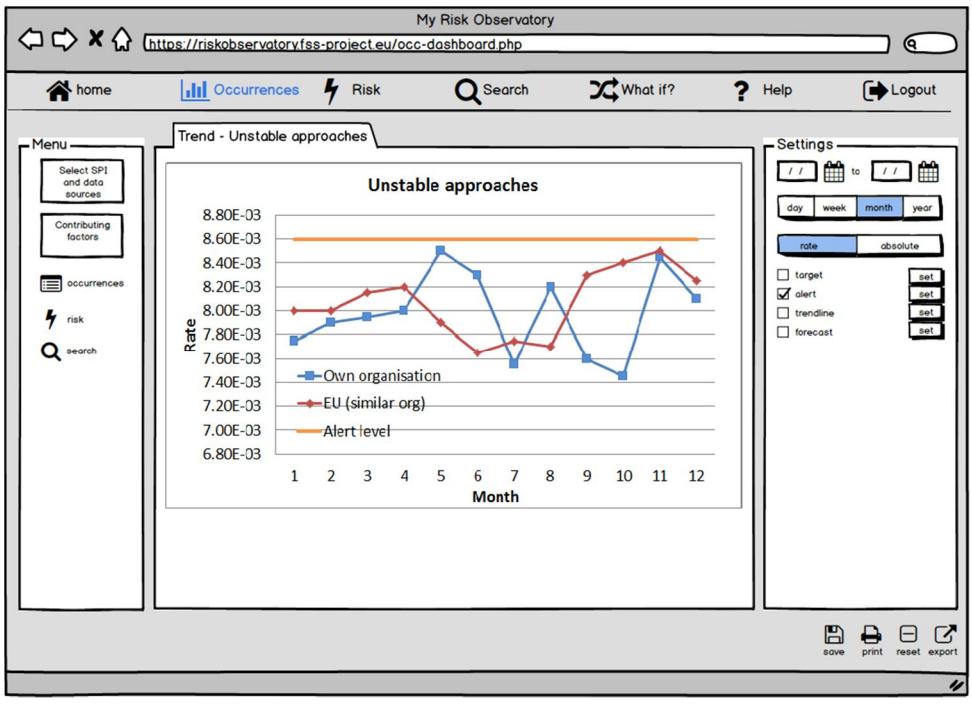

Figure 3: Occurrences dashboard.

Figure 4 shows the risk dashboard where the user can observe the accident risk probability and trend for a particular accident type for their own organisation, and compare that against for instance the EU safety level and an user defined alert level. The data shown in the dashboard is derived from combining actual reported occurrences, observations, and measured data with risk models to estimate an accident probability. In other words the risk dashboard combines data and risk model based information. An individual organisation may have no or too few events to calculate directly an accident probability. Therefore, the risk models are used to estimate an accident probability using event data on precursors to feed the risk model.

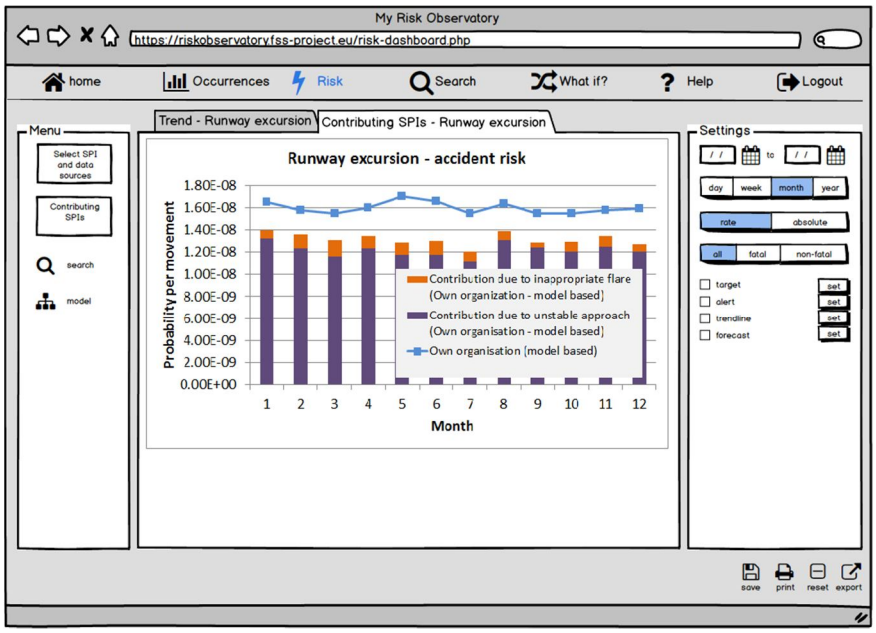

Figure 4: Risk dashboard.

Figure 5 shows a screenshot of a dashboard that can be sued to search for hazards, occurrences, best practices, mitigation actions stored in a database in the Risk Observatory. The idea is that other stakeholders share such information and best practices, which are made available to other organisation through the search dashboard. A “Google” type of search engine is foreseen.

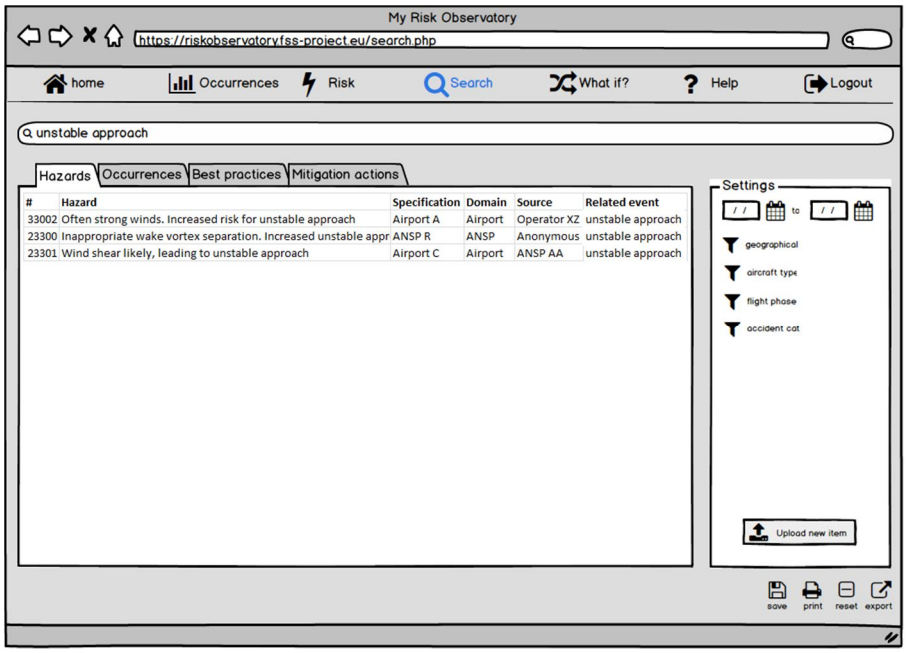

Figure 5: Search dashboard.

Figure 6 shows the what-if analysis dashboard where the user can perform comparative analysis of different SPIs and their effect on accident risk. This shows the relative importance and effect of a change in SPI on accident risk. The user can select SPIs and associated accident risks (accident types) and then assess the impact of changing the frequency of occurrence of certain SPIs on the accident risk level. The what-if analysis functionality makes use of risk models in the background.

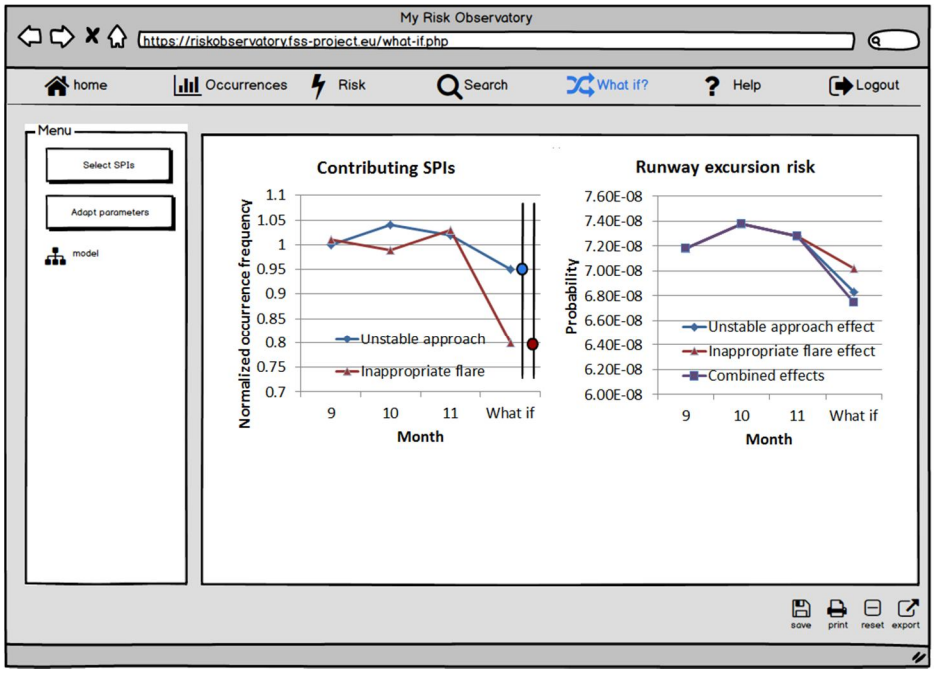

Figure 6: What-if analysis dashboard.

3 EARLY PROTOTYPE DEMONSTRATION AND EVALUATION

3.1. Objective of the evaluation

The purpose of the evaluation sessions with stakeholders was to collect feedback using the early prototype as a mock-up of the Risk Observatory's functionalities and design in order to evaluate and, if necessary, update the business, user and system requirements. Secondly, the early prototype serves as a means to communicate to stakeholders what the Risk Observatory could encompass in order to get feedback from users on functionalities, design, and user interface.

In preparation for the evaluation sessions, two types of evaluations were defined with corresponding success criteria, see Appendix D. The two evaluations are:

- Evaluation of the early prototype implemented functionalities and design against the business, user and system requirements document. The result of this evaluation is described in section 2.1 and Appendix A.
- Evaluation of the early prototype implemented functionalities and design with stakeholders in the form of an interactive session and feedback collection process. The result of this evaluation is described in the next sections.

Section 3.2 explains the organisation and set-up of the evaluation with stakeholders. In the sections 3.3 through 3.8 the feedback, concerns and recommendations from the interviewed stakeholders are summarised. Table 2 shows the interviewed stakeholders. The interviewed personnel included safety managers, safety data analysts, and flight data analysists.

Table 2: Interviewed organisations for feedback on the early prototype.

Organisation	Number of interviews
Aircraft operators	5
Helicopter operators	1
ANSP	2
Authority	1

3.2. Organization of the evaluation sessions

In this stage of development the early prototype has limited functionalities which provide little room for the potential users to really interact with the prototype. Therefore, it was decided to demonstrate the prototype's functionalities and design by following the step-by-step script or guide developed for each use case (see Appendix B and Appendix C). The project team members explained and demonstrated the early prototype following this script to ensure a standard and consistent evaluation during the sessions.

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A formal evaluation form was developed that can be used for the evaluation of the final version of the prototype, see Appendix E. However, the early prototype is not mature enough to use the developed questionnaire and rating scale. Instead, the following four questions were addressed in the evaluation:

- What overall recommendations do you have for the early prototype?
- What are the most interesting features or functionalities of the early prototype?
- What features or functionalities do you miss in the early prototype?
- What is required to ensure that you and your organisation will be using the Risk Observatory?

3.3. General feedback received from stakeholders

In general the demonstration and evaluation of the early prototype was successful in the sense that the prototype proved to be an excellent way to discuss functionalities of the Risk Observatory with stakeholders. The prototype was quite helpful to confirm the identified business, system and user requirements. In addition, the participants could quickly and easily grasp the idea of the Risk Observatory prototype. The evaluation provided useful feedback and recommendations that shall be considered in the further development of the Risk Observatory prototype.

The project team received a positive response on the demonstrated functionalities and design of the early prototype. The most interesting features were the risk dashboard, the search dashboard and the what-if analysis dashboard. The general opinion on the occurrences dashboard is that this sort of analysis is already done by most organisations. The possibility to benchmark safety performance in the occurrences and risk dashboards received mixed feedback. Some stakeholders appreciate this feature, whereas others are more reluctant to compare safety performance and question the added value of benchmarking their operations.

Today, the challenge for the aviation industry is to conduct safety risk management and safety performance monitoring from a systemic perspective, not from the perspective of a single organisation or single domain. The Risk Observatory could create added value in this system-wide risk assessment by addressing questions like: what are the risks that have to be dealt with system-wide? What risks can be dealt with together and which ones by each organisation?

Airlines are required to report certain safety related events to authorities (as required by EU directive 376/2014). The Risk Observatory is a type of tool that will be needed to put the reported data to good use and get useful information out of the data repository.

Concerns raised by the stakeholders:

- Concern 1: One airline foresees that the analysis of the data in the Risk Observatory (e.g. FDM events, occurrence data, etc.) will require contextual information to which the Risk Observatory Organisation will not have access. An airline will not be able to analyse occurrence or FDM data from other operators presented on the Risk Observatory dashboards because it lacks the contextual information on the organisation, operation, operating conditions, SOPs, aircraft types

from other airlines to be able to make a proper assessment of their own performance compared to the others. The validation of events and providing context to events shared with the Risk Observatory can only be conducted by the operator from which the data comes, and not by an external party such as the Risk Observatory Organisation. In a Risk Observatory it will be impossible to contact the crews/airlines to get the proper context for the occurrences and FDM events that are provided by organisations. As a result the occurrences and risk dashboards in the Risk Observatory can lead to comparing 'apples with oranges'.

In the opinion of this airline the left side in Figure 7 should be conducted by the operators as it requires the collection, processing, interpretation, validation analysis of various safety data with the contextual data. These activities cannot be "outsourced" to a third party, like the Risk Observatory, as it will lack the capabilities, expertise, knowledge specific for the airline's aircraft type, SOPs etc. Sharing "raw" safety data (as in the left side) between stakeholders in the Risk Observatory will be less useful than sharing the output of the operators' risk management, the right side of Figure 7. It is worth adding, however that the capability of organisations to process safety data is known to vary significantly and that many may benefit from at least exposure to a third party other than regulatory oversight.

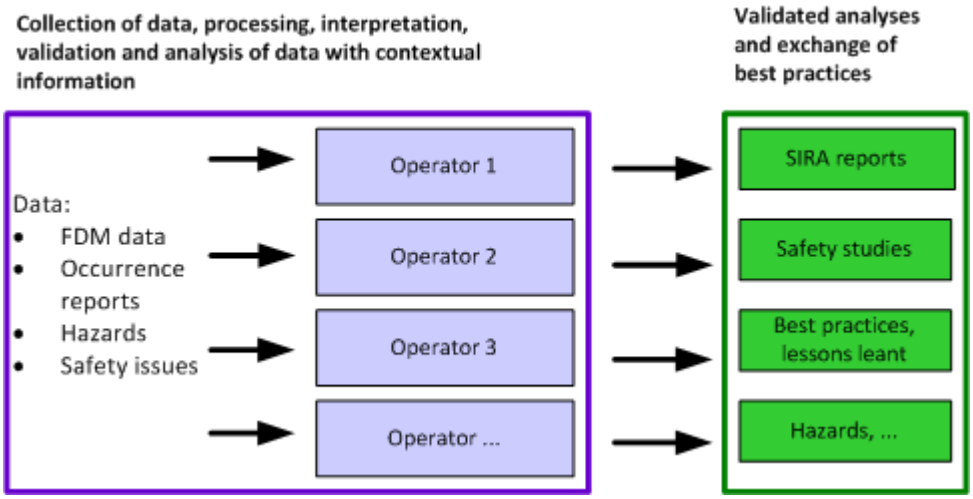

Figure 7: Potential scope of Risk Observatory (purple versus green).

- Concern 2: Lack of access to data is a concern mentioned by all stakeholders. FDM data is protected by agreements between unions and the airlines. Detailed data such as contributing factors (which may be many, quite subtle and hence potentially not even recognised) to events are currently not required to be reported.
- Concern 3: The stakeholders observe that many initiatives are underway with a lot of similarities, both within and outside their organisations and they express a concern regarding the potential lack of standardisation, lack of exchange of information and cooperation. To some extent, 'Big Data' and data mining techniques are technologies that have increasing prominence, not only in

the aviation safety world. At this stage, one would expect diversity of approach, with techniques evolving to best meet user need, ultimately resulting in the setting of standards.

- Concern 4: The potentially slow 'speed' of the system is a concern. If the Risk Observatory dashboards and database are large and when many users simultaneously access the system the Risk Observatory operating speed may be slow and negatively impact user-friendliness.

Recommendations from the stakeholders:

- Recommendation 1: One airline recommends that the Risk Observatory only shares validated safety analyses, and not "raw" FDM or occurrence data without the proper context. In the light of Concern 1, this airline considers the Risk Observatory as a method to facilitate the exchange of validated, interpreted, and assessed safety issues or safety occurrences, good practices etc. between stakeholders (represented by the right side of Figure 7). Sharing these data would be a solution to ensure that contextual information is taken into account and part of the shared information.
- Recommendation 2: Stakeholders recommend that the FSS P4 project discusses the Risk Observatory project with on-going similar initiatives in order to align the current projects to ultimately come up with one Risk Observatory for Europe. Similar initiatives include ASIAS [6], IATA Flight Data Exchange (FDX), and EASA's big data for aviation safety programmes, called Data4Safety.
- Recommendation 3: Achieve quick wins or early success in the Risk Observatory prototype development and demonstration. It is recommended to focus on one or two specific events to build confidence in the Risk Observatory. In the end, managers will need to trust the outcomes of the Risk Observatory, rather than their intuition or 'gut feeling'. In the first months the Risk Observatory outcomes should be in line with their gut feeling, and counterintuitive results need to be well explained, in order to build trust.
- Recommendation 4: Consider in the architecture development the operating speed of the system and databases as an important success factor.

3.4. Feedback on Homepage functionalities and design

It was remarked that in the current design of the Homepage the occurrences cannot directly be attributed to risks and vice versa. It is recommended that the Homepage should present a risk overview, whereas occurrences would be a drill down from risk, i.e. the occurrence dashboard forms the foundation for the risk dashboard.

3.5. Feedback on Occurrences dashboard

The airlines indicate that the occurrences dashboard is in line with the current practice. The added value of this dashboard is the capability to compare the own organisation's performance with other airlines or the EU average. This capability is currently not available to them. One airline commented that the SPI on unstable approach serves more to assess compliance than safety.

The airlines raised three concerns:

- Concern 5 (see also Concern 1): A lack of standardisation and criteria for events and SPIs leads to comparing apples and oranges on the dashboard.
- Concern 6: Application of one airline's unstable approach criteria to another airline's flight data will not be completely representative for the unstable approach rate, since pilots will act according to their company's own unstable approach criteria. The application of unstable approach criteria (event definition) to raw flight data may be useful, as it will provide more insight in the airline's performance compared to others. However, the analysist should take into account that the flight crew of another airline will operate with their company's criteria/standard operating procedures.
- Concern 7 (see also Concern 1 and 5): A lack of context information in the occurrences dashboard. Due to the aggregation of data or standardisation of data such as presented on the occurrences dashboard, one loses contextual information (e.g. specific conditions, circumstances), which is necessary to really understand the occurrence and associated risk.

Recommendations from the stakeholders:

- Recommendation 5: Enable the user to select criteria for the right reference set for comparison of safety performance so that the comparison can be made with a certain organisational or operational "profile" (e.g. similar fleet, similar size, destinations, etc.). This recommendation also applies to the risk dashboard.
- Recommendation 6: Develop and assure standardisation of taxonomy, definitions and (risk) classifications of events and SPIs (such as unstable approach) to be able to compare safety performance.
- Recommendation 7: Provide a (hyper)link on the dashboards to the supporting dataset so that the user can access to the underlying data when he/she exports a figure.
- Recommendation 8: Provide an indication on the background of the dataset and the size of dataset corresponding with the figures on the dashboards.
- Recommendation 9: Allow the user to "zoom in" on occurrences by for example location (e.g. airspace, airport, runway) and aircraft type.
- Recommendation 10: Provide an assessment about the trend line to the user, for example by an indication whether the trend is good or bad.

- Recommendation 11: It is suggested to add best and worst performing organisations in the comparison (for example by brackets above and below the average) in the benchmark figures.

3.6. Feedback on Risk dashboard

The risk dashboard is an important feature of the prototype. The contribution of factors and the notion of a risk picture are valuable. The latter visualisation is helpful since it is understandable to management.

The airlines raised two concerns:

- Concern 8: There is currently insufficient trust in the capability of risk models to make a proper estimation of accident risk. One airline expressed little interest in quantifying estimated accident risks for that reason.
- Concern 9: Another concern is the effect of reporting culture (willingness to report) on the observed trend line. The fact that the trend is increasing or decreasing should be considered in relation to the reporting culture. This concern also applies to an observed trend on the occurrences dashboard.

Recommendations from the stakeholders:

- Recommendation 12: Allow the user to identify and select safety barriers in the generic risk model that are specific to the organisation. The barriers that an organisation has put in place determine the conditional probability of an accident outcome given an initiating event (threat). It would be helpful if the risk model reflects as best as possible the particular organisation when transforming data into safety intelligence using risk models. If the user can select the barriers in the generic risk model that are applicable to the own organisation, then the generic risk model could be better tailored to the own organisation. Based on the safety barriers you have in place (selected in the model), you can “upgrade” or “downgrade” the accident outcome probability.
- Recommendation 13: It would be helpful if the user can apply within the Risk Observatory’s risk dashboard the company specific risk matrix, e.g. what risk is acceptable/what not, used in the own safety management system.
- Recommendation 14: For graphs of risk on the dashboards it is recommended to have quantities on the axes that are common to the end users. For instance, the x-axis should show an actual month, quarter or year. The y-axes scale should expresses probability as number of events per 1000 sectors or as a percentage (e.g. x% unstable approaches). For the risk picture the severity scale should have distinct levels in line with common risk classification definitions.
- Recommendation 15: If the generic risk model contains safety barriers, it is recommended that the barrier quality or strength is visualised, for example by using a colour coding.

- Recommendation 16: Consider using the database of occurrences classified with the Eurocontrol Risk Analysis Tool (RAT)[1] for use in the ANSP version of the Risk Observatory prototype to avoid additional effort to collect data for the Risk Observatory.

3.7. Feedback on Search dashboard

All stakeholders find this feature useful, especially for hazard identification and management of change. The ability to share qualitative safety information (good practices, safety concerns, safety reports etc.) between organisations is highly appreciated as they currently have no or limited access to such information. In addition, a link between a hazard and related occurrence reports was considered helpful.

Recommendations from the stakeholders:

- Recommendation 17: The project shall consider if and how to make use of the EU 376/2014 based occurrence data repository. Reporting hazards and mitigation means is required in the new regulation EU 376/2014, which can provide input for the risk observatory database and the search functionality.
- Recommendation 18: Enable the sharing of safety studies or Safety Issue Risk Assessment reports (SIRA according to the ARMS methodology [5]) that are the result of the operator's own analyses. These studies contain the assessment of validated data with the proper context information. Refer also to Concern 1 in section 3.3.
- Recommendation 19: Provide the opportunity to learn from (large) changes in trends at other operators. The Risk Observatory could assess the reason for the change in a trend and draft measures or best practices (in case of a positive trend) or hazards (in case of a negative trend).

3.8. Feedback on What-if analysis dashboard

The interviewed stakeholders consider the what-if analysis dashboard an interesting application, although there are varying opinions about its usefulness. The what-if analysis tool can be useful for assessing and demonstrating internally in the company what the impact of certain measures on risk will be. These analyses support the safety department in discussions with flight crews and management to demonstrate the effectiveness of risk mitigation measures and the impact of certain events on risk. It is regarded as a decision support tool to help to determine priorities. In general the actual probabilities are not so important, more the percentage change observed in the what-if graph. It would be good to evaluate the what-if prediction afterwards with the actual data, which will help improve the modelling.

The concerns about the usefulness of this functionality relate to the reliability and validation of risk models used in the what-if analysis. The risk models are simplifications of complex operations and include

[1] The RAT provides a severity and risk assessment methodology for reported ATM incidents.

assumptions. A few stakeholders question the representativeness of the risk models and the reliability of the outcome. The what-if analysis may be used qualitatively in safety assessments to show the impact of an event on risk. Other than that, these what-if predictions may give false pictures of risk and may lead to misconceptions and wrong expectations in their view.

Recommendations from the stakeholders:

- Recommendation 20: Address the concern regarding the reliability and validity of the risk models and causal relations used in the what-if analysis.
- Recommendation 21: For graphs of risk on the dashboards it is recommended to have quantities on the axes that are common to the end users (e.g. per number of sectors or a percentage).
- Recommendation 22: Provide an indication or suggestion for risk mitigation measures based on the user's input data in the prototype. The Risk Observatory should provide a link to the "knobs" that management can "turn".
- Recommendation 23: The risk models should also support what-if analysis for future changes. It helps to write models in terms of operational functions, e.g. "land", "take-off", because it is then easier to define how these functions change in future scenarios.

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4 CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The project team reviewed all business, user and system requirements defined in D4.1 [2], and identified the following main dashboards for the early prototype:

- A homepage (start page after a login page)
- Occurrences dashboard
- Risk dashboard
- Search dashboard
- What-if analysis dashboard

During the review, the project team determined which requirements could be implemented in the early prototype based on the definition of the requirement, the available resources and expected maturity level and scope of the early prototype. The majority of the business, user and system requirements are allocated to the occurrences and risk dashboard.

Furthermore the maturity level of the implementation of requirements in the early prototype was assessed. About half of the requirements are (partly) implemented in the early prototype, while about half of the requirements are at this stage of development considered to be not applicable to the early prototype. The reasons that a portion of the requirements could not be assigned to one of the five dashboards or was considered “not relevant for early prototype” include: the requirement refers to a generic feature of the Risk Observatory, relates to an advanced feature, or is of an organisational nature.

The project team selected the software tool Balsamiq to implement the early prototype in the form of a mock-up of web-based dashboards. Balsamiq enables you to build website wireframes, or screen blueprints, which presents the visual aspects and possible interaction of a user with a website. Based on the ease of use, licence costs and results that could be achieved with Balsamiq, this tool was considered the best solution in the current phase of project.

A portion of the Risk Observatory’s required features can be developed using existing, commercial software applications. The development of an occurrence dashboard can for example be easily performed using Tableau. Note that ASIAS is also using Tableau for presenting data and safety information on its dashboards. On the other hand, the prototype Risk Observatory has some innovative functionalities (e.g. risk models, a risk picture, the what-if analysis) which are most likely not available in current software applications, and will require dedicated software development.

The early prototype is an excellent method to validate the identified business, system and user requirements from deliverable D4.1 [2] with stakeholders. The demonstration and evaluation of the early prototype with stakeholders provided useful feedback and recommendations that shall be considered in the further development of the Risk Observatory prototype. The following stakeholders were interviewed: five aircraft/helicopter operators, one authority/regulator, and two ANSPs.

The project team received a positive response on the demonstrated functionalities and design of the early prototype. The most interesting features according to the interviewed stakeholders are the risk dashboard, the search dashboard and the what-if analysis dashboard.

The general opinion on the occurrences dashboard is that this sort of analysis is already done by most organisations. The possibility to benchmark safety performance in the occurrences and risk dashboards received mixed feedback. Some stakeholders appreciate this feature, whereas others are more reluctant to compare safety performance and question the added value of benchmarking their operations. It may appear to be of safety value to know if, for example, the safety performance of one's own organisation is better than the competition. However, there may be a corporate view that disproportionate resources are being employed that might be better spent elsewhere on a less well-managed safety aspect or worse from a safety viewpoint, a corporate temptation to make cost savings as the performance.

During the feedback sessions concerns were raised on different topics, including accessibility of data, reliability and validation of risk models, lack of standardisation and criteria, and lack of context information to understand the occurrence and associated risk.

In addition to stakeholder feedback, the FSS P4 project has recognised that a significant aspect of the work is to provide some leadership towards safety intelligence, i.e. it is not enough to be just responsive to user need. There is a need to offer new potential routes forward, going beyond the state-of-the-art.

4.2. Recommendations

During the development and evaluation of the early prototype Risk Observatory with stakeholders, they provided 23 recommendations, which have been reported in section 3. In addition, the following recommendations are defined by the authors. Two of these recommendations are generic, while the rest are intended to mitigate the concerns raised by the stakeholders during the evaluation sessions (see section 3). All recommendations are allocated to the FSS P4 project team. (The numbering of recommendations continues from section 3).

To the FSS P4 project partners:

24. The project team should consider software applications on the market for implementation of the Risk Observatory prototype, and assess the need and feasibility to develop specific software applications for the implementation of (specific aspects of) the Risk Observatory prototype's functionalities and design.
25. The project team is recommended to develop a strategy to interact with, complement and strengthen similar data sharing activities like the EASA big data programme for aviation safety (Data4Safety). The P4 project team should interact on a regular basis with the EASA big data programme to ensure that both activities complement each other. It will be beneficial to both programmes to exchange information on progress, use cases and development of analytical

capabilities. The FSS P4 project should avoid duplication of efforts done in similar initiatives. (Recommendation to address Concern 3 from the stakeholder evaluation).

To FSS P4 project work package 4.2 "Risk assessment within domains":

26. The project team should develop an approach to build trust in the risk models and their output used in the Risk Observatory. Therefore, the project team is recommended to address the validation and verification of the risk models applied in the Risk Observatory, especially the risk models that generate results for the risk dashboard and what-if analysis dashboards, in the further development of the Risk Observatory prototype. (Recommendation to address Concern 8 from the stakeholder evaluation).

To FSS P4 project work package 4.3 "Integrated risk assessment framework", and

To FSS P4 project work package 4.4 "Prototype risk observatory development:

27. The project team should consider to develop a method to ensure that contextual information can be maintained during data fusion and made available in the Risk Observatory's dashboards. It is recommended to demonstrate in the Risk Observatory prototype (e.g. through use cases) the way in which contextual information is available to the end user. (Recommendation related to Concern 1 and 7 from the stakeholders). In addition, the project team should consider what sort of contextual data (e.g. specific conditions and circumstances) are needed on the occurrence dashboard for the specific use cases when the dashboards are developed and implemented in the Risk Observatory prototype. (Recommendation to address Concern 7 from the stakeholder evaluation).
28. The project team should consider the development of a functionality to share validated analyses, stakeholders' safety reports, and best practices through the Risk Observatory dashboard(s). The early prototype's search dashboard could be a way to make this type of information available to the end user. (Recommendation to address Concern 1 from the stakeholder evaluation, and related to recommendation 1 from the stakeholders (section 3.3)).
29. The project team should address the data collection to populate the Risk Observatory prototype as soon as possible to ensure that the project has timely access to data needed for further development of the Risk Observatory prototype, including the demonstration of use cases. It is essential to have access to data of sufficient variety, quality and detail to demonstrate the prototype's functionalities. The project team is recommended to investigate the availability of data from different data sources. Part of that activity should be to initiate communication with project partners and stakeholders about their potential contribution of data for the prototype. (Recommendation to address Concern 2 from the stakeholder evaluation).
30. The project team shall consider the system performance of the Risk Observatory (technical) operating system as an important design factor during the functional and technical (architecture)

design, and the development and implementation of the Risk Observatory prototype. The system performance needs includes for instance short response time to user input, high throughput of data, high availability of system, fast data processing and analyses. (Recommendation to address Concern 4 and recommendation 4 from the stakeholder evaluation).

31. It is recommended to define standards, definitions and criteria for events and SPIs presented on the dashboards of the Risk Observatory prototype to assure standardization and consistency of information and data (statistics) presented. (Recommendation to address Concern 5 from the stakeholder evaluation).
32. It is recommended that the project team explains the application of unstable approach criteria to datasets of different airlines for benchmarking, addressing the advantages and pitfalls in this approach. Such an explanation should be available to the user in the Risk Observatory. (Recommendation to address Concern 6 from the stakeholder evaluation).
33. The project P4 should consider the developed success criteria and evaluation form (Appendix D and Appendix E) for the evaluation of the 'final' Risk Observatory prototype.

Stakeholders raised a concern on the effect of reporting culture of the observed statistics and trends for reported occurrences (Concern 9). This concern is considered out of scope for the P4 project team as this issue is an inherent feature of data analysis of reported occurrences.

5 REFERENCES

Ref	Name
1.	Annex 1 - Description Of Action (part A)
2.	D4.1 Risk Observatory Requirements, G. Gigante, D. Pascarella, A. Vozella (CIRA), A. Roelen, J. Verstraeten (NLR), S. Metge (Airbus), G. Greene (CAA UK), v2.0.
3.	Causal model for air transport safety. Final Report, 2 March 2009.
4.	CAA UK significant seven bow-ties. https://www.caa.co.uk/Safety-Initiatives-and-Resources/Working-with-industry/Bowtie/
5.	Methodology for Operational Risk Assessment for Aviation Organisations. Airline Risk Management Solutions Working Group. http://www.skybrary.aero/index.php/ARMS_Methodology_for_Risk_Assessment
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Appendix A REQUIREMENT MAPPING FOR EARLY PROTOTYPE

Appendix A.1 Business requirements

Table 3: Implementation of business requirements in the early prototype.

	Implemented in early prototype		
	Partly implemented in early prototype		
	Not relevant for early prototype		
ID	**Title & Description**	**Tab in early prototype**	**Implementation in early prototype and remarks**
BRQ_ 001	Scope The Risk Observatory's scope shall be the EASA Member States and the operations performed by service providers within the EASA Member States.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. Project P4 should consider occurrences in civil aviation to be mandatorily reported: Commission implementing regulation (EU) 2015/1018 of 29 June 2015 laying down a list classifying occurrences in civil aviation to be mandatorily reported according to Regulation (EU) No 376/2014 of the European Parliament and of the Council.
BRQ_ 005	Mission The Risk Observatory shall be structured and marketed to be a framework for European aviation safety data analysis.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. See BRQ_001.
BRQ_ 010	Business context The Risk Observatory shall support activities in safety management, specifically: • Safety risk management. • Hazard identification. • Safety risk assessment and mitigation. • Safety assurance. • Safety performance monitoring and measurement. • The management of change.	Not relevant for early prototype	This BRQ is too generic to be able to allocate to a page in the early prototype. The dashboards, what-if analysis dashboard and search/query dashboard support safety management activities.

BRQ_ 011	Stakeholders The Risk Observatory shall target the following stakeholder domains: • Aircraft operators. • ANSPs. • Aircraft manufacturers. • Aviation regulators. • Airports.	Not relevant for early prototype	In the early prototype there is not yet a distinction in users. The functionalities are generic for the different users in the early prototype. In later versions of the prototype the dashboards and content can be made user specific. The philosophy of Risk Observatory should be that a domain can look at another domain, but you can also see entities related to a single domain. It is important that user have access to data at a total aviation system level, not limiting to the domain they represent. The P4 project should consider the following questions: • How do we differentiate between users of different domains? • How does a user of a certain domain have access to information of other domains? • Do we split risks per domain?
BRQ_ 014	Safety data collection - sources The Risk Observatory shall be able to acquire safety data from different stakeholder domains in Europe. At least from: • Aircraft operators. • ANSPs. • Aircraft manufacturers. • Aviation regulators.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. The exact process and methods for data acquisition will depend on the architecture development and are out of scope for the early prototype.
BRQ_ 015	Safety data collection – additional sources The Risk Observatory shall be able to acquire safety data from the following additional stakeholder domains in Europe: • Airports	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_ 016	Safety data collection - automation The Risk Observatory shall be able to fuse and structure the acquired safety data. This should be done mostly automatically.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_ 017	Safety data collection - Characteristics Data going into the RO shall be: • Valid. • Complete. • Timely. • Accessible. • Secure. • Accurate.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.

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BRQ_020	Safety data type The Risk Observatory shall acquire safety data of different types. The following safety data shall be collected: • Occurrence data. • Flight data (FDM/FOQA). • Radar data. • Exposure data.	Risk dashboard	The P4 project should make sure examples of the use of all these types of data are included in the early prototype. Ideally examples of the use of a combination of different data types should be included.
BRQ_021	Safety data type The Risk Observatory shall acquire safety data of different types. The following safety data should be collected: • Identified hazards • Best practices (e.g. mitigating measures) • Safety survey data (observations from normal operations) • Aircraft manufacturers data • Aircraft maintenance data	Other	The search/query dashboard in the prototype allows the identification and documentation of hazards and best practices. This supports the first two bullets in the requirement. Safety survey data, manufacturers data and aircraft maintenance data are assumed to be part of the data repository in the background. These data are used to quantify ("feed into") SPIs that are calculated by the RO. This specific aspect is not yet demonstrated in the early prototype.
BRQ_022	Additional data type The Risk Observatory shall acquire additional data of different types. The following data should be collected: • Weather data • Infrastructural data	Risk dashboard	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources.
BRQ_030	European Safety Databases Interface The Risk Observatory shall interface with the currently most used European aviation safety databases.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_035	Taxonomy The Risk Observatory shall comply with a defined accepted taxonomy of safety information at European level (e.g. ADREP taxonomy for occurrence reporting).	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. In our examples it is probably a good idea to follow the ICAO ADREP taxonomy.
BRQ_040	Safety Risk Management – Hazard Identification The Risk Observatory shall support hazard identification in a combination of reactive, proactive and predictive methods. This includes hazards that overarch the hazards of an individual organization.	Search dashboard	This requirement is in general supported by the functionalities in the early prototype. In particular, the search/query dashboard helps to search for hazards, mitigation means, best practices etc.
BRQ_041	Safety Risk Management – Hazard Inventory The Risk Observatory shall be able to store previously identified hazards and provide a hazard inventory.	Search dashboard	The early prototype demonstrates a search/query dashboard that allows the user to document and retrieve hazards and mitigation means (best practices). A hazard inventory could be a hazard tab, with

			search function, and ability to connect to occurrence data.
BRQ_ 045	Safety Risk Management -Risk Assessment The Risk Observatory shall implement a risk framework made up of risk models for each domain, enabling quantification of accident risk and effectiveness of risk controls. The outcomes should be actionable safety information that can be used by decision makers.	Not relevant for early prototype	Risk models will be used in the prototype to prioritise risks, to quantify risks and possibly to identify mitigation actions. The first two elements are demonstrated in the risk dashboard. The latter is partly implemented in the search/query dashboard of the early prototype. The implementation of the actual risk models is not relevant for the early prototype.
BRQ_ 050	Safety Assurance -Performance Monitoring The Risk Observatory shall support Safety Performance Monitoring by: • Defining SPI, safety targets, and alerts; • Monitoring SPIs against safety targets and alerts; • Allowing historical trend analysis, including identification of positive trends and the causes of these trends; • Allowing comparison of safety performance of different service providers.	Occurrences dashboard	This requirement is implemented in the occurrences dashboard, where the user can select SPIs, and define targets/thresholds. It allows the monitoring of the trend of SPIs and a comparison against other references. There is a drill down feature to link the SPI to risk, and to the dataset of occurrences feeding the SPI. The following should be shown on the occurrences dashboard: • Trends of SPI (including visualisation of targets and alert settings); • Comparison of SPI with others (or averages); • Drill down capability for finding causes of trends.
	• Allowing correlation analysis between indicators and safety outcomes (accidents and serious incidents).	Risk dashboard	This requirement is implemented in the risk dashboard, where the user can select risks (accident categories) and define targets/ thresholds. It allows the monitoring of the trend of accident risks and a comparison against other references. There is a drill down feature to link the risk to a dataset of occurrences, or back to the occurrences dashboard for trend monitoring of individual SPIs related to that particular risk. The following should be shown on the 'risks' dashboard: • Trends of risks (including targets and alerts); • Comparison of risks with other service providers (or averages); • Drill down capability for finding causes of trends.

BRQ_ 055	Risk Observatory effectiveness evaluation The Risk Observatory shall track metrics that will enable the evaluation of its effectiveness.	Not relevant for early prototype	This is a generic requirement that is not addressed by the early prototype. The early prototype focus is on GUI and functionality development.
BRQ_ 065	Configurability The Risk Observatory shall be kept as much configurable as possible.	Not relevant for early prototype	This requirement is out of scope for the early prototype. First, the basic capabilities and functionalities need to be determined before configuration of these elements can be developed. The need to reconfigure elements is clear, however, it is less relevant for the prototype.
BRQ_ 070	Scalability The Risk Observatory shall be designed to be scalable against the growing number of users with respect to, at least: data processing times, data storage capacity, availability.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_ 075	Service Delivery The Risk Observatory shall guarantee an appropriate service level to encourage stakeholder usage and feeding.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_ 080	Trust The Risk Observatory shall provide a suitable policy of data management to be agreed with stakeholders in order to facilitate framework use and data feeding.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
BRQ_ 085	Maintenance organization The Risk Observatory shall be maintained by an independent organization of sufficient size to conduct the required tasks with an appropriate level of administrative support, including financial management.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.

Appendix A.2 User requirements

Table 4: Implementation of the user requirements in the early prototype.

	Implemented in early prototype
	Partly implemented in early prototype
	Not relevant for early prototype

ID	Title & Description	Tab in early prototype	Implementation in early prototype and remarks
URQ_ 001	Access to pan-European data The RO shall have access to all relevant data from EASA member states and service providers with EASA licenses.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. Basically, access to data shall be available via all pages in the prototype, including risk and what-if analysis dashboards. These data form the building blocks or foundation for the RO. The prototype shows aggregated data and analysis results.
URQ_ 005	Use of data The RO shall enable the use of ATC data, flight data, radar data, infrastructure data (airport runway layout, runway dimensions, ground based navigation equipment, airspace structure and classification, SID and STAR design), weather data (wind speeds, wind direction, precipitation, visibility, temperature, cloud base), aircraft system reliability data, ATM reliability data, exposure data.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. Basically, access to data shall be available via all tabs in the prototype, including risk and what-if dashboards. These data form the building blocks or foundation for the risk observatory. The risk observatory prototype shows aggregated data and analysis results.
URQ_ 010	Accommodation of occurrence types The RO shall be able to accommodate the occurrence types that are mandatory reported according to Regulation (EU) No. 376/2014. A List of occurrence types is available in Regulation (EU) No. 2015/1018.	Occurrences dashboard	The early prototype occurrences dashboard shows SPIs that can be determined/quantified based on mandatory occurrence reports. Basically, access to data on these occurrence types shall be available via all dashboards in the prototype, including risk and what-if analysis dashboards. The early prototype should show a few examples of how the occurrence types are included, e.g. by allowing the user to query or filter by occurrence type.

URQ_ 015	Access to outside data for safety investigations The RO shall enable a user from a particular organisation to get data from other organisations to support safety investigations within that particular organisation.	Occurrences dashboard	The early prototype demonstrates that a user can access data from various sources/different stakeholders. The variety of data, including data from other sources than the own organisation, can be used in a safety investigation. The early prototype could demonstrate a search/query dashboard where the user can access data from other sources, e.g. safety studies, accident reports, etc.
URQ_ 020	Access to non-technical event data The RO shall have access to information from airlines and repair stations that are not systematically recorded in technical event reports such as information on the contribution of human factors to the occurrence of the event.	Not relevant for early prototype	The early prototype demonstrates a search/query dashboard where the user can access hazards and other data from e.g. safety studies, accident reports, etc. In addition, the early prototype should demonstrate how this non-technical info becomes visible.
URQ_ 030	Aircraft data harmonisation The RO shall facilitate the harmonisation of recorded parameters across aircraft manufacturers' models and comparison of aircraft parameters managed and used by other organisations.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. Data should be harmonised in order to facilitate comparison. This is partly an organisational issue, i.e. to determine and agree the harmonisation standard amongst stakeholders.
URQ_ 035	Data completeness Data shall be complete, including contextual information for adequate analysis/understanding.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
URQ_ 040	Data structure The data shall be well structured and enable efficient querying (allowing multiple keywords to be applied simultaneously) and shall support safety argumentations and decision making.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
URQ_ 045	Information linking capability The RO shall enable linking information regarding a specific event to data from other sources to be able to understand the context of the event.	Risk dashboard	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources. This may also be relevant for the homepage (if it contains a list of recent occurrences) and the what-if analysis dashboard. In the latter, a scenario building block may be clickable to see underlying occurrences.

URQ_ 050	Identification of correlations The risk observatory shall enable identification of correlations between parameters/safety data, including correlations that were previously unknown.	Risk dashboard	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources. This is also relevant for the what-if analysis dashboard. This issue is: how to visualise these correlations?
URQ_ 055	Identification of recurring conditions The RO shall enable to extract the most recurrent operating conditions of a flight for a selected failure scenario.	Occurrences dashboard	The occurrences dashboard shows a graph ("spider plot") with ratios for contributing factors to the SPI. These risk ratios show the relative importance of a factor to the risk. It is an interpretation of the operating condition as a risk factor, and "most recurrent" is considered "most relevant to risk". This requirement is not clear: what is a recurrent operating condition? What is a failure scenario? Is this about the relative importance of a hazard in an accident scenario? Or the question which hazard is most often present or has the most impact on the outcome in an accident scenario?
URQ_ 060	Classification of input into type of operation The RO shall allow classification of input data into type of operation. Multiple ways of classification shall be possible.	Not relevant for early prototype	This is requirement is not yet specifically addressed by the early prototype. This requirement is not clear: does it mean that a user who uploads data can classify it according to operation? If so, the RO would need an upload portal. Who can classify input data? All users or only administrators?
URQ_ 065	Accident event sequences The RO shall represent accidents as a sequence of events.	Not relevant for early prototype	This requirement is not implemented at the front end of the prototype (user interface). It is expected that risk models run in the backend of the prototype, producing data and information that is presented on the dashboard. The models itself are not directly applicable or useable by the end user.
URQ_ 070	EASp accident rates The RO shall show (national) accident rates (number of accidents per flight or flight hour) for the accident categories described in the EASp: • Runway excursion • Mid-air collision • Controlled flight into terrain • Loss of control in flight • Runway incursion • Fire/smoke/fumes	Risk dashboard	This is implemented in the risk dashboard.

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URQ_ 075	Combination of data The RO shall be able to combine data from a single source and combination of sources to quantify event occurrence.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.
URQ_ 080	Automatic update of top risks The RO shall enable automatic extraction of an up-to-data periodic (e.g. weekly) list of top risks.	Risk dashboard	This requirement is implemented in the risk dashboard and in addition on the homepage where the user receives indications of the top risks (main accident categories) and changes therein. Top risks as in URQ_070 will not change much from week to week.
URQ_ 085	Show origin of risk The RO shall show the origin/causes of risk.	Risk dashboard	This requirement is implemented in the risk dashboard, where the user can drill down from accident category (risk) to contributing factors of the risk level. The early prototype shows an example of relative contribution of causal factors to the overall risk level. This will also be supported by the scenario simulation.
URQ_ 090	Show risk level RO shall calculate the (level of) risk.	Risk dashboard	The requirement is implemented in the risk dashboard.
URQ_ 095	Low risk events information The RO shall enable extraction of low probability events as well as events with low severity, i.e. 'minor' or 'major' as per CS25.1309 definitions.	Risk dashboard	The requirement is implemented in the risk dashboard, including the risk picture functionality. This requirement needs further specification. What is expected as extraction? What should be visible? Should the user be able to select/query in the database based on risk level or severity level?
URQ_ 100	Accident risk The RO shall determine risks of specific types of accident scenarios as well as overall risk.	Risk dashboard	The requirement is implemented in the risk dashboard.
URQ_ 105	Effectiveness risk control measures The RO shall: • Allow the evaluation of effectiveness of existing and proposed risk control measures. • Allow calculation of the effect of proposed risk control measures on accident risk. • Provide statistics that indicate the effectiveness of existing risk control measures.	What-if analysis dashboard	This requirement is not yet implemented in the prototype. The what-if analysis dashboard shows the effect of a change in SPI on risk. There is no clear connection (yet) to risk controls. These three bullets can be implemented using scenario models (e.g. bow-tie model).
URQ_ 110	Support prioritisation of risk mitigation actions The RO shall support prioritization of risk mitigation actions.	What-if analysis dashboard	This requirement is not fully implemented in the prototype, only a single SPI can be evaluated.

URQ_ 115	Predictive risk modelling The RO shall apply predictive/pro-active risk modelling.	What-if analysis dashboard	This is implemented in the what-if tool.
URQ_ 120	Effect on risk The RO shall enable to determine the effect on risk of a great number of parameters.	Risk dashboard	This requirement is implemented in the risk dashboard, where the user can drill down from accident category (risk) to contributing factors of the risk level. The early prototype shows an example of relative contribution of causal factors to the overall risk level. This requirement needs improvement. What is considered "great number of parameters"?
URQ_ 125	Standardised cause detection process The RO shall propose a standardized data analysis for determining causes of reported in-service events.	Not relevant for early prototype	This is requirement is not yet specifically addressed by the early prototype.
URQ_ 130	Unusual pattern alert The RO shall alert the user to unusual patterns in data to identify hazards.	Homepage	On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs. The related SPIs can be monitored with the occurrences dashboard. This information can be used to identify hazards by the subject matter expert. This requires a hazard identification page, but could also be part of the trend analysis on the dashboard, where the user gets an alert when there is an unusual pattern observed.
URQ_ 135	Wide impact hazard identification The RO shall facilitate the identification of hazards that may have a wide impact on the aviation system.	Other	The wide impact of a hazard could be determined by the relative importance to risk, i.e. the probability that the result in an accident outcome. This requires a hazard identification page.
URQ_ 145	Provide statistics of failure conditions The RO shall provide statistics that can be used to consolidate the estimated probability and safety effects of failure conditions based on real events.	Occurrences dashboard	The occurrences dashboard shows statistics, e.g. the frequency of occurrence. From the occurrences dashboard the user can drill down to the risk dashboard to determine the associated risk level ("safety effects") of the SPI ("failure condition"). The dashboard for occurrences (or SPIs) can be used to present data on probability. The safety effects of failure conditions may be best presented in a scenario simulation, qualitatively show the remaining barriers and the end state.
URQ_ 150	Quantification of SPIs The RO shall combine data to quantify Safety Performance Indicators.	Occurrences dashboard	This requirement is implemented in the occurrences dashboard, which shows the frequency of occurrence of the SPI over time. Also applies to Dashboard (risks, data + model driven) and Forecast (occurrences + risks, data + model driven), assuming the RO makes use of SPIs on these 3 tabs.

URQ_ 155	Safety barrier effectiveness • The RO shall calculate the effectiveness of safety barriers. • The RO shall be able to demonstrate at which points the accident sequence of events can be stopped. • The RO shall identify the barriers remaining after failure of a particular barrier. • The RO shall identify to which hazards the barriers are vulnerable (i.e. which hazards are able to penetrate the barriers) and what is the likelihood of barrier failure (conditional to the presence of the hazard).	What-if analysis dashboard	Although the first bullet refers to a calculation of effectiveness, a qualitative assessment of the barrier's effectiveness may be more realistic and feasible approach.
URQ_ 160	Safety performance alert The RO shall alert if safety performance (expressed as risk, overall and per accident category) is not as expected.	Homepage	On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs. In the risk dashboard the user can select a target/threshold for alerting when the risk exceeds a user defined level. Note that this refers to risk.
URQ_ 165	Event frequency alert The RO shall alert if event frequency (expressed as rate or absolute value) is not as expected.	Homepage	On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs. In the occurrences dashboard the user can select a target/threshold for alerting when the SPI frequency of occurrence exceeds a user defined level. Note that this refers to a single event frequency.
URQ_ 170	Calculate safety performance The RO shall calculate (based on past performance, desired performance as defined by the user, sample size, etc.) expected performance and associated uncertainty.	Occurrences dashboard	This requirement is implemented in the occurrence and risk dashboards where a forecast is simply assumed to be the extension of the trend line.
URQ_ 175	Dashboard The RO shall produce a safety dashboard that includes safety assurance information.	Other	This is a generic requirement that is not specifically addressed by the early prototype. In general the early prototype will have functionalities that support the requirement. Safety assurance information should be further defined, or it should be specified what additional information is needed besides the information that is already specified in the requirements in the table.

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URQ_ 180	Useable for continued airworthiness The RO shall be usable for continued airworthiness activities.	Other	This is a generic requirement that is not specifically addressed by the early prototype. In general the early prototype will have functionalities that support the requirement. This is too generic. What sort of data shall be presented to be useful for the continued airworthiness activities? When is this requirement successfully met?
URQ_ 185	Indicators of safety effect of new aircraft functionalities The RO shall provide indicators that can be used to express the safety effect of new functionalities implemented in aircraft.	Not relevant for early prototype	Basically the early prototype's occurrences dashboard would be suitable to define and monitor SPIs related to new functionalities of aircraft (provided that these can be included in the underlying risk models, and can be related to an existing or new SPI). What are the indicators of safety effects? Safety effects can be accidents, incidents, injuries, fatalities etc. New functionalities could introduce new hazards or impact existing hazards. Both mechanisms can be modelled or assessed in a scenario.
URQ_ 190	User selection of type of result User shall have the ability to select which type of result is displayed/produced by the RO. The following is at least required: • Trend (trend is variation of level over time) of SPI for individual organisation and at State level. • Trend of risk (overall and per accident scenario) for individual organisation and at State level. • Combination plot of trends (e.g. runway excursion risk and mid-air collision risk in one plot) for individual organisation and at State level. • Compare own performance (trend) with that of other aircraft operators and/or (European) average trend.	Risk dashboard	This requirement is implemented in the risk dashboard. An SPI may be directly associated with a single occurrence (first bullet).
URQ_ 191	Data retrievability The data source shall be retrievable for each operation conducted in/with the RO.	Other	This requirement is implemented by allowing the user to access the (processed) data in a tabular format for instance. The user can review the dataset associated with the occurrences and risk dashboard. For all tabs this requirement should be implemented, so that the user can always check or lookup the data source. Access to the data source itself may be excluded.

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URQ_195	Data timeliness The RO shall assure timeliness of the data.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. This user requirement may be difficult to validate if timeliness is not defined.
URQ_200	User selection of time span The user shall be able to set the time span for trend and the granularity (per year/month/week/day/hour etc.).	Occurrences dashboard	This requirement is implemented in the occurrences and risk dashboards where the user can define a time frame for the analysis. Also applies to what-if analysis dashboard. This is a general requirement that could be applied to any graph/chart produced by the RO. Additionally, the requirement may also imply that rates can be expressed in different units, e.g. per flight, per flight hour, movement etc.
URQ_205	Drill down capability The RO shall allow drill down from trend to individual occurrences.	Occurrences dashboard	The occurrences dashboard shows the trend line of an SPI. The user can drill down into the associated, underlying data for the SPI.
URQ_210	Dashboard configuration The user shall be able to configure the safety dashboard.	Not relevant for early prototype	This requirement is out of scope for the early prototype. First, the basic capabilities or functionalities need to be determined, before configuration of these elements can be developed. This requirement needs further specification: what elements should be configurable? It would be good if the early prototype shows a few options and is used to collect user feedback on the need to be configurable.
URQ_215	User defined SPIs The user shall be able to define SPIs in addition or in place of SPIs predefined by the system.	Not relevant for early prototype	This requirement is out of scope for the early prototype. First, the basic capabilities or functionalities need to be determined, before configuration of these elements can be developed.
URQ_220	Safety analysis credibility The RO shall assure the credibility of the safety analysis performed by it.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. This requirement needs further explanation. What is defined as "credibility", what criteria are used to determine the credibility "score"?
URQ_225	Desk-top computer The RO shall be accessed using a desk-top computer.	Other	This is a generic requirement that is not specifically addressed by the early prototype. The early prototype can be demonstrated on a desk-top computer/laptop.

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URQ_ 230	Protection against unauthorised access The RO shall be protected against unauthorised access.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype. Although this is not relevant for the early prototype, the early prototype demonstrates that the user is provided with a log in page for instance, and that accessibility is arranged though accounts/user groups with certain rights.
URQ_ 235	De-identified access The RO shall enable access to data stored in the European common repository but in an anonymous and de-identified manner.	Not relevant for early prototype	This is a generic requirement that is not specifically addressed by the early prototype.

Appendix A.3 System requirements

Table 5: Implementation of system requirements in early prototype.

	Implemented in early prototype
	Partly implemented in early prototype
	Not relevant for early prototype

ID	Title & Description	Tab in early prototype	Implementation in early prototype and remarks
SYS_ GEN_ 001	Representation of European aviation safety processes RO shall support the safety management processes of European aircraft operators, ANSPs, aircraft manufacturers, aviation authorities and airports. It shall implement tasks to support the following safety management activities [2]: • Safety Risk Management • Safety Assurance	Homepage	The homepage provides links to functionalities of the RO that cover this requirement. At this moment the early prototype does not have a customization per domain. The philosophy of Risk Observatory should be that a domain can look at another domain, but you can also see entities related to a single domain. It is important that user have access to data at a total aviation system level, not limiting to the domain they represent.
SYS_ GEN_ 005	RO General Inputs RO shall allow user to access and to elaborate the following: • Accident investigation data. • Mandatory reporting data. • Voluntary reporting data. • Continuing airworthiness reporting data. • Operational data (procedures, flight data, radar data, exposure data, weather data, airport infrastructure data). • Safety oversight data. • Data from audit findings/reports. • Data from regional accident and incident investigation organizations (RAIOs), etc.	Search dashboard	The search dashboard gives access to occurrence data and hazards. From the occurrences and risk dashboards access to data is also possible. Currently, the early prototype's focus is on occurrence and FDM data.
SYS_ GEN_ 010	RO General Processing RO shall implement the following processes: • Collect data. • Identify emerging risks. • Assess known and emerging risks. • Elaborate safety indicators.	Not relevant for early prototype	Data mining of emergent issues is out of scope for the early prototype.

SYS_ GEN_ 020	RO General Outputs RO shall provide to the user at least the following general outputs: • Comparative analyses. • Historical trend analyses. • Position in safety space. • Risk analysis/assessment, top risks, parameters affecting the risk. • Top hazards contributing most to accident risk (which hazard if removed results in the largest reduction of accident risk). • Top effective safety mitigation actions. • Cost benefit analysis. • Data query results.	Occurrences dashboard	Comparative analyses and historical trend analysis can be performed on the occurrences and risk dashboards. Top risks, top hazards, top effective safety mitigation actions, cost benefits are not yet implemented in the early prototype. A data query can be performed on the search dashboard. The safety space can be implemented as a risk picture (part of the risk dashboard).
SYS_ FUN_ 001	Events Management RO shall allow a privileged user (cf. SYS_QUAL_015) to manage events with following software operations: insert, updating, deleting	Not relevant for early prototype	An advanced user can define events (e.g. extract all occurrence from FDM data where approach speed was >X). In the early prototype a GUI for such advanced data manipulations or settings is not incorporated.
SYS_ FUN_ 002	Events attribute RO shall manage at least the following event attributes: • Description. • Domain. • Operation. • Status (Approved, Identified, Outdated). • Alert threshold. • Explicitly safety related (Y or N).	Not relevant for early prototype	This functionality is not foreseen in the early prototype.
SYS_ FUN_ 003	Events Analysis RO shall identify discrete events from input data and shall insert them into a database.	Not relevant for early prototype	This functionality is not foreseen in the early prototype.
SYS_ FUN_ 004	Events Alert RO shall allow to verify how many times each event has occurred in a predefined data set.	Occurrences dashboard	This functionality is demonstrated by the occurrence dashboard showing the number or frequency of events over time.
SYS_ FUN_ 005	Approval and characterization RO shall provide to the user the output of Hazard Identification for user approval, its characterization and automatic update in the system.	Not relevant for early prototype	

SYS_ FUN_ 006	Access to mandatory occurrence reports RO shall have access to a dataset of European occurrence reports originating from the mandatory reporting scheme.	Not relevant for early prototype	This requirements relates to database architecture.
SYS_ FUN_ 007	Safety occurrences RO shall allow user to manage any safety occurrences with following software operations: insert, updating, deleting.	Not relevant for early prototype	The idea is that the RO could also be used as a reporting tool to minimize the number of software tools that are in use. See SYS_ FUN_001.
SYS_ FUN_ 008	Safety occurrences attributes RO shall allow the definition of safety occurrences at least, by means the same attributes characterizing incident reports of a mandatory occurrence reporting scheme.	Not relevant for early prototype	
SYS_ FUN_ 010	Safety occurrences classification RO shall allow the allocation of safety occurrences to the proper category.	Not relevant for early prototype	
SYS_ FUN_ 015	Safety occurrences Analysis RO shall enable analysis on safety occurrences to: • Support hazard identification. • Correlate between parameters/safety data. • Identify recurring operating conditions for a certain failure scenario.	Occurrences dashboard	The contributing factors are presented in e.g. spider plots in the dashboard.
SYS_ FUN_ 020	Operations management RO shall allow the management of operation type and phase, allowing the following functions: insert, update, delete.	Not relevant for early prototype	This requirement will be available to an advanced user only, and not relevant for the early prototype.
SYS_ FUN_ 025	Operations attributes RO shall manage at least the following attributes: • Description. • Status. • Domain. • Class.	Not relevant for early prototype	
SYS_ FUN_ 030	Hazard Management RO shall allow the management of hazards allowing the following software operations: insert, update, delete, search.	Search dashboard	Submit hazard

SYS_ FUN_ 035	Hazard Identification RO shall enable hazard identification using the RO input data.	Search dashboard	The search dashboard is a supporting tool that the user can employ during hazard identification. The user can search for certain hazards or circumstances to identify hazards.
SYS_ FUN_ 040	Approval of New Hazards RO shall provide to the user the output of the hazard identification for user approval, further characterisation and automatic update in the system.	Not relevant for early prototype	
SYS_ FUN_ 045	Hazard Status RO shall track and manage at least the following hazard status (for privileged users only): • "Approved" meaning a user approved/consolidated hazard. • "Identified" meaning identified by the RO analysis but not confirmed by the user. • "Outdated".	Not relevant for early prototype	This requirement will be available to an advanced user only, and not relevant for the early prototype.
SYS_ FUN_ 050	Hazard Prioritization The RO shall assign a priority to hazards categorizing it according to risk (i.e. the severity/likelihood of its projected consequences).	Risk dashboard	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 055	Hazard attributes RO shall manage at least the following hazards attributes: description, applicability to different domains (aircraft, ANSPs, airlines, aircraft manufacturers), source, location, priority, RO shall track for each hazard the relative priority in each domain (if it is common to different domains).	Search dashboard	A subset of required attributes available in hazard log on the search dashboard.
SYS_ FUN_ 060	Risks Data Management RO shall manage risks allowing the following operations: • Calculate (for one or more hazards). • Insert new consequence of hazard. • Update. • Delete. • Search.	Other	The ability to conduct risk classification in hazard log is not foreseen in early prototype. The insert/update/delete functionalities are not yet implemented. See also SYS_ FUN_050.
SYS_ FUN_ 061	Enabling Safety Risk Assessments RO shall enable Risk Assessment on data set defined by user to identify emerging risks.	Risk dashboard	Emergent risk can be determined from the risk dashboard, if emergent risk is defined as a changing risk level.

SYS_ FUN_ 062	Risk approval RO shall provide to the user the output of Risk Assessment for user approval, further characterization and insertion in the system.	Not relevant for early prototype	
SYS_ FUN_ 065	Emerging Risk status RO shall track and manage the risk status at least: • Approved meaning a user approved/consolidated risk. • Identified meaning identified by the RO analysis but not confirmed by the user. • Outdated.	Not relevant for early prototype	
SYS_ FUN_ 070	Risk Attributes RO shall manage at least the following attributes for risks: • Description. • Status. • Likelihood. • Severity. • Referring hazard. • ICAO Classification.	Risk dashboard	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 075	Performing Safety Risk Assessment RO shall assess risks by: Evaluating the likelihood that a certain harmful scenario may occur (that the harmful consequences of hazards will materialize during aviation activities) evaluating the severity of the harmful consequences (the impact on safety it can have).	Risk dashboard	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 080	Risk probability RO shall evaluate the risk likelihood using the risk assessment framework as developed within P4 WP4.3.	Risk dashboard	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 085	Risk severity evaluation RO shall evaluate the risk severity (severity of hazard consequences).	Risk dashboard	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 090	Risk Severity Classification It shall allow user to insert, delete, update its own severity classification different from ARP4761.	Not relevant for early prototype	It is recommended to adopt a common risk classification scheme (risk matrix and definitions) in order to allow stakeholders (user) to benchmark and compare risks. Using different user-specific definitions of risk makes comparison of results on the risk dashboard impossible.
SYS_ FUN_ 105	Risk Classification RO shall allow users to classify risks according to an classification: acceptable, tolerable or intolerable.	Not relevant for early prototype	It is recommended to adopt a common risk classification scheme (risk matrix and definitions) in order to allow stakeholders (user) to benchmark and compare risks.

			Using different user-specific definitions of risk makes comparison of results on the risk dashboard impossible.
SYS_ FUN_ 110	Safety Risk Mitigation Actions management RO shall allow user to manage risk mitigation actions by at least the following software operations: • Insert a new mitigation action. • Searching among existing mitigation actions. • Updating mitigation actions. • Associating mitigation actions to risks. • Referring operations.	Search dashboard	The required operations were partly implemented in the early prototype.
SYS_ FUN_ 115	Effectiveness of mitigation actions RO shall assess the effectiveness of mitigation actions by considering all the associated risks and deriving statistics on their occurrences among accidents/incidents and safety occurrences.	What-if analysis dashboard	In the early prototype a link between mitigating actions and what-if tab is established.
SYS_ FUN_ 120	Mitigation actions priority RO shall assign priority to mitigation actions by analysing statistics relatives to their application and reduced safety occurrences.	What-if analysis dashboard	In the early prototype a link between mitigating actions and what-if tab is established.
SYS_ FUN_ 125	Cost Benefit Analysis RO shall execute at run time basic cost benefit analysis by considering the costs to put in place a mitigation action and the expected benefits over time.	Not relevant for early prototype	
SYS_ FUN_ 130	Mitigation actions attributes RO shall manage at least the following attributes on mitigation actions/best practices: • Description. • Status. • Applicable Domain. • Priority according to risk. • Referring operation. • Referring risk. • Cost. • Effect mitigation weight (mitigation on risk effect). • Actor in charge of implementing it. • Duration	Search dashboard	A subset of required attributes is available on the search dashboard.

SYS_ FUN_ 135	Risk Sensitivity Analysis The RO shall enable to determine the effect on risk of a great number of parameters, e.g. traffic growth, changes in traffic mix, changes in operation.	What-if analysis dashboard	
SYS_ FUN_ 200	SPI management RO shall manage SPIs by allowing the following software operations: • Insert a new SPI. • Update. • Delete. • Search. • Calculate SPIs.	Not relevant for early prototype	This requirement will be available to an advanced user only, and not relevant for the early prototype.
SYS_ FUN_ 205	SPIs attributes RO shall manage at least the following attributes for each SPI: • Description. • Type (Qualitative, Quantitative). • Alert threshold. • Target threshold. • Evaluation Frequency. • Related risk. • Formula (cf. SYS_FUN_215). • Status (active, outdated).	Occurrences dashboard	A subset of required attributes is available on the occurrences dashboard.
SYS_ FUN_ 210	Default SPIs RO shall implement default SPIs that monitor the risk associated with the following occurrence categories: • Runway excursion. • Mid-air collision. • Controlled flight into terrain. • Loss of control in flight. • Runway incursion. • Fire/smoke/fumes.	Occurrences dashboard	This requirement is implemented on the occurrences and risk dashboard. The early prototype only contains a limited number of default SPIs.
SYS_ FUN_ 215	SPIs definition formula RO shall allow the user to define new SPIs (different from proposed ones) with the related formula in a “metalanguage” that RO shall be able to execute.	Not relevant for early prototype	This requirement will be available to an advanced user only, and not relevant for the early prototype.
SYS_ FUN_ 220	SPIs Evaluation RO shall implement evaluation of SPIs according to the defined formula and on the defined data set and assessing: if the target values have been reached; if the alert values have been overcome.	Occurrences dashboard	Target and alert level are implemented in the occurrence dashboard.

SYS_ FUN_ 300	Historical Statistical Analysis RO shall provide the user a set of statistical functions to apply to a predefined set of data with related plots (if selected by the user)	Occurrences dashboard	Trends can be visualised in the occurrence dashboard.
SYS_ FUN_ 310	SPIs Comparison RO shall execute a comparison by SPIs on a predefined set of data with related plots (if selected by the user).	Occurrences dashboard	A “compare to” functionality is implemented in the occurrence dashboard.
SYS_ FUN_ 315	Risk Trend Analysis RO shall execute a risk trend analysis on a predefined set of data with related plots (if selected by the user).	Occurrences dashboard	Trends can be visualised in the occurrence dashboard.
SYS_ FUN_ 320	Predefined set of data RO shall allow the user to identify the set of data to which to apply analysis according to different level of aggregations. At least the following should be selectable: • Data type (accidents, incidents, safety occurrences, FDM data, radar track data, combination of data sources, etc.). • Period (from - to). • Scope. • Local (on data relative to the organization itself). • State domain (organizations in the same domain and state). • European domain (European organizations in the same domain). • State (all organizations in the state). • Europe (all organization in Europe).	Occurrences dashboard	Period and scope can be selected in the occurrence dashboard. A 'select data type option' is not foreseen.
SYS_ FUN_ 330	RO Analysis Scheduler RO shall implement an internal scheduler to allow the user to plan analysis periodically. (For each provided analysis RO shall allow the definition of a period according to which it will start its batch analysis) and plan any alert threshold (if applicable). In this case the RO shall: save the output in a report on file system, trigger the warning function if alert has been overcome.	Not relevant for early prototype	

SYS_ FUN_ 335	RO run time execution analysis RO shall allow the execution at run time of the foreseen analysis. In this case RO shall display the output and shall allow user to save a report on local file system.	Not relevant for early prototype	
SYS_ FUN_ 340	RO warning function RO shall implement a warning function triggered by the scheduler if any defined alert threshold has been exceeded. Recording warning shall be dispatched at user login and shall be always active until they are deactivated by the user.	Homepage	On the homepage the “traffic lights” represent this warning function.
SYS_ FUN_ 350	RO query RO shall allow the user: • To define and save queries. • To define the relative report format. • To export the format on file system.	Other	Print and export functionalities are implemented in the early prototype.
SYS_ FUN_ 355	Reporting RO shall provide at least the following default reports: • Trends of SPI. • Trends of risks. • Hazards. • Risks. • Mitigation Actions/Best practices. • Event occurrences.	Occurrences dashboard	
SYS_ FUN_3 60	Reporting Configuration RO shall allow the user to define its own report with existing information in RO database.	Other	An export “button” is implemented in the early prototype
SYS_ FUN_4 00	Configuration Setting RO shall provide a configuration setting function to insert its local settings.	Not relevant for early prototype	
SYS_ FUN_ 405	Logging RO shall maintain the logging of the software application.	Not relevant for early prototype	
SYS_ FUN_ 410	Query results storing RO shall save the results of every user query on the databases.	Not relevant for early prototype	
SYS_ QUAL_ 001	User id and password RO shall allow the access to its functionalities by user id and password.	Homepage	A login page is developed in the early prototype.

SYS_ QUAL_ 005	User and password management RO shall manage the user with at least the following attributes: • Id. • Password. • Domain. • Profile. • Status.	Homepage	A login page is developed in the early prototype. In the early prototype there is no differentiation between domains for the login and homepage yet.
SYS_ QUAL_ 010	Password Management RO shall implement mechanisms to manage passwords.	Homepage	A login page is developed in the early prototype.
SYS_ QUAL_ 015	User Profiling RO shall manage the user profiling by allowing the user to define profile, selecting the level of data access and the kind of functionalities (analysis, reporting, entities, …).	Not relevant for early prototype	In the early prototype there is no differentiation between domains and types of users.
SYS_ QUAL_ 020	User Profile RO has to manage user profiles to access data and functionalities. Profiles can be defined: • Local Level: accessing only to its own data. • State Domain Level: accessing to data relative to state organizations in the same domain without knowing the organization source. • European domain level: accessing to data relative to European organizations in the same domain without knowing the organization source. • State level: accessing to data relative to state organizations also in different domains without knowing the organization source. • European level: accessing to data relative to European organizations also in different domains without knowing the organization source. • State Aviation authorities level: accessing to overall data for the belonging state. • European Aviation authorities level: accessing to overall data in Europe.	Not relevant for early prototype	In the early prototype there is no differentiation between domains and types of users.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

SYS_ QUAL_ 050	Safety Database RO Architecture shall be designed to provide a web server application with at least these three kind of databases to query: • Local database with user local settings (configuration, internal security). • Server databases with main RO data entities. • External databases (with accidents, incidents, FDM data, radar track data, weather data, traffic data, data on airport and airspace infrastructure).	Not relevant for early prototype	This requirement refers to the architecture, and is not relevant for the early prototype.
SYS_ QUAL_ 055	Architecture RO Architecture shall be designed thinking of the following main aspects: • Extensive modularity to facilitate maintenance. • A weak coupling with user interfaces by defining format for importing and uploading information (by considering existing taxonomies like ADREP). • An accurate management of software errors. • Local changes to the RO should not require extensive redevelopment of underlying models, data query structure, etc. • An error management in I/O software operation on DB preserving the data integrity.	Not relevant for early prototype	This requirement refers to the architecture, and is not relevant for the early prototype.
SYS_ QUAL_ 060	Design/Coding RO design shall consider at least the following aspect: • Check on insert, update and delete operation to preserve the integrity of data. • Adopt and comply to coding standard to facilitate maintenance.	Not relevant for early prototype	
SYS_ QUAL_ 065	Performance RO shall guarantee response to user no later than 5 minutes. Anyway in procedures like analysis on a great set of data, RO shall warn user of the response time and as it progresses of the remaining time	Not relevant for early prototype	Note that the 5 min. requirement is considered a maximum value. From a user friendliness perspective a much quicker response time is expected.

SYS_ QUAL_ 070	User Interface RO user interface shall be designed at least by considered the following aspects: • System management aspects: entities management and local settings, importing and exporting. • Safety Management aspects: Hazard Identification Analysis, Risk Assessment, SPI trends. • Data Queries. For each Analysis if different models are foreseen the interface shall allow the choice of the model	Not relevant for early prototype	
SYS_ QUAL_ 100	RO user satisfaction RO shall allow the user to record his/her satisfaction or complain by internal mechanisms.	Homepage	A contact form is implemented in the early prototype.
SYS_ QUAL_ 105	RO quality of service RO shall calculate some SPIs related to its working: • Coverage of Classes of data. • Coverage of European organization data for domain. • Number of new identified hazards. • Number of new identified mitigation actions. • Number of signalled faults in a year.	Not relevant for early prototype	

Appendix A.4 Requirements applicable to homepage

Table 6: List of identified requirements applicable to the homepage.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
URQ_130	Unusual pattern alert The RO shall alert the user to unusual patterns in data to identify hazards.	On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs. The related SPIs can be monitored with the occurrences dashboard. This information can be used to identify hazards by the subject matter expert. This requires a hazard identification page, but could also be part of the trend analysis on the dashboard, where the user gets an alert when there is an unusual pattern observed.
SYS_GEN_001	Representation of European aviation safety processes RO shall support the safety management processes of European aircraft operators, ANSPs, aircraft manufacturers, aviation authorities and airports. It shall implement tasks to support the following safety management activities [2]: • Safety Risk Management • Safety Assurance	The homepage provides links to functionalities of the RO that cover this requirement. At this moment the early prototype does not have a customization per domain.
SYS_FUN_340	RO warning function RO shall implement a warning function triggered by the scheduler if any defined alert threshold has been exceeded. Recording warning shall be dispatched at user login and shall be always active until they are deactivated by the user.	On the homepage the “traffic lights” represent this warning function.
SYS_QUAL_001	User id and Password RO shall allow the access to its functionalities by user id and password.	A login page is developed in the early prototype.
SYS_QUAL_005	User and Password Management RO shall manage the user with at least the following attributes: Id; Password; Domain; Profile; Status.	A login page is developed in the early prototype. In the early prototype there is no differentiation between domains for the login and homepage yet.
SYS_QUAL_010	Password Management RO shall implement mechanisms to manage passwords.	A login page is developed in the early prototype
SYS_QUAL_100	RO user satisfaction RO shall allow the user to record his/her satisfaction or complain by internal mechanisms.	A contact form is implemented in the early prototype.

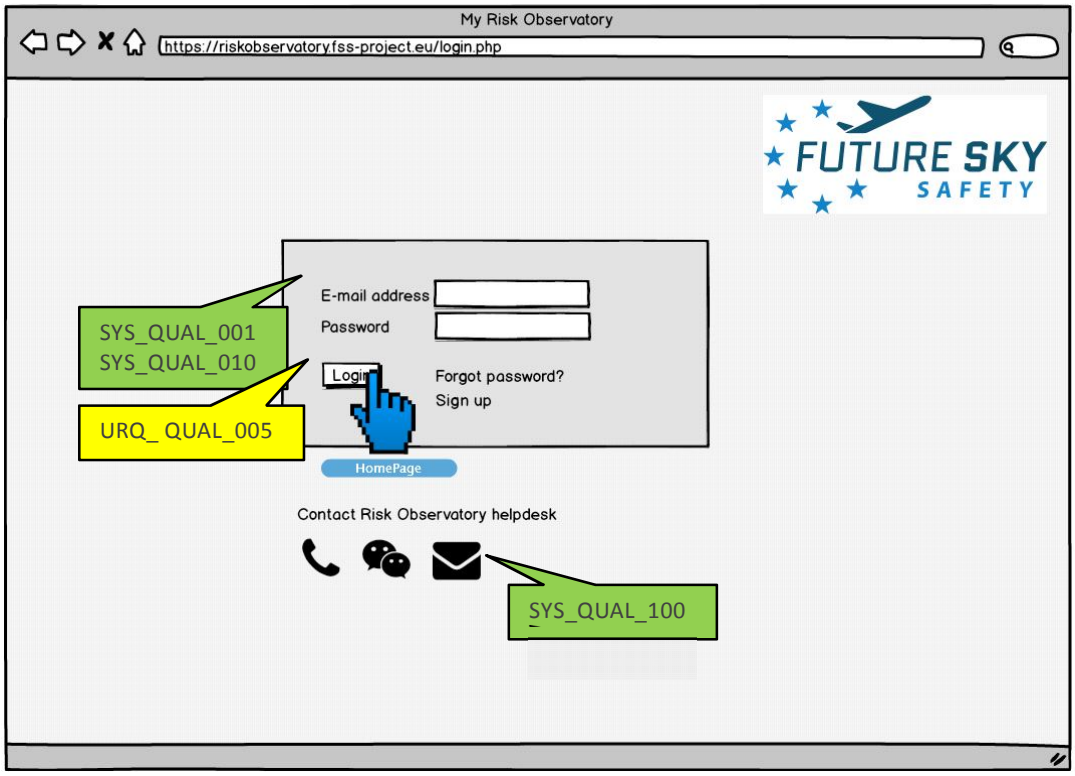


Figure 8: Screenshot of login page with requirements allocation.

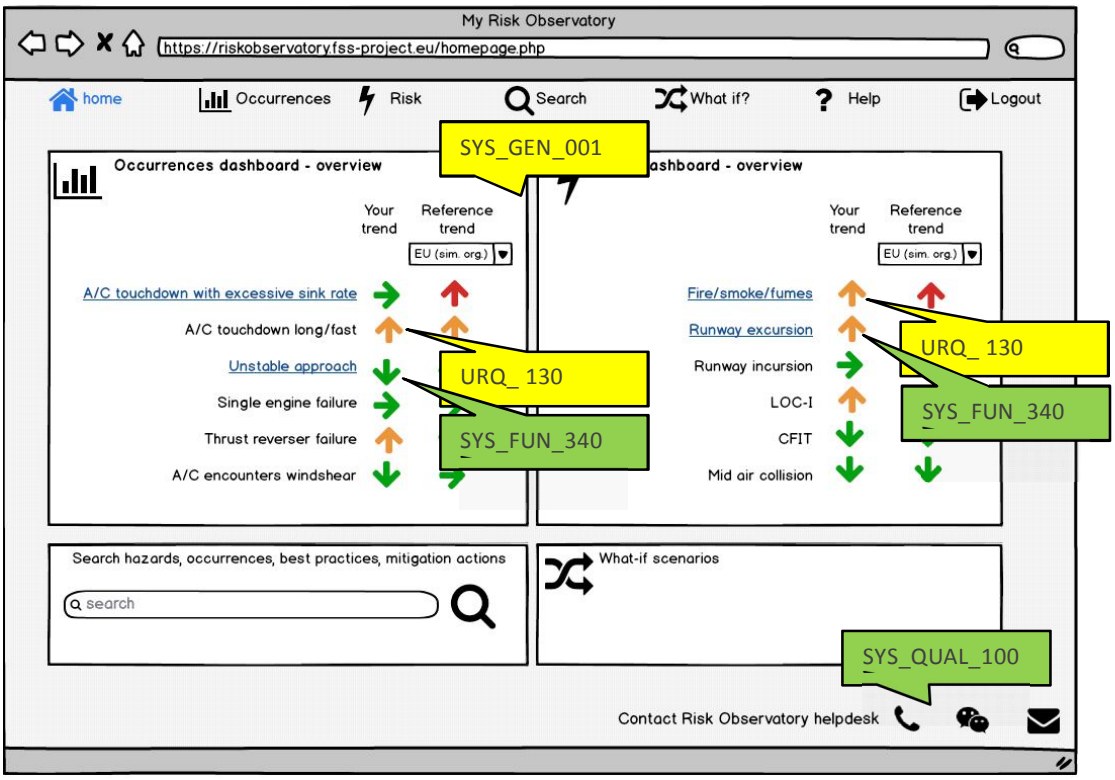


Figure 9: Screenshot of homepage with requirements allocation.

Appendix A.5 Requirements applicable to the occurrences dashboard

Table 7: List of identified requirements applicable to the occurrences dashboard.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
BRQ_ 050	Safety Assurance -Performance Monitoring The Risk Observatory shall support Safety Performance Monitoring by: • Defining SPI, safety targets, and alerts; • Monitoring SPIs against safety targets and alerts; • Allowing historical trend analysis, including identification of positive trends and the causes of these trends; • Allowing comparison of safety performance of different service providers.	This requirement is implemented in the occurrences dashboard, where the user can select SPIs, and define targets/thresholds. It allows the monitoring of the trend of SPIs and a comparison against other references. There is a drill down feature to link the SPI to risk, and to the dataset of occurrences feeding the SPI. The following should be shown on the occurrences dashboard: • Trends of SPI (including visualisation of targets and alert settings); • Comparison of SPI with others (or averages); • Drill down capability for finding causes of trends.
URQ_ 010	Accommodation of occurrence types The RO shall be able to accommodate the occurrence types that are mandatory reported according to Regulation (EU) No. 376/2014. A List of occurrence types is available in Regulation (EU) No. 2015/1018.	The early prototype occurrences dashboard shows SPIs that can be determined/quantified based on mandatory occurrence reports. Basically, access to data on these occurrence types shall be available via all pages in the prototype, including risk and what-if analysis dashboards. The early prototype should show a few examples of how the occurrence types are included, e.g. by allowing the user to query or filter by occurrence type.
URQ_ 015	Access to outside data for safety investigations The RO shall enable a user from a particular organisation to get data from other organisations to support safety investigations within that particular organisation.	The early prototype demonstrates that a user can access data from various sources/different stakeholders. The variety of data, including data from other sources than the own organisation, can be used in a safety investigation. The early prototype could demonstrate a search/query dashboard where the user can access data from other sources, e.g. safety studies, accident reports, etc.

URQ_ 055	Identification of recurring conditions The RO shall enable to extract the most recurrent operating conditions of a flight for a selected failure scenario.	The occurrences dashboard shows a graph ("spider plot") with ratios for contributing factors to the SPI. These risk ratios show the relative importance of a factor to the risk. It is an interpretation of the operating condition as a risk factor, and "most recurrent" is considered "most relevant to risk". This requirement is not clear: what is a recurrent operating condition? What is a failure scenario? Is this about the relative importance of a hazard in an accident scenario? Or the question which hazard is most often present or has the most impact on the outcome in an accident scenario?
URQ_ 145	Provide statistics of failure conditions The RO shall provide statistics that can be used to consolidate the estimated probability and safety effects of failure conditions based on real events.	The occurrences dashboard shows statistics, e.g. the frequency of occurrence. From the occurrences dashboard the user can drill down to the risk dashboard to determine the associated risk level ("safety effects") of the SPI ("failure condition"). The dashboard for occurrences (or SPIs) can be used to present data on probability. The safety effects of failure conditions may be best presented in a scenario simulation, qualitatively show the remaining barriers and the end state.
URQ_ 150	Quantification of SPIs The RO shall combine data to quantify Safety Performance Indicators.	This requirement is implemented in the occurrences dashboard, which shows the frequency of occurrence of the SPI over time. Also applies to Dashboard (risks, data + model driven) and Forecast (occurrences + risks, data + model driven), assuming the RO makes use of SPIs on these 3 tabs.
URQ_ 165	Event frequency alert The RO shall alert if event frequency (expressed as rate or absolute value) is not as expected.	In the occurrences dashboard the user can select a target/threshold for alerting when the SPI frequency of occurrence exceeds a user defined level. Note that this refers to a single event frequency. On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs.
URQ_ 170	Calculate safety performance The RO shall calculate (based on past performance, desired performance as defined by the user, sample size, etc.) expected performance and associated uncertainty.	This requirement is implemented in the occurrence and risk dashboards where a forecast is (in the early prototype version) simply assumed to be the extension of the trend line.
URQ_ 200	User selection of time span The user shall be able to set the time span for trend and the granularity (per year/month/week/day/hour etc.).	This requirement is implemented in the occurrences and risk dashboards where the user can define a time frame for the analysis. Also applies to what-if analysis dashboard. This is a general requirement that could be applied to any graph/chart produced by the RO. Additionally, the requirement may also imply that rates can be expressed in different units, e.g. per flight, per flight hour, movement etc.

URQ_205	Drill down capability The RO shall allow drill down from trend to individual occurrences.	The occurrences dashboard shows the trend line of an SPI. The user can drill down into the associated, underlying data for the SPI.
SYS_GEN_020	RO General Outputs RO shall provide to the user at least the following general outputs: • Comparative analyses. • Historical trend analyses. • Position in safety space. • Risk analysis/assessment, top risks, parameters affecting the risk. • Top hazards contributing most to accident risk (which hazard if removed results in the largest reduction of accident risk). • Top effective safety mitigation actions. • Cost benefit analysis. • Data query results.	Comparative analyses and historical trend analysis can be performed on the occurrences and risk dashboards. Top risks, top hazards, top effective safety mitigation actions, cost benefits are not yet implemented in the early prototype. A data query can be performed on the search dashboard. The safety space can be implemented as a risk picture (part of the risk dashboard).
SYS_FUN_004	Events Alert RO shall allow to verify how many times each event has occurred in a predefined data set.	
SYS_FUN_015	Safety occurrences Analysis RO shall enable analysis on safety occurrences to: • Support hazard identification. • Correlate between parameters/safety data. • Identify recurring operating conditions for a certain failure scenario.	The contributing factors are presented in e.g. spider plots in the dashboard.
SYS_FUN_205	SPIs attributes RO shall manage at least the following attributes for each SPI: • Description. • Type (Qualitative, Quantitative). • Alert threshold. • Target threshold. • Evaluation Frequency. • Related risk. • Formula (cf. SYS_FUN_215). • Status (active, outdated).	A subset of required attributes is available on the occurrences dashboard.
SYS_FUN_210	Default SPIs RO shall implement default SPIs that monitor the risk associated with the following occurrence categories: • Runway excursion. • Mid-air collision. • Controlled flight into terrain. • Loss of control in flight. • Runway incursion. • Fire/smoke/fumes.	This requirement is implemented on the occurrences and risk dashboard. The early prototype only contains a limited number of default SPIs.

SYS_ FUN_ 220	SPIs Evaluation RO shall implement evaluation of SPIs according to the defined formula and on the defined data set and assessing: if the target values have been reached; if the alert values have been overcome.	Target and alert level are implemented in the occurrence dashboard.
SYS_ FUN_ 300	Historical Statistical Analysis RO shall provide the user a set of statistical functions to apply to a predefined set of data with related plots (if selected by the user)	Trends can be visualised in the occurrence dashboard.
SYS_ FUN_ 310	SPIs Comparison RO shall execute a comparison by SPIs on a predefined set of data with related plots (if selected by the user).	A “compare to” functionality is implemented in the occurrence dashboard.
SYS_ FUN_ 315	Risk Trend Analysis RO shall execute a risk trend analysis on a predefined set of data with related plots (if selected by the user).	Trends can be visualised in the occurrence dashboard.
SYS_ FUN_ 320	Predefined set of data RO shall allow the user to identify the set of data to which to apply analysis according to different level of aggregations. At least the following should be selectable: • Data type (accidents, incidents, safety occurrences, FDM data, radar track data, combination of data sources, etc.). • Period (from - to). • Scope. • Local (on data relative to the organization itself). • State domain (organizations in the same domain and state). • European domain (European organizations in the same domain). • State (all organizations in the state). • Europe (all organization in Europe).	Period and scope can be selected in the occurrence dashboard. A 'select data type option' is not foreseen.
SYS_ FUN_ 355	Reporting RO shall provide at least the following default reports: • Trends of SPI. • Trends of risks. • Hazards. • Risks. • Mitigation Actions/Best practices. • Event occurrences.	

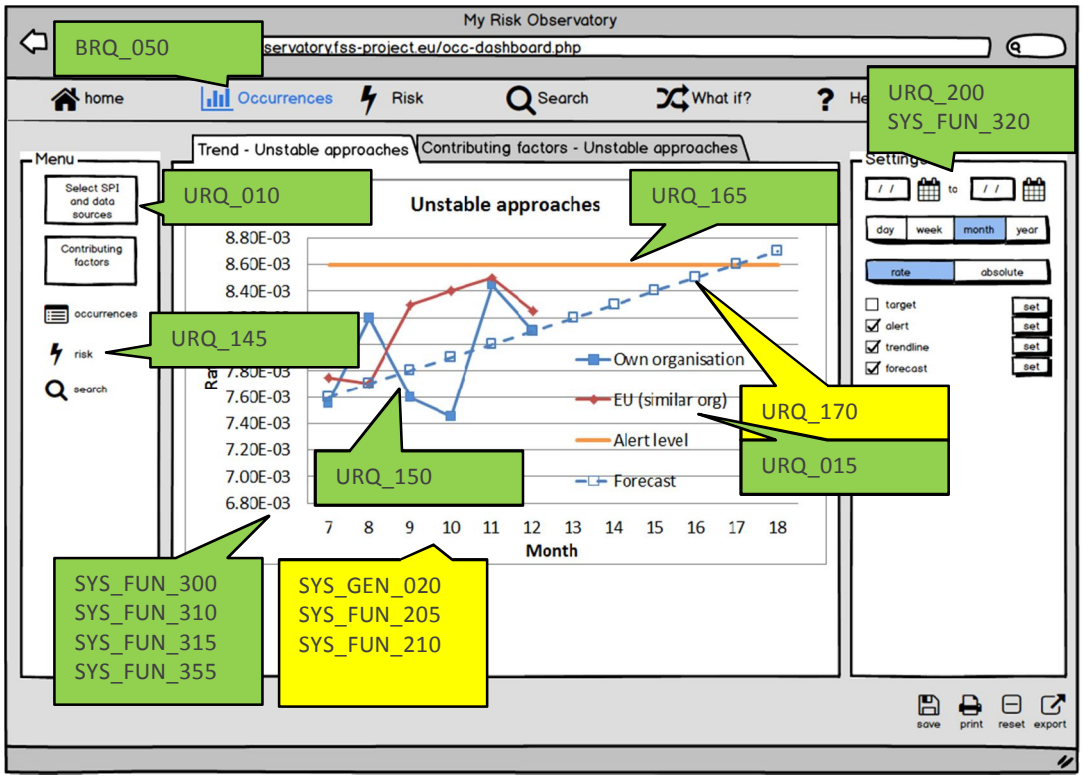


Figure 10: Screenshot of occurrences dashboard with requirements allocation.

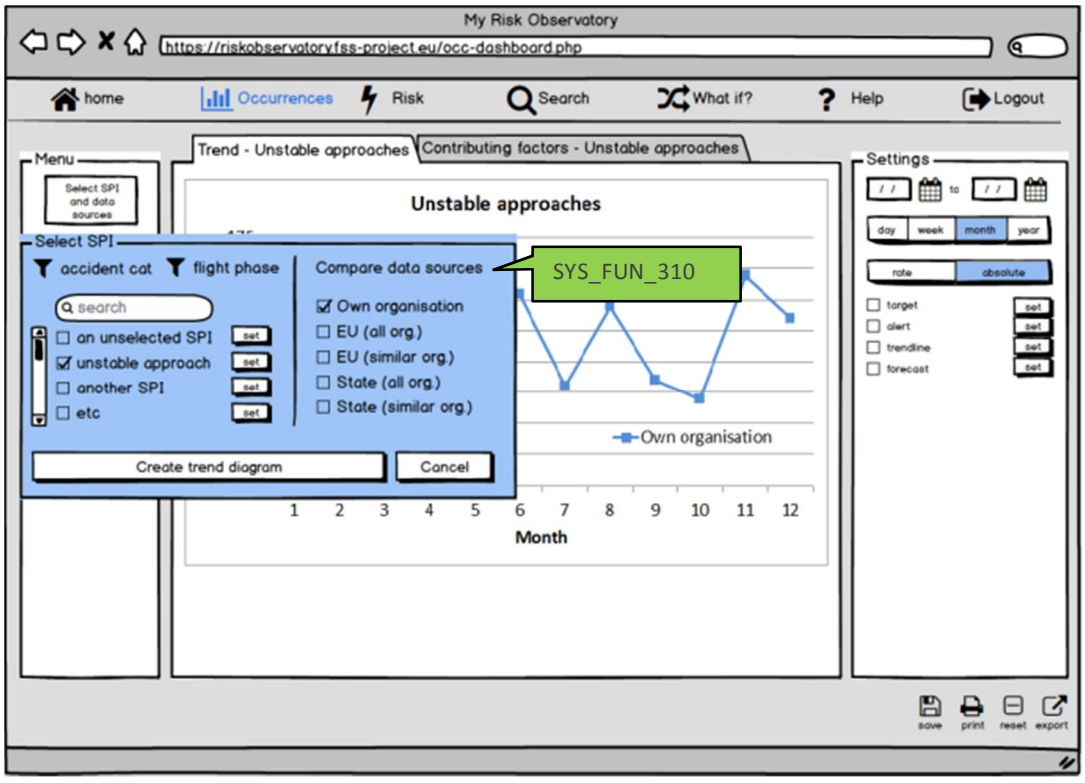


Figure 11: Screenshot 2 of occurrences dashboard with requirements allocation.

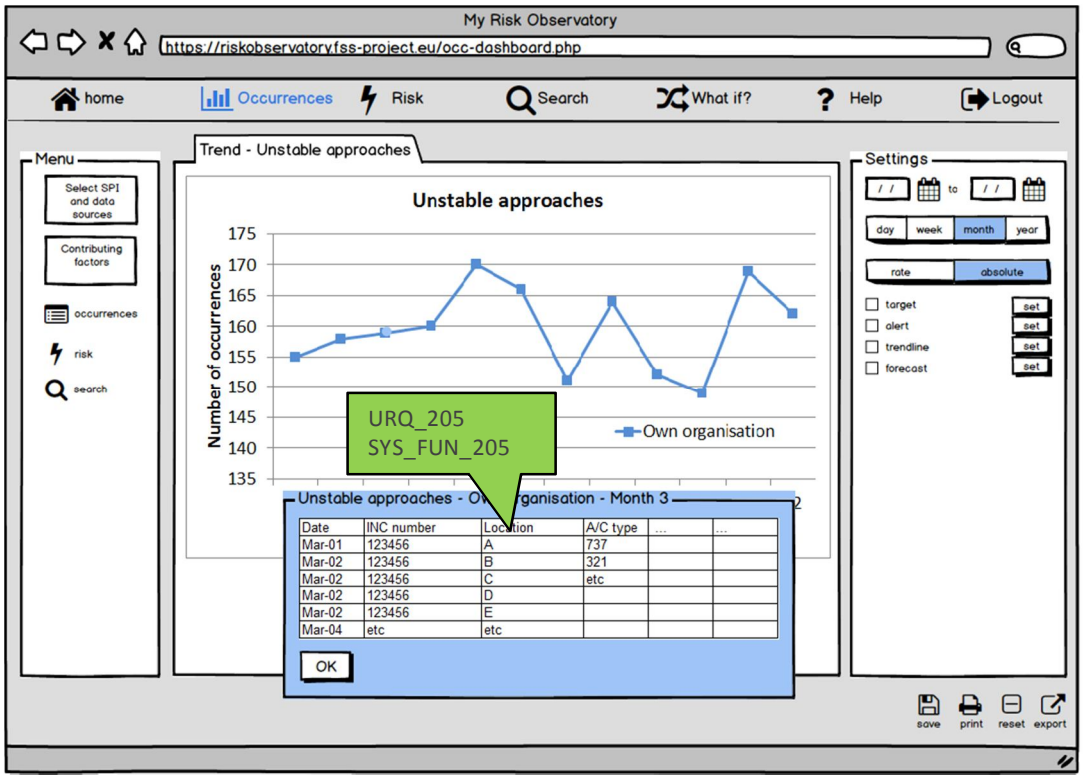


Figure 12: Screenshot 3 of occurrences dashboard with requirements allocation.

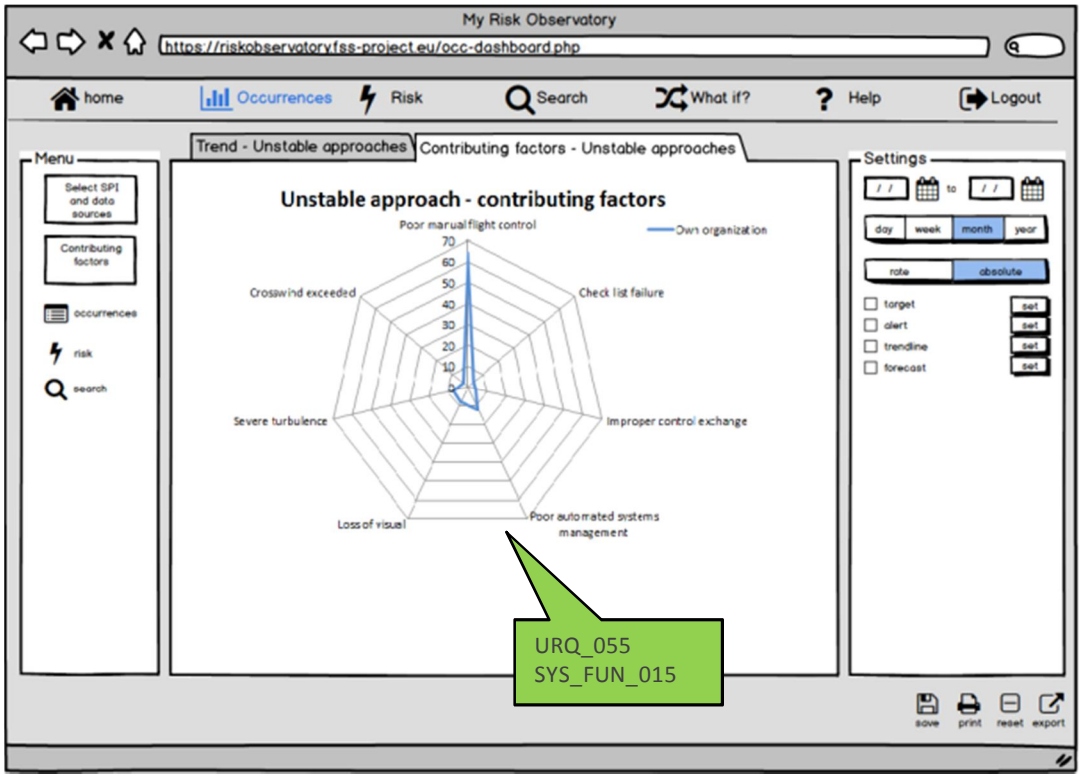


Figure 13: Screenshot 4 of occurrences dashboard with requirements allocation.

Appendix A.6 Requirements applicable to the risk dashboard

Table 8: List of identified requirements applicable to the risk dashboard.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
BRQ_020	Safety data type The Risk Observatory shall acquire safety data of different types. The following safety data shall be collected: • Occurrence data. • Flight data (FDM/FOQA). • Radar data. • Exposure data.	The P4 project should make sure examples of the use of all these types of data are included in the early prototype. Ideally examples of the use of a combination of different data types should be included.
BRQ_022	Additional data type The Risk Observatory shall acquire additional data of different types. The following data should be collected: • Weather data • Infrastructural data	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources.
BRQ_050	Safety Assurance -Performance Monitoring The Risk Observatory shall support Safety Performance Monitoring by: • Allowing correlation analysis between indicators and safety outcomes (accidents and serious incidents).	This requirement is implemented in the risk dashboard, where the user can select risks (accident categories) and define targets/ thresholds. It allows the monitoring of the trend of accident risks and a comparison against other references. There is a drill down feature to link the risk to a dataset of occurrences, or back to the occurrences dashboard for trend monitoring of individual SPIs related to that particular risk. The following should be shown on the 'risks' dashboard: • Trends of risks (including targets and alerts); • Comparison of risks with other service providers (or averages); • Drill down capability for finding causes of trends.
URQ_045	Information linking capability The RO shall enable linking information regarding a specific event to data from other sources to be able to understand the context of the event.	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources. This may also be relevant for the homepage (if it contains a list of recent occurrences) and the what-if analysis dashboard. In the latter, a scenario building block may be clickable to see underlying occurrences.

URQ_ 050	Identification of correlations The risk observatory shall enable identification of correlations between parameters/safety data, including correlations that were previously unknown.	The risk dashboard shows a graph ("spider plot") with risk ratios for runway excursion risk. These risk ratios were calculated using a combination of occurrence data, FDM data, weather data and airport data. This demonstrates that the results are obtained by data fusion and/or analysing data from different sources. This is also relevant for the What-if analysis dashboard. This issue is: how to visualise these correlations?
URQ_ 070	EASp accident rates The RO shall show (national) accident rates (number of accidents per flight or flight hour) for the accident categories described in the EASp: • Runway excursion • Mid-air collision • Controlled flight into terrain • Loss of control in flight • Runway incursion • Fire/smoke/fumes	This is implemented in the risk dashboard.
URQ_ 080	Automatic update of top risks The RO shall enable automatic extraction of an up-to-data periodic (e.g. weekly) list of top risks.	This requirement is implemented in the risk dashboard, and in addition on the homepage where the user receives indications of the top risks (main accident categories) and changes therein. Top risks as in URQ_070 will not change much from week to week.
URQ_ 085	Show origin of risk The RO shall show the origin/causes of risk.	This requirement is implemented in the risk dashboard, where the user can drill down from accident category (risk) to contributing factors of the risk level. The early prototype shows an example of relative contribution of causal factors to the overall risk level. This will also be supported by the scenario simulation.
URQ_ 090	Show risk level RO shall calculate the (level of) risk.	The requirement is implemented in the risk dashboard.
URQ_ 095	Low risk events information The RO shall enable extraction of low probability events as well as events with low severity, i.e. 'minor' or 'major' as per CS25.1309 definitions.	The requirement is implemented in the risk dashboard, including the risk picture functionality. This requirement needs further specification. What is expected as extraction? What should be visible? Should the user be able to select/query in the database based on risk level or severity level?
URQ_ 100	Accident risk The RO shall determine risks of specific types of accident scenarios as well as overall risk.	The requirement is implemented in the risk dashboard.

URQ_ 120	Effect on risk The RO shall enable to determine the effect on risk of a great number of parameters.	This requirement is implemented in the risk dashboard, where the user can drill down from accident category (risk) to contributing factors of the risk level. The early prototype shows an example of relative contribution of causal factors to the overall risk level. This requirement needs improvement. What is considered "great number of parameters"?
URQ_ 160	Safety performance alert The RO shall alert if safety performance (expressed as risk, overall and per accident category) is not as expected.	In the risk dashboard the user can select a target/threshold for alerting when the risk exceeds a user defined level. Note that this refers to risk. On the homepage the user is informed about the trend in main accident categories and/or selected set of SPIs.
URQ_ 190	User selection of type of result User shall have the ability to select which type of result is displayed/produced by the RO. The following is at least required: • Trend (trend is variation of level over time) of SPI for individual organisation and at State level. • Trend of risk (overall and per accident scenario) for individual organisation and at State level. • Combination plot of trends (e.g. runway excursion risk and mid-air collision risk in one plot) for individual organisation and at State level. • Compare own performance (trend) with that of other aircraft operators and/or (European) average trend.	This requirement is implemented in the risk dashboard. An SPI may be directly associated with a single occurrence (first bullet).
SYS_ FUN_ 050	Hazard Prioritization The RO shall assign a priority to hazards categorizing it according to risk (i.e. the severity/likelihood of its projected consequences).	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 061	Enabling Safety Risk Assessments RO shall enable Risk Assessment on data set defined by user to identify emerging risks.	Emergent risk can be determined from the risk dashboard, if emergent risk is defined as a changing risk level.
SYS_ FUN_ 070	Risk Attributes RO shall manage at least the following attributes for risks: • Description. • Status. • Likelihood. • Severity. • Referring hazard. • ICAO Classification.	The risk picture presents hazards and outcomes as risk.

SYS_ FUN_ 075	Performing Safety Risk Assessment RO shall assess risks by: Evaluating the likelihood that a certain harmful scenario may occur (that the harmful consequences of hazards will materialize during aviation activities) evaluating the severity of the harmful consequences (the impact on safety it can have).	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 080	Risk probability RO shall evaluate the risk likelihood using the risk assessment framework as developed within P4 WP4.3.	The risk picture presents hazards and outcomes as risk.
SYS_ FUN_ 085	Risk severity evaluation RO shall evaluate the risk severity (severity of hazard consequences).	The risk picture presents hazards and outcomes as risk.

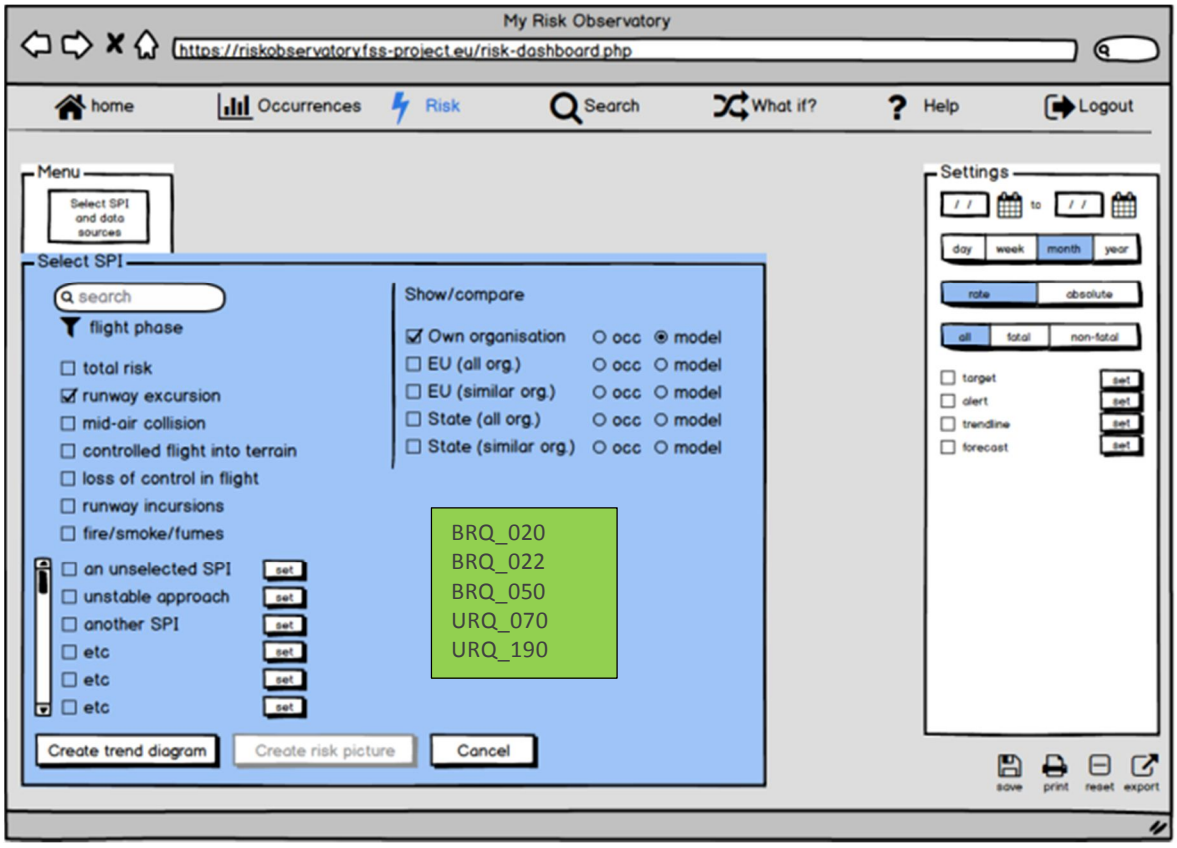


Figure 14: Screenshot of risk dashboard with requirements allocation.

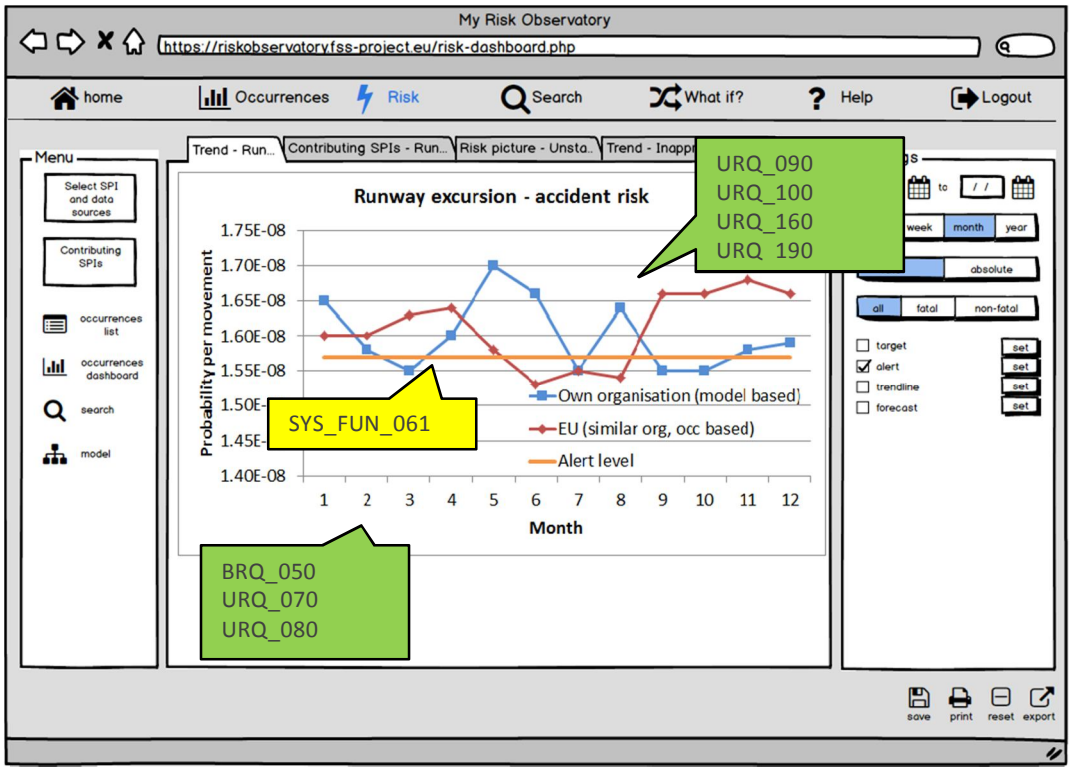


Figure 15: Screenshot 2 of risk dashboard with requirements allocation.

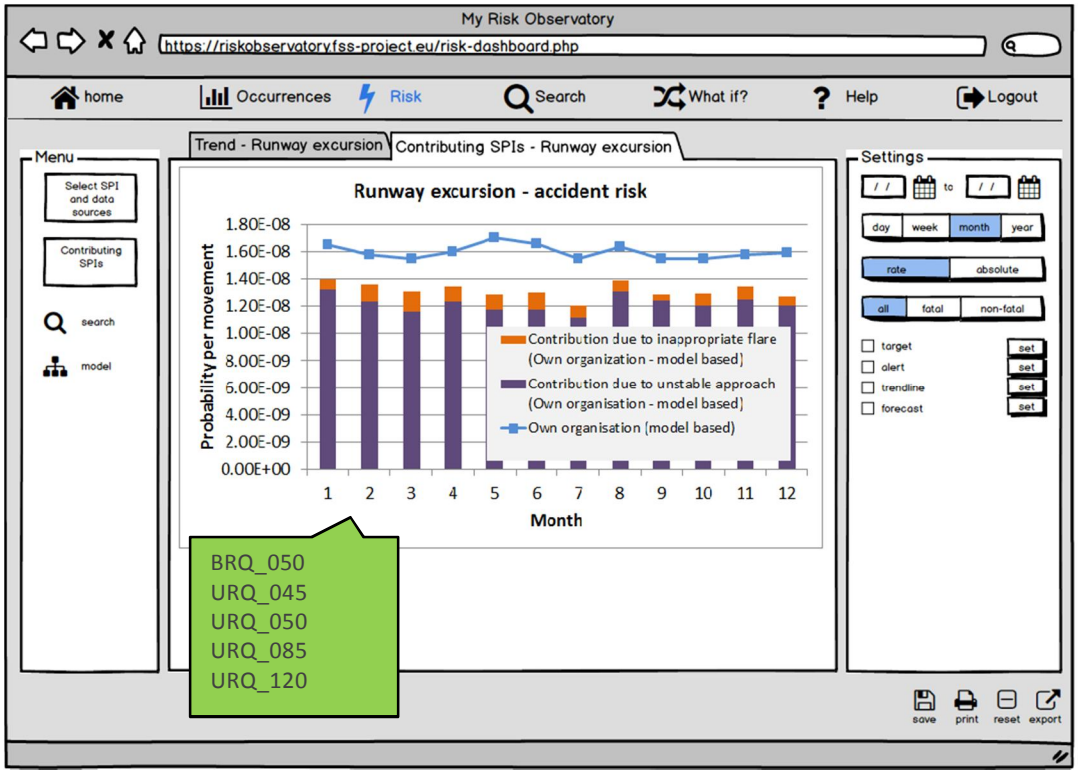


Figure 16: Screenshot 3 of risk dashboard with requirements allocation.

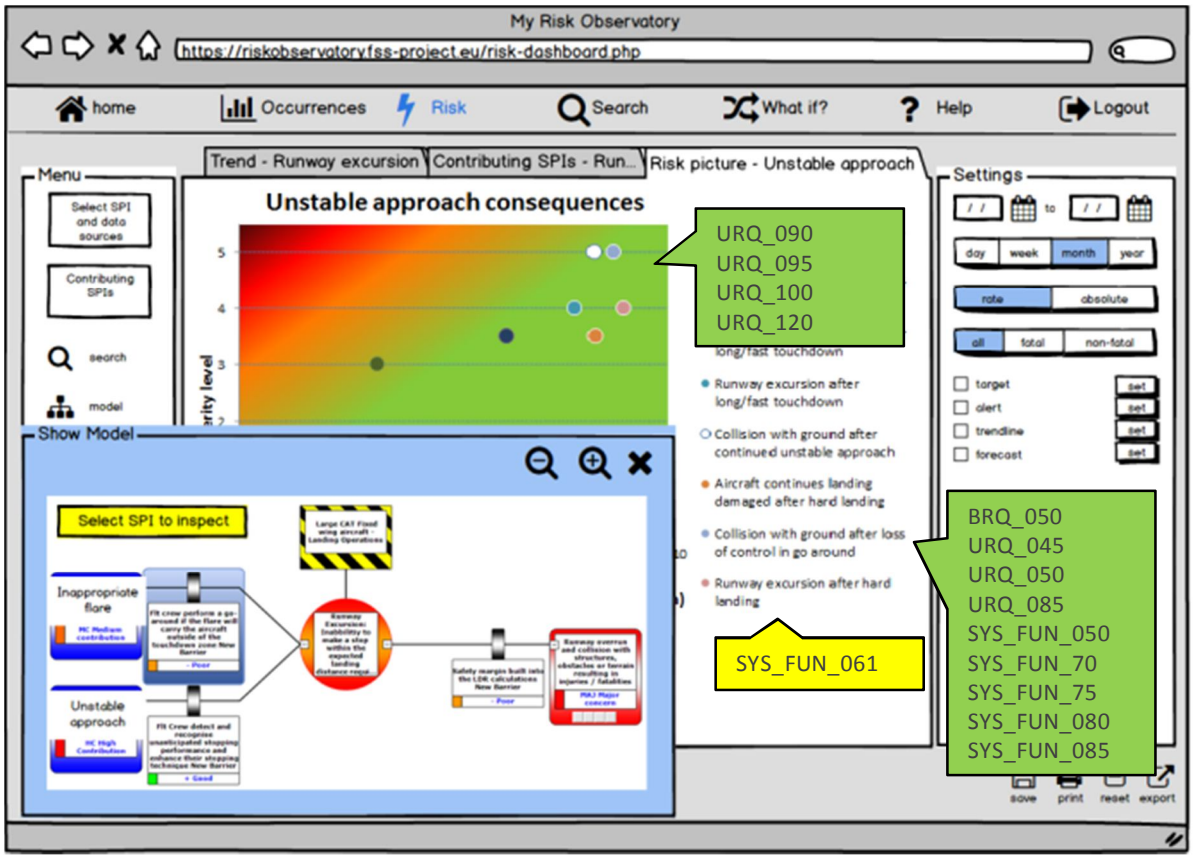


Figure 17: Screenshot 4 of risk dashboard with requirements allocation.

Appendix A.7 Requirements applicable to the search dashboard

Table 9: List of identified requirements applicable to the search dashboard.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
BRQ_040	Safety Risk Management – Hazard Identification The Risk Observatory shall support hazard identification in a combination of reactive, proactive and predictive methods. This includes hazards that overarch the hazards of an individual organization.	This requirement is in general supported by the functionalities in the early prototype. In particular, the search/query dashboard helps to search for hazards, mitigation means, best practices etc.
BRQ_041	Safety Risk Management – Hazard Inventory The Risk Observatory shall be able to store previously identified hazards and provide a hazard inventory.	The early prototype demonstrates a search/query dashboard that allows the user to document and retrieve hazards and mitigation means (best practices). A hazard inventory could be a hazard tab, with search function, and ability to connect to occurrence data.
SYS_GEN_005	RO General Inputs RO shall allow user to access and to elaborate the following: • Accident investigation data. • Mandatory reporting data. • Voluntary reporting data. • Continuing airworthiness reporting data. • Operational data (procedures, flight data, radar data, exposure data, weather data, airport infrastructure data). • Safety oversight data. • Data from audit findings/reports. • Data from regional accident and incident investigation organizations (RAIOs), etc.	The search dashboard gives access to occurrence data and hazards. From the occurrences and risk dashboards access to data is also possible. Currently, the early prototype's focus is on occurrence and FDM data.
SYS_FUN_030	Hazard Management RO shall allow the management of hazards allowing the following software operations: insert, update, delete, search.	Submit hazard
SYS_FUN_035	Hazard Identification RO shall enable hazard identification using the RO input data.	The search dashboard is a supporting tool that the user can employ during hazard identification. The user can search for certain hazards or circumstances to identify hazards. The RO does not identify hazards automatically.
SYS_FUN_055	Hazard attributes RO shall manage at least the following hazards attributes: description, applicability to different domains (aircraft, ANSPs, airlines, aircraft manufacturers), source, location, priority, RO shall track for each hazard the relative priority in each domain (if it is common to different domains).	A subset of required attributes available in hazard log on the search dashboard.

SYS_ FUN_ 110	Safety Risk Mitigation Actions management RO shall allow user to manage risk mitigation actions by at least the following software operations: • Insert a new mitigation action. • Searching among existing mitigation actions. • Updating mitigation actions. • Associating mitigation actions to risks. • Referring operations.	The required operations were partly implemented in the early prototype.
SYS_ FUN_ 130	Mitigation actions attributes RO shall manage at least the following attributes on mitigation actions/best practices: • Description. • Status. • Applicable Domain. • Priority according to risk. • Referring operation. • Referring risk. • Cost. • Effect mitigation weight (mitigation on risk effect). • Actor in charge of implementing it. • Duration	A subset of required attributes is available on the search dashboard.

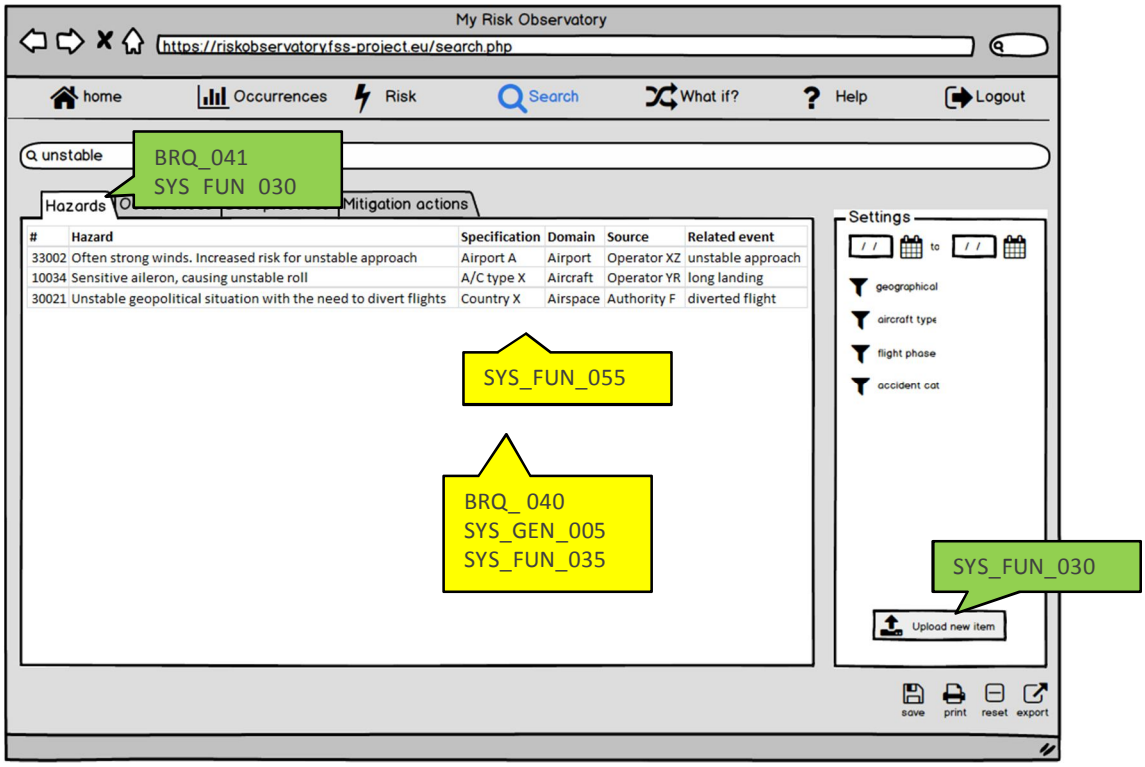


Figure 18: Screenshot of search dashboard with requirements allocation.

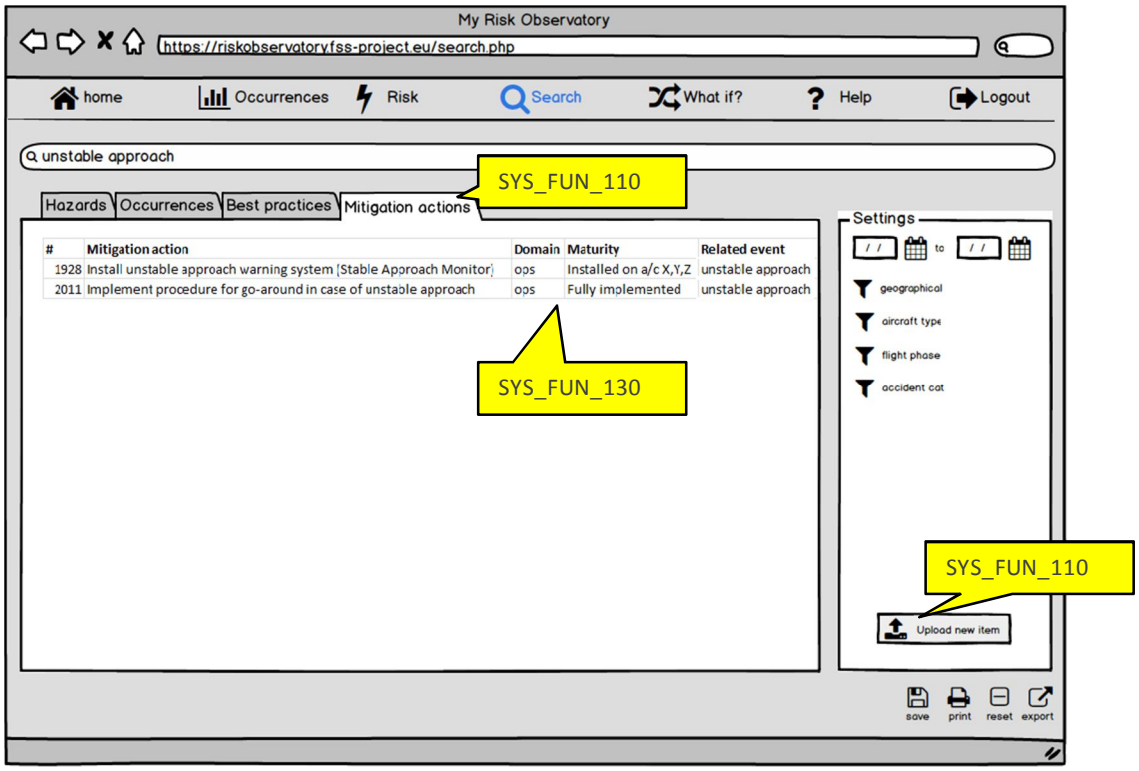


Figure 19: Screenshot 2 of search dashboard with requirements allocation.

Appendix A.8 Requirements applicable to the what-if analysis dashboard

Table 10: List of identified requirements applicable to the what-if analysis dashboard.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
URQ_105	Effectiveness risk control measures The RO shall: • Allow the evaluation of effectiveness of existing and proposed risk control measures. • Allow calculation of the effect of proposed risk control measures on accident risk. • Provide statistics that indicate the effectiveness of existing risk control measures.	This requirement is not yet implemented in the prototype. The what-if analysis dashboard shows the effect of a change in SPI on risk. There is no clear connection (yet) to risk controls. These three bullets can be implemented using scenario models (e.g. bow-tie model).
URQ_110	Support prioritisation of risk mitigation actions The RO shall support prioritization of risk mitigation actions.	This requirement is not fully implemented in the prototype, only a single SPI can be evaluated.
URQ_115	Predictive risk modelling The RO shall apply predictive/pro-active risk modelling.	This is implemented in the what-if tool.
URQ_155	Safety barrier effectiveness • The RO shall calculate the effectiveness of safety barriers. • The RO shall be able to demonstrate at which points the accident sequence of events can be stopped. • The RO shall identify the barriers remaining after failure of a particular barrier. • The RO shall identify to which hazards the barriers are vulnerable (i.e. which hazards are able to penetrate the barriers) and what is the likelihood of barrier failure (conditional to the presence of the hazard).	
SYS_FUN_115	Effectiveness of mitigation actions RO shall assess the effectiveness of mitigation actions by considering all the associated risks and deriving statistics on their occurrences among accidents/incidents and safety occurrences.	In the early prototype a link between mitigating actions and what-if tab is established.
SYS_FUN_120	Mitigation actions priority RO shall assign priority to mitigation actions by analysing statistics relatives to their application and reduced safety occurrences.	In the early prototype a link between mitigating actions and what-if tab is established.

SYS_ FUN_ 135	Risk Sensitivity Analysis The RO shall enable to determine the effect on risk of a great number of parameters, e.g. traffic growth, changes in traffic mix, changes in operation.	

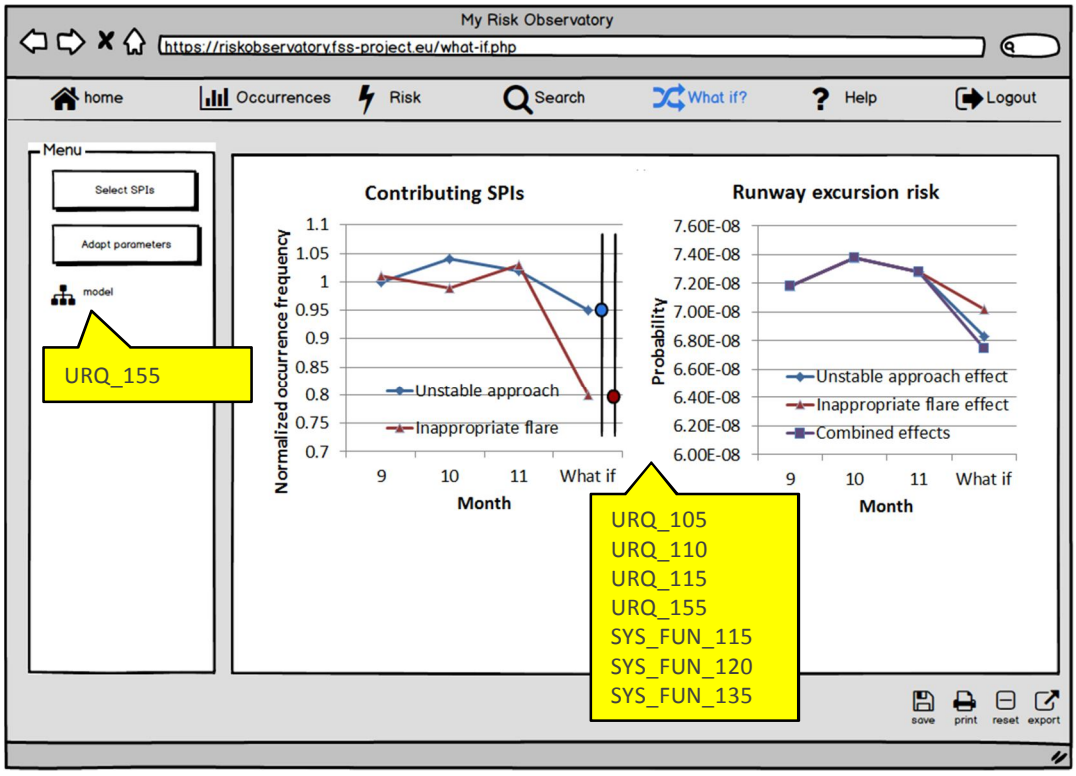


Figure 20: Screenshot of what-if analysis dashboard with requirements allocation.

Appendix A.9 Requirements for an "other" page

Table 11: List of identified requirements applicable to an "other" page.

	Implemented in early prototype	
	Partly implemented in early prototype	
ID	**Title & Description**	**Implementation in early prototype and remarks**
BRQ_ 021	Safety data type The Risk Observatory shall acquire safety data of different types. The following safety data should be collected: • Identified hazards • Best practices (e.g. mitigating measures) • Safety survey data (observations from normal operations) • Aircraft manufacturers data • Aircraft maintenance data	The search/query dashboard in the prototype allows the identification and documentation of hazards and best practices. This supports the first two bullets in the requirement. Safety survey data, manufacturers data and aircraft maintenance data are assumed to be part of the data repository in the background. These data are used to quantify ("feed into") SPIs that are calculated by the RO. This specific aspect is not yet demonstrated in the early prototype.
URQ_ 135	Wide impact hazard identification The RO shall facilitate the identification of hazards that may have a wide impact on the aviation system.	The wide impact of a hazard could be determined by the relative importance to risk, i.e. the probability that the result in an accident outcome. This requires a hazard identification page.
URQ_ 175	Dashboard The RO shall produce a safety dashboard that includes safety assurance information.	This is a generic requirement that is not specifically addressed by the early prototype. In general the early prototype will have functionalities that support the requirement. Safety assurance information should be further defined, or it should be specified what additional information is needed besides the information that is already specified in the requirements in the table.
URQ_ 180	Useable for continued airworthiness The RO shall be usable for continued airworthiness activities.	This is a generic requirement that is not specifically addressed by the early prototype. In general the early prototype will have functionalities that support the requirement. This is too generic. What sort of data shall be presented to be useful for the C.A. activities. When is this requirement successfully met?
URQ_ 191	Data retrievability The data source shall be retrievable for each operation conducted in/with the RO.	This requirement is implemented by allowing the user to access the (processed) data in a tabular format for instance. The user can review the dataset associated with the occurrences and risk dashboard. For all tabs this requirement should be implemented, so that the user can always check or lookup the data source. Access to the data source itself may be excluded.

Future Sky Safety has received funding from the EU's Horizon 2020 Research and Innovation Programme, under Grant Agreement No. 640597.

URQ_ 225	Desk-top computer The RO shall be accessed using a desk-top computer.	This is a generic requirement that is not specifically addressed by the early prototype. The early prototype can be demonstrated on a desk-top computer/laptop.
SYS_ FUN_ 060	Risks Data Management RO shall manage risks allowing the following operations: • Calculate (for one or more hazards). • Insert new consequence of hazard. • Update. • Delete. • Search.	The ability to conduct risk classification in hazard log is not foreseen in early prototype. The insert/update/delete functionalities are not yet implemented. See also SYS_ FUN_050.
SYS_ FUN_ 350	RO query RO shall allow the user: • To define and save queries. • To define the relative report format. • To export the format on file system.	Print and export functionalities are implemented in the early prototype.
SYS_ FUN_ 360	Reporting Configuration RO shall allow the user to define its own report with existing information in RO database.	An export “button” is implemented in the early prototype

Figure 21: Screenshot of search dashboard for allocation of requirements in “other” category.

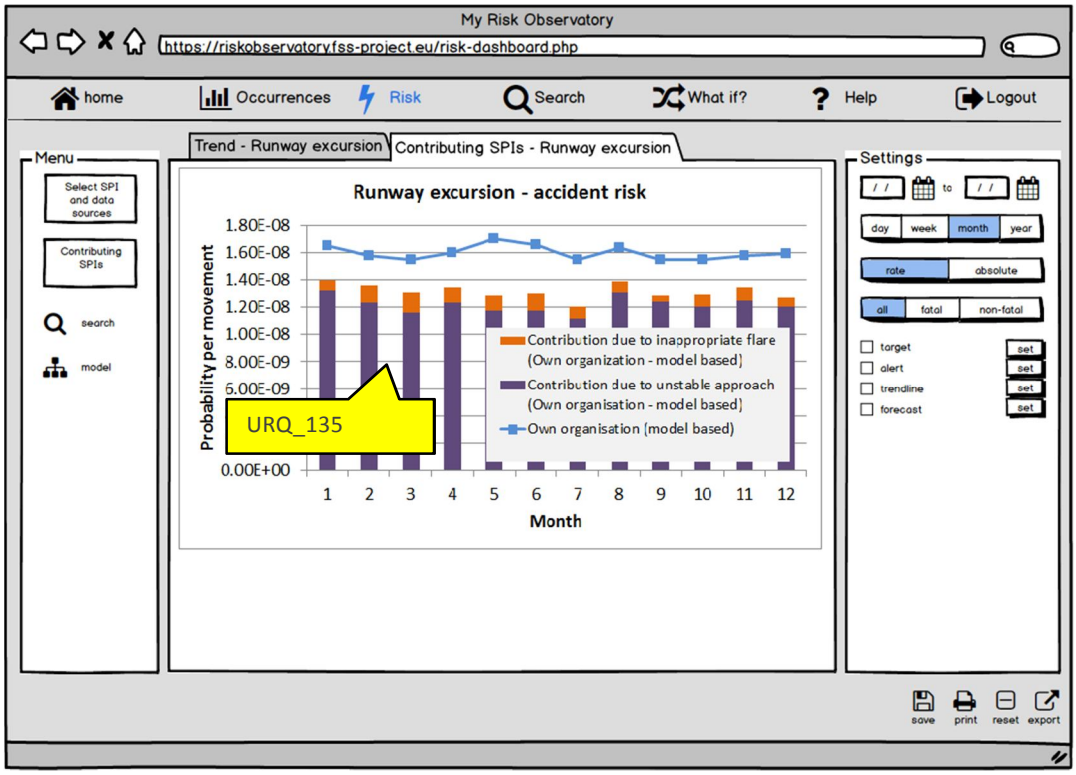


Figure 22: Screenshot of risk dashboard for allocation of requirement in "other" category.

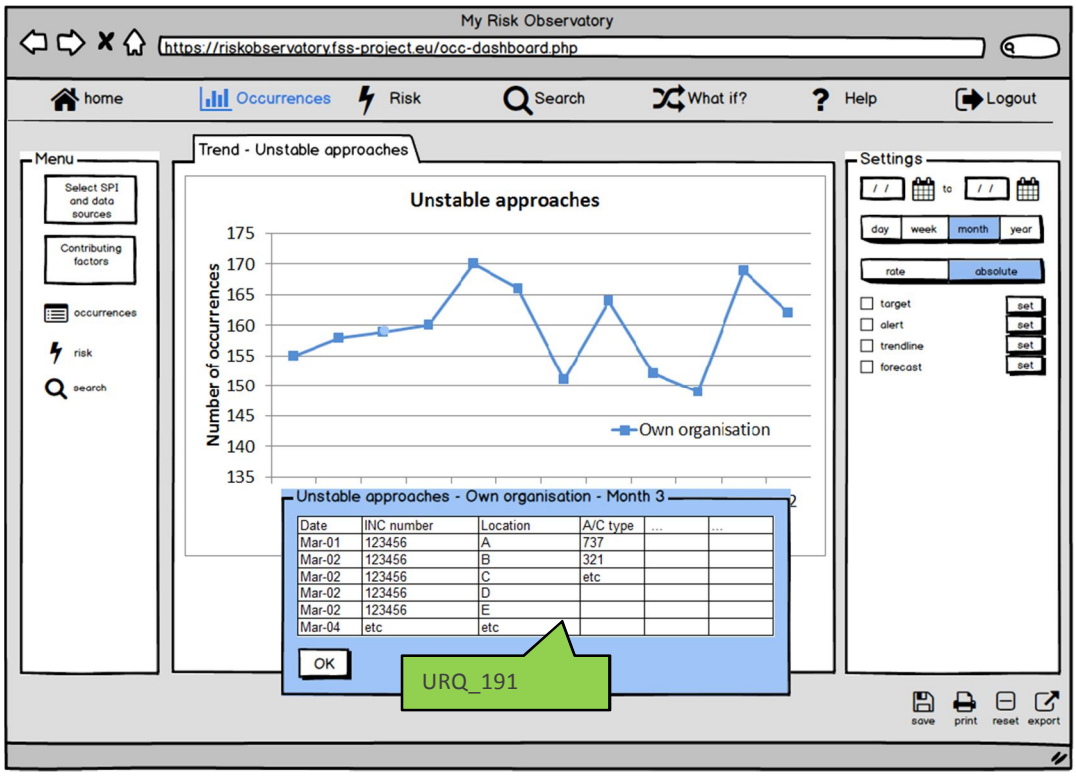
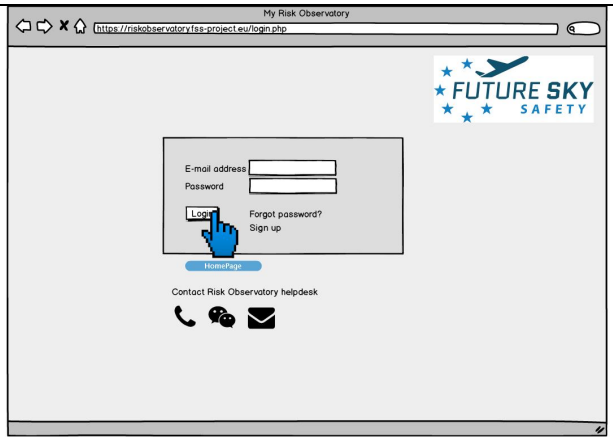


Figure 23: Screenshot of occurrences dashboard for allocation of requirement in "other" category.

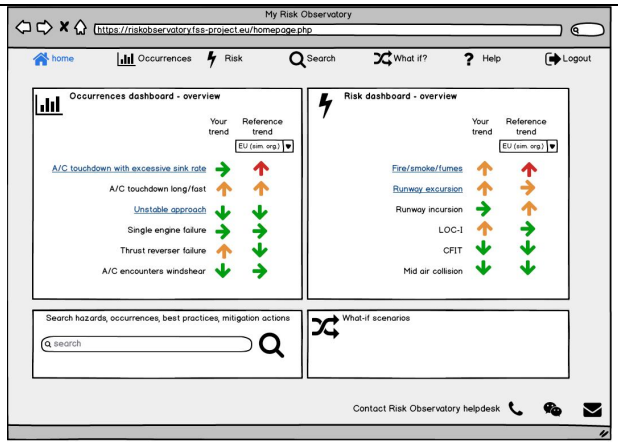
Appendix B EARLY PROTOTYPE USE CASE RUNWAY EXCURSION

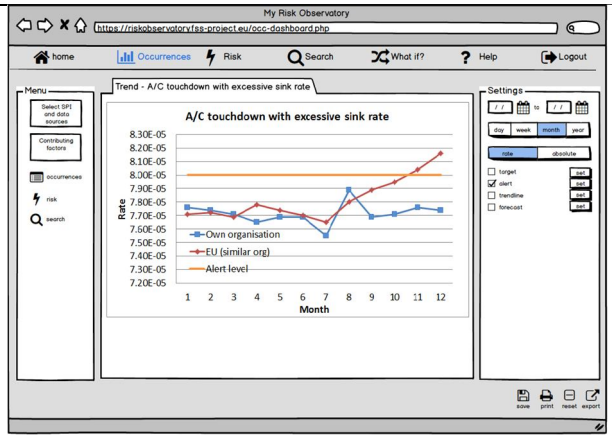
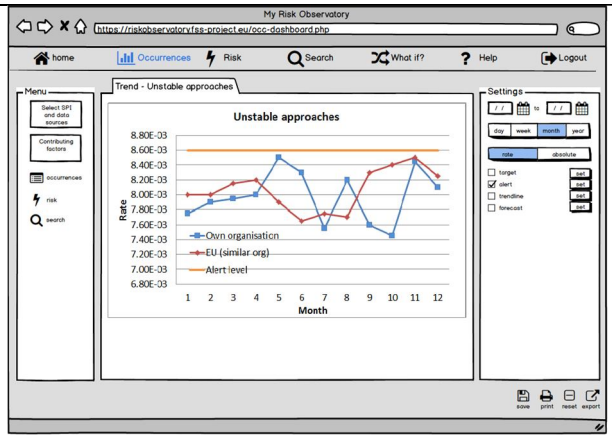
Appendix B.1 Login

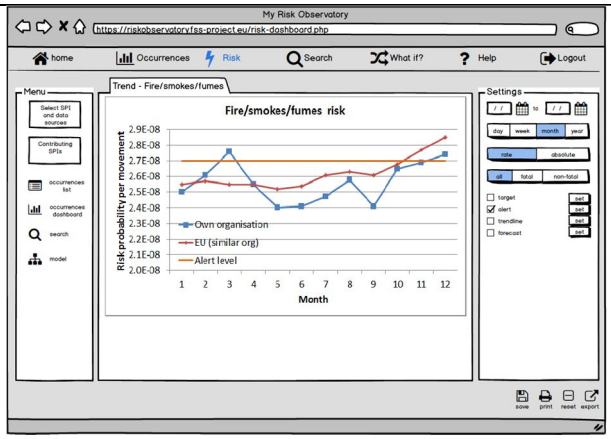
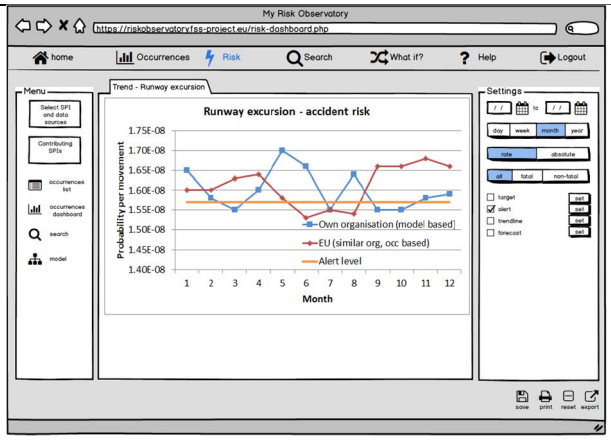
Description	*Screen dump*
• First, the user logs in. After login the user enters the Homepage.	

Appendix B.2 Homepage

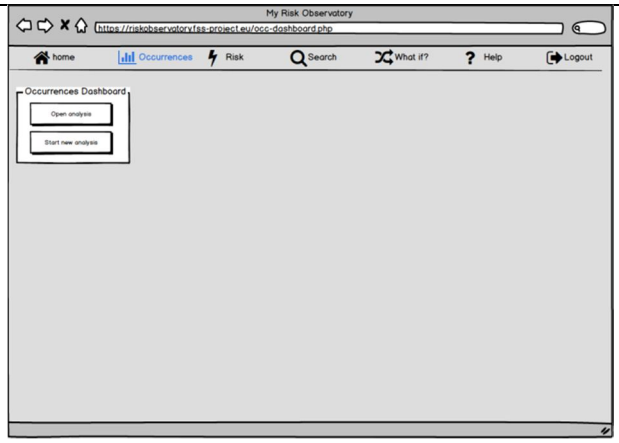
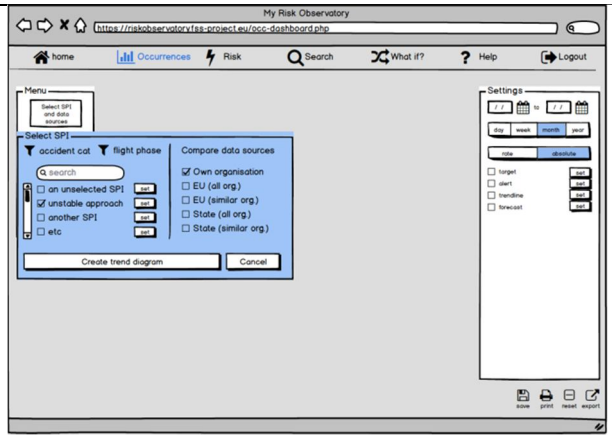
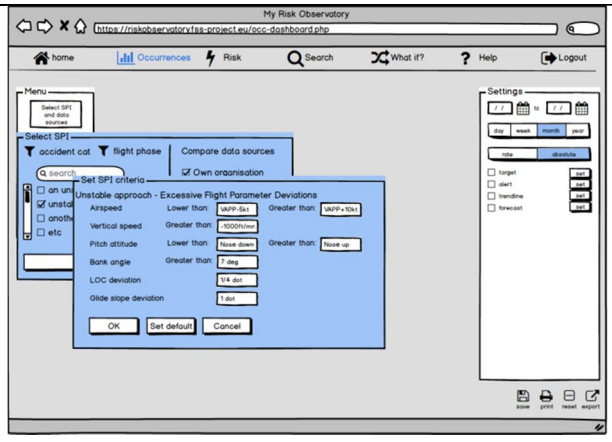
Description	*Screen dump*

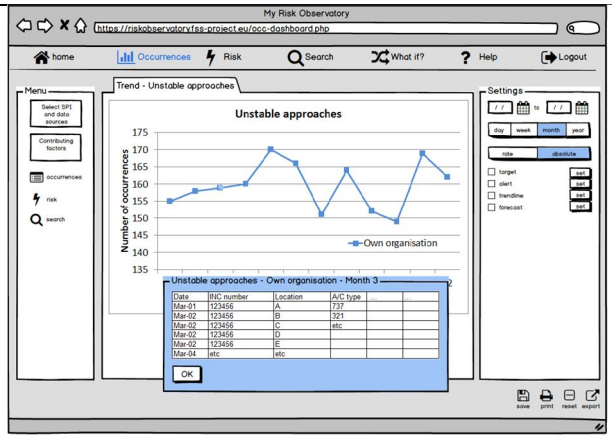
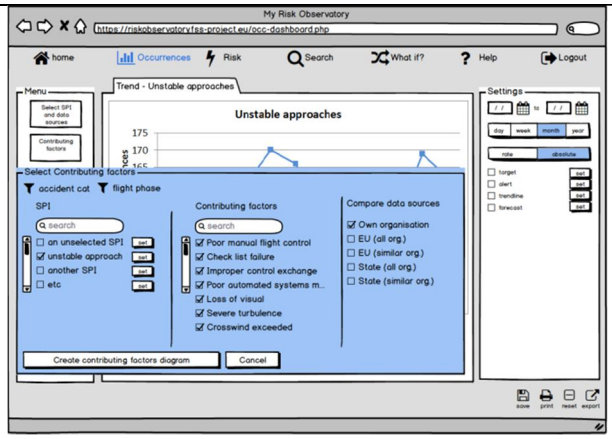
• On the Homepage the user sees an overview of the occurrences dashboard and the risk dashboard with trend indicators (green, orange, red arrows) for selected SPIs.
  ○ Green horizontal or downward arrows indicate a level trend or a declining trend.
  ○ Orange horizontal arrow indicate a level trend, but above a certain alert threshold.
  ○ An upward arrow (orange/red) indicates an increasing trend.
  ○ The user can directly access the SPIs shown on the Homepage, by clicking on the SPI name.
  This is demonstrated in this prototype by clicking on the “A/C touchdown with excessive sink rate”, “unstable approach”, “fire/smoke/fumes”, and “runway excursion” links.
• The user can select a dashboard of interest or enter a “tab” of the Risk Observatory:
  ○ Occurrences dashboard, showing information (frequencies) based on actual
	

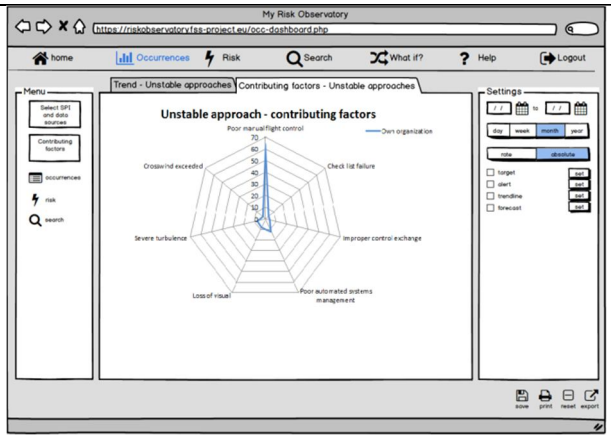
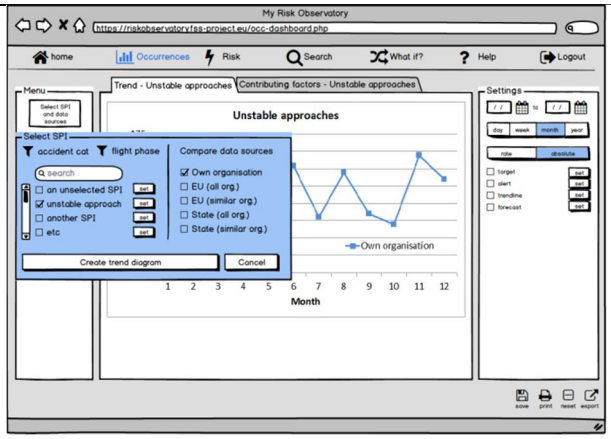
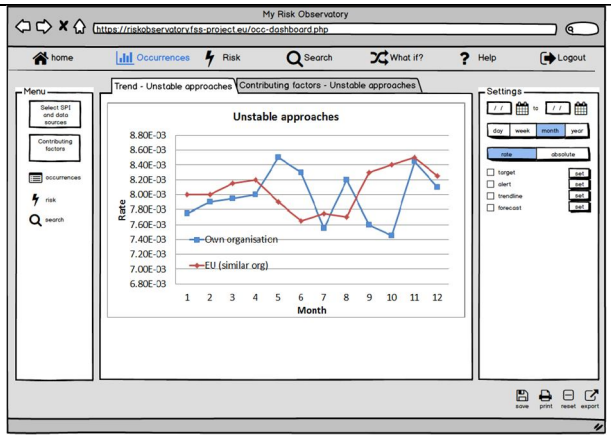
occurrences within the own and/or reference organizations. ○ Risk dashboard, showing information (frequencies, probabilities and severities) based on actual occurrences in combination with model estimates for the own and/or reference organization. ○ Search a database for occurrences, hazards, best practices, and mitigations. ○ What-if scenarios, offering the opportunity to vary SPI frequencies/probabilities and see the estimated effect on another SPI.	
• "A/C touchdown with excessive sink rate" on the Occurrences dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average, which exceeds an alert threshold and is therefore notified on the Homepage. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	
• "Unstable approach" on the Occurrences dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average, which both remain below an alert threshold. The SPI is shown on the Homepage because the user has selected it to appear on the Homepage. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	

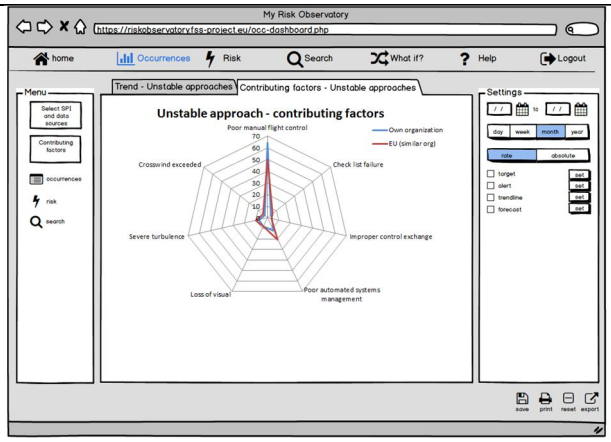
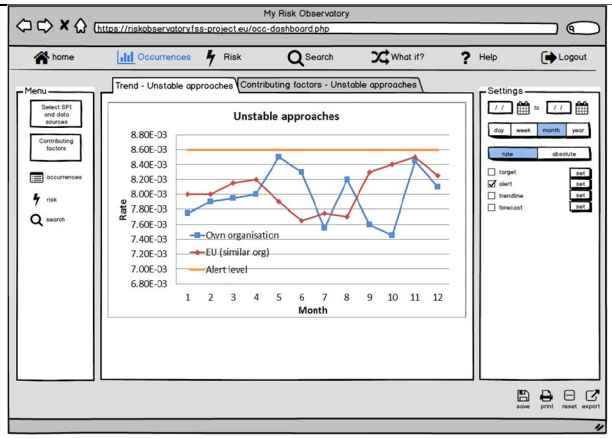
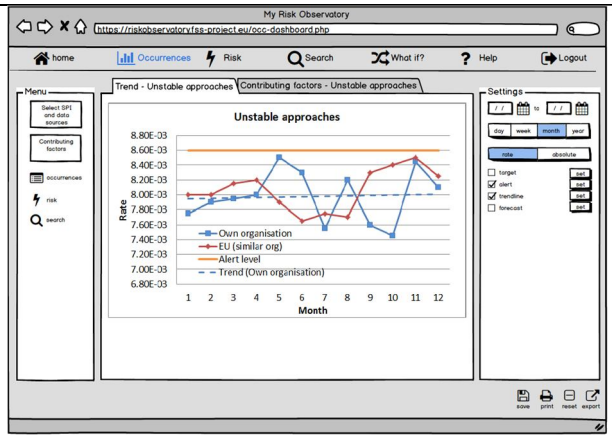
• "Fire/smoke/fumes" on the Risk dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average, which both exceed the alert threshold, though for the own organization the exceedance is less significant, resulting in the orange indicator. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	
• "Runway excursion" on the Risk dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average. The trend of the own organization has exceeded the alert level, resulting in an orange indicator. The trend of the reference data set is stable, although above the alert level. Depending on the setting of the alert, this results in a green indicator. ○ It is noted that because of lack of actual occurrence data, the trend for the own organization is based on model estimates, while for the reference data, it is based on occurrences. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	

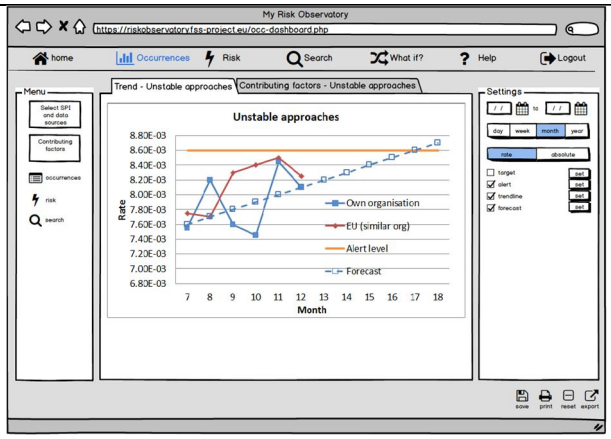
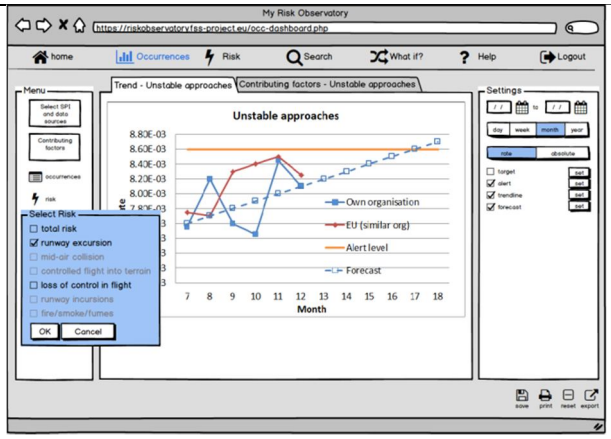
Appendix B.3 Occurrences dashboard

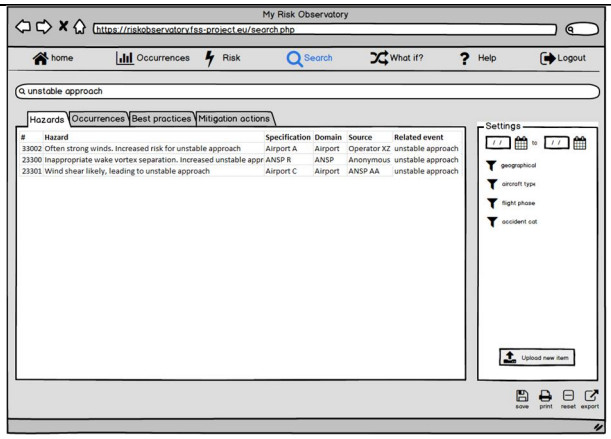
Description	*Screen dump*
• When entering the Occurrences dashboard, the user can choose to open an existing analysis, or start a new one. When entering the Occurrences dashboard from clicking the Homepage trend indicators directly, this is not applicable.	
• When starting a new analysis, the user can select an SPI from a list of SPIs and can select which data sources to compare. E.g. own organization for unstable approach.	
• It is possible to specify the criteria for an SPI, e.g., for unstable approach, by clicking the 'set' button behind the selected SPI. This facilitates users to use their own criteria and apply these to the underlying flight data. By clicking OK, the user returns to the previous screen.	

• The trend diagram of the selected SPI and data sources appears.	
• The underlying occurrence data can be shown by clicking on a data point (E.g., for month 3) or on the occurrences button on the right side of the trend diagram.	
• Contributing factors to the SPI can be selected by the button “Contributing factors”. A list of factors (as e.g., identified in research) for the selected SPI appears.	

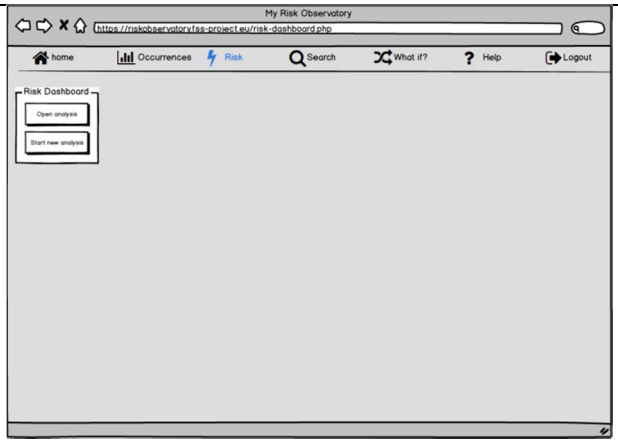
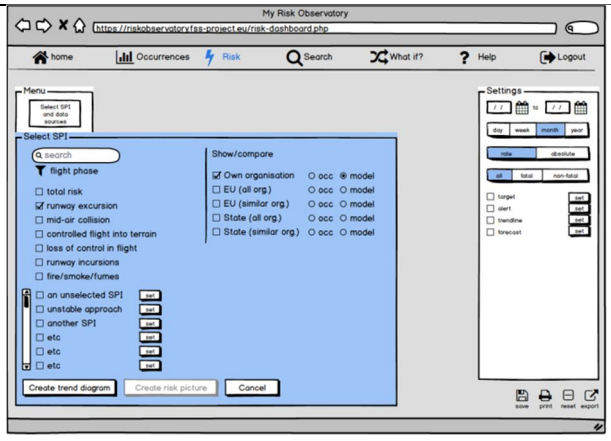
• The contributing factors diagram shows a spider plot of the relative importance of contributing factors to the SPI.	
• For comparing the data of the own organization with a reference set, click ‘Select SPI and data sources’ and select (e.g.) ‘EU (similar org.)’.	
• Now both the trend diagram and the contributing factors diagram show the data for both sources.	

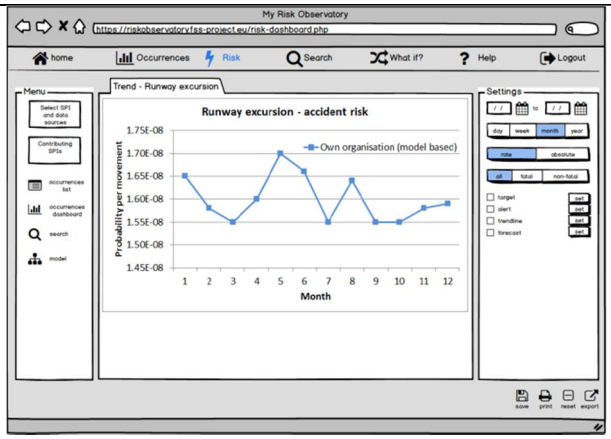
	
• The user can tick the boxes for a: target value, alert threshold, trend line and forecast in the trend diagram. This is illustrated in this prototype for the alert threshold, trend line and forecast.	
	

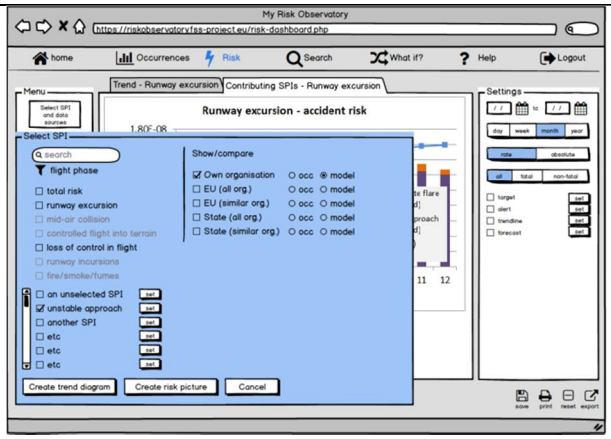
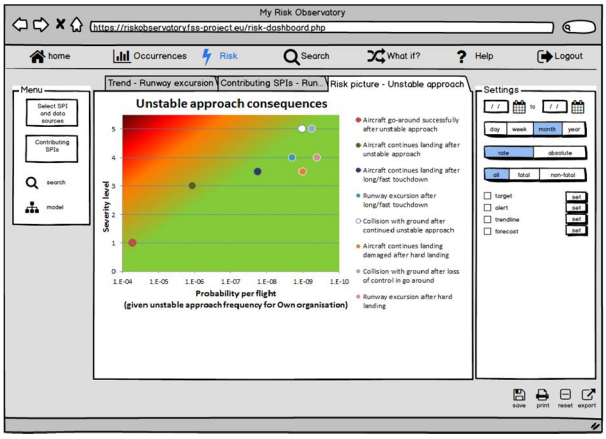
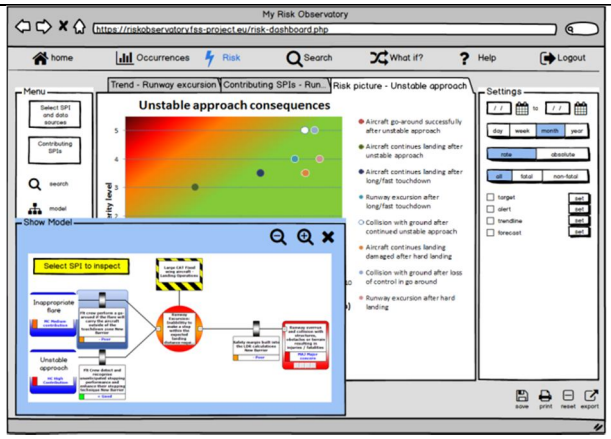
	
• The user can select a timeframe, set the metric of the frequency axis (per day, week, etc.) and y-axis (numbers or a rate). This is not yet implemented in this prototype.	
• By clicking on Risk in the left menu, the user enters the Risk dashboard to view the risk associated with the SPI. Since an SPI can be associated with more than one accident category, the user will need to select which accident categories (accident risks) will be viewed in the trend diagram on the risk dashboard. The trend diagram will show the same data sources as selected on the Occurrences dashboard. • Because the Risk dashboard was invoked from the Occurrence dashboard for Unstable approaches, both the total runway excursion accident risk (blue solid line) as well as the contribution to the risk by unstable approaches (dashed bars) is shown. • Please note that in the risk dashboard it may be possible to show a combination of occurrences based and model based information. In this case, for the own organization it is model based and for the reference EU it is occurrence based. • As for the Occurrences dashboard, there are options to set target, alert, trend line and forecast, set time frame and units of the axis. These are not yet implemented in this prototype.	
• The ‘occurrences dashboard’ button in the left menu brings you back to the Occurrences dashboard.	

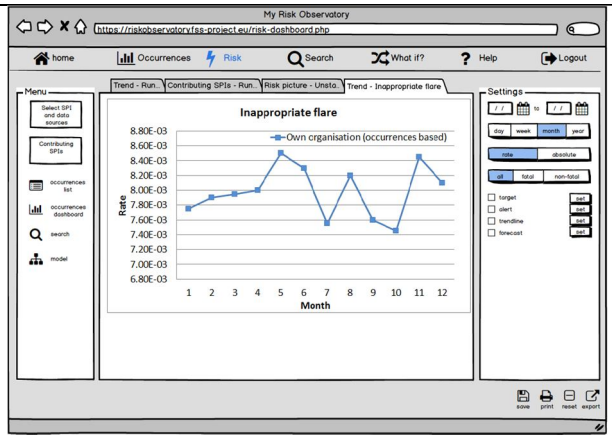
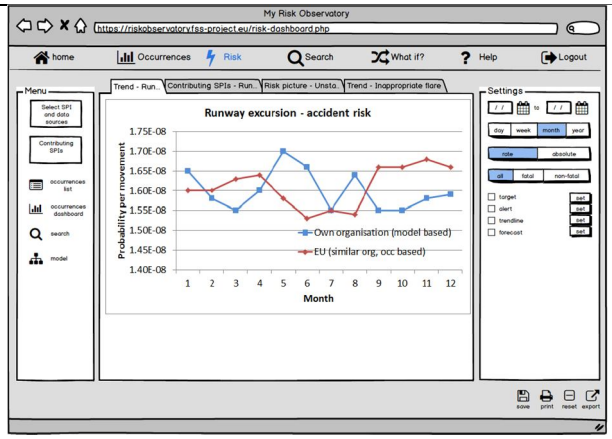
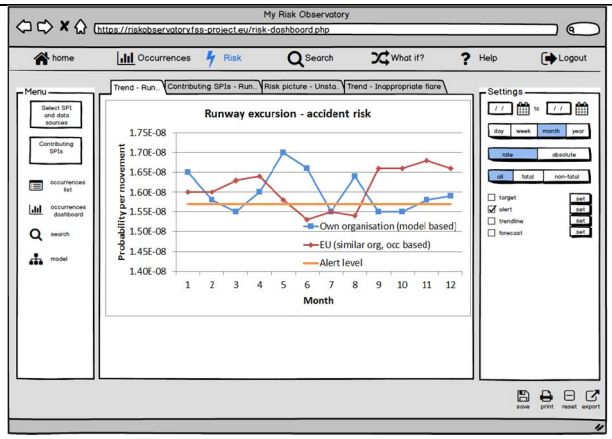
• Back on the Occurrences dashboard, by clicking on 'search' in the left menu the user has access to related hazards, best practices and mitigation means for the selected SPI. Via the 'related event' in the right column, the Occurrences dashboard for that SPI (re)appears. It is assumed that each hazard, occurrence, best practice, and mitigation action, can be related to an event.	

Appendix B.4 Risk dashboard

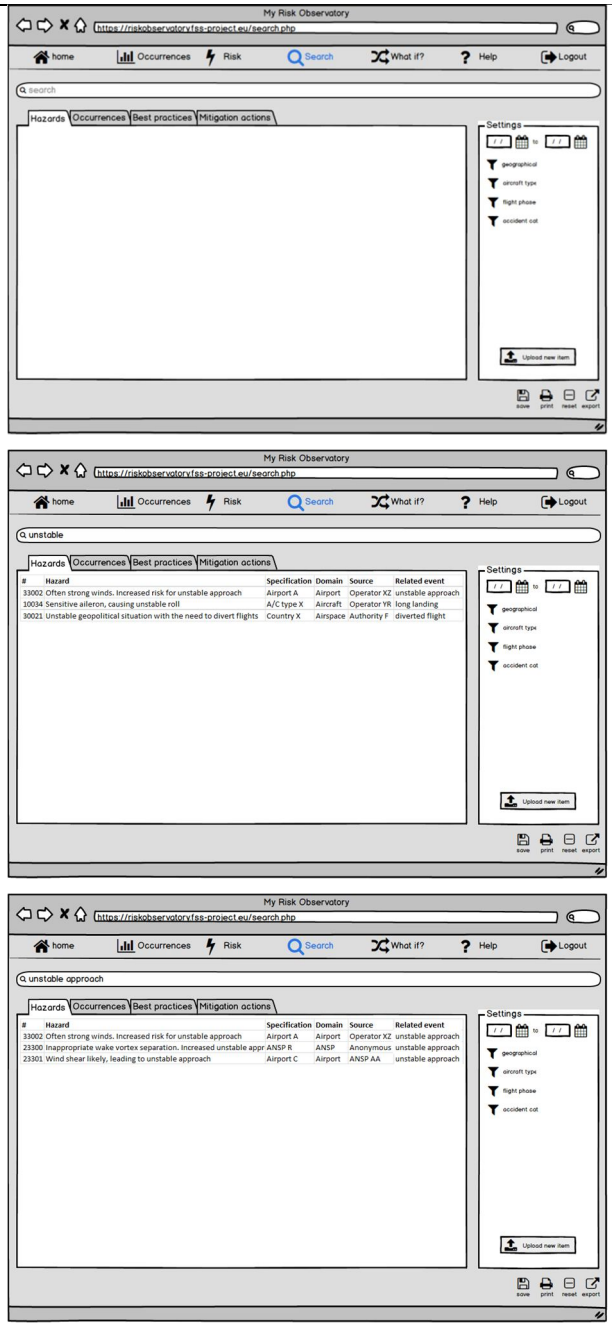
Description	*Screen dump*
• When entering the risk dashboard from the homepage, the user can choose to open an existing analysis, or start a new one. When entering the risk dashboard from clicking the Homepage trend indicators directly, this is not applicable.	
• Firstly, when starting a new analysis, the user can select a risk from a list of accident types or select total risk (aggregate accident probability of all accident types), or select a 'lower level' SPI.	

• In our example the user selects runway excursion risk for the own organization, and creates a trend diagram.	
• Secondly the user can select the SPIs that contribute to this risk to view the relative importance/contribution of these SPIs to the selected risk. The selected SPIs in our example are inappropriate flare and unstable approach, they are a subset of causal factors. The graph shows that there are other factors since these two do not add up to the "full" runway excursion risk.	 

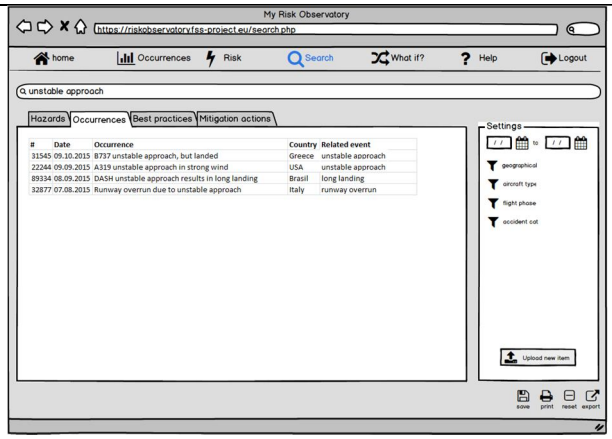
• Another option in the Risk dashboard is to create a risk picture for a selected SPI, e.g., unstable approach, via the 'Select SPI and data sources' button. The resulting risk picture shows the potential consequences (in severity and probability) of the SPI, based on the occurrences data in the own organization in combination with a model. The risk picture included in the prototype shows that the unstable approach can evolve into a runway excursion but also into other end states.	 
• Via the 'model' button in the left menu, it is now possible to get insight in the position of the currently selected SPI (e.g., the unstable approach) in the models available (e.g., a BowTie model).	

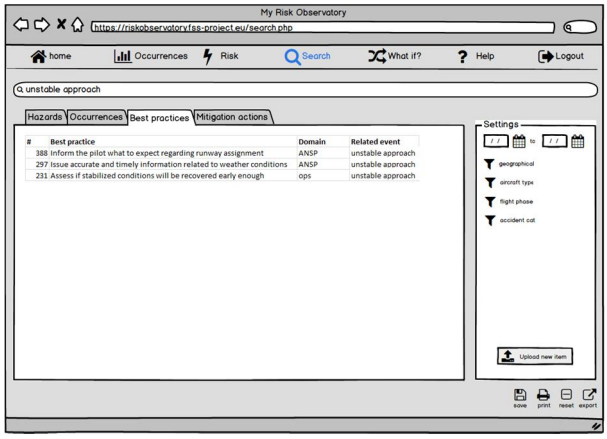
• On the model, it is possible to select a neighbouring SPI. In this prototype, it is illustrated by the option to select 'inappropriate flare'. A trend diagram appears within the Risk dashboard, it may be envisaged to select whether the data displayed is occurrence or model based.	
• After returning to the trend diagram, the user can make a comparison (benchmark) for the selected risk/SPI, e.g. own organization against EU level, by 'Select SPI and data sources'.	
• As for the Occurrences dashboard, there are options to set target, alert, trend line and forecast, set time frame and units of the axis. In this prototype, the alert option can be illustrated.	

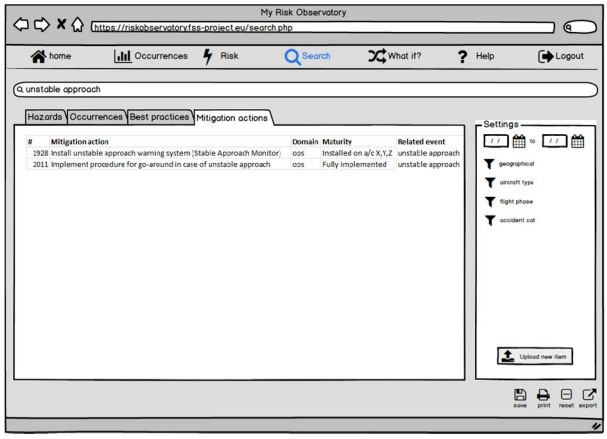
Appendix B.5 Search dashboard

Description	*Screen dump*
• When entering the search dashboard from the homepage, the user can search for occurrences, hazards, best practices and mitigation actions by entering a free text search. This is first illustrated for a search on 'unstable', and secondly for search on 'unstable approach'. • It may be possible to filter the query by accident category, flight phase and geographical region. This is not yet implemented. • It may be possible that a user can upload an item, i.e., a hazard, best practice or mitigation action. This is not yet implemented.	

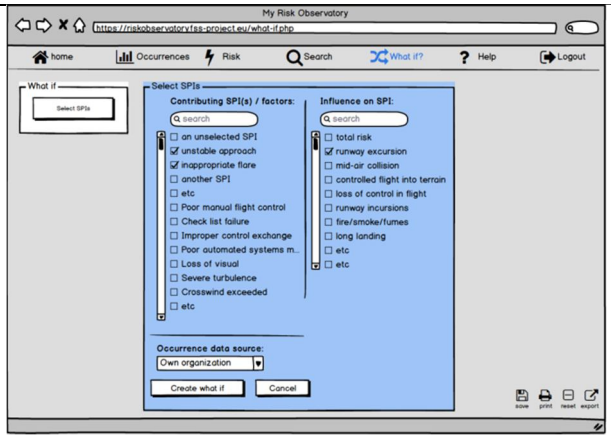
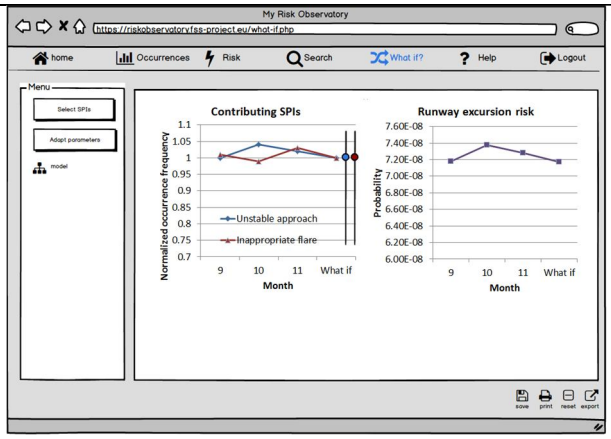
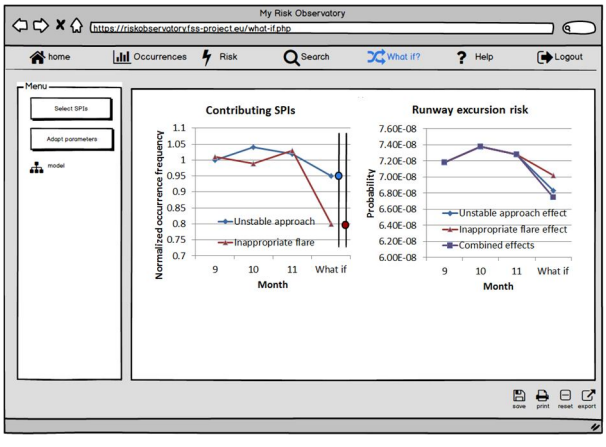
- The tabs for hazards, occurrences, best practices, and mitigation actions now list the results for this search, showing relevant attributes and the related event.

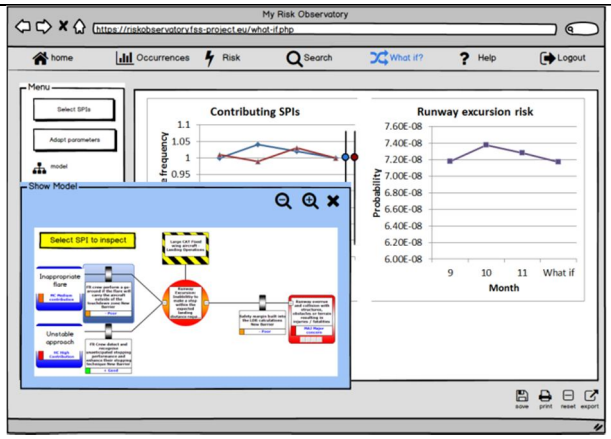
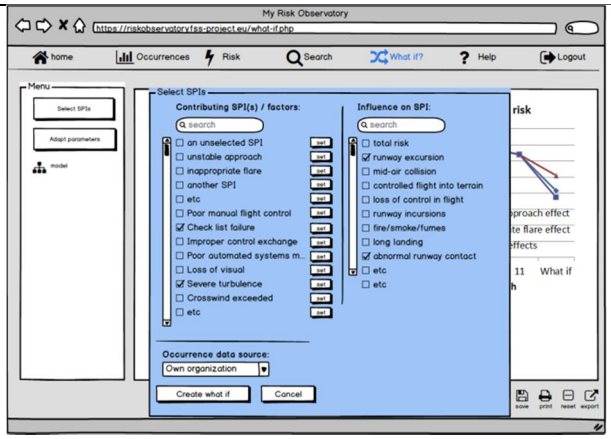






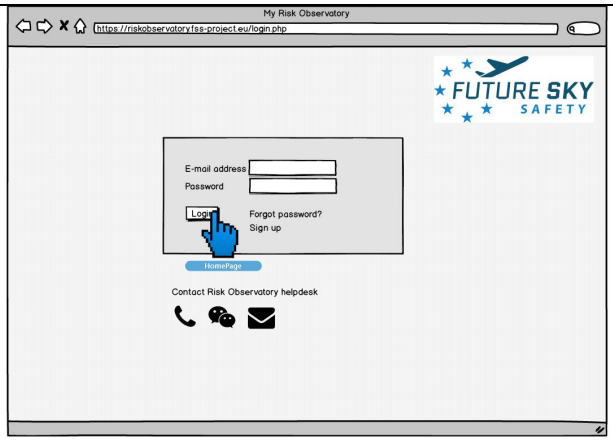
Appendix B.6 What-if analysis dashboard

Description	*Screen dump*
• When entering the What-if analysis dashboard from the homepage, the user can select SPIs or contributing factors for which he wants to conduct a what-if analysis. I.e. investigate the effect of changing the frequency or distribution of occurrence of the SPI(s) or contributing factor(s), which can e.g., be achieved in the operation by implementing a mitigation action. The estimated effect on the SPI(s) is shown. • It may become possible to adapt model parameters, e.g., the expected traffic growth.	
• In a first example, the effect of unstable approach and inappropriate flare on runway excursion accident risk is analysed.	 

• It is possible to inspect the position of the SPIs in the model that is used to estimate the effects.	
• In a second example the effect of two contributing factors ('Check list failure' and 'Severe turbulence') on runway excursion risk and abnormal runway contact risk is analysed.	
• This example shows that reducing the rate or distribution of the contributing factors reduces the runway excursion accident risk, but increases the ARC incident risk.	

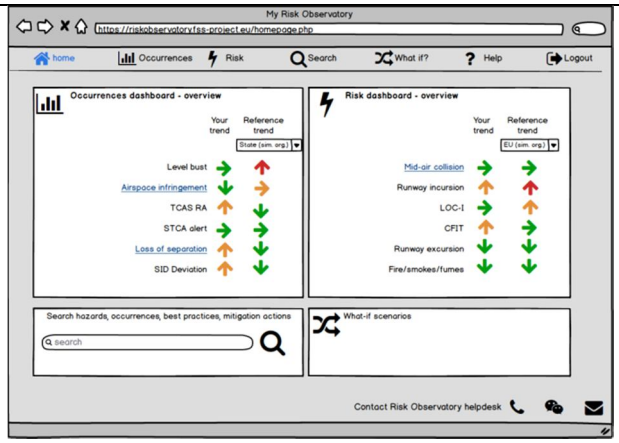
Appendix C EARLY PROTOTYPE USE CASE MID-AIR COLLISION

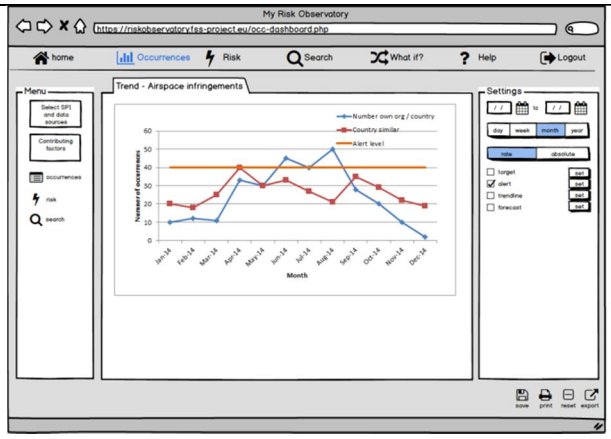
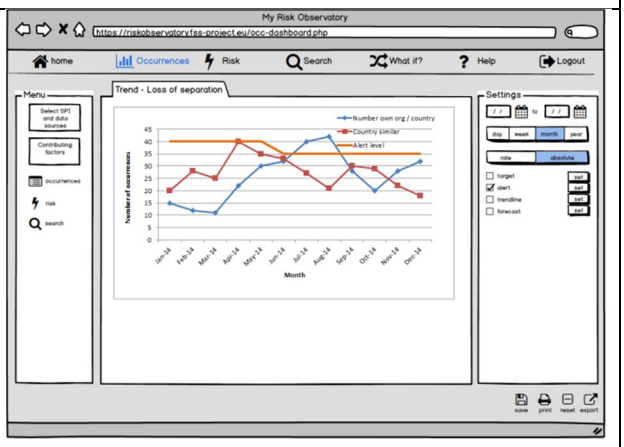
Appendix C.1 Login

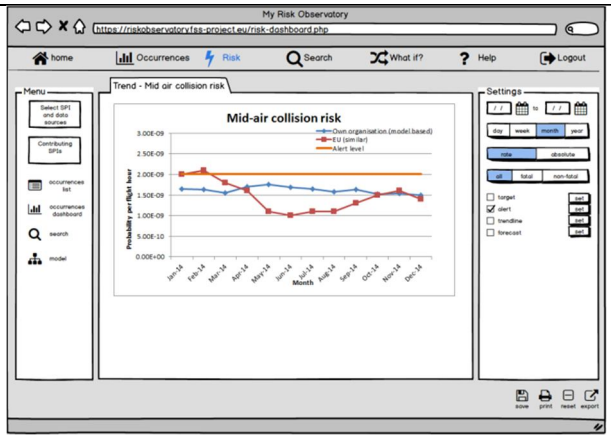
Description	*Screen dump*
• First, the user logs in. After login the user enters the Homepage.	

Appendix C.2 Homepage

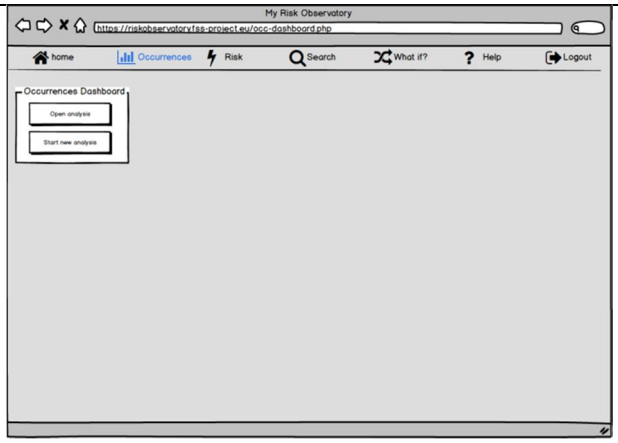
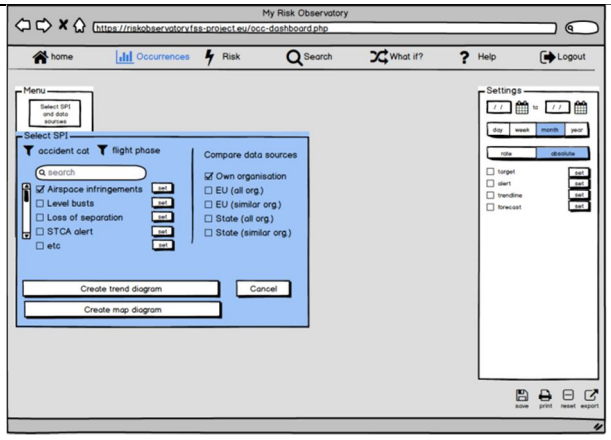
Description	*Screen dump*

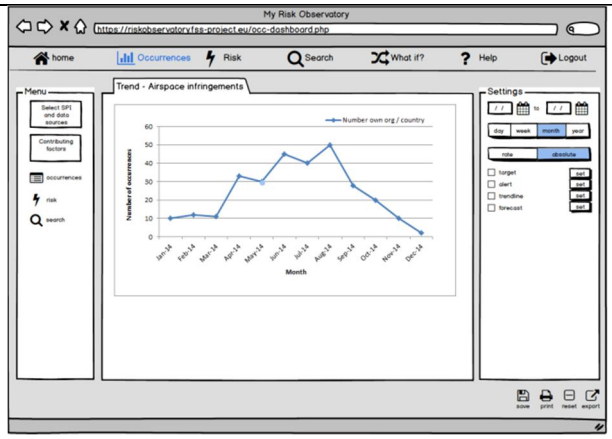
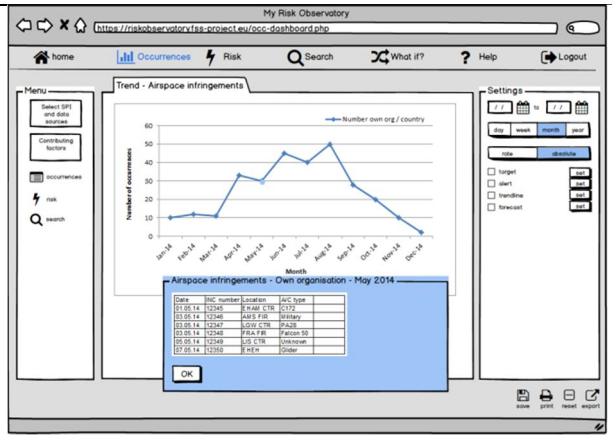
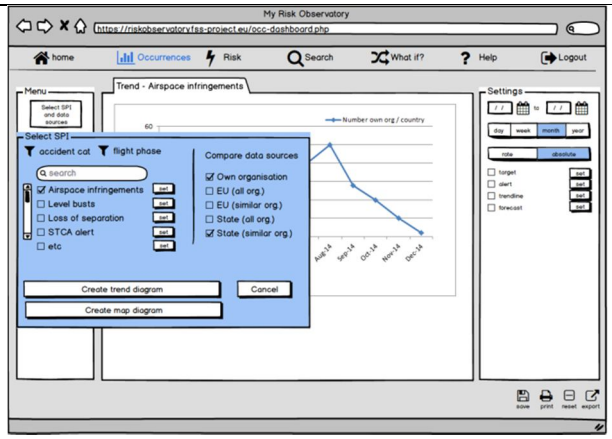
• On the Homepage the user sees an overview of the occurrences dashboard and the risk dashboard with trend indicators (green, orange, red arrows) for selected SPIs.
  ○ Green horizontal or downward arrows indicate a level trend or a declining trend.
  ○ Orange horizontal arrow indicate a level trend, but above a certain alert threshold.
  ○ An upward arrow (orange/red) indicates an increasing trend.
  ○ The user can directly access the SPIs shown on the Homepage, by clicking on the SPI name.
  This is demonstrated in this prototype by clicking on the “Airspace infringement”, “Loss of separation”, “Mid-air collision” links.
• The user can select a dashboard of interest or enter a “tab” of the Risk Observatory:
  ○ Occurrences dashboard, showing information (frequencies) based on actual occurrences within the own and/or
	

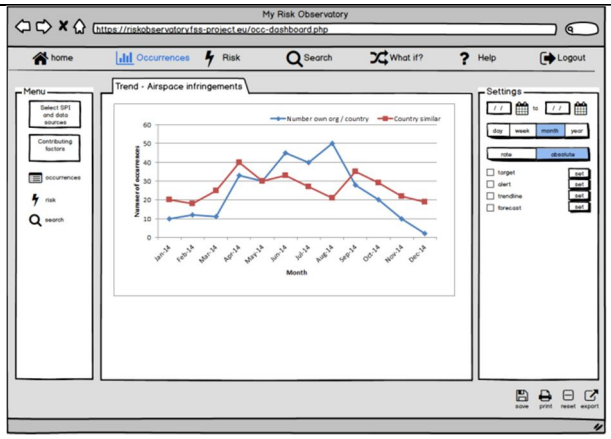
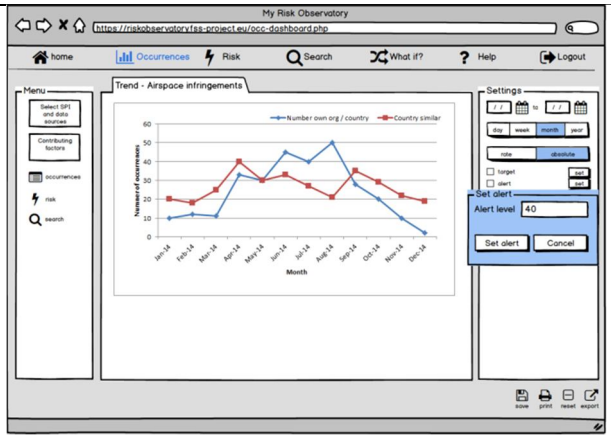
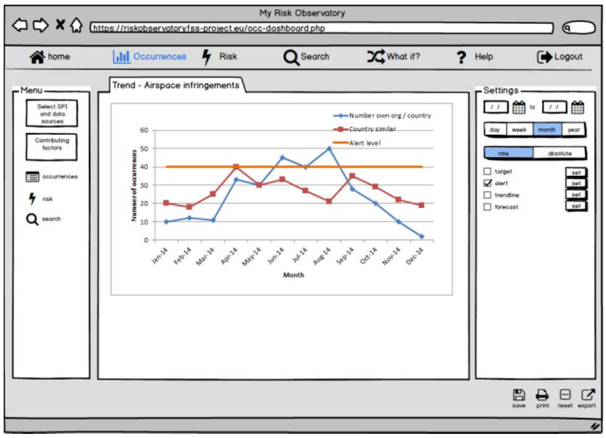
reference organizations. ○ Risk dashboard, showing information (frequencies, probabilities and severities) based on actual occurrences in combination with model estimates for the own and/or reference organization. ○ Search a database for occurrences, hazards, best practices, and mitigations. ○ What-if scenarios, offering the opportunity to vary SPI frequencies/probabilities and see the estimated effect on another SPI.	
• "Airspace infringement" on the Occurrences dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	
Button: Unstable approach • "Loss of separation" on the Occurrences dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average, which both remain below an alert threshold. The SPI is shown on the Homepage because the user has selected it to appear on the Homepage. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	

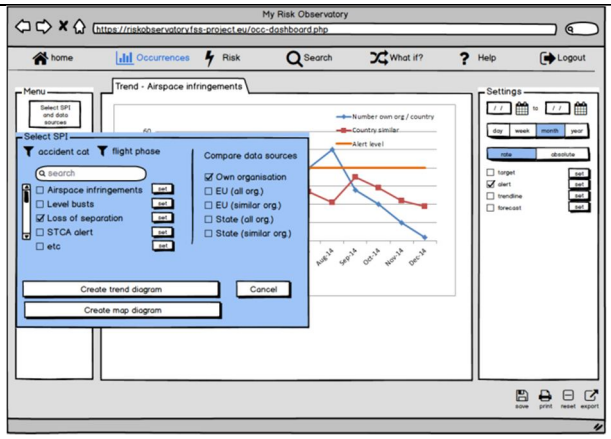
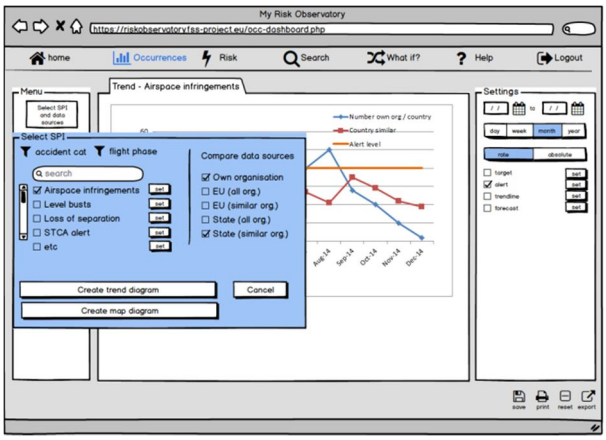
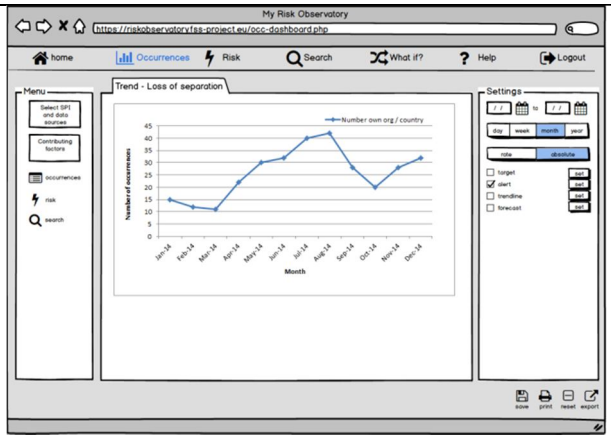
• "Mid-air collision" on the Risk dashboard – overview: ○ Trend diagram of the SPI; In our example, the SPI of the own organization is compared to the EU average. ○ It is noted that because of lack of actual occurrence data, the trend for the own organization is based on model estimates, while for the reference data, it is based on occurrences. ○ Go back to the Homepage by clicking on 'home' in the top left corner.	

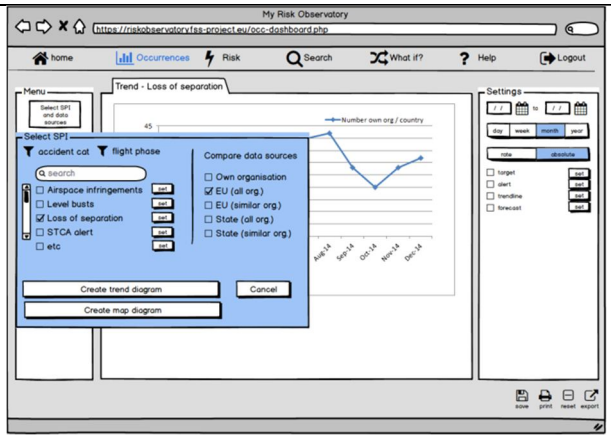
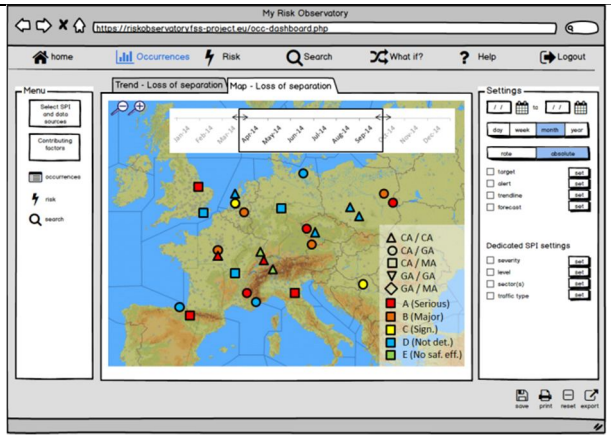
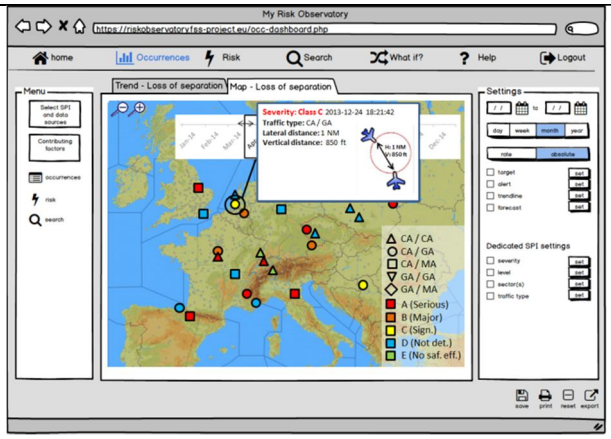
Appendix C.3 Occurrences dashboard

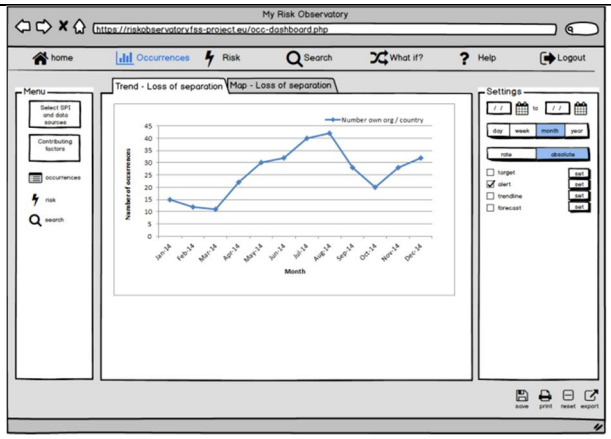
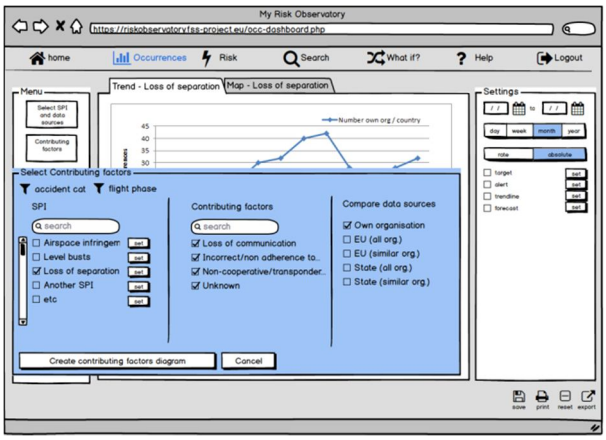
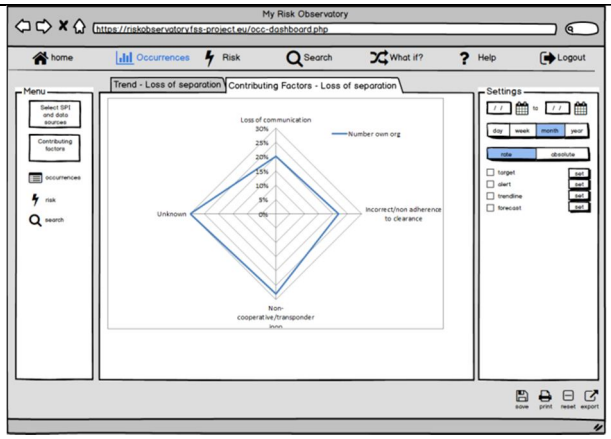
Description	*Screen dump*
• When entering the Occurrences dashboard, the user can choose to open an existing analysis, or start a new one. When entering the Occurrences dashboard from clicking the Homepage trend indicators directly, this is not applicable.	
• When starting a new analysis, the user can select an SPI from a list of SPIs and can select which data sources to compare. E.g. own organization for unstable approach.	

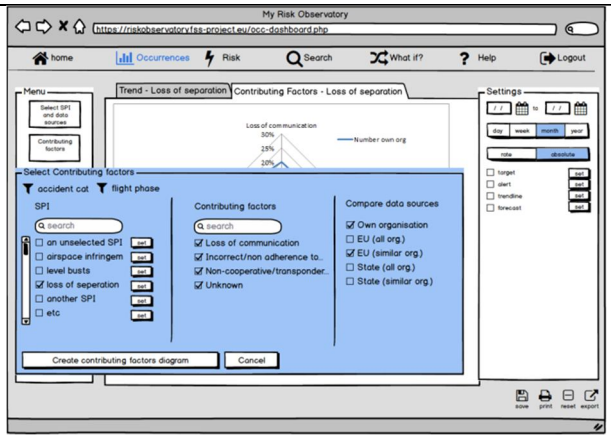
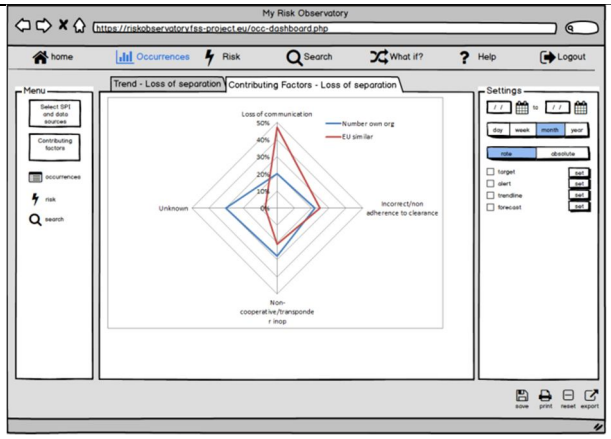
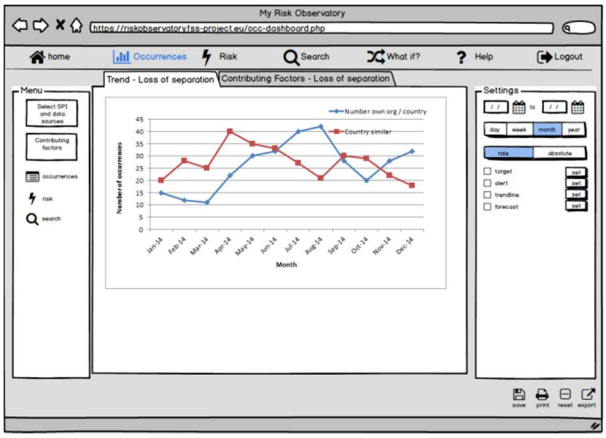
• The trend diagram of the selected SPI and data sources appears.	
• The underlying occurrence data can be shown by clicking on a data point (E.g., for May 2014).	
• For comparing the data of the own organization with a reference set, click 'Select SPI and data sources' and select (e.g.) 'EU (similar org.)'.	

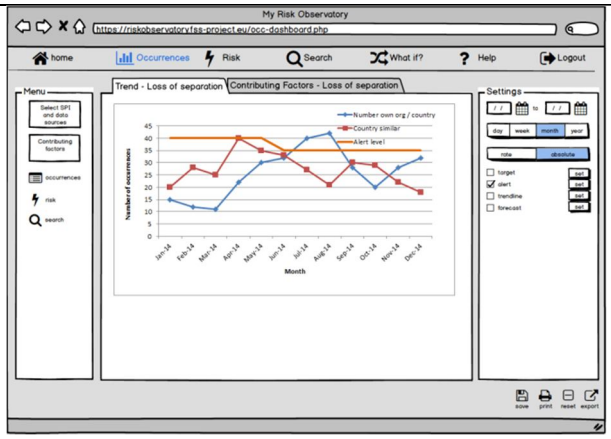
• Now the trend diagram shows the data for both sources.	
• The user can tick the boxes for a: target value, alert threshold, trend line and forecast in the trend diagram. This is illustrated in this prototype for the alert threshold, trend line and forecast.	 

• Now, select another SPI, “Loss of separation”.	 
• First, create a trend diagram.	

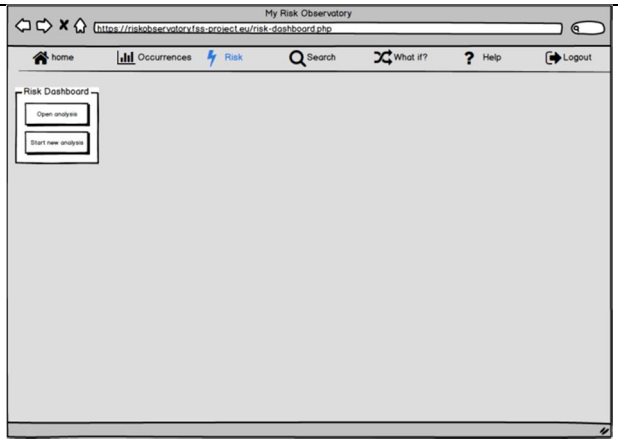
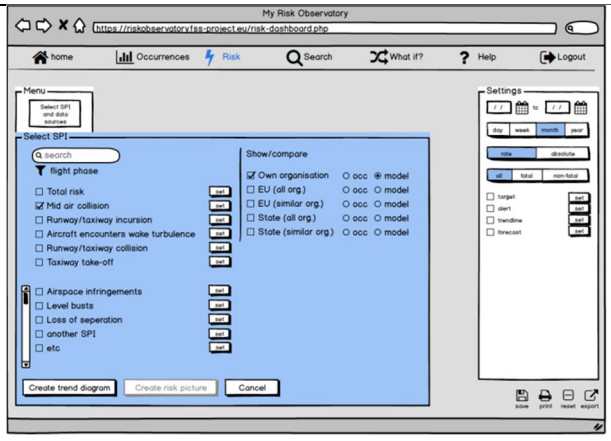
• Next, create a map diagram for all EU organizations.	
• The map diagram shows the locations of Loss of separation events, distinguishing different traffic types and severities.	
• It is possible to select an event and get more information on the event.	

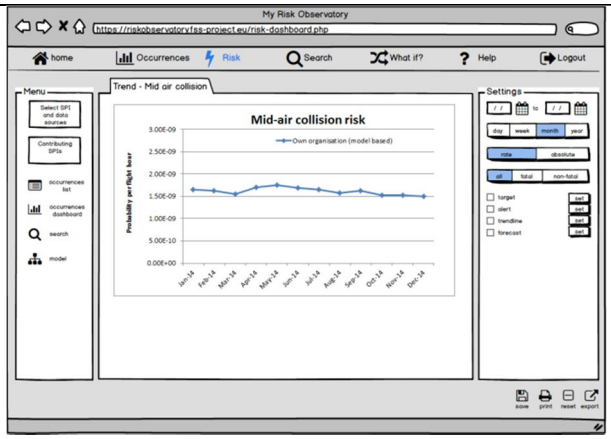
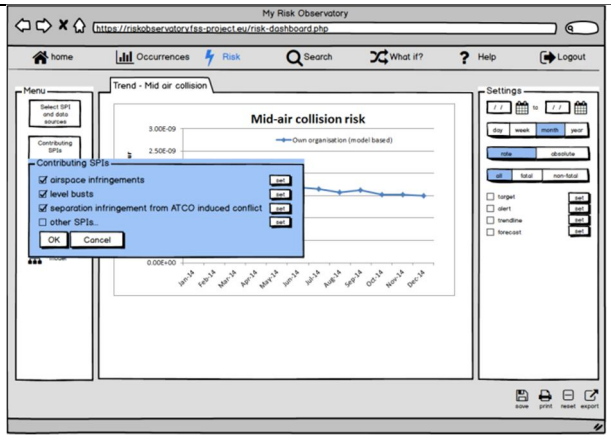
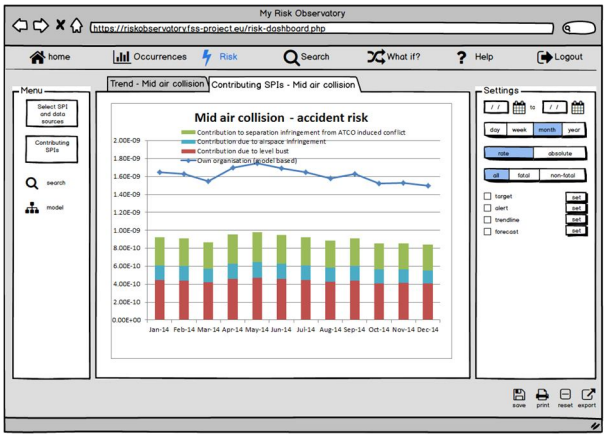
• Contributing factors to the SPI can be selected by the button “Contributing factors”. A list of factors (as e.g., identified in research) for the selected SPI appears.	 
• The contributing factors diagram shows a spider plot of the relative importance of contributing factors to the SPI.	

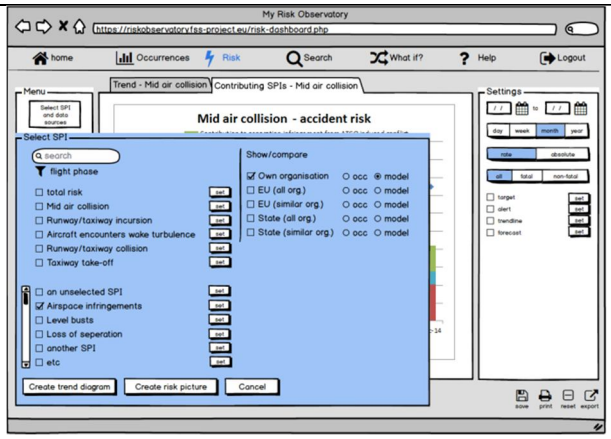
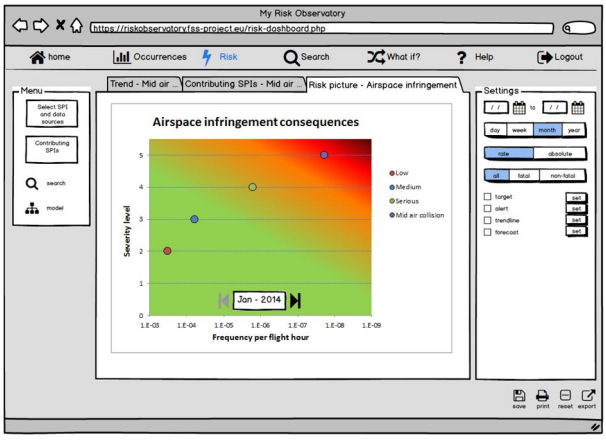
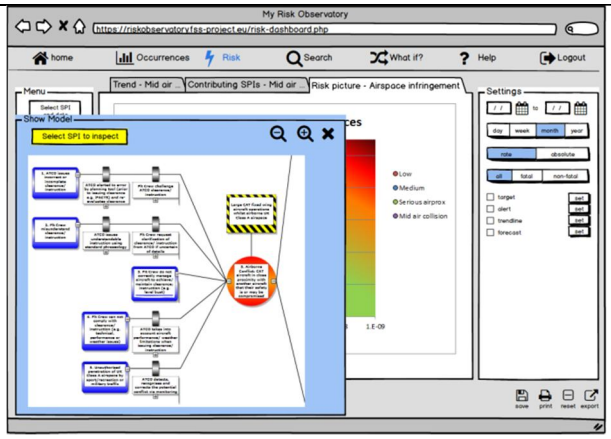
• For comparing the data of the own organization with a reference set, click 'Select SPI and data sources' and select (e.g.) 'EU (similar org.)'.	
• Now both the trend diagram and the contributing factors diagram show the data for both sources.	 

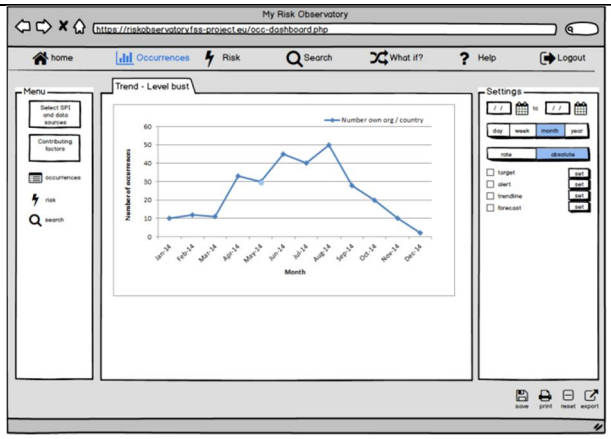
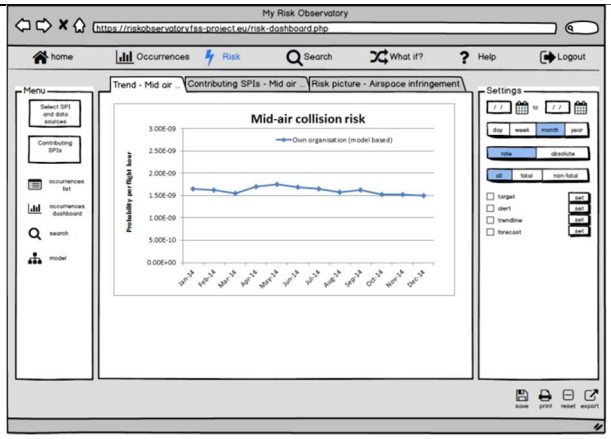
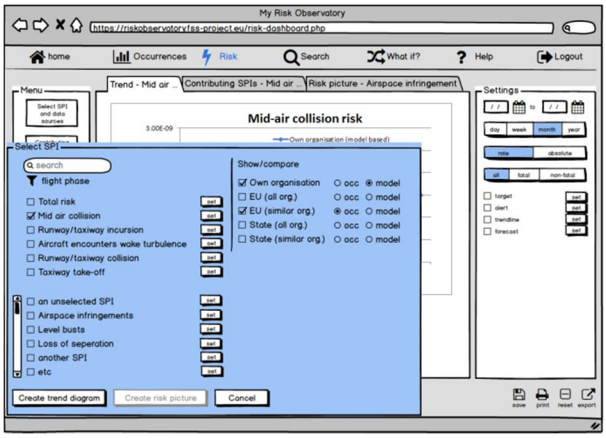
• The user can tick the boxes for a: target value, alert threshold, trend line and forecast in the trend diagram. This is illustrated in this prototype for the alert threshold.	

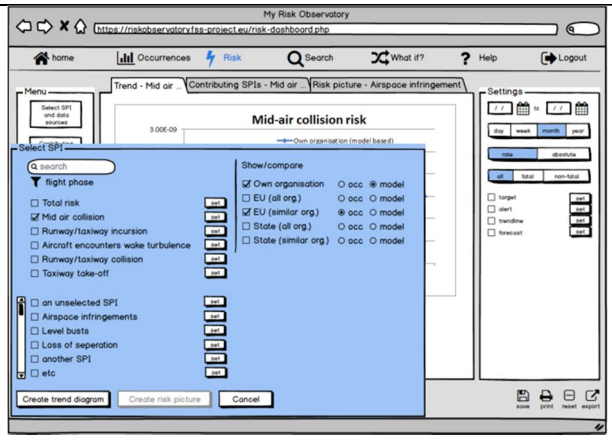
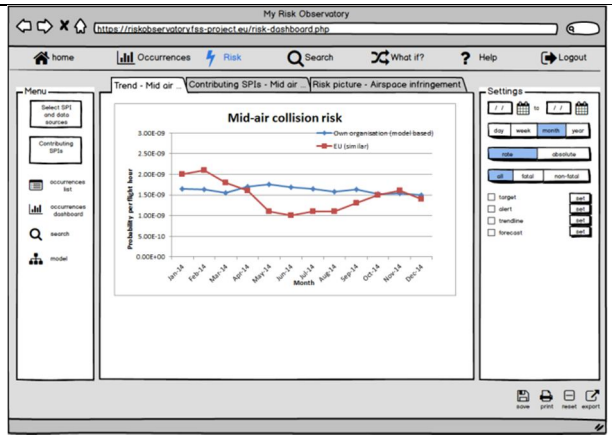
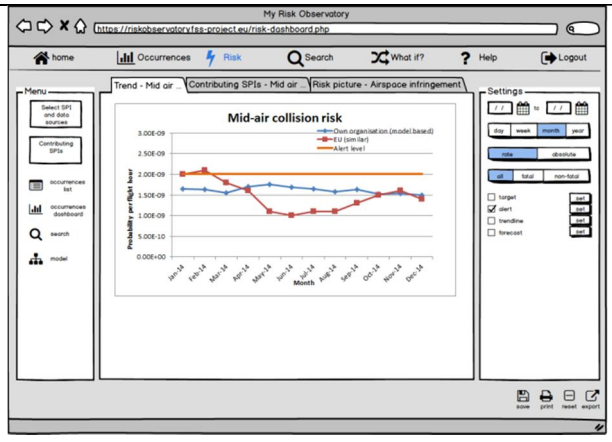
Appendix C.4 Risk dashboard

Description	*Screen dump*
• When entering the risk dashboard from the homepage, the user can choose to open an existing analysis, or start a new one. When entering the risk dashboard from clicking the Homepage trend indicators directly, this is not applicable.	
• Firstly, when starting a new analysis, the user can select a risk from a list of accident types or select total risk (aggregate accident probability of all accident types), or select a 'lower level' SPI.	

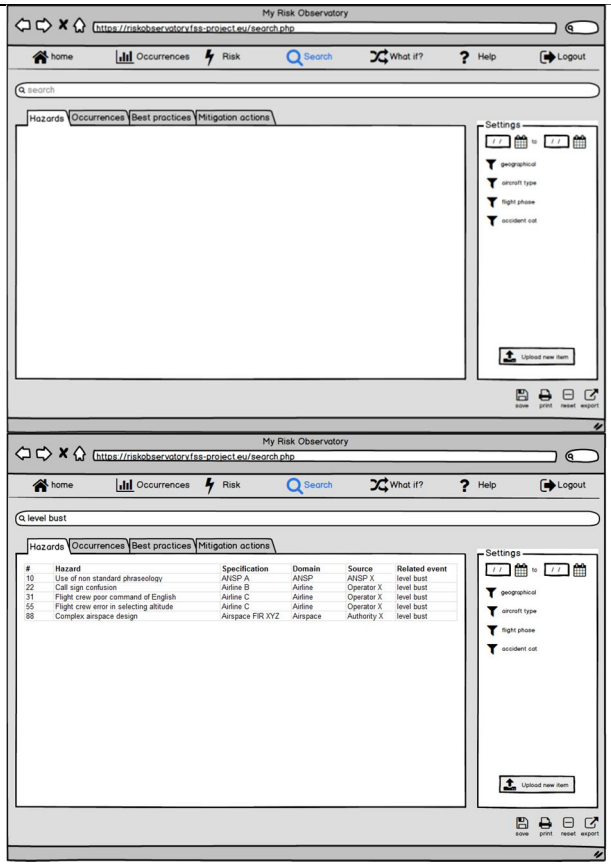
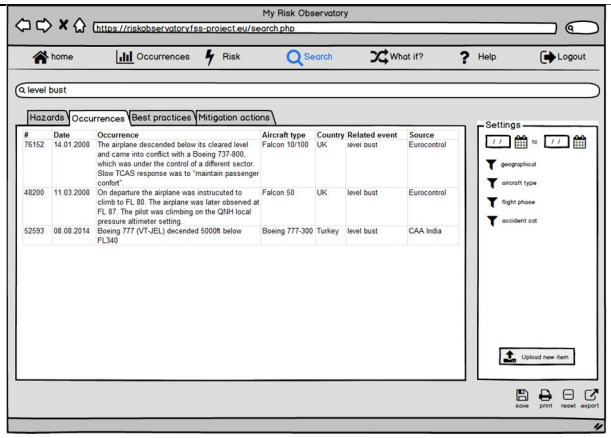
• In our example the user selects mid-air risk for the own organization, and creates a trend diagram.	
• Secondly the user can select the SPIs that contribute to this risk to view the relative importance/contribution of these SPIs to the selected risk. The selected SPIs in our example are airspace infringements and level busts, they are a subset of causal factors. The graph shows that there are other factors since these two do not add up to the "full" mid-air collision risk.	 

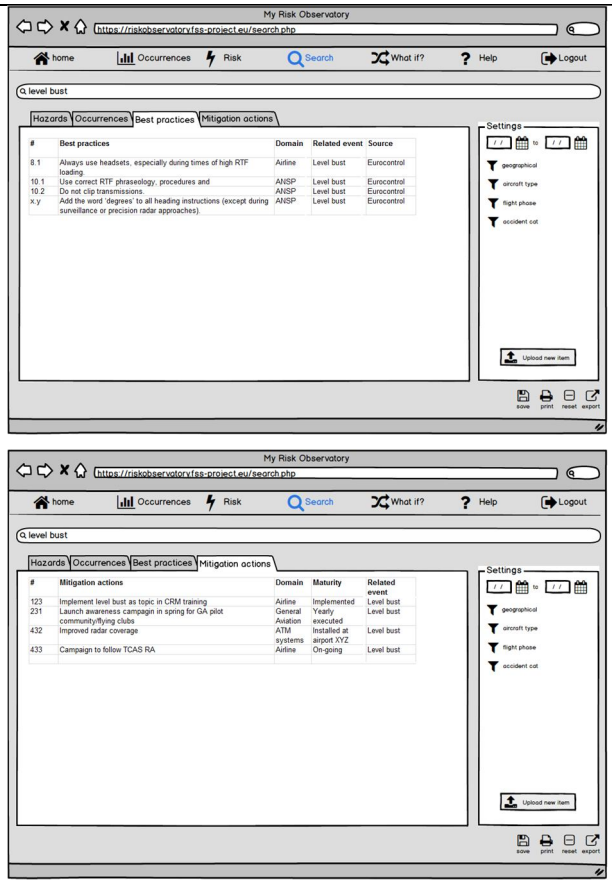
• Another option in the Risk dashboard is to create a risk picture for a selected SPI, e.g., airspace infringement, via the 'Select SPI and data sources' button. The resulting risk picture shows the potential consequences (in severity and probability) of the SPI, based on the occurrences data in the own organization in combination with a model. The risk picture included in the prototype shows that the airspace infringement can evolve into different end states with different severities.	 
• Via the 'model' button in the left menu, it is now possible to get insight in the position of the currently selected SPI in the models available (e.g., a BowTie model).	

• On the model, it is possible to select a neighbouring SPI. In this prototype, it is illustrated by the option to select 'level bust'. A trend diagram appears.	
• After returning to the trend diagram, the user can make a comparison (benchmark) for the selected risk/SPI, e.g. own organization against EU level, by 'Select SPI and data sources'.	 

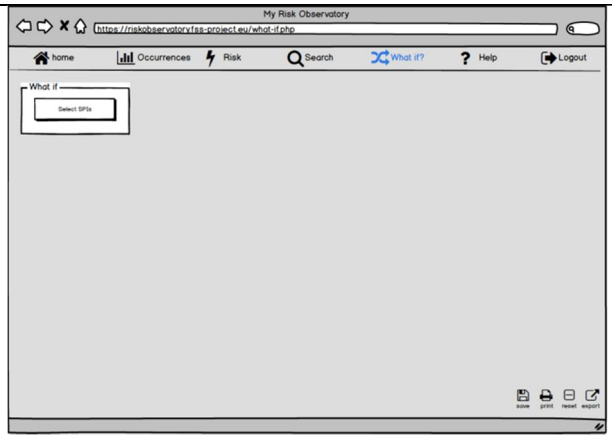
	
• As for the Occurrences dashboard, there are options to set target, alert, trend line and forecast, set time frame and units of the axis. In this prototype, the alert option can be illustrated.	
	

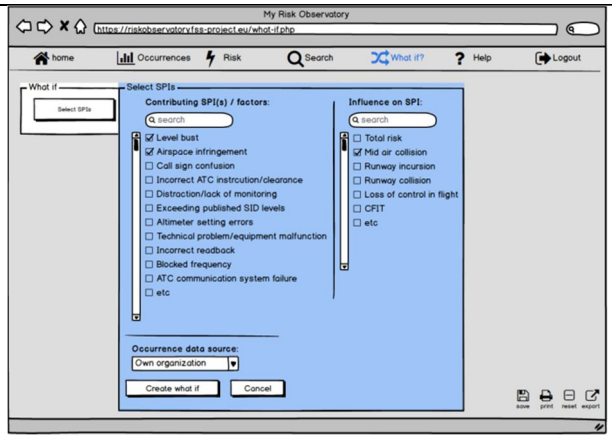
Appendix C.5 Search dashboard

Description	*Screen dump*
• When entering the search dashboard from the homepage, the user can search for occurrences, hazards, best practices and mitigation actions by entering a free text search. This is illustrated for a search on 'level bust'. • It may be possible to filter the query by accident category, flight phase and geographical region. This is not yet implemented. • It may be possible that a user can upload an item, i.e., a hazard, best practice or mitigation action. This is not yet implemented.	
• The tabs for hazards, occurrences, best practices, and mitigation actions now list the results for this search, showing relevant attributes and the related event.	

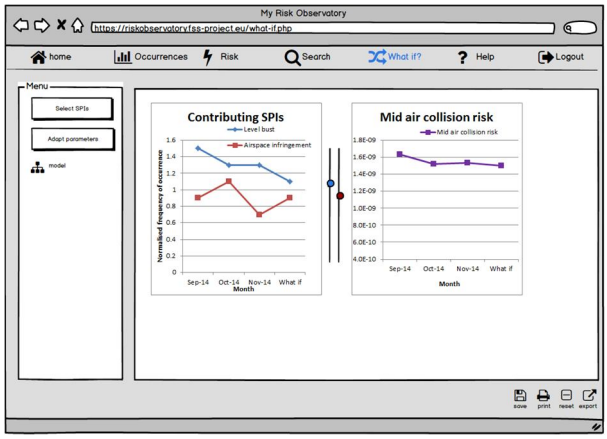
	

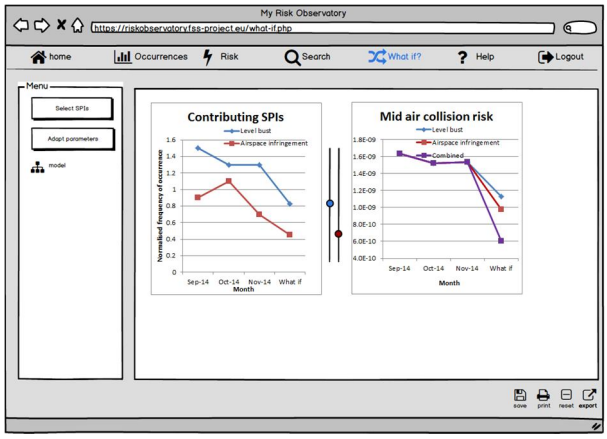
Appendix C.6 What-if analysis dashboard

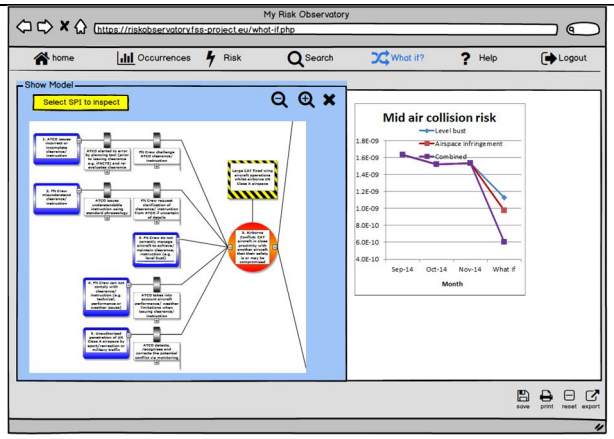
Description	*Screen dump*
• When entering the What-if analysis dashboard from the homepage, the user can select SPIs or contributing factors for which he wants to conduct a what-if analysis. I.e. investigate the effect of changing the frequency or distribution of occurrence of the SPI(s) or contributing factor(s), which can e.g., be achieved in the operation by implementing a mitigation action. The estimated effect on the SPI(s) is shown. • It may become possible to adapt model parameters, e.g., the expected traffic growth.	



- In a first example, the effect of unstable approach and inappropriate flare on runway excursion accident risk is analysed.





• It is possible to inspect the position of the SPIs in the model that is used to estimate the effects.	

Appendix D SUCCESS CRITERIA FOR EVALUATION OF A PROTOTYPE

The early prototype and the 'final' prototype will be evaluated with stakeholders that were involved in the interviews in support of the identification of business, user and system requirements (developed in WP4.1 "Risk observatory requirements"). The purpose of the evaluation sessions with stakeholders is to assure that the Risk Observatory's functionalities and user interface meet the business and user needs, and bring the expected benefits. The prototype is used as a demonstrator of the Risk Observatory's functionalities and design (user interface)

Two types of evaluations will be conducted.

- Evaluation of the early prototype implemented functionalities and design (user interface) against the business, user and system requirements document. The D4.1 document lists the business, respectively, the user and system requirements. Each requirement will be reviewed against the early prototype to check if the requirement is valid or relevant for the prototype, and secondly, if the requirement has been implemented "conceptually" in the prototype. This activity provides information about the coverage of the requirements by the early prototype and its maturity level ('level of representativeness') with respect to the expected prototype Risk Observatory and/or a final, full-scale Risk Observatory.
- Evaluation of the early prototype implemented functionalities and design (user interface) with stakeholders in the form of an interactive session and feedback collection process. The exercise will be set-up as follows. The early prototype will be available as a document, for example as .pdf file, and/or web-based application. The early prototype will be distributed before the interactive session with the stakeholder so that the interviewees will have the opportunity to get a look and feel of the prototype. During the session the prototype will be explained and demonstrated by the project team. User feedback about the prototype, its functionalities and design will be elicited using a questionnaire or structured interview. At the same time, feedback and suggestions for improvement of the business, user and system requirements will be collected.

The evaluation of the usability and user acceptance of the early prototype requires the participation of typical users and an evaluation protocol to use in the evaluation and feedback collection interview. The evaluation with the stakeholders will be a qualitative evaluation.

This activity provides user feedback to the project team about the expected functionalities and design of the Risk Observatory prototypes and allows for the further specification of the requirements. User involvement in the design and development of the prototype helps to deliver a fit for purpose Risk Observatory prototype.

Success criteria for evaluation 1

- For each business, user and system requirement it has been documented whether it is relevant or applicable for the early prototype.
- For each relevant/applicable business, user and system requirement it has been documented in what form it will be represented in the early prototype. If a requirement is considered relevant/applicable, but will not (yet) been implemented in the early prototype, then an explanation will be provided for the reason.

Success criteria for evaluation 2:

- Each stakeholder that was interviewed as part of the WP4.1 has been invited to participate in the evaluation of the early prototype.
- Evaluations of the early prototype implemented functionalities and design (user interface) with at least (to be determined) stakeholders of at least aircraft operators, ANSPs, manufacturers and authorities have been completed.
- The evaluation results with respect to the refinement of and/or definition of additional business, user and system requirements have been communicated to WP4.1, and D4.1 has been updated accordingly.
- The evaluation results with respect to the feedback and suggestions for improvement of the early prototype's functionalities and design have been documented for future use in WP4.4, i.e. the Risk Observatory prototype design and development phase.
- At least a selection of the Key Performance Areas for the validation of the Risk Observatory prototype (see below) are addressed in the evaluation of the early prototype.
- Areas that need to be addressed in the evaluation of the Risk Observatory prototype with typical users are listed below. These areas reflect aspects (or Key Performance Areas) in which the Risk Observatory prototype must be acceptable, demonstrate a perceived benefit, and meet user expectations. These areas can be discussed with the users in a validation of the Risk Observatory prototype, and they can be subjectively rated by the uses in the evaluation/validation using a qualitative rating scale for instance.

The following Key Performance Areas can be evaluated for a prototype. A few aspects on the list cannot yet be evaluated with the early prototype, but only with an operational Risk Observatory prototype.

- Usefulness: The perceived or expected benefit by the user of the functionalities of the Risk Observatory prototype and of the presented type of information and data in the prototype. This area concerns the applicability of functionalities and information and data presented by the Risk Observatory prototype in current safety management practices and day-to-day activities of the user.

- Quality: The type of information, data and results presented by the Risk Observatory prototype, and the related reliability or credibility of the output. (Not applicable for early prototype evaluation.)
- Trust: The user has sufficient level of trust or confidence in the system and the outcomes. The users find the Risk Observatory prototype acceptable to use in the organization, in support of Safety Management. (Not applicable for early prototype evaluation.)
- User friendliness: This concerns the level of user friendliness regarding the user interface (GUI), the design and functionalities of the prototype. It concerns the user's opinion on the prototype's level of complexity or simplicity (of functionalities, design, models, data and information presented), ease of use of features, interactions with the data and safety information etc., an intuitive use of the graphical user interface, help function etc. Level of integration or lack of integration of functionalities, duplication of tasks in the Risk Observatory prototype. Inconsistencies in functionalities or design in the Risk Observatory prototype.
- Effectiveness: The ability of users to complete tasks using the Risk Observatory prototype. The ability of the user to achieve his task objective using the Risk Observatory prototype. (Not applicable for early prototype evaluation.)
- Efficiency: The level of effort (workload), time or resources required to perform tasks in the Risk Observatory prototype. (Not applicable for early prototype evaluation.)
- Accessibility: The accessibility to different sorts of data, safety information, models, analyses, results etc. in the in the Risk Observatory prototype. (Not applicable for early prototype evaluation.)
- Acceptability: The user finds it acceptable to acquire, operate and maintain a Risk Observatory prototype for use in the business, sees a positive business case for the Risk Observatory. (Not applicable for early prototype evaluation.)
- Flexibility: The flexibility provided by the Risk Observatory prototype in the different functionalities and the design. Aspects like flexibility in analysis, custom-made homepages, queries, exports, handling data sets etc. are covered in this area. (Not applicable for early prototype evaluation.)
- Level of training: The required expertise/knowledge to operate the Risk Observatory prototype, i.e. need for training, engineering support, helpdesk, required prior knowledge of models, SPIs, data, ease of learning how to use the system. (Not applicable for early prototype evaluation.)

Appendix E PROTOTYPE EVALUATION FORM

The following evaluation form and questionnaire was developed in WP4.1 "Risk observatory requirements". This form can also be used for the evaluation of the final Risk Observatory prototype.

Part A - General information – General questions		
ID	Questions	Answer
A1	Type of organisation	
A2	What is your role and responsibility in relation to safety management in your organization?	
A3	What overall recommendations do you have for the early prototype?	
A4	What are the most interesting features or functionalities of the early prototype?	
A5	What features or functionalities do you think are missing in the early prototype?	
A6	What is required to ensure that you and your organisation will be using the Risk Observatory?	

Part B 1 – Questionnaire/rating scale – HOMEPAGE						
	Disagree					**Agree**
	0	**1**	**2**	**3**	**4**	**5**
1. Usefulness: The functionalities available are **useful and add value** in current safety management practices and day-to-day activities of the user.	☐	☐	☐	☐	☐	☐
Explanation						
2. User friendliness: The functionalities available are **user friendly, seem easy to use**, and are **understandable**.	☐	☐	☐	☐	☐	☐
Explanation						
3. What recommendations or suggestions for improvement of this page of the prototype do you have?						

Part B 2 – Questionnaire/rating scale – OCCURRENCES DASHBOARD						
	Disagree					**Agree**
	0	**1**	**2**	**3**	**4**	**5**
1. Usefulness: The functionalities available are **useful and add value** in current safety management practices and day-to-day activities of the user.	☐	☐	☐	☐	☐	☐
Explanation						
2. User friendliness: The functionalities available are **user friendly**, **seem easy to use**, and are **understandable**.	☐	☐	☐	☐	☐	☐
Explanation						
3. What recommendations or suggestions for improvement of this page of the prototype do you have?						

Part B 3 – Questionnaire/rating scale – RISK DASHBOARD						
	Disagree					**Agree**
	0	**1**	**2**	**3**	**4**	**5**
1. Usefulness: The functionalities available are **useful and add value** in current safety management practices and day-to-day activities of the user.	☐	☐	☐	☐	☐	☐
Explanation						
2. User friendliness: The functionalities available are **user friendly**, **seem easy to use**, and are **understandable**.	☐	☐	☐	☐	☐	☐
Explanation						
3. What recommendations or suggestions for improvement of this page of the prototype do you have?						

Part B 4 – Questionnaire/rating scale – SEARCH DASHBOARD						
	Disagree					**Agree**
	0	**1**	**2**	**3**	**4**	**5**
1. Usefulness: The functionalities available are **useful and add value** in current safety management practices and day-to-day activities of the user.	☐	☐	☐	☐	☐	☐
Explanation						
2. User friendliness: The functionalities available are **user friendly**, **seem easy to use**, and are **understandable**.	☐	☐	☐	☐	☐	☐
Explanation						
3. What recommendations or suggestions for improvement of this page of the prototype do you have?						

Part B 5 – Questionnaire/rating scale – WHAT-IF ANALYSIS DASHBOARD						
	Disagree					**Agree**
	0	**1**	**2**	**3**	**4**	**5**
1. Usefulness: The functionalities available are **useful and add value** in current safety management practices and day-to-day activities of the user.	☐	☐	☐	☐	☐	☐
Explanation						
2. User friendliness: The functionalities available are **user friendly**, **seem easy to use**, and are **understandable**.	☐	☐	☐	☐	☐	☐
Explanation						
3. What recommendations or suggestions for improvement of this page of the prototype do you have?						