ASCOS certification case study: Certification of an organisation

Case study for the testing of a novel certification approach

J.J. Scholte (NLR), S. Bull (Ebeni), G. Temme (CertiFlyer), S. Bravo Muñoz (Apsys), A.D. Balk (NLR), N. Aghdassi (Avanssa).

This is one of four certification case studies that aim to test and evaluate the certification approach proposed by ASCOS (as documented in ASCOS D1.3) and supporting safety tools. This specific case study considers their practical application to the certification of a hypothetical organisation. It provides conclusions regarding the practical feasibility and provides feedback for improvement.

Coordinator	L.J.P. Speijker (NLR)
Work Package Manager	A.L.C. Roelen (NLR)

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NLR	L. Speijker, A. Rutten, M.A. Piers, P. van der Geest, A. Roelen, J.J Scholte, J. Verstraeten, R. Wever, E. van de Sluis, M. Stuip
Thales Air Systems GmbH	G. Schichtel, J.-M. Kraus, H. Neufeldt
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ESA	T. Sgobba, M. Trujillo
EUROCAE	A. n'Diaye
TUV NORD Cert GmbH	H. Schorcht
FAST	R. den Hertog

Acronyms

Acronym	Definition
ACARE	Advisory Council for Aeronautics Research and innovation in Europe
AEA	Association of European Airlines
AFM	Aeroplane Flight Manual
AMC	Acceptable Means of Compliance
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
AoC	Area of Change
AOC	Air Operator's Certificate
ARD	Aerospace Resource Document
ARP	Aerospace Recommended Practice
ASCOS	Aviation Safety and Certification of new Operations and Systems
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
CAT	Commercial Air Transport
CATS	Causal model for Air Transport Safety
CNS	Communication Navigation Surveillance
CS	Certification Specifications
DSR	Design Safety Requirements
EASA	European Aviation Safety Agency
EC	European Commission
ESD	Event Sequence Diagram
EU	European Union
EUROCAE	European Organisation for Civil Aviation Equipment
FAST	Future Aviation Safety Team
FHA	Functional Hazard Analysis
FT	Fault Tree
GM	Guidance Material
HoT	Hold-over Time

Acronym	Definition
HSR	High-level Safety Requirement
ICAO	International Civil Aviation Organization
ISO	International Organization for Standardization
SAM	Safety Assessment Methodology
SMS	Safety Management System
SRC	Safety Regulation Commission
TAS	Total Aviation System
VHF	Very High Frequency
WP	Work Package

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Executive Summary

The ASCOS project aims to outline a newly proposed approach to certification that is more flexible and more efficient than the current certification processes, and that considers the impact on safety of all elements of the Total Aviation System (TAS) and the entire system lifecycle in a complete and integrated way. ASCOS D1.3 proposed an outline certification approach, while a number of other ASCOS documents describe associated supporting safety methodologies and tools for this certification approach. The ASCOS project includes four certification case studies that aim to test and evaluate the certification approach and the supporting safety tools by applying these to a potential safety enhancement.

This certification case study aims to test the certification approach and supporting safety tools in their application to the certification of an organisation. The potential safety enhancement selected for this case study is the certification of a de-icing/anti-icing service provider. Currently, such service providers operate under the Air Operator's Certificate of the air operator they are part of, and/ or the air operators to which they provide their services. This case study assumes a hypothetical situation in which this is no longer the case, and in which the de-icing/anti-icing service provider is responsible and accountable for their safe operations in compliance with assumed novel regulations. The supporting safety tools considered are the ASCOS tool for safety risk assessment and the Area of Change list from FAST.

Practical feasibility

Several issues arose in applying the D1.3 approach and the supporting safety tools to the certification of a de-icing / anti-icing service provider. Example issues are that it was difficult to determine the scope of the change to focus on, how to develop an appropriate argument structure, and when and how to take into account changes in safety management.

The identified issues indicate that use of the D1.3 approach and supporting safety tools may not be optimal for certifying a de-icing/anti-icing service provider. Certifying such provider should be rather straightforward, and less laborious and complex then it appeared to be in this case study. The main complexities of certifying such provider are of an organizational nature, with for example shifted responsibilities. The D1.3 approach and the supporting safety tools appeared to deliver limited added value in that area. Furthermore, the approach appeared to be rather 'heavy' when compared to the technical complexity of the subject of certification.

There are also other causes of the identified issues that arose. Notably, the practical application suffered from the hypothetical character of this case study, which considered a certification process for which no regulation is yet available. Furthermore, the guidance available for the approach was of limited detail and had a preliminary character.

Feedback regarding D1.3 approach

The core of this document has provided detailed feedback regarding the D1.3 approach. The main identified areas of improvement are summarised:

Argument approach: The key innovation of the D1.3 approach is that an overall top level claim of an acceptably safe change to the TAS is decomposed into supporting claims that are aligned with individual aviation domains, such that the approach dovetails with the individual certification approaches existing within those domains. The main comments from this case study to this argument approach are:

- The added value of the argument approach did not become clear. In the decomposition of the claims, the lower claims are not very different from the higher claims. Most stages of the certification approach were conducted without being driven by the argument.
- It was difficult to determine how to develop the arguments for the considered claims, and to understand what these claims should entail.
- The wording of the arguments is such that it may be difficult for applicants to grasp the exact meaning of the claims (e.g., use of terms as functional specification and logical design).

Development of organisational changes: The certification approach is divided into eleven stages, of which Stage 1 through 3 were evaluated in some detail, and Stages 4 and 5 in a more exploratory way. Stage 4 focuses on the consequences of those hazards that the function under consideration is designed to mitigate. Stage 5 also considers their causes, and also the hazards associated to failures of the function under consideration itself. These stages are supported by a safety risk assessment tool that makes use of chronological descriptions of series of events leading up to an accident, and supporting fault trees. It is questioned whether this type of development process and safety analysis process are appropriate for changes with a strong socio-technical character such as considered in this study, since event-based models are generally poor at representing systemic accident factors such as structural deficiencies in the organization.

Defining requirements against which to certify: D1.3 describes how to take into address existing regulations in certification. It became apparent that potentially the D1.3 approach might also be used for the development of the regulatory requirements against which to certify the product, but it is not clear from D1.3 how this should be done.

Scope and level of detail: A recurring issue in the case study was the exact scope and level of detail to be considered in the various stages of the certification process. Example questions that arose were:

- Why does Stage 1 focus on defining a ‘change’ rather than on defining the ‘subject of certification’ or the ‘scope of the certificate’?
- What is the scope of functional requirements and safety requirements that may be identified per stage? E.g., for which stakeholders are they identified, and should they be limited to the technical and operational level, or also consider items as safety management and the required level of safety?
- What is the scope and level of detail to be considered as ‘logical design’ in Stage 5 of the process, and which elements are considered as ‘internal’ and which as ‘external’?

Risk acceptance criteria: The proposed certification approach does not aim to replace or adapt the existing certification regimes in the individual aviation domains, but merely to provide structure to the certification of the overall change in the TAS. As such, the risk acceptance criteria or safety targets applied currently in safety

assessment in the individual domains remain applicable. It is not well understood whether additional risk acceptance criteria or safety targets need to apply at the overall TAS level, for use in combination with the ASCOS tool for safety risk assessment, and how such criteria should be defined. Associated questions are whether such additional risk acceptance criteria form an additional hurdle for introducing safe changes, and whether the approach should accommodate introducing changes in which safety in one domain increases considerably but at the cost of a slight decrease in safety in another domain.

Feedback regarding the supporting safety tools

ASCOS tool for safety risk assessment: In line with the adopted study focus, the evaluation of the ASCOS tool for safety risk assessment [14][12] had an exploratory character. The tool includes two event sequence diagrams of relevance for this case study, which could be used for identifying high level safety requirements. It was unclear how to use the tool for specification of safety requirements at a lower level. One cause for this is that it is not clear how to take into account changes in safety management using this tool. Another main cause is that it is not clear how to identify requirements for individual design elements, because 1) events and faults in the tool are generally not at the level at which the safety requirements need to be identified, and 2) the tool does not include quantification of intermediate events and underlying faults.

Area of Change list from FAST: The Area of Change list was used in the definition of the change (Stage 1). It was well possible to determine the subset of Areas of Change that may be relevant for the certification of the service provider. This resulted however in a quite large subset of potentially relevant areas, which were not further used in the study. This is due to the exploratory character of the main Stages 4 and 5 in this case study, and to lack of clarity on how these Areas of Change should be used.

Recommendations

It is recommended to take into account the identified feedback in the further development of a novel certification approach for use in the TAS. The certification approach of ASCOS D1.3 [9] and the supporting tools may be improved using the feedback from this case study, or alternative certification approaches may be considered.

This case does not draw firm conclusions about the effects on safety of certifying a de-icing/anti-icing service provider. It is recommended to be reluctant in drawing conclusions on this matter from this case study.

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1 Introduction

1.1 Background

Several developments call for the adaptation of existing certification processes. These developments include fundamental changes in the institutional arrangements for aviation regulation in Europe, the introduction of new technologies and operations, and demands for higher levels of safety performance.

The European Commission (EC) sponsored ASCOS project (Aviation Safety and Certification of new Operations and Systems) aims to contribute to the removal of certification obstacles. By this, it also aims to contribute to realizing the EU ACARE Vision 2020 [1][2][32] and Flight Path 2050 [33] goals. ASCOS aims to outline a newly proposed approach to certification that [15]:

- Is more flexible with regard to the introduction of new operations, systems and products;
- Is more efficient, in terms of cost, time and safety, than the current certification processes;
- Considers the impact on safety of all elements of the Total Aviation System (TAS) and the entire system lifecycle in a complete and integrated way.

ASCOS D1.1 [7] provided an analysis of existing regulations and certification processes. ASCOS D1.2 [8] developed and evaluated a long-list of innovative certification approaches. Based on these, ASCOS D1.3 [9] proposed an outline certification approach. Other ASCOS documents describe supporting safety methodologies and tools for this certification approach, among which a tool for safety risk assessment [14][12], a tool for continuous safety monitoring [11], and an Area of Change list ([34], from the Future Aviation Safety Team (FAST)).

ASCOS Work Package 4 (WP4) is named “Certification case studies” and has the following aims:

- To apply the proposed certification approach and supporting safety tools in example case studies;
- To evaluate the practical application of the proposed certification process adaptations; and
- To assess the overall safety impact of bringing safety enhancements in operational use.

ASCOS WP4 consists of 4 sub-tasks (4.1 through 4.4) that each consider an individual certification case study, and one sub task (4.5) that evaluates the results of these case studies.

1.2 Objective and scope

This ASCOS D4.3 document describes one of the four certification case studies of ASCOS WP4. The primary objective of such certification case study is to test and evaluate the certification approach proposed in ASCOS D1.3 [9] and the supporting safety tools by applying these to a potential safety enhancement. The certification approach and supporting safety tools that the case aims to test and evaluate are [13]:

- The certification approach proposed in ASCOS D1.3 [9];
- The ASCOS tool for safety risk assessment [14][12]; and
- The Area of Change list from FAST [34].

It is noted that there is a further supporting tool for continuous safety monitoring (selected and further developed by ASCOS [11]). The case study aims to test Stages 1 through 6 of the 11-stages certification approach, which will be further introduced in Section 2. The later stages require the subject of certification to be implemented, which is not feasible for this case study. This also means that testing and evaluating the tool for continuous safety monitoring falls outside the scope of this document.

The case study described in this D4.3 document aims to test the approach and the tools in their application to the certification of an organisation. The potential safety enhancement selected for this case study is the certification of a de-icing/anti-icing service provider. Currently, such service providers operate under the Air Operator's Certificate (AOC) of the air operator they are part of, and/ or the air operators to which they provide their services. The case study assumes a hypothetical situation in which this is no longer the case, and in which the de-icing/anti-icing service provider is responsible and accountable for their safe operations in compliance with assumed novel regulations.

This document does not suggest that certification of a de-icing/anti-icing service provider is the preferred solution to all icing-related aviation safety problems. Rather, it describes the testing of a novel certification approach by applying it to the hypothetical certification of such organisation. While doing this, the study aims to collect material of use to determine the effect on safety of such certification.

1.3 Approach

This study tests the certification approach and supporting safety tools by applying these to a specific case. This way it studies the feasibility of their practical application, and collects feedback for their improvement.

This case study has specific characteristics that make it significantly different from the other case studies considered in ASCOS WP4. The main differences are:

- This case study considers the certification of an organisation, while the other case studies consider the certification of equipment.
- Whereas the other case studies consider the certification of a potential safety enhancement, in this case the potential safety enhancement is in the certification itself: it considers the certification of an organisation that currently operates under the certificate of a different organisation.
- This case study considers a certification process by an organisation that is not yet used to certification.

Partly because of these differences, the application of the certification approach of ASCOS D1.3 [9] and supporting safety tools to this case study is not straightforward. Important lessons for improvement of the certification approach and supporting tools are already identified during the definition of this case study, while defining its exact scope and necessary assumptions, and during the application of the early stages of the certification approach. This already lead to the identification of a significant number of observations, which made application of all planned stages of the certification approach in this case study unfeasible.

This document therefore has a focus on the definition of the case study and on Stages 1, 2 and 3 of the certification approach. For Stages 4 and 5 of the certification approach the study has a more exploratory character, which also means that Stage 6 could not be tested and evaluated.

For each considered stage of the D1.3 approach, this document includes a separate chapter. Each such chapter firstly summarises the available guidance, then describes the application of the stage, and then provides an evaluation. Each of these chapters, and also a chapter regarding definition of the case study, is aimed at collecting feedback to the certification approach and supporting safety tools. For this feedback use is made of boxes:

Feedback to the proposed certification approach and supporting safety tools is described in boxes.

Each of these chapters ends with an evaluation. This evaluation consolidates the feedback from the boxes, and is aimed at describing which parts went well, which parts did not go well, and what are the probable causes. Where possible it provides suggestions for improvement, but the main focus is on describing well why the application is successful or problematic.

The guidance regarding the certification approach and supporting safety tools that was available at the beginning of the case study was mainly from ASCOS deliverables [9][14][12][34]. The case study was conducted by the authors of this document, which include an author with specific expertise regarding the D1.3 approach and supporting tools.

1.4 Document structure

This document is structured as follows:

- Section 2 describes the main subject of study: the certification approach of ASCOS D1.3 and the supporting safety tools.
- Section 3 describes the potential safety enhancement selected for testing these.
- Section 4 describes the definition of the case study, including definition of scope and assumptions.
- Sections 5 through 9 each describe the application of one of the stages of the certification approach considered, with Section 5 describing the change (Stage 1), Section 6 the definition of the certification argument (Stage 2), Section 7 the development and agreement over the certification plan (Stage 3), Section 8 the specification (Stage 4), and Section 9 the design (Stage 5).
- Section 10 provides the conclusions and recommendations.

2 The certification approach and supporting safety tools

This section describes the main subject studied in this document: the certification approach of ASCOS D1.3 and supporting safety tools.

2.1 Stages of the proposed certification approach

The certification approach proposed by ASCOS D1.3 consists of the following stages:

1. Define the change
2. Define the certification argument (architecture)
3. Develop and agree certification plan
4. Specification
5. Design
6. Refinement of argument
7. Implementation
8. Transfer into operation – transition safety assessment
9. Define arrangements for continuous safety monitoring
10. Obtain initial operational certification
11. Ongoing monitoring and maintenance of certification

This case study focuses on lessons learned during the definition of the case study and during Stages 1 through 3. For Stages 4 and 5 of the certification approach the study has a more exploratory character, while the later stages are not considered.

The available guidance for this case study is included in version 1.2 of ASCOS D1.3 [9]. This guidance consists of:

- A generic description regarding applying logical arguments;
- A discussion of a logical argument approach to aviation certification; and
- A description of a staged application of the approach.

The latter two parts have some attention for use of the supporting tools as described in the following sections.

2.2 Safety risk assessment tool

The ASCOS risk assessment tool [14] aims to enable safety practitioners to model risk scenarios in order to derive safety requirements and safety objectives. The tool describes accident scenarios and accident avoidance scenarios as event sequence diagrams (ESDs) and fault trees (FT). ASCOS D3.3 [12] provides a user manual for the tool. ASCOS D3.2 [10] describes the development of the risk model and accident scenarios. The ASCOS model is based on the CATS (Causal Model for Air Transport Safety) model [18] and consists of 29 accident scenarios that represent virtually all major aviation safety risks. The model is quantified in the sense that probabilities of occurrence are assigned to the various elements of the different pathways of the accident scenarios.

ASCOS D1.3 mentions the following use of the safety risk assessment tool in the certification approach:

- The tool supports the analysis required to support the argument for Stages 4, 5, and 7 of the certification approach. The tool describes prevention models that should be considered in the argument, as part of the demonstration that the application of these models delivers a system which meets its safety criteria.
- In Stage 4, the tool may provide support to identifying:
    - Safety objectives for the system;
    - Safety requirements which specify what the system is required to do (not how it does it) in order to achieve the safety objectives;
    - The degree of assurance required that the system will meet its requirements; and
    - Any additional functionality requirements or assumptions to capture any external means of mitigating the consequences of the hazards caused by failure of the system.
- In Stage 5, the tool may provide support to setting requirements without necessarily prejudging how that design should be physically implemented. This assessment also needs to consider the achievability of any requirements and therefore must consider whether the requirements can be met (at least in principle) by the preliminary design.

2.3 FAST Area of Change list

The Future Aviation Safety Team (FAST) identified and maintains a repository of Area of Changes (AoCs) [34] that aims to:

- Provide all actors during the entire life cycle with a wide scope list of emerging risks;
- Allow providing design and certification justification of systems robustness to new risks; and
- Allow enriching the analysis and efficacy of risk control measures and clarifies whether or not safety enhancements resist to emerging risks.

Per Area of Change, the repository [34] provides a description, associated potential hazards, and a source and comments.

ASCOS D1.3 mentions the following use of the Area of Change list in the certification approach:

- In Stage 1 (Define the change), identifying the what Areas of Change within the TAS are expected within the defined time frame; and next identifying which of the AoCs are expected within the applicable time frame and would possibly affect the change to be made.
- More in general, the AoCs may support hazard identification and classification.

3 The potential safety enhancement

This section introduces the certification of a de-icing/anti-icing service provider as the potential safety enhancement selected for this case study. It describes the motivation for this selection (Section 3.1), and provides a short introduction to ground de-icing/anti-icing (Section 3.2) and associated current safety arrangements (Section 3.3). It provides a description of the potential safety enhancement at the level of knowledge and detail available at the start of this case study (Section 3.4).

3.1 Motivation

The motivation for selecting the certification of a de-icing/anti-icing service provider for this case study is:

- The ASCOS Description of Work [6] describes that this case study will focus on a potential safety enhancement in the *ground handling domain*, since this is a key safety priority area. This follows from an analysis of the European Aviation Safety Programme Manual [26], the European Aviation Safety Plan [25], and Annual Safety Reviews 2010 from EASA [24] and SRC [30].
- Certification of an *organisation* is expected to provide best added value to ASCOS WP4's testing of the certification approach and supporting safety tools, since all other WP4 case studies consider certification of equipment.
- The ASCOS User Group expects that certification of a *de-icing/anti-icing service provider* can enhance safety, and prefers it as case study subject. Several accidents and incidents associated to ground de-icing/anti-icing have occurred (see, e.g., [41],[46],[5],[40]). Certifying the organisation may increase safety with respect to the current practice in which airlines are responsible for safe ground de-icing/anti-icing.

As potential secondary benefits of certifying a de-icing/anti-icing service provider, efficiency may increase (one organisation becomes responsible for safe de-icing/anti-icing operations instead of all airlines that use its services) and de-icing/anti-icing service providers may get an incentive to innovate and improve their performance.

3.2 Ground de-icing and anti-icing

Frozen and semi-frozen moisture on critical aircraft surfaces may affect the aerodynamic effectiveness of an airframe, which may just reduce the performance of the aircraft, but can even result in a sudden loss of control. Also, ice from the wings and from the engine blades of an aircraft may be ingested into the engines and lead to a loss of thrust or an engine failure. Ground de-icing and anti-icing play an important role in protecting the aircraft from such hazards[1]:

- Ground de-icing serves to remove frost, ice, snow or slush from an aircraft in order to provide uncontaminated surfaces.
- Ground anti-icing aims to provide protection against the formation of frost or ice and accumulation of snow on treated surfaces of the aircraft for a certain period of time.

[1] Other icing scenarios exist that are unrelated to ground de/anti-icing, e.g. failure of probes and windshield heating

The terms 'ground de-icing' and 'ground anti-icing' mark the difference with in-flight de-icing and anti-icing (e.g., engine core and fan de-icing and anti-icing).

3.3 Current arrangements for safety

Currently, air operators are responsible for establishing procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow safe aircraft operations, and for compliance of the de-icing/anti-icing service with applicable regulations. In Europe the main relevant regulations are in IR-OPS (EU 965/2012 [22], amended by EU 800/2013 [21] and EU 71/2014 [20]), which lays down technical requirements and administrative procedures related to air operations. For Commercial Air Transport (CAT), IR-OPS specifies the following requirements (CAT.OP.MPA.250: Ice and other contaminants — ground procedures):

a. "The operator shall establish procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow the safe operation of the aircraft.
b. The commander shall only commence take-off if the aircraft is clear of any deposit that might adversely affect the performance or controllability of the aircraft, except as permitted under (a) and in accordance with the AFM."

In many situations, the airline contracts ground de-icing and anti-icing activities from an external service provider. IR-OPS requirements for such contracted activities (ORO.GEN.205, Contracted activities) are:

a. Contracted activities include all activities within the operator's scope of approval that are performed by another organisation either itself certified to carry out such activity or if not certified, working under the operator's approval. *The operator shall ensure that when contracting or purchasing any part of its activity, the contracted or purchased service or product conforms to the applicable requirements.*
b. When the certified operator contracts any part of its activity to an organisation that is not itself certified in accordance with this Part to carry out such activity, the contracted organisation shall work under the approval of the operator. The contracting organisation shall ensure that the competent authority is given access to the contracted organisation, to determine continued compliance with the applicable requirements."

The competent authority responsible for oversight over and inspection of air operations consequently also addresses ground de-icing and anti-icing.

EASA's Acceptable Means of Compliance (AMC) and Guidance Material (GM) [31] to PART-CAT provide 3 sets of guidance material (GM1 through GM3) for requirement CAT.OP.MPA.250:

- GM1 provides terminology and anti-icing codes.
- GM2 describes procedures, addressing e.g., operator procedures, specific operational considerations, communications, hold-over protection, training, contracting, and maintenance considerations.

- GM3 provides background information by referring to further guidance material in ICAO's manual of aircraft ground de-icing/anti-icing operations (Doc 9640 [36]), and listing further documents for establishing operational procedures.

Further documents with standards or guidance, all listed by GM3, include ICAO Annex 3 (Meteorological services for international air navigation), and documents from ISO (International Organization for Standardization), AEA (Association of European Airlines), EUROCAE (European Organisation for Civil Aviation Equipment), and SAE International (formerly the Society of Automotive Engineers). These documents consider, e.g.,:

- Several types of de-icing/anti-icing fluids;
- Ground-based de-icing/anti-icing methods and operational procedures;
- De-icing/anti-icing vehicles;
- Training regarding de-icing/anti-icing; and
- Quality programs regarding de-icing/anti-icing.

3.4 The potential safety enhancement

The potential safety enhancement considered is that the de-icing/anti-icing service provider becomes certified. The air operator is then no longer responsible for a safe ground de-icing/anti-icing service; the de-icing/anti-icing service provider becomes responsible and accountable for providing a safe service. This is principally a change in responsibilities. This requires an associated change in regulations, which is further considered in defining the case study (Section 4).

4 Defining the case study

This section describes the definition of the case study. This addresses the following questions in applying the certification approach in the certification of a de-icing / anti-icing service provider:

- Which organisation(s) is/ are assumed to follow the D1.3 certification approach?
- Which (assumed) regulations does the certification process use?
- Which change is considered in application of the D1.3 process?

4.1 Organisations following the proposed certification approach

During the definition of the case study it was identified that the certification approach could be applied in two distinct ways. In one of these, a group of de-icing / anti-icing service providers and competent authorities apply it jointly in order to develop regulations or standards against which to certify, and supporting justification of such requirements. In the other way, an individual de-icing / anti-icing service provider applies the approach in order to get certified. In line with this, it was identified that the certification approach of D1.3 may also be used twice, in two different phases

- Phase 1: Application to develop requirements against which organisations can be certified. This would be done by a combination of interested parties: multiple de-icing/anti-icing service providers, competent authorities and rulemaking or standardisation bodies, involving also ANSPs, airlines, and airports.
- Phase 2: Application by an individual de-icing/anti-icing service provider for obtaining a certificate. Then the individual service provider follows the process in coordination with its competent authority, also involving other relevant stakeholders as the relevant ANSP, airlines and airport.

The application in both phases may be different: Phase 1 application may be limited to early stages of the certification approach (e.g., Stages 1 through 4), while the Phase 2 application may revisit such stages and focus on the next stages. The argument structure developed in Phase 1 may be useful to an individual service provider in developing their own argument in the Phase 2 application. One may debate whether the Phase 1 application is formally part of certification. Essentially, applicants and authorities work together in this phase to develop requirements against which certification will take place.

This case study considers the application by an individual service provider to become certified, and thus the Phase 2 application. The reason is that a main objective of this case study is to consider the suitability of the D1.3 approach for use for certification of an individual organisation. The Phase 1 application is not considered. A consequence of this is that no regulations are available from such application, as such regulations for certification of a de-icing / anti-icing service provider in reality also do not exist. The next subsection therefore considers assumptions regarding available regulations and their character.

The D1.3 approach might be applied twice, once in a Phase 1 application by multiple stakeholders to develop regulations or standards against which one can certify, and once in a Phase 2 application for the true certification of an individual service provider against available regulations. This was realised during the definition of the case study, and it was not straightforward to determine which approach would be chosen in

the case study.

It is not clear from D1.3 whether such double application is indeed possible, and whether it would be a good idea to allow or even promote such double application. If this is indeed the case then many further questions may arise, e.g.,:

- What are the differences and commonalities between the two phases?
- How does Phase 2 re-use (and adapt) material from Phase 1?
- In which situation does each phase apply?
- In case regulations already exist against which to certify, can a Phase 1 application then still be sensible, e.g., to develop more detailed regulations or standards for situations in which the certification process is expected to be 'repeatable' with minor variations for many different stakeholders?

4.2 Assumptions regarding applicable regulations

The case study focuses on an individual ground service provider aiming to get certified, but there are no regulations available for such process. Therefore this section proposes assumptions regarding such regulations.

The assumed regulations are based on the following considerations:

- The potential safety enhancement requires a main change in regulations such that the de-icing/anti-icing service provider is certified to be responsible and accountable for the procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow safe operation of the aircraft.
- The ASCOS certification approach aims to accommodate a more performance-based approach to certification. It is a safe assumption that the regulation will include performance-based and complementary prescriptive elements.
- The potential safety improvement aims to improve safety by making the de-icing/anti-icing service provider responsible for the safety of their own operations. Safety Management Systems (SMSs) play an increasingly important role in aviation safety improvement. Having an SMS is thus a logical regulatory requirement for a provider applying for a certificate.
- The assumed regulations may or may not have been developed using the D1.3 approach. If the D1.3 approach was used (in a Phase 1 application, cf. Section 4.1), then there would be material available for re-use in the certification of the individual provider, such as an argument structure and identified hazards. However, as this material is not available, this case study simply makes assumptions regarding the regulations for provision of the service.
- The performance-based part of the regulations is assumed to require that the service provider demonstrates that their operations reach certain levels of performance with respect to safety. Different responsibilities with respect to safety may be distinguished. E.g., a recent EASA document [23] describes that service providers may have different responsibilities with respect to safety, depending on whether they have a 'view of safety'. The document discusses that ATS providers have final responsibility with

respect to aircraft separation, therefore have a view of safety, and can consider safety risks in terms of accident and incident probabilities. Also it discusses how CNS providers provide services used for provision of separation, and therefore do not have a view of safety, and can consider the performance of their service in terms of quality. Hence, the document proposes that ATC providers develop safety assessments, and CNS providers develop safety support assessments. This line of thought can also be applied to the responsibilities of the de-icing/anti-icing service provider:

  - For accident scenarios for which the service provider will have primary responsibility, a safety assessment may be required, and the performance may be considered in terms of accident or incident probabilities. An example is the prevention of collisions between de-icing vehicles and aircraft.
  - For accident scenarios for which the service provider will not have primary responsibility, a safety assessment is not required, but arguments and evidence will need to be provided regarding the quality of the service. An example is loss of control during take-off after inadequate de-icing/anti-icing.

- Safety risks are also associated with labour of de-icing personnel. This includes consequences as personal injury, death, and damage to equipment, which could follow from e.g., an accident with a vehicle or dealing with dangerous circumstances. These types of consequences are assumed not to be considered as part of the certification of the de-icing/anti-icing company, but to part of a separate labour health and safety oversight process. In line with this, it is noted that the considered certification approach and supporting safety tools do not pay specific attention to these types of risks.
- The performance-based part of the regulations could either prescribe criteria for required safety performance, or require the organisation itself to define such criteria. For example, EASA's notice of proposed amendment for requirements for safety assessment of changes to ATM/ANS functional systems [23] proposes that the ATM/ANS service provider selects criteria for tolerable safety risks.

This leads to the following assumptions:

Assumptions:

A1. Novel regulations are in place that require a de-icing/anti-icing service provider to have procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow safe operation of the aircraft.
A2. No supporting material (e.g. argument structure or list of hazards) is available from the development of the assumed regulations.
A3. The assumed regulations require the de-icing/anti-icing service provider to have an effective SMS.
A4. The assumed regulations require the de-icing/anti-icing service provider to provide assurance that their services will behave and will continue to behave only as specified in the specified context.
A5. The provider shall provide as safety assurance:
  - For accident scenarios for which the provider has primary responsibilities: a safety assessment that provides the arguments and evidence that the associated safety risks are sufficiently low;

- For accident scenarios to which the provider contributes but does not have primary responsibilities: arguments and evidence for sufficient quality of the delivered service.

A6. The safety assurance activities may be done using relative arguments comparing to current operations, by which it is sufficient to show that:

- For accident scenarios for which the provider has primary responsibilities: the safety risks are not higher than in current operations; and
- For accident scenarios to which the provider contributes, but does not have primary responsibility: The quality of the delivered service is not lower than in current operations.

It was not clear how appropriate safety targets can be obtained, specifically in situations in which there are different stakeholders with different roles and responsibilities all contributing to the same accident types.

4.3 Assumption about the change considered

The change considered in the application of the D1.3 process firstly follows from the choice made in Section 4.1. It is the first certification of a de-icing/anti-icing service provider against assumed novel regulations. This change is not to be mixed with the potential safety enhancement itself, which is the general idea that de-icing/anti-icing service providers become certified.

Since the assumed novel regulations to accommodate this are more performance-based (Section 4.2), the change may involve further adaptations to the involved operations and organisations. The assumptions regarding such further adaptations aim to keep things as simple as possible and to focus on the effects of certifying an organisation using the certification approach. Alternate, more innovative ways of de-icing may provide improved performance, but are not considered in this case study. To provide a logical design in line with the new split of responsibilities, some human roles and responsibilities and associated procedures may need to change.

A7. The actual provision of the de-icing/anti-icing service itself remains as much as possible the same; all involved equipment remains the same, and the proposed way of de-icing as well.

For the potential safety enhancement considered in this document it was far from straightforward how to determine which change should be focused on.
This may be partly due to the complexity of the case study selected, since it considers the certification of an organisation that is in the current practice not certified, and since regulations for this certification do not yet exist.

4.4 Evaluation

Defining the case study was a complex task. Specific difficulties were:

- Determining when and by whom the certification approach of D1.3 is to be applied, most notably:
  - By multiple stakeholders to develop regulations or standards against which one can certify; or

- By an individual organisation in order to become certified.

- Determining against which regulations or assumed regulations the certification should take place. In particular, determining how appropriate safety targets can be obtained is not straightforward, even more for situations in which there are different stakeholders with different roles and responsibilities all contributing to the same accident types.
- Determining which change should be considered in the case study.

5 Stage 1: Definition of the change

This section describes the application of Stage 1 of the certification approach, and hence aims to ensure that the subject of certification in the TAS is fully understood.

5.1 Available guidance

The core of the ASCOS D1.3 [9] guidance for this stage is as follows: "This stage is focussed on ensuring that the proposed change to the TAS is fully understood. This includes defining / identifying:

- The overall goal of the change;
- Definition of the change to be made, including the intended functions and an operational concept;
- Initial high level architecture for the change, sufficient to allocate requirements between the domains of the TAS;
- Definition of the time frame for the actual implementation of the change (target year);
- What Areas of Change (AoC) within the TAS are expected within the defined time frame;
- Which of the AoCs, expected within the time frame, would possibly affect the change to be made;
- What part(s) of the system will be changed (including operational processes, products, roles for human actors), or affected by the change – this includes, but is not limited to, identifying the domains changed or affected;
- What organisations are involved in making the change (e.g. introduction of a new ATM system will involve, at least, the ANSP and the equipment manufacturer);
- How the external environment may be affected by the change;
- Initial argument architecture related to the change based on the above including identification of assurance contracts;
- What existing regulations, certification specifications, standards, AMCs or other relevant guidance material are applicable to the change;
- What requirements (including safety requirements) the change needs to fulfil."

The 'change' considered is the first certification of a de-icing/anti-icing service provider against the assumed novel regulations.

5.2 Application

5.2.1 Overall goal of the change

The overall goal of the change is that the de-icing/anti-icing service provider wants to get certified, because this is required according to assumed novel regulations.

5.2.2 Definition of the change

This section describes the definition of the change to be made, including the intended functions and an operational concept.

Current situation

Currently, air operators are responsible for ensuring that ground de-icing and anti-icing are performed in compliance with the requirements discussed in Section 3.3. Hence, the competent authority responsible for oversight over and inspection of the air operations also addresses ground de-icing and anti-icing. The air operators can use various means (e.g., service level agreements, reviews, audits) to assure that ground de-icing and anti-icing are done in line with requirements.

The objective of ground de-icing and anti-icing is well described in the regulatory definitions of these activities:

- De-icing, in the case of ground procedures, means a procedure by which frost, ice, snow or slush is removed from an aircraft in order to provide uncontaminated surfaces [21].
- Anti-icing, in the case of ground procedures, means a procedure that provides protection against the formation of frost or ice and accumulation of snow on treated surfaces of the aircraft for a limited period of time (hold-over time) [22].
- Hold-over time (HoT) means the estimated time the anti-icing fluid will prevent the formation of ice and frost and the accumulation of snow on the protected (treated) surfaces of an aircraft [21].

Frozen and semi-frozen moisture on critical aircraft surfaces may affect the aerodynamic effectiveness of an airframe, which may just reduce the performance of the aircraft, but can even result in a sudden loss of control. Also, ice from the wings and from the engine blades of an aircraft may be ingested into the engines and lead to a loss of thrust or an engine failure.

The following summarizes the current, recommended way in which de-icing and anti-icing operations are being conducted, including a description of the functions and an operational concept. It is primarily based on the Association of European Airlines' (AEA) recommendations for de-icing/anti-icing of aircraft on the ground [3], as this source is recent (Ed. 28, July 2013), relevant for the European situation, and it well describes operations including equipment, procedures, and human roles and responsibilities. Further relevant documents that describe the principles of ground de-icing/anti-icing operations include EASA's Guidance Material 2 [31] to PART-CAT, ICAO Doc 9640 [36], and Transport Canada's guidelines for aircraft ground icing operations [45]. All these documents provide generic information, which is to be complemented by particular air operator or aircraft manufacturer's documents. SAE's Aerospace Recommended Practice 5660A [43] provides more detail about the operational procedures of the de-icing facility. All citations in this section are from the AEA document [3].

> The top-level function to be performed is to ensure that the aircraft are free of ice when in take-off. Two main organisations involved in the ground de-icing/anti-icing operations are the de-icing/anti-icing service provider and the air operator. Their functions are as follows:
>
> 1. The air operator determines the need for de-icing/anti-icing, and makes a request (if any) to the de-icing/anti-icing service provider.
> 2. The de-icing/anti-icing service provider de-ices and/ or anti-ices and informs the flight crew after completion.
> 3. The air operator conducts checks prior to take-off.

Aircraft de-icing and anti-icing methods can be done using fluids, infrared technology, and forced air. The AEA document [3] applies a focus on an operator using fluids, and refers to SAE ARP 4737 (Section 6) for the use of infrared technology, and to SAE ARD 50102 for forced air. The following operational description assumes that the de-icing/anti-icing operator uses fluids.

1. The air operator determines the need for de-icing/anti-icing, and makes a request (if any) to the de-icing/anti-icing service provider.
    a. The commander conducts a contamination check. The contamination check is a check for the need to de-ice. Specific areas of the aircraft shall be considered, and this shall be done from points offering sufficient visibility (e.g., a de-icing vehicle, or a piece of equipment). Any contamination found shall be removed by de-icing.
    b. The commander determines the required actions (de-icing, anti-icing) and communicates this to the de-icing/anti-icing service provider. This includes a specification of the aircraft parts requiring treatment.
    The conditions for de-icing and anti-icing are as follows:
        - When aircraft surfaces are contaminated, they shall be de-iced prior to dispatch.
        - When there is a risk of contamination of the aircraft surfaces at the time of dispatch, these surfaces shall be anti-iced.

2. The de-icing/anti-icing service provider de-ices and/ or anti-ices and informs the flight crew after completion.
    a. The de-icing/anti-icing service provider de-ices and/ or anti-ices.
    The service provider first requests the commander to confirm the treatment required (areas to be de-iced, anti-icing requirements, special de-icing procedures), and then to configure the aircraft for de-icing/anti-icing. Only after confirmation that this has been completed, the service provider commences the treatment.
    If both de-icing and anti-icing are required, the procedure may be performed in one or two steps, depending on e.g., weather conditions, equipment, fluids, and holdover time to be achieved.
        - De-icing: The de-icing operator is responsible for ensuring that all frozen deposits (i.e., ice, snow, slush, and frost) are removed from the specified surfaces during the de-icing. This is done by applying fluids close to the surface. Specific procedures are provided depending on the type of deposit (frost and light ice, snow, and ice). Specific strategies are provided regarding how to de-ice various parts of the aircraft. For example, for the wings, horizontal stabilizer and elevators, one should spray from the leading edge to the trailing edge, and not start spray from the rear. Also, one should start from the highest point and work towards the lowest parts.
        - Anti-icing: Anti-icing fluid shall be applied to the aircraft surfaces when freezing precipitation may adhere to the aircraft at the time of aircraft dispatch. It may also be applied onto clean aircraft surfaces at the time of arrival, in case of a short turnaround during freezing precipitation, and in case of overnight parked aircrafts. This optional use minimises ice accumulation prior to departure and often makes subsequent de-icing easier. It has a number of specific conditions and cautions.

Additional limits, precautions, and general aircraft requirements are described in AEA, Section 3.9.3 and 3.10 [25].

b. The de-icing/anti-icing service provider conducts a post de-icing/anti-icing check. A trained and qualified person provides a specific visual check of the aircraft. In case any contamination is found, then this shall be removed by further de-icing/anti-icing and then the check shall be repeated.
c. The de-icing/anti-icing service provider communicates the completed check, the type of operation performed, and an all-clear signal to the commander. A qualified person shall do this at the completion of the treatment, indicating that the checked surfaces are free of ice, frost, snow, and slush, and in addition includes the necessary information to allow the commander to estimate the holdover time to be expected under the prevailing weather conditions. The all clear-signal indicates to the flight crew that all de-icing/anti-icing operations are complete and that all personnel and equipment are clear, such that the aircraft may be reconfigured or moved.

3. The air operator conducts checks prior to take-off.
   a. The commander conducts a pre-take-off check. The commander shall continually monitor the weather conditions after the performed de-icing/anti-icing treatment. Prior to take-off he shall assess whether the applied holdover time is still appropriate and/or if untreated surfaces may have become contaminated. This check is normally performed from inside the flight deck.
   b. The commander conducts a pre-take-off contamination check. This is a check of the critical surfaces for contamination. This check shall be performed when the condition of the critical surfaces of the aircraft cannot be effectively assessed by a pre-take-off check or when the applied holdover time has been exceeded. This check is normally performed from outside the aircraft. The alternate means of compliance to a pre-take-off contamination check is a complete de-icing/anti-icing re-treatment of the aircraft.

Further operational specifics are as follows:

- Communication between the de-icing/anti-icing service provider and the flight crew: This is usually achieved using a combination of printed forms and verbal communication. For treatments carried out after aircraft doors are closed, use of flight interphone (headset) or VHF radio will usually be required. In specific situations, electronic message boards may be used and also hand signals for the final ‘all clear’ signal.
- Treatments carried out without the flight crew present: in this case a suitably qualified individual (Ground Engineer or Aircraft Maintenance Technician) shall be nominated by the aircraft operator to confirm the treatment required and to confirm correct configuration of the aircraft.
- Estimation of hold-over time: the flight crew may use tables that give an indication as to the time frame of protection that could reasonably be expected under conditions of precipitation. The responsibility for the application of these data remains with the user.
- Fluid handling: There are detailed requirements regarding storage of fluids, pumping, transfer lines, heating, and application. The relevance of these requirements is mainly that de-icing/anti-icing fluid is a chemical product with environmental impact. This is where the de-icing and anti-icing operations interface with the responsibilities and operations of the aerodrome. The

aerodrome provides the facilities for de-icing and anti-icing and is responsible for the control of safety at, and the safe use of, the aerodrome [37].

- Staff training and qualification: De-icing/anti-icing procedures must be carried out exclusively by personnel trained and qualified on this subject. For this, the service provider should have a qualification programme. AEA has a dedicated document on training for ground de-icing/anti icing [4].
- Quality assurance program: The service provider should have a quality assurance programme to monitor and maintain an acceptable level of competence. This should address a station quality assurance program, the fluid sampling procedure, and the checking procedure for aircraft de-icing anti-icing fluids

Assumptions taken in the above descriptions are as follows:

- The de-icing and anti-icing service provider is responsible for both the de-icing/anti-icing treatment and the post de-icing/anti-icing check (in practice sometimes two separate service providers are involved).
- The de-icing and anti-icing service provider exclusively uses fluids for de-icing and anti-icing (in practice also infrared technology or forced air may be used).

Situation under analysis

The de-icing/anti-icing service provider wants to become certified itself, since this is required according to the assumed novel regulations. In line with the assumed regulations, the de-icing/anti-icing service provider becomes responsible for providing a safe service in line with applicable requirements, the oversight authority is then responsible for providing oversight to this, and the air operator is no longer responsible for assuring that ground de-icing and anti-icing are done in line with requirements.

The objective of de-icing/anti-icing does not change, and remains as in the current situation. The description of the recommended way in which de-icing and anti-icing operations are being conducted, including a description of the functions and an operational concept, remains largely the same in the proposed situation. All equipment involved remains the same. However, human roles, responsibilities and procedures may change. For example, the responsibilities of the de-icing/anti-icing service provider might be expanded to include the decision to apply de-icing or anti-icing, or the pre-take-off check. Accordingly, it remains to be decided who performs which function. The following high-level functions are identified from this:

1. Determine the need for ground de-icing and anti-icing, taking into account the expected weather conditions and holdover time
2. Perform ground de-icing and anti-icing
3. Perform post de-icing / anti-icing check
4. Check aircraft for contamination in pre-take-off check

5.2.3 Initial high level architecture

An initial high-level architecture follows from the operational description of the current situation in Section 5.2.2, based on (AEA) recommendations for de-icing/anti-icing of aircraft on the ground [3], which is summarised as:

1. The air operator determines the need for ground de-icing and anti-icing, taking into account the expected weather conditions and holdover time;
2. The de-icing/anti-icing service provider performs ground de-icing and anti-icing;
3. The de-icing/anti-icing service provider performs a post de-icing / anti-icing check;
4. The air operator checks the aircraft for contamination in the pre-take-off check.

This is an initial architecture only. Depending on the further stages in this document, changes may take place, such as expanding the responsibilities of the de-icing/anti-icing service provider to include the decision to apply de-icing or anti-icing, or to include the pre-take-off check.

The precise operation of the de-icing/anti-icing service provider may depend on many factors, including:

- Location of the operation (at the gate or remote);
- Different weather conditions (including strong wind, cold, precipitation, thunderstorms, reduced visibility);
- Airline served;
- Aircraft type served;
- New airline or aircraft type served;
- Normal turn-around process or an expedited turn-around process.
- Non-nominal conditions as the limited availability of equipment, liquids, or personnel.

For the purpose of this study the following scenarios are considered:

1. Normal conditions, remote. This is a baseline scenario.
2. Normal conditions, at the gate. Difference with scenario 1 is that the hold-over time may be more limiting.
3. Poor weather conditions, remote. This scenario assumes cold, poor visibility, and strong wind. The de-icing/anti-icing service provider may therefore use more vehicles (to treat more surfaces in parallel), more attention for radio telephony, and more intensive application of the liquids.

For each of these scenarios hazards will be considered that can be caused by several of the factors that were introduced (e.g., limited availability of equipment may be a cause of poor de-icing). This includes also, e.g., the expiration of hold-over time.

5.2.4 Time-frame

It is assumed that the certification of a de-icing/anti-icing service provider will take place in 2020, and that the assumed change in regulations is then in place.

5.2.5 Expected Areas of Change

ASCOS D1.3 proposes to first identify which Areas of Change are expected within the considered time-frame, and next to identify which of these would possibly affect the change. Appendix A lists the Areas of Change [39] (version 15 November 2013), identifies which areas are relevant for certification of de-icing and anti-icing in the time frame considered (2020), and indicates the main relevant effect for the relevant areas.

5.2.6 Domains and organisations

The following figure presents relevant organisations, with the main organisations indicated in red:

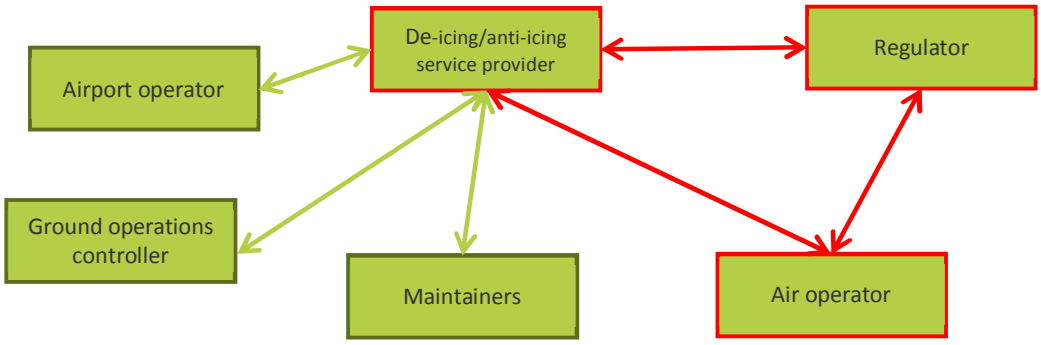

Figure 5-1: Interfaces

Besides the three organisations of main importance in this document (the de-icing/anti-icing service provider, the air operator and the regulator), this figure includes the following organisations:

- The ground operations controller. In this document it is assumed that this controller is employee of the ANSP.
- The maintainers. These are responsible for maintenance of the de-icing/anti-icing equipment.
- The airport operator. This operator is responsible e.g., for making available the location for ground de-icing/anti-icing. This usually involves also responsibility for environmental requirements.

The main changes with respect to the current situation are:

- The de-icing/anti-icing service provider becomes responsible for providing a safe service in line with applicable requirements.
- The oversight authority becomes responsible for providing oversight to the de-icing/anti-icing service provider.
- The air operator is no longer responsible for assuring that ground de-icing and anti-icing are done in line with requirements.

The following table discusses the relevant interfaces:

Table 5-1: Relevant interfaces

Interface		Relevant issues
Between	**And**	
de-icing / anti-icing service provider	regulator	The service providers take responsibility for the safety of their operations, over which the regulator will provide oversight.
air operator	regulator	The provision of ground de-icing / anti-icing service is removed from the scope of the air operator's AOC, which changes the scope of the oversight that the regulator provides to the air operator.
de-icing / anti-icing service provider	air operator	The air operator is no longer responsible for assuring the safety of the ground de-icing / anti-icing service. Further changes of responsibilities may follow; this will be considered in Stage 5.
de-icing / anti-icing service provider	ground operations controller	Possibly, the communication between the service provider and the ground operations controller may change following the defined shift in responsibility.
de-icing / anti-icing service provider	maintainers	No changes.
de-icing / anti-icing service provider	airport operator	No changes.

5.2.7 Effect on external environment

No significant relevant effects on the external environment have been identified of certifying a de-icing/anti-icing service provider.

5.2.8 Initial argument structure

The following figure provides an initial argument structure for the certification of a de-icing/anti-icing service provider. Section 2 details and enhances this initial structure.

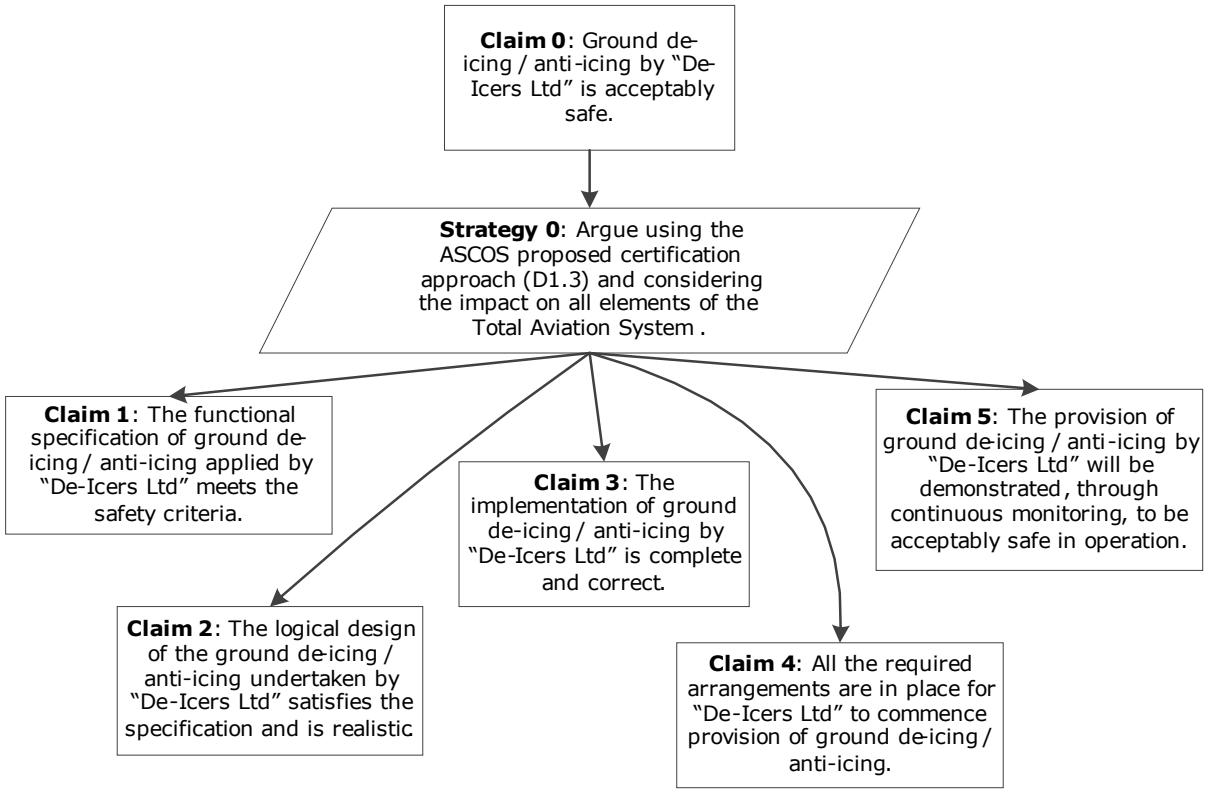

Figure 5-2: Initial argument structure for the certification of a de-icing/anti-icing service provider[2].

5.2.9 Regulations, means of compliance and guidance

Section 4.2 explained that this case study assumes that there is novel regulation in place such that the de-icing/anti-icing service provider is certified to be responsible and accountable for the procedures to be followed when ground de-icing and anti-icing and related inspections of the aircraft are necessary to allow safe operation of the aircraft. Associated means of compliance and guidance to these novel regulations could also be in place. All this material would be described here.

For comparison, Section 3.3 provided a description of relevant *current* regulations, means of compliance and guidance for ground de-icing/anti-icing.

5.2.10 Requirements

Requirements are presented in a top-down structure.

- Top-level functional requirement: the aircraft shall be free of ice when in take-off.
- Derived functional requirements are as follows:

[2] This figure and other argument structure figures make refer to "De-Icers Ltd" as the assumed hypothetical de-icing/anti-icing organization.

1. The need for ground de-icing and anti-icing must be determined, taking into account the expected weather conditions and holdover time
2. If needed, ground de-icing and anti-icing must be performed
3. After ground de-icing and/or anti-icing, a check must be performed.
4. In the pre-take-off check, the aircraft must be checked for contamination.

- Requirements at lower levels remain to be defined.

5.3 Evaluation

Once it was clear what this stage should focus on, the application of Stage 1 of the certification approach was relatively straightforward.

A main issue in the application of Stage 1 was to decide what to focus on. E.g., it was not well understood why a 'change' needs to be defined in detail, rather than the 'subject of certification', or the 'scope of the certificate'. This may specifically be the case in this case study since it focuses on certification of an organisation rather than a change or a system, and since the potential safety enhancement considered is a change to certification itself. Example questions are:

- Should the 'requirements' of Section 5.2.10 be requirements to the changed certification process, to the de-icing operation, or to the de-icing organisation?
- Should the 'architecture' of Section 5.2.3 be architecture for the change, for the changed certification process, for the de-icing operation, or for the de-icing organisation?
- To which extent should various scenarios be identified for the functions considered, and why is this the case?
- Should the scope of the certificate also be described? This could consider, e.g., methods to be applied, locations at which the service takes place, and aircraft types and air operators to be serviced.
- Should requirements regarding SMS also already be considered, and if so, why or under which conditions?

This stage also included the identification of relevant expected Areas of Change for the timeframe considered. It appeared well possible to determine which Areas of Change may be relevant, but this did deliver quite a large subset of potentially relevant areas.

6 Stage 2: Definition of the certification argument

6.1 Available guidance

This section presents the ASCOS D1.3 [9] guidance for this stage.

"The generic argument to be adopted should be chosen and developed into an argument architecture. It is proposed that, for each of the case studies, the generic argument (*cf. Section 5.2.8*) is initially adopted, unless it is evident from the outset that an alternative argument is appropriate. (In the event that alternative top level arguments are identified during the case studies, these will be documented in the presentation of the refined approach.). Note however, that variation in the argument approach is not likely to affect the modularisation of the argument as this is driven more by the existing commercial and physical partitions within the TAS. It may affect the links between modules but this should be avoided especially if it affects an existing assurance contract. At this stage the argument should identify any potential impact either on or from existing assurance contracts or modules outside the initial scope of the change. Note the full impact may not be realised until later (e.g. during implementation) but consideration should still be given to any known impacts at this stage, as they may alter or undermine key assumptions in the design of the change.

The development of the argument architecture should follow the principles identified in *[ASCOS D1.3]* section 2.2 and section 3.3. The architecture will follow existing established certification approaches where these remain appropriate (e.g. compliance with CSs for airborne equipment) while ensuring that any consequences of using this approach are fully understood and managed – for example the need to establish that the CS remains applicable within the context of the specific change. The argument should then be developed by the argument architect (see *[ASCOS D1.3]* section 2.2.1). It remains the argument architect's responsibility to maintain the argument throughout the lifetime of the change. The level to which the argument can be developed at this stage is limited until the assessment activities associated with Specification (Stage 4; *cf. Section 8*) and Design (Stage 5 – *cf. Section 9*) have been completed. However, it is important to develop the initial argument to provide a basis for development and agreement of the certification plan. The argument is then refined)."

6.2 Application

6.2.1 Overview of argument

The basic top level argument was presented in Section 5.2.8. The argument presented below (in Figure 6-1) is the same argument, with clarifying context items.

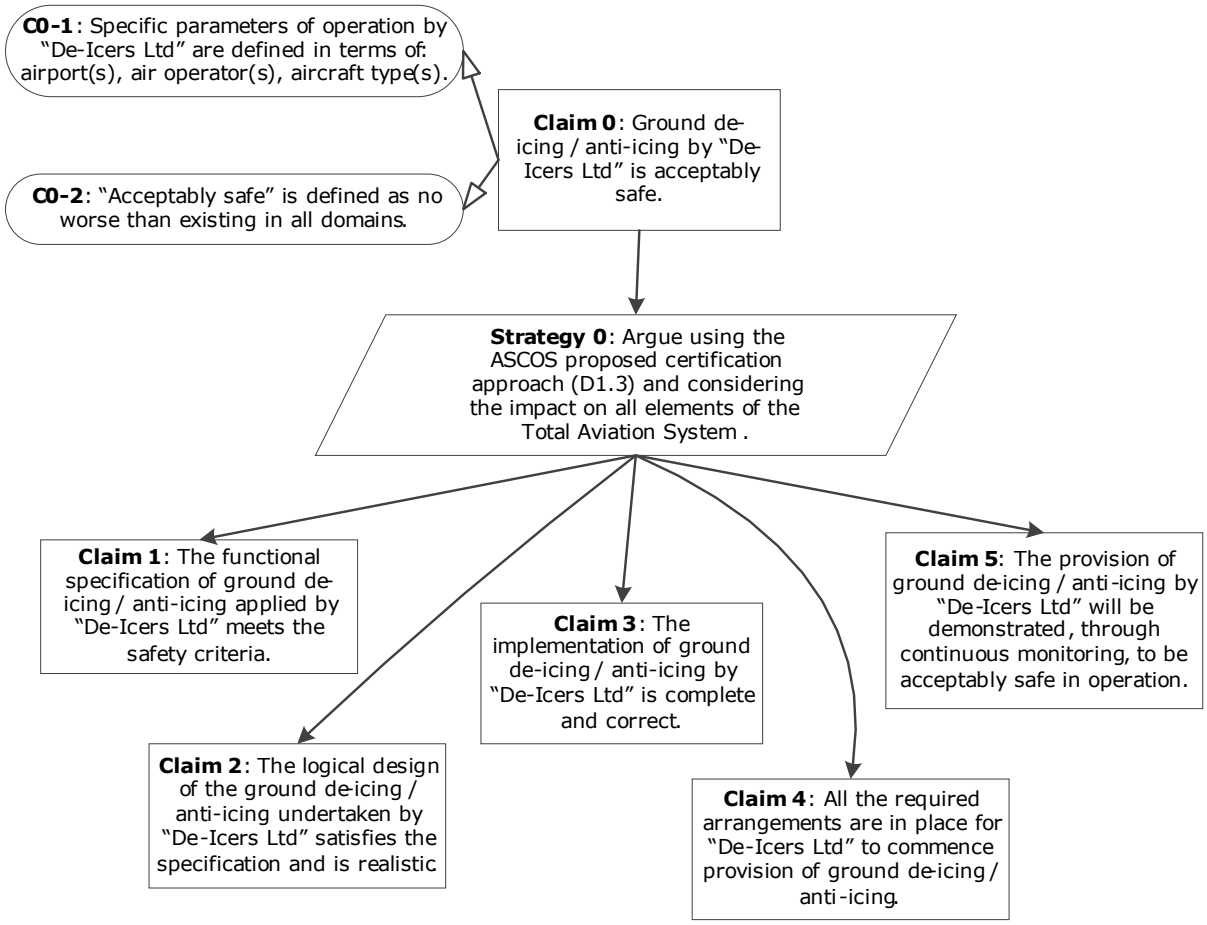

Figure 6-1: Initial argument structure for the certification of a de-icing/anti-icing service provider.

6.2.2 Top level claim

The top-level claim is that, the ground de-icing / anti-icing provided by the service provider achieves an acceptable level of safety. The following items of context provide detail to the claim being made:

- C0-1 defines the scope of operations to be provided by the service provider, in terms of the airports at which they operate, the air operators who they serve and the aircraft types for which they provide a service – this is necessary because the argument made by the operator will be specific to the parameters of the operation.
- C0-2 interprets "acceptable safety". As discussed in Section 4.2, the service provider is required to make a safety assessment for risks for which it has a 'view of safety'. For other risks it will also need to provide assurance that it delivers a required level of service. The safety assurance activities may be done using relative arguments comparing to current operations, by which it is sufficient to show that the safety risks accident scenarios for which the provider has primary responsibilities are not higher than in current operations; and the quality of the delivered service for accident scenarios to which the provider contributes is not lower than in current operations.

Other context and assumptions will be introduced at the level at which they are required when the argument is developed further.

6.2.3 Decomposition of the top level claim

The top level claim (Claim 0) is decomposed into subclaims (Claims 1 – 5), each making a "smaller" claim about the ground de-icing / anti-icing operations to be provided by the service provider. The premise of the argument is that, when taken together, the subclaims are sufficient to demonstrate that the top level claim has been achieved.

Strategy 0 documents the approach which is taken in subdividing the claim – i.e. the approach proposed in ASCOS D1.3 [9] which covers:

- Claim 1: demonstration that the (functional level) specification of what must be achieved by the service provider will achieve the required (high level) safety criteria (corresponding to Stage 4);
- Claim 2: demonstration that the (logical) design of the way in which the service provider will deliver the operation, including the interactions between the different stakeholders and the tasks which they carry out, will fulfil the specification safely (corresponding to Stage 5);
- Claim 3: demonstration that the actual arrangements for implementation of the operation (definition of SMS, procedures, training requirements, equipment and materials to be used) safely satisfy the logical design (corresponding to Stage 7);
- Claim 4: demonstration that the arrangements for migration from current arrangements to the new regime are in place (corresponding to Stage 8);
- Claim 5: demonstration that the arrangements for monitoring of the safety of the operation are in place to ensure that the required level of safety is actually achieved in practice (corresponding to Stage 9).

The following briefly discusses Claims 1 through 5. A separate subsection discusses the further detailing of Claim 1. For Claims 2 through 5, such further detailing is not included. Stage 5, corresponding to Claim 2, is tested without detailed argument. Stages 7 through 9, corresponding to Claims 3 through 5, are not in scope of the ASCOS case studies.

Claim 1: Specification of ground de-icing / anti-icing

Claim 1 is that the ground de-icing / anti-icing function delivered by the de-icing/anti-icing service provider is specified to achieve an acceptable level of safety. This considers ground de-icing / anti-icing at a conceptual level, without considering how it is actually implemented. At this level there is no consideration of equipment or specific human roles – the function considered is the abstract function of de-icing and anti-icing a plane on the ground. Claim 1 considers:

- What has to be achieved (functionally) by the de-icing function and the quality of service required to ensure safety with respect to the accident scenario of a loss of control due to surface contamination. This is an accident scenario for which the service provider does not have primary responsibility, since the pilot

eventually takes the main actions and decisions. Accordingly for this scenario the provider needs to provide arguments and evidence for sufficient "quality of service".

- The level of safety or the quality of service which must be achieved for other accident scenarios.

Part of the work of the service provider to support Claim 1 is to demonstrate that the regulations are applicable to the precise operations to be provided by the service provider. In most cases, this should be straightforward, especially if the regulations clearly define the scope of operations to which they apply.

Also part of Claim 1 is to determine the applicable safety targets, which may be available from regulations.

(Section 6.2.4 includes the feedback regarding the decomposition of Claim 1).

Claim 2: Logical design of ground de-icing / anti-icing

Claim 2 is that the logical design of the ground de-icing / anti-icing operations as provided by the de-icing/anti-icing service provider satisfies the specification which was defined in support of Claim 1 and is realistically achievable. At this level the actors implementing the provision and the interfaces between them are identified, along with the interfaces with the other elements of the TAS (including the aircraft operator, the other ground staff at the aerodrome and the aircraft manufacturer). The assessment will include these interfaces and the interactions needed to ensure the safety of the ground de-icing / anti-icing operations.

Introduction of the actors and the specific methods of de-icing / anti-icing may introduce further hazards and accident scenarios which are not evident at the functional level. For example, the hazard of collision with ground vehicles only arises because ground vehicles are used; if (for example) it were practical to use a heated hangar, this hazard would not exist. Similarly, if de-icing/anti-icing fluids are not used, the hazard of exposure to these fluids would not exist. It is noted that if the service provider would use a novel de-icing / anti-icing technique, this is where it would need to be justified.

The main assessment to support this claim will be an assessment of a logical model of the operations, using techniques which are well-established in assessing concepts (rather than equipment). In order to make a complete argument, the service provider should consider different logical models of operation and compare them to confirm that the chosen model satisfies the selected safety criteria.

It appeared difficult to develop Claim 2 of the argument. It was not clear which process could be followed to undertake the assessment to satisfy Claim 2. Also, it was not clear what kind of decomposition of the claim could be followed for this type of change, which is more of an organisational nature than of a technical nature.

Claim 3: Implementation of ground de-icing / anti-icing

Claim 3 is that the implementation of ground de-icing / anti-icing operations by the de-icing/anti-icing service provider is complete and correct. At this stage the actual equipment, procedures and staffing used to

implement the provision of ground de-icing / anti-icing are defined. The corresponding stage of the certification approach (Stage 7) is not part of the scope of this case study.

This definition would include the organisation structure of the service provider, the safety management system, any licensing requirements, and definitions of responsibilities of the different roles. The definition would also include fully detailed definitions of the interfaces between the de-/anti-icing provider and the other elements of the TAS, which would be specific to the individual airlines and airports served by the service provider. The assessment process then demonstrates that the chosen equipment, procedures and staffing fulfil the requirements derived in Claim 2.

Although decomposition of Claim 3 is not in scope, it is expected that this would encounter issues similar to those which would have been encountered for Claims 1 and 2.

Claim 4: Arrangements for operation are in place

Claim 4 is that all the required arrangements are in place for the de-icing/anti-icing service provider to commence provision of ground de-icing / anti-icing. This includes demonstrating that:

- The equipment has been procured and tested, any required spares are available and arrangements are in place to ensure suitable maintenance of the equipment;
- Suitably qualified staff have been recruited;
- Staff have been trained in the procedures; and
- Any arrangements for interfacing with other organisations (e.g. ground operations, air operator) are in place and any affected staff (e.g. pilots) have been suitably briefed.

Note: where the process of introduction of the change to operations is complex, it would also be necessary to demonstrate that the transition process itself is acceptably safe and that, where appropriate, fallback or reversion procedures are in place.

The corresponding stage of the certification approach (Stage 8) is not part of the scope of this case study.

Claim 5: Acceptable safety is maintained in operation

Claim 5 is that ongoing operations demonstrate an acceptable level of safety. When the first application is made for a certificate, the evidence in claim 5 will be largely or entirely in the form of plans for:

- Continuous safety monitoring to collect appropriate metrics to confirm the results of the safety assessments undertaken under earlier claims;
- Reporting and investigating any safety-related incidents and making any changes required as a consequence of the investigations;
- Maintaining staff competence (e.g. through refresher training);
- Maintaining equipment; and

- Assessing any subsequent changes to the operation.

During the provision of service, the above data will be collected and used by the provider to substantiate the claim with direct evidence. This evidence would then form a major part of the regular review conducted by the authority leading to periodic renewal of the provider's certificate.

The corresponding stage of the certification approach (Stage 9) is not part of the scope of this case study.

6.2.4 Decomposition of Claim 1 (Specification)

Claim 1 is that "The functional specification of ground de-icing / anti-icing applied by the de-icing/anti-icing service provider meets the safety criteria". This claim is decomposed into subclaims, in the same manner as Claim 0 was decomposed into Claims 1-5: when taken together these subclaims are sufficient to meet claim 1. The decomposition of Claim 1 is shown in Figure 6-2 and further explained below.

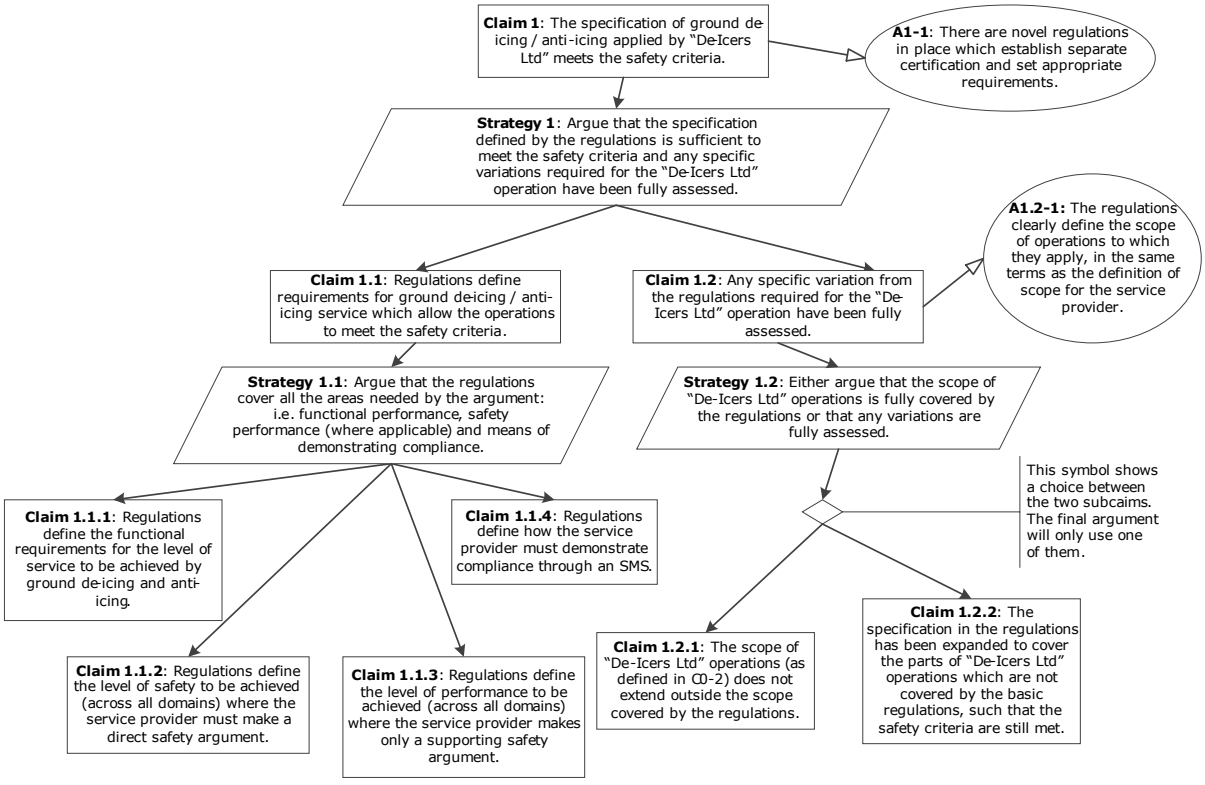

Figure 6-2: Argument structure for Claim 1 (functional specification)

The specific areas which the regulations need to cover are discussed in more detail below.

In order to support Claim 1, we need to

(a) Demonstrate that the regulations specify all the requirements for the general provision of the de-icing / anti-icing service; and

(b) Demonstrate that, if necessary, additional requirements have been set to cover any part of the de-icing/anti-icing service considered which is not fully covered by the requirements in the regulations.

Strategy 1 introduces these two strands in the argument, which are then addressed by Claim 1.1 and Claim 1.2 respectively: these are discussed in more detail below.

Claim 1.1: Regulations define generic requirements

As discussed in section 4.2, the regulations need to provide requirements in the following areas. In each case, the requirements are expected to be at a high level, in the spirit of performance-based specification, to allow the service provider a significant degree of flexibility[3] in how they choose to deliver the service.

(a) Functional performance (Claim 1.1.1): The regulations need to specify the functional performance required from the de-icing / anti-icing service provider in order to provide sufficient protection against contamination at the time of take-off. This could be done e.g., in terms of hold-over times to be achieved for specific types of aircraft and specific meteorological conditions.
(b) Level of safety (where appropriate) (Claim 1.1.2): The regulations include requirements regarding safety criteria. This will be for risks where the service provider has a view of safety - for example, collisions between ground vehicles and aircraft during the de-icing operation.
(c) Level of performance (where appropriate) (Claim 1.1.3): The regulations include requirements regarding performance levels. As discussed in section 4.2, performance criteria will be specified for risks where the service provider only has a supporting role in the demonstration of safety - for example, in the achievement of the primary objective of de-icing, i.e. preventing loss of control.
(d) Demonstration of compliance (Claim 1.1.4): The service provider will need to demonstrate that they control their service delivery so that they can assure that their operation meets the requirements. It is expected that they will demonstrate this through establishing a Safety Management System (SMS).

Claim 1.2: Specific variations are assessed

Ideally, the regulations would cover all possible variations of de-icing / anti-icing service delivery. However, it is very likely that there will be specific scenarios (e.g. aircraft types or extreme meteorological conditions) which are not covered by the regulations.

This is why it is important both that the regulations identify the scope of service to which they apply (C1.2-1) and that the scope of the service provider's activities are also defined (C0-1). When this has been done, the two scopes can be compared to check whether the service provider will be providing a service which is not covered by the scope of the regulations.

The argument shows that a choice needs to be made here (Strategy 1.2). It is necessary either:

[3] This case study assumes that the service provider operates according to established techniques and processes. However the argument structure deliberately allows flexibility to allow the development of improved processes where appropriate.

(a) To argue that the operations of the service provider do not extend outside the scope covered by the regulations (Claim 1.2.1): if the service provider can demonstrate this, then no further assessment is required to support Claim 1.2; OR
(b) To demonstrate that the specification defined in the regulations has been expanded to cover the entire scope of the service to be provided (Claim 1.2.2).

In Figure 6-2, the diamond shape below Strategy 1.2 indicates a choice – the argument (for Claim 1.2) would be satisfied by either Claim 1.2.1 or Claim 1.2.2. When developed, the final argument submitted by the service provider to obtain a certificate would only show one of these claims.

For the purposes of the case study, it is assumed that the considered services to be provided will be entirely within the scope of the regulations, and therefore it is assumed that Claim 1.2.1 will be used. For this reason, Claim 1.2.2 is not developed further here. If it were further developed it would be necessary to show how the additional scope had been assessed to develop the additional specification.

It appeared difficult to develop Claim 1 of the argument. It was not clear which process could be followed to undertake the assessment to satisfy Claim 1. Specific questions include:

- How may Claim 1 be simplified?
- Should safety management requirements already be included in Claim 1? On one hand, an SMS is required by regulations. On the other hand, it is not clear how such requirement follows from a functional specification.
- How is development of Claim 1 dependent on whether regulations already exist for the considered change, and on the nature of these regulations?
- In which situations is the D1.3 approach valid, e.g., depending on the type of change and the nature of the associated regulations?

6.3 Evaluation

It appeared difficult to determine how to develop the arguments for Claims 1 and 2; the same difficulties are also expected for Claim 3 and possibly other claims. It was difficult to understand what these claims should entail, and what exactly needs to be done in the corresponding stages. These difficulties address particularly:

- Which process can be followed for decomposing the claims;
- From which claim on and how to address safety management requirements;
- How to take into account whether associated regulations already exist, and how to do this;
- Whether the D1.3 approach is in all situations valid.

7 Stage 3: Development of and agreement over the certification plan

7.1 Available guidance

The guidance for stage 3, as provided in D1.3, is as follows:

"The role of the certification plan is to show how the certification argument architecture will be developed and substantiated with evidence to the point where it can be presented for acceptance by the relevant authorities.

The certification plan presents the argument architecture, along with the certification activities to be undertaken, including how impacts, if any, on existing assurance contracts will be addressed.

It is recognised that a given change may require endorsement from multiple authorities, each of which may only be competent to endorse the residual risk for part of the system. Thus it may not be possible for any one authority to endorse the top level of the argument. Consequently it is necessary for the certification plan to clearly define the parts of the argument which require endorsement by each authority.

The certification plan is presented to the relevant authorities and other stakeholders, to gain their agreement that, if the plan is followed and the evidence is presented, they will accept the change into service. Although lack of agreement at this stage does not prevent progress to later stages, the benefit of gaining agreement is to reduce the risk to the certification programme at later stages. This approach can be developed further into progressive certification where agreement is obtained for the argument progressively as the individual claims (Cl 1 through to Cl 5 in the generic argument (...)) as they are completed.

Stakeholders / authorities all have different perspectives and often introduce differing / additional requirements. These requirements may all (or mostly) be beneficial, but they introduce significant cost increases if they are introduced progressively through the project."

7.2 Application

The interpretation of D1.3 is that the certification plan would need the following elements:

A. *General description*: An overall description of the change, its limits and the way it is interfaced with other domains. This description is primarily intended for the experts of the authority. It may highlight relevant aspects as technical novelties, and, for changes involving multiple stakeholders, relationship with other domains. Main elements are descriptions of (A1) the change, and (A2) the interface with other stakeholders and domains.
B. *Applicable requirements, standards and related guidance*: A description of a full and consistent set of applicable regulatory requirements and related guidance material. This requires agreement with the authority, and possibly a common agreement between the different authorities involved. Also, it should include a framework on how to seek agreement on any further technical issues related to the interpretation of the regulatory requirements that may arise during the development of the change. Elements to be considered include: (B.1) the certification basis; (B.2) the claims and argument architecture; (B.3) the certification review items and issue papers; (B4) interpretative material; (B.5)

tests to be performed for new technologies for certification; (B.6) other requirements and reference documents; (B.7) a means of compliance checklist; and (B.8) the relations with certification requirements in other domains, usually in the form of assumptions.

C. *Compliance demonstration*. This is a comprehensive description of how the evidences will be produced by which all regulatory requirements are complied with. A main element, and core part of the certification plan, is formed by the list of planned certification deliverables, which requires agreement with the authority. These are documents that need either to be approved or agreed or received by the authority prior to granting the certificate. Probable elements of this list of planned certification deliverables are: (C1) a summary of the safety assessment documents, (C2) a determination of levels for the assurance of the change (e.g., Design Assurance Levels are used in the aircraft domain), (C3) assumptions between domains, (C4) test results, (C5) Human Factors considerations.

D. *Transition requirements.* This is a comprehensive description of requirements to the transition. In response to these requirements in the certification plan, usually a transition document will be developed, which is a document that lists the actions and documents needed for the transition from the old to the new situation. This may also include any "fall back scenario" in case the new situation does not work properly.

E. *Continuing safety activities*. This is an overall description of how the "continuing safety activities" will be organised in compliance with the reference standards as the response to the mandatory requirements on safety. It describes actors, activities and key outputs, including safety activity interface with partnering stakeholders. Elements are: (E1) the scope of the safety activities; (E2) the main safety actors and outputs; (E3) the relationship with the certification requirements in neighbouring domains; and (E.4) personnel training requirements.

The above parts D and E refer to the transition phase and the operational phase, which are not part of this case study. Therefore, the remainder of this section focuses on testing the development of the main elements A through C of the certification plan.

7.2.1 General description (A)

This part of the certification plan would provide an overall description of the change, the involved stakeholders and domains, their limits and the way they interface with other, unaffected or affected domains. This description is primarily directed at the authority experts, who may have to undertake the supervision of the organisational change and activities performed by the applicant. This part would highlight relevant aspects as technical novelties and changes in the organisations, especially where multiple organisations are involved.

Main elements are as follows: descriptions of (A1) the change, and (A2) the interface with other stakeholders and domains.

- (A1) A description of the change: A summary of the change is that the de-icing/anti-icing service wants to become certified itself instead of the air operator, since this is required according to the assumed novel regulations. In line with the assumed regulations, the de-icing/anti-icing service

provider becomes responsible for providing a safe service in line with applicable requirements, the oversight authority is then responsible for providing oversight to this, and the air operator is no longer responsible for assuring that ground de-icing and anti-icing are done in line with requirements. The change is described in more detail in Section 5.

- (A2) Interface with other stakeholders and domains: the interfaces between stakeholders, and the changes therein, have been summarised in Figure 5-1 in Section 5.2.6.

The output of Stage 1 of the certification approach can readily be used in the certification plan.

7.2.2 Applicable requirements, standards and related guidance (B)

(B1) Certification basis

The likely certification basis would consist of the assumed novel regulations for certification of ground de-icing/anti-icing service providers, as described in Section 4.2. Associated standards or means of compliance, and related guidance would also be described here.

For comparison, Section 3.3 provided a description of relevant *current* regulations, means of compliance and guidance for ground de-icing/anti-icing.

In addition, for those topics for which it can be known in the first step of the change that a discussion and agreement needs to be conducted with the authority, due to the specifics of the organisational change, a list of "Certification Review Items" or "Issue Papers" will be appended to the baseline. For example, the following topics can be presumed to be opened in order to agree on interpretation material:

- Change of responsibilities between the Air Operator and the service provider
- Tests for Certification (planning and extent of tests to be conducted) if new techniques are being proposed
- Human Factors considerations;
- Relationship with Certification Requirements used in other domains than the Operational domain

(B2) Claims and argument architecture: This part describes how the claims generated in Stage 2 need to be satisfied by logical arguments. This important part of the certification plan is separately discussed in Section 7.2.3.

(B.3) Issue papers and certification review items: As all aspects of certification cannot realistically be completed prior to the starting of design activities, the certification plan should propose to the authority a framework on how to seek agreement on any further technical issues related to the interpretation of the regulatory requirements and the need to consolidate the certification basis during the design and development of the change. This part would describe issue papers and certification review items issued by the authorities to cover:

a) Special conditions for novel techniques, for which no requirements exist
b) Equivalent Safety Findings

c) Additional Means of Compliance

At this moment, no such special conditions, equivalent safety findings or additional Means of Compliance are known.

(B4) Interpretative material: This part would describe interpretative material focussed on the service provider. In practice, it is likely that this will have been developed alongside the novel assumed regulations described in Section 4.2.

(B.5) Required tests for new technologies: This part would describe the required tests for new technologies. The applicant must seek agreement with the regulator on the required testing to prove the safety level of this new technology. In the case study considered, there are no new technologies.

(B.6) Other requirements and reference documents: This section would mention requirements and reference documents that have a relation with the application of the service provider. These requirements and documents are not part of the certification basis but can support the safety claim. An example of this could be a standard that describes detailed de-icing techniques, as developed by the sector itself.

(B.7) Means of Compliance checklist: This part will provide a checklist for all relevant means of compliance. All the agreed requirements and the related compliance material will be captured here. When all the requirements have been complied with and this document is duly checked-off, the regulator will be in a position to release the certificate to the service provider. Considering the hypothetical character of the regulations considered (cf. Section 4.2), not means of compliance can yet be identified. For comparison, Section 3.3 describes means of compliance currently in place.

(B.8) Relations with certification requirements in other domains: This part would describe the relations with certification requirements in other domains, and by this support the compliance process with Claim 2. At this point this claim has not been detailed. Hence, this cannot yet be described in this case study.

7.2.3 Claims and argument architecture (B2)

Here, it is described how evidence is collected to satisfy the claims in the argument architecture of Stage 2. It is of importance that this is presented to the relevant authorities and other stakeholders, to gain their agreement that, if the plan is followed and the evidence is presented, they will accept the change into service. Although lack of early agreement does not prevent progress to later stages, the benefit of gaining agreement is to reduce the risk to the certification programme at later stages. This approach can be developed further into requirements. These requirements may all (or mostly) be beneficial, but they introduce significant cost increases if they are introduced progressively through the project.

Obtaining their agreement can also be done in stages. Hence, this section is described per level as follows:

- First, the means of compliance is discussed for the high level claim and associated context;
- Next, this is done at the level of the sub-claims (1 through 5);

- Next, more detail is provided for the lower claims of claim 1.

High level claim and means of compliance

In an early stage the focus is on the top-level claim, its context, and the associated strategy:

Claim 0 is the top level safety claim that the ground de-/ anti-icing by the provider achieves an acceptable level of safety. Relevant context was provided as follows:

- C0-1 defines the scope of operations to be provided by the service provider, in terms of the airports at which they operate, the air operators who they serve and the aircraft types for which they provide a service.
- C0-2 interprets "acceptable safety". As discussed in Section 4.2, the service provider is required to make a safety assessment for risks for which it has a 'view of safety'. For other risks it will also need to provide assurance that it delivers a required level of service (Assumption A5). For both, it is assumed to be sufficient to provide evidence that the safety performance does not decrease (Assumption A6).

The main strategy to provide evidence for this claim was described as follows:

- *Strategy 0*: Argue that the provider achieves an acceptable level of safety, using the ASCOS proposed certification approach and considering the impact on all elements of the TAS.

In this stage it is of importance that agreement is reached over the context elements, and the strategy to be followed. Accordingly:

- The required level of safety will need to be agreed upon. This could include considering the current level of safety combined with the required improvement as defined by EASA in their Safety Plan. In this case, it has been assumed that the current level of safety and level of quality are required levels.
- Agreement is reached over the conditions in which the service provider takes action. These are not crisply defined; the likely requirement is that the service provider must take action based on the inspection of aircraft if the conditions are "conducive to ice accretion". This philosophy is not likely to change in the near future. There have been attempts to design systems that can measure ice accretion on aircraft services, but these have not been found acceptably reliable yet.
- Agreement is reached over the main requirements and acceptable means of compliance. By complying with those requirements, the applicant shows compliance with the required safety level. This can also require that a check of whether the rules and standards are an adequate argument to satisfy the claims. It must also be checked whether the assumptions that are used between the domains are adequately addressed.

The following feedback to the D1.3 approach is provided:

- It is not always clear in the process where and when coordination between stakeholders and domains needs to take place.
- It is not so clear at which stage in the process the safety targets are to be defined, nor who is responsible

for the safety target. A risk of not having the safety target right at the beginning is that it may be difficult for the applicant to start the application procedure. A risk of overly ambitious safety targets is that it may preclude a profitable business, which is likely to be unacceptable to the applicant.

- It is not so clear which elements need to be included as context to the main Claim 1. E.g.,:
  - One could include as context that the plan is to work as much as possible in line with the currently applicable de-icing regulations and standards.
  - One could include that even though the change includes demonstration of a required safety level and the implementation of a SMS, the main difference with current operations may lie in the division of responsibilities. These will have to be defined in detail and laid down in the compliance documents.

Sub claims and means of compliance

Claim 1 is that the ground de-icing / anti-icing function delivered by the de-icing/anti-icing service provider is specified to achieve an acceptable level of safety. This considers ground de-icing / anti-icing at a conceptual level, without considering how it is actually implemented. At this level there is no consideration of equipment or specific human roles – the function considered is the abstract function of de-icing and anti-icing of an airplane on the ground. The means of compliance argument for Claim 1 is summarised in the following strategy:

- *Strategy 1:* Argue that the specification as defined by the regulations is sufficient to meet the safety criteria and any specific variations required for the provider's operation have been fully assessed.

The main assessment to support Claim 1 will be an assessment of the operations at a conceptual level, using a technique that assesses the process of ground de- anti icing operations and establishes safety objectives for those operations. This is likely to be a relative assessment, which compares the operations with current operations, and assesses the associated change in level of safety. This strategy is further detailed using more detailed claims and compliance arguments below under a separate header.

Claim 2 is that the logical design of the ground de-icing / anti-icing operations as provided by the de-icing/anti-icing service provider satisfies the specification which was defined in support of Claim 1 and is realistically achievable. At this level the actors implementing the provision and the interfaces between them are identified, along with the interfaces with the other elements of the TAS (including the aircraft operator, the other ground staff at the aerodrome and the aircraft manufacturer). This will require an assessment that includes these interfaces and the interactions needed to ensure the safety of the ground de-icing / anti-icing operations. The associated means of compliance argument could include:

- A main assessment of a logical model of the operations and the establishment of requirements. This model needs also to take into account all the assumptions that are coming from the other domains, in line with element CO-1. It will be argued that the techniques currently used are effective[4].

Claim 3 is that the implementation of ground de-icing / anti-icing operations by the de-icing/anti-icing service provider is complete and correct. At this stage the actual equipment, procedures and staffing used to implement the provision of ground de-icing / anti-icing are defined. For the associated means of compliance argument this could mean:

- The applicant will show that the actual procedures documented and used by the applicant fulfil the requirements as derived in Claim 2.
- The applicant must show that all the assumptions as coming from other domains are still fulfilled.

Claim 4 is that all the required arrangements are in place for the de-icing/anti-icing service provider to commence provision of ground de-icing / anti-icing. The associated means of compliance argument could include evidence that:

- The equipment has been procured and tested, any required spares are available and arrangements are in place to ensure suitable maintenance of the equipment.
- Suitably qualified staff has been recruited.
- Staff has been trained in the procedures.
- Any arrangements for interfacing with other organisations (e.g., ground operations, air operator) are in place and any affected staff (e.g., pilots) have been suitably briefed.
- The transition between the old and the new process is properly documented and organized. Where appropriate, fall back or reversion procedures are in place.

Claim 5 is that ongoing operations demonstrate an acceptable level of safety. The associated means of compliance argument could include:

- Continuous safety monitoring to collect appropriate metrics to confirm the results of the safety assessments undertaken under earlier claims.
- Reporting and investigating any safety-related incidents and making any changes required as a consequence of the investigations.
- Maintaining staff competence (e.g. through refresher training).
- Maintaining equipment.
- Assessing any subsequent changes to the operation.

The following feedback to the D1.3 approach is provided:

- Once claims 1 through 5 are defined, it is reasonably well possible to describe in generic terms how the associated evidence will be collected.

[4] If the way of working will be different from the current standard, the applicant will argue the effectiveness to the authority by tests. In that case new requirements need to be defined.

Decomposition of sub claim 1 and means of compliance

Claim 1.1 states that regulations define requirements for ground de-icing and anti-icing service. The associated means of compliance argument could include evidence that the regulations cover all the areas needed by the argument; i.e. functional performance, safety performance (where applicable) and means of demonstrating compliance. To this end, it is subdivided into sub claims as follows:

- *Claim 1.1.1*: Regulations define the functional requirements for the level of service to be achieved by ground de-icing and anti-icing.
- *Claim 1.1.2*: The regulations include requirements regarding safety criteria. This will be for risks where the service provider has a view of safety - for example, collisions between ground vehicles and aircraft during the de-icing operation.
- *Claim 1.1.3*: The regulations include requirements regarding performance levels, specifically for risks where the service provider only has a supporting role in the demonstration of safety (e.g., preventing loss of control).
- *Claim 1.1.4*: Regulations define that the service provider demonstrates that they control their service delivery so that they can assure that their operation meets the requirements. Evidence to this is provided by means of the SMS. It is expected that the regulations will provide clear requirements for this SMS.

The following feedback to the D1.3 approach is provided:

- It is not fully clear for which elements of Claim 1.1 the applicant is responsible, and for which the authority. Specifically the authority may define the target level of safety, or may need to accept a level defined by the applicant.

Claim 1.2 states that any specific variation from the regulations required for the considered de-icing/anti-icing operation have been fully assessed. To this end, it shall either be argued that the scope of the provider's operations is fully covered by the regulations or that any variations are fully assessed. For this, one of the following sub-claims is used:

- *Claim 1.2.1*: the scope of the considered de-icing/anti-icing operation (as defined in CO-2) does not extend outside the scope covered by the regulations; OR
- *Claim 1.2.2:* the specification in the regulations has been expanded to cover the parts of the considered de-icing/anti-icing operation that are not covered by the regulations, such that the safety criteria are still met.

The following feedback to the D1.3 approach is provided:

- It is not fully clear for which elements of Claim 1.1 the applicant is responsible, and for which the authority. Specifically the authority may define the target level of safety, or may need to accept a level defined by the applicant.
- It is not clear from the available guidance which type of assessment is needed, and how it is performed.
- The difference between Claims 1.2 and 1.2.2 is not clear.

- It is not specified whether the limitations in scope will form part of the certificate limitations.

7.2.4 Compliance demonstration (C)

This part of the certification plan would describe the work to comply with the Means of Compliance as described in Section 7.2.2. The regulator would, in the end, use this section in order to check whether the certification basis is properly complied with. The Means of Compliance checklist (Section 7.2.2, (B.7)) would then be used to check the completeness.

As listed in section 7.2 the probable deliverables are:

C1. Summary of the Functional Hazard Assessment and System Safety Assessment
C2. Determination of levels for the assurance of the change (e.g., Design Assurance Levels are used in the aircraft domain)
C3. Assumptions between domains9
C4. Test results
C5. Human Factors considerations

7.3 Evaluation

The main observations from the application of Stage 3 (Development of and agreement over the certification plan) to this case study are as follows:

- Many parts of this stage of the certification approach appeared in principle relatively straightforward to apply, once it was clear what this stage should focus on.
- The application the certification approach seems to be rather heavy compared to the technical complexity of the change. Looking at the decomposition of the claims, it can be seen that the lower claims are not very different from the higher claims. This could indicate the lack of complexity of the change. In fact, the change is mainly the change of the responsible party. The way of working itself may not be very different.
- On the other hand, this case study considers a change with a significant number of stakeholders and domains involved, and it has a focus on changing responsibilities. Although Claim 2 does mention this element, it is unclear how the argument structure tackles a complexity of this kind.
- It is not clear how the argument structure covers the issue of which type(s) of regulators are involved. For example, it needs to be specified whether EASA or the National Authority will be responsible for the oversight over the service provider.
- The wording of the arguments is such that it may be difficult for applicants to grasp the exact meaning of the claims. Example terms are: functional specification, logical design, complete and correct implementation, required arrangements, functional performance, et cetera.
- As one result of this stage, there is an acceptable set of documents that need to be provided to and agreed with the regulator. In this way, application of this stage seems to be successful. The available

guidance in D1.3 does not seem to be sufficient to guide an applicant for this kind of change to a successful completion of the application.

It is noted that application of this stage could have been easier in case the regulations against which to certify were available, instead of a set of assumptions regarding such regulations.

8 Stage 4: Specification

8.1 Available guidance

It is reminded from Section 1.3 that this study has a more exploratory character for Stages 4 and 5 than for the previous stages. This section firstly summarises guidance for this stage as available from ASCOS D1.3 [9] and from an additional note developed over the course of ASCOS WP4.3 [16].

The guidance for this stage from ASCOS D1.3 [9] is summarised as follows:

"This stage is focused on demonstrating that Claim 1 of the generic argument is met, namely that the change is specified to achieve an acceptable level of safety. (...) this focuses on the behaviour of the changed system in the absence of failure – i.e. does the changed system sufficiently mitigate the pre-existent hazards within the TAS? As part of this stage the argument for Claim 1 is fully developed and substantiated with relevant evidence.

Safety assessment in this stage is used to identify the pre-existing hazards relevant to the system and assesses the consequences of these hazards on the safety of the TAS. This assessment is used to derive definitions of:

- The safety objectives for the system;
- The safety requirements which specify what the system is required to do (not how it does it) in order to achieve the safety objectives;
- The degree of assurance required that the system will meet its requirements;
- Any additional functionality requirements or assumptions to capture any external means of mitigating the consequences of the hazards caused by failure of the system.

The techniques developed as part of WP3 provide support to this assessment. However, it should be noted that many of these techniques focus on the assessment of hazards resulting from system failure.

At this stage the modularisation is reassessed to make sure all relevant external modules and any assurance contracts are linked and impacts identified. This will include an initial assessment of claim / context matching based on the context captured to support Claim 1, especially any scoping statements, assumptions and dependencies or other claims that are needed to support the argument under Claim 1.

The safety assessment in this stage broadly aligns with the FHA process as further described in (...)[5]".

A briefing guide regarding this stage [16], developed by one of the D1.3 authors for WP4.3, provides additional guidance. It firstly highlights the following:

- The assessment does more than just consider the failures of the ground de/anti-icing process. The first stage of the assessment is to understand how ground de/anti-icing (when it functions as designed) mitigates external hazards within the TAS. This assessment includes variations in the process which are

[5] The document refers to a reference to EUROCAE ED-79A [27] (also available as SAE ARP4754A) and SESAR Safety Reference Material [44].

due to the state of the TAS (e.g. severe weather, fast turnarounds) but which are not due to failure of the ground de/anti icing process itself.

- The assessment is undertaken at the operational level, considering how the proposed change will affect the Total Aviation System (TAS). The impact on all parts of the TAS must be considered, including effects on e.g., aircraft performance, ground operations, ATM and other air traffic.
- The Stage 4 assessment avoids identifying actors and does not contribute towards definition of the interfaces between different parts of the TAS; that is left for Stage 5.
- The process is similar to the FHA (Functional Hazard Assessment) process described in the Eurocontrol publication Safety Assessment Made Easier [29] (adapted from the earlier Safety Assessment Methodology (SAM) [28]), but it is applied at a higher level than usual assessments in the aircraft domain.
- This material also clarifies that the hazards focused upon should be "external hazards" rather than "pre-existing" hazards. It states that an external hazard is one which is already present in the aviation environment, which the function under consideration (in this case ground de-icing / anti-icing) is designed to mitigate.

The briefing note [16] proposes the following steps in performing Stage 4: "

1. Define the reference scenario for ground de-icing / anti-icing at an abstract functional level: at this level the process of de-icing / anti-icing (including the activities currently undertaken by the flight crew) is described, but without identifying the actors in the process. (...)
2. Identify the hazards to be considered during the assessment. (...)
3. Define high level safety requirements for each stage of the process: these define the safety properties which must be achieved by the process in order to mitigate the hazards identified in step 2. (...)
4. Identify and analyse variant scenarios:
   a) Identify different ways in which ground de-icing / anti-icing might be undertaken due to variations in initial conditions (e.g. extreme weather, short turn-around time, different aircraft types).
   b) Describe these scenarios at the same level of abstraction as the reference scenario.
   c) Assess the impact of these scenarios on the safety of all affected parts of the TAS, using an agreed severity scale (...).
   d) Derive any additional safety requirements required to mitigate these consequences.
5. Identify and analyse failure scenarios:
   a) Identify ways in which the ground de-icing / anti-icing process could fail, concentrating on the effects of the failure: causes are assessed in Stage 5 of the process.
   b) Assess the impact of these failure scenarios on the safety of all affected parts of the TAS, using an agreed severity scale.
   c) Derive any additional safety requirements required to mitigate these consequences."

The note also includes example scenarios, hazards, and requirements for steps 1 through 3 above, and proposes an initial severity scale for step 4c above, derived from ICAO's Safety Management Manual [35].

8.2 Application

This section tests Stage 4 and possible supporting tools by exploring how the application would go for the case study. To this end, it is discussed how the application of the stage using the available guidance would go, typically using examples, and while collecting feedback to the certification approach and the supporting guidance. This section follows the 5 steps in performing Stage 4 that are proposed in the briefing guide [16].

8.2.1 Definition of reference scenario

The guidance for Stage 4 proposes as first step the definition of the reference scenario. Section 5.2.2 already described the overall process of de-icing/anti-icing, including the following reference scenario:

1. Determine the need for ground de-icing and anti-icing, taking into account the expected weather conditions and holdover time
2. Perform ground de-icing and anti-icing
3. Perform post de-icing / anti-icing check
4. Check aircraft for contamination in pre-take-off check

Step 1 of the guidance for Stage 4 [16] can straightforwardly be applied. Its added value is not completely understood, since step 1 describes activities that also were conducted as part of Stage 1.

8.2.2 Identification of hazards

The guidance for Stage 4 [16] proposes as second step the identification of the hazards to be considered in this stage. The approach taken here is to first consider a large and diverse set of hazards of possible relevant hazards for this stage, and only then consider which ones are indeed to be considered.

A large set of de-icing / anti-icing hazards is available from the Resilience2050 project [42]. This source seems to use a wider hazard definition than the briefing note [16] for Stage 4, which mentions a small number of example hazards which appear to be all on a certain interface. In line with e.g., the definitions of ICAO's Safety Management Manual [35] and the EC regulations for ATM/ANS EC 1035/2011 [19] here the wider definition is adopted, since this way more relevant hazards can be identified. The later analysis can then still focus on hazards on a certain interface, taking into account other hazards that can be considered causes or associated consequences.

The hazards from Resilience2050 [42] are of an operational type, and related to a loss of control of an aircraft due to problems involving ground de-icing/anti-icing. This ASCOS case study has a different scope, in which complimentary types of hazards are relevant such as:

- Hazards related to collisions between a de-icing vehicle and the aircraft (e.g., aircraft allowed to taxi out before de-icing vehicles have been removed from the aircraft); and

- Hazards related to the functioning of the Safety Management System that the service provider has to establish according to the assumed regulations (e.g., de-icing service provider not aware of new changes to regulations, earlier identified safety problem not solved due to poor SMS).

Furthermore, it is noted that hazards describing the event of an aircraft taking off without appropriate de-icing/anti-icing are not yet included. Hence, a small number of additional hazards are added, as identified by the writers of this report. The resulting list of hazards from Resilience2050 [42] and complementary hazards is included in Appendix B.

In Stage 4 only a subset of hazards is to be considered. The original D1.3 description [9] of the certification approach and the available briefing guide regarding this stage [16] provide different descriptions of this subset:

- D1.3 proposes to focus on *pre-existent* hazards, i.e., "the behaviour of the changed system in the absence of failure – i.e. does the changed system sufficiently mitigate the pre-existent hazards within the TAS?"
- The briefing note uses the term *external* hazards: "an external hazard is one which is already present in the aviation environment, which the function under consideration (in this case ground de-icing / anti-icing) is designed to mitigate."

The latter description still leaves room for ambiguity: the term "*external* hazards" suggests that a hazard such as ATC delay during taxiing and line-up (hazard 37), weather deterioration between gate and take-off; anti-icing should have been done (4), and flight crew does not notice engine problems during take-off (45) are of relevance, since they consider actors, actions or events outside the scope of the de-icing/anti-icing service provider. These are however not hazards that the function under consideration is designed to mitigate. Taking this latter description as leading, the hazard selected for Stage 4 is the one related to ice adversely affecting the performance or controllability of an aircraft in take-off (hazard 60).

Step 2 of the guidance for Stage 4 can reasonably well be applied, but some questions remain:

- There is confusion about which hazards are to be addressed in Stage 4. The terms 'pre-existing' hazards and 'external' hazards and the associated definition (hazards already present in the aviation environment, which the function under consideration is designed to mitigate) seem to address different subsets of hazards.
- It is not clear which hazard definition is used. Regulations generally use a wide definition (e.g., "any condition, event, or circumstance which could induce an accident" [35], while the guidance seems to suggest a definition restricting to events on a certain interface.

8.2.3 Definition of high-level safety requirements

The guidance for Stage 4 [16] proposes as third step the identification of high level safety requirements are defined for each stage of the de-icing/anti-icing process. These requirements should mitigate the hazards listed in Step 2. The guidance includes a number of example high-level safety requirements (e.g., "aircraft surfaces shall be checked for contamination to determine the need for ground de-icing".

Accordingly, each of the four steps of the de-icing/anti-icing process listed in Section 8.2.1 is considered, and a high-level safety requirement is defined that is aimed at preventing the hazards selected in 8.2.2. This straightforwardly leads to the following high-level safety requirements:

HSR1. The need for ground de-icing and anti-icing shall be determined, taking into account the expected weather conditions and holdover time.

HSR2. If there is a need, ground de-icing and anti-icing shall be performed.

HSR3. After ground de-icing/anti-icing, a post de-icing / anti-icing check shall be performed.

HSR4. After ground de-icing/anti-icing, the aircraft shall be checked for contamination as part of the pre-take-off check.

It is reminded from Section 6.2.3 that Stage 4 aims to address Claim 1 of the certification argument. From Section 6.2.4 it is known that Claim 1 consists of a sub-claim 1.1 corresponding to generic requirements for a reference scenario and a sub-claim 1.2 corresponding to specific requirements for variant and failure scenarios. Sub-claim 1.1 was further subdivided into three sub-claims 1.1.1 (functional performance), 1.1.2 (level of safety), and 1.1.3 (demonstration of compliance).

The identification of above high-level safety requirements seems to satisfy the guidance for step 3 of Stage 4 [16]. The identified high-level safety requirements however all address sub-claim 1.1.1. It is suspected that high-level safety requirements need to be identified as well for sub-claims 1.1.2 and 1.1.3 (cf. Section 6.2.4).

Sub-claim 1.1.2 considers the level of safety to be achieved. It is not clear how a high-level safety requirement can be identified for this following the guidance [16] for stage 4. Nevertheless, a plausible high-level safety requirement seems to be:

HSR5. The de-icing/anti-icing operation shall satisfy the selected target level(s) of safety.

Sub-claim 1.1.3 considers the demonstration of compliance to the regulations that require the service provider to have an SMS. From this another high-level safety requirement is easily identified:

HSR6. The de-icing/anti-icing service provider shall have an SMS.

Step 3 of the guidance for Stage 4 can reasonably well be applied. The main questions identified or remaining are:

- It is not clear whether high-level safety requirements should be identified only considering the de-icing *operations*, as was the result following the guidance [16], or whether high level safety requirements should also be identified for other claims in the certification argument, regarding e.g., safety management and regarding required level of safety.
- In the latter case, it is not fully clear how high level safety requirements should be identified for claims of the certification argument that do not consider the operations, but e.g., safety management and regarding required level of safety.

8.2.4 Identification and analysis of variant scenarios

The guidance for Stage 4 [16] proposes as fourth step the identification and analysis of variant scenarios. For this, it lists several sub-steps, as listed in Section 8.1. These are considered in the following:

a) "Identify different ways in which ground de-icing / anti-icing might be undertaken due to variations in initial conditions (e.g. extreme weather, short turn-around time, different aircraft types)": In Section 5.2.3 one reference scenario and two such variant scenarios were identified:
   1. Normal conditions, de-icing at a remote location (reference scenario).
   2. Normal conditions, but de-icing at the gate instead of remote.
   3. Poor weather conditions, de-icing at remote location.

b) "Describe these scenarios at the same level of abstraction as the reference scenario." This would go completely similar as the description of the reference scenario in Section 8.2.1.

c) "Assess the impact of these scenarios on the safety of all affected parts of the TAS, using an agreed severity scale". The available guidance proposes a severity scale from ICAO's Safety Management Manual [35] for this (see Table 8-1). It is not well understood how the two variant scenarios selected in step a) can be associated with a severity.

d) "Derive any additional safety requirements required to mitigate these consequences." Safety requirements could not be retrieved this way since sub-step c) could not be completed. Nevertheless, a logical high-level safety requirement in line with the already identified HSR1 through HSR6 is straightforwardly identified:

HSR7. High-level safety requirements HSR1 through HSR6 shall also apply in scenarios 2 and 3.

Table 8-1: Severity scale from ICAO's Safety Management Manual [35]

		Severity Description					
Level	Descriptor	Safety of aircraft	Physical Injury	Damage to assets	Potential revenue loss	Damage to environment	Damage to corporate reputation
1	Insignificant	No significance to aircraft-related operational safety	No injury	No damage	No revenue loss	No effect	No implication
2	Minor	Degrades or affects normal aircraft operational procedures or performance	Minor injury	Minor damage Less than $__	Minor loss Less than $__	Minor effect	Limited localized implication
3	Moderate	Partial loss of significant/major aircraft systems or results in abnormal flight operations procedure application	Serious injury	Substantial damage Less than $__	Substantial loss Less than $__	Contained effect	Regional Implication

		Severity Description					
Level	Descriptor	Safety of aircraft	Physical Injury	Damage to assets	Potential revenue loss	Damage to environment	Damage to corporate reputation
4	Major	Complete failure of significant/major aircraft systems or results in emergency application of flight operations procedures	Single fatality	Major damage Less than $__	Major loss Less than $__	Major effect	National Implication
5	Catastrophic	Aircraft/hull loss	Multiple fatality	Catastrophic damage More than $__	Massive loss More than $__	Massive effect	International

Step 4 of Stage 4 could thus be applied, but not following the detailed sub-steps a) through d) in the guidance for Stage 4 [16]. The main questions remaining are:

- Many separate scenarios can be considered in operations. Which ones should be distinguished as 'variant scenarios'?
- Why do separate high-level safety requirements need to be identified for variant scenarios, and is it not sufficient to require that the high-level safety requirements and/ or associated safety targets should take into account variant scenarios?
- What is the role of severity assessment in the analysis of variant scenarios, considering that variant scenarios are usually still nominal situations, especially since these variant scenarios are here still considered without the occurrence of hazards?

8.2.5 Identification and analysis of failure scenarios

The guidance for Stage 4 [16] proposes as fifth step the identification and analysis of failure scenarios. For this, it lists several sub-steps, as listed in Section 8.1. These are considered in the following:

a) "Identify ways in which the ground de-icing / anti-icing process could fail, concentrating on the effects of the failure": This is understood as the identification of different types of scenarios that could occur as a consequence of the hazard selected in step 2 (Ice adversely affects the performance or controllability of an aircraft in take-off). Essentially, the consequence of this hazard is a reduced controllability or performance of the aircraft, which could end up in a rejected take-off, a loss of control, and disruption of the traffic flows.

b) "Assess the impact of these failure scenarios on the safety of all affected parts of the TAS, using an agreed severity scale". Using the types of consequences identified and Table 8-1, this could go as follows:
   - Severity of a loss of control could range from major to catastrophic;
   - Severity of a rejected take-off could range from minor to catastrophic;
   - Severity of a disruption of traffic flows would be insignificant.

c) "Derive any additional safety requirements required to mitigate these consequences." Assuming that the selected safety targets state that the risks per flight may not increase when compared to current operations, this provides the following high-level safety requirement:

HSR8* The probability that ice adversely affects the performance or controllability of an aircraft in take-off in such a way that it ends up in a loss of control or rejected take-off with catastrophic consequences shall not be higher than in current operations.

For lower severity classes similar high-level safety requirements may be identified. The high-level safety requirement above for catastrophic consequences can be further specified using the safety risk assessment tool [14]. One of the event sequence diagrams of this tool, ESD ASC-6, represents a scenario in which ice adversely affects the performance or controllability of an aircraft in take-off. This event sequence diagram has one end state with catastrophic consequences: a collision with the ground. Event sequences in which an aircraft rejects its take-off due to icing are not included in this event sequence diagram; apparently such event sequences are not included in the historic occurrence data set used for development and quantification of the tool.

The probability of the catastrophic scenario in which ice adversely affects the performance or controllability of an aircraft in take-off is $1.88 \cdot 10^{-8}$ per flight according to the tool [14]. This provides the following alternative formulation of HSR8:

HSR8. The probability that ice adversely affects the performance or controllability of an aircraft in take-off in such a way that it leads to catastrophic consequences shall not be higher than $1.88 \cdot 10^{-8}$ per flight.

Step 5 of the guidance for Stage 4 could be applied, and it seems it generally leads to sensible high level safety requirements. Questions remaining are:

- What exactly is the role and added value of the arguments and claims in the determination of these high-level safety requirements?
- It is not so clear what the failure scenarios exactly are, and/ or how the approach deals with the various severity classes that may apply to a failure scenario.
- Claim 1 also considers safety management; the role of this in these failure scenarios is not clear.

8.3 Evaluation

With some puzzling, it seems reasonably possible to complete Stage 4 of the process. It is not clear how the argument structure of Stage 2 should drive this process; the process was mainly done by pursuing the Stage 4 objectives, with help of the available guidance [9] [16]. The main questions that did arise were:

- The role of safety regulations and safety management in Claim 1 and in the definition of associated high level safety requirements is not well understood.

- The role of variant scenarios and their necessity is not well understood. As an example, questions arose to the application of severity classification to such scenarios. It seems to be sufficient to require that the high-level safety requirements and/ or associated safety targets should take into account variant scenarios.
- What exactly is the role and added value of the arguments and claims in the determination of high-level safety requirements?

Furthermore, several questions were identified regarding the available guidance [16]; these are considered to be of a more detailed character and consider, e.g., the added value of step 1 of the guidance, the formulation and definition of the type of hazards to be covered in stage 1, the hazard definition used, the role of severity analysis in failure scenarios analysis.

9 Stage 5: Design

9.1 Available guidance

This section summarises guidance for this stage as available from ASCOS D1.3 [14] and additional notes developed over de course of ASCOS WP4.3. The guidance from ASCOS D1.3 [14] is summarised as follows:

"This stage is focused on demonstrating that Claim 2 of the generic safety argument is met, namely that the logical design for the change satisfies the specification derived within Claim 1.

Safety assessment at this stage considers what the elements of the logical design need to do to ensure safety and the degree of assurance required. Requirements derived during this stage are set without necessarily prejudging how that design should be physically implemented. However, the assessment also needs to consider the achievability of any requirements and therefore must consider whether the requirements can be met (at least in principle) by the preliminary design.

This stage identifies hazards resulting from failures of the system and produces a set of Design Safety Requirements (DSRs) which define what each element of the design has to do, in terms of functionality and performance, in order to mitigate these hazards. This stage also demonstrates that the design would actually work as intended under all expected normal and abnormal conditions. The assessment should also identify high level causes of system-generated hazards and specify Safety Assurance Requirements for each element of the design.

The main output of the safety assessment is as follows:

- Design Safety Requirements for each element of the logical architecture, as necessary to provide the functionality and performance specified in the specification stage.
- Safety Assurance Requirements for each element of the logical architecture, as necessary to satisfy the level of assurance specified in the specification stage.
- Additional Design Safety Requirements (or assumptions, where appropriate) to capture any internal means of mitigating the causes of the hazards arising from failure of the system."

The document defines the logical design as: "a high-level architectural representation of the system, independent from the physical implementation. As such it considers the functions provided by the system elements (i.e. human roles and tasks and machine-based functions), but not the equipment, personnel or procedures which provide these functions".

Additional guidance for this stage is available from a briefing guide [17] for one of the other case studies, WP4.2. It proposes the following steps in performing Stage 5: "

1) Identify the logical elements of the design – including the external elements, so that interfaces with these are fully explored;
2) Assess how the elements work together to satisfy the high level safety requirements;
   a) including the interfaces with external elements;

b) exploring the same scenarios identified in Stage 4 – this could be done using sequence diagrams;
c) thus identifying the Design Safety Requirements for each element of the logical architecture;

3) Assess what could fail within each of the logical elements (and in the interfaces between them);
   a) by considering how the failures identified at Stage 4 could be caused (this may reveal additional ways in which the logical elements could fail);
   b) by considering whether there are any other ways in which the logical elements could fail (this may reveal additional failures at the Stage 4 level);
   c) by considering what mitigating requirements (additional design safety requirements) are needed to prevent these failures;
4) Assess the levels of development assurance needed to ensure that the mitigating requirements (see 3)c)) are successful in making the system sufficiently safe;
5) Confirm that the system as designed will meet the requirements, including the required level of safety performance."

The note furthermore presents how development of a "sequence diagram" may assist in ensuring that the interactions between logical elements are fully explored.

9.2 Application

This section tests Stage 5 and possible supporting tools by exploring how the application would go for the case study. To this end, it is discussed how the application of the stage using the available guidance would go, typically using examples, and while collecting feedback to the certification approach and the supporting guidance. This section follows the 5 steps in performing Stage 5 proposed by the guidance [17]. Considering the exploratory character of this section, the focus in the provision of feedback is on the identification of remaining questions.

9.2.1 Identification of logical elements

The guidance for Stage 5 [17] proposes as first step the identification of the logical elements in the design, including external elements. This considers "the functions provided by the system elements (i.e. human roles and tasks and machine-based functions), but not the equipment, personnel or procedures which provide these functions" [14].

The previously identified functions (cf. Sections 5.2.2 and 8.2.1) are:

- Determine the need for ground de-icing and anti-icing, taking into account the expected weather conditions and holdover time
- Perform ground de-icing and anti-icing
- Perform post de-icing / anti-icing check
- Check aircraft for contamination in pre-take-off check

It is understood that at this stage, roles/ tasks and functions must be determined at a deeper level, e.g.,:

- Determine/ assess weather conditions;
- Determine associated hold-over time;
- Determine need for ground de-icing and anti-icing;
- Determine types of fluids to be applied;
- Determine quantity of fluids to be applied;
- Determine areas of aircraft to be treated;
- Apply de-icing and anti-icing fluids to areas to be treated; et cetera.

It is not exactly understood at what level exactly this should be done, nor what is to be considered an internal element, and what an external element.

The main questions arising in step 1 of the guidance for Stage 5 are:

- What is the exact level at which the elements are to be identified?
- What is the exact scope to be covered in identifying logical elements, and which elements and which stakeholders are considered to be internal elements, and which external elements? It seems strange that Stage 4 and step 1 of Stage 5 do not yet distinguish to which stakeholders functions are allocated, but that there is already a consideration of 'internal' and 'external' events.
- How exactly does the identification of internal and external elements lead to the identification of interfaces?

9.2.2 Assessment of interaction versus high level safety requirements

The guidance for Stage 5 [17] proposes as second step the assessment of how the various stakeholders work together to satisfy the high level safety requirements. It proposes to do this including the interfaces with external elements, and exploring the same scenarios as identified in Stage 4. Then Design Safety Requirements could be identified for each element of the logical architecture, possibly using sequence diagrams.

As an example, Figure 9-1 presents a sequence diagram for the considered operation. For the completion of this step it may be necessary to make a similar diagram at the level of the logical elements of Section 9.2.1.

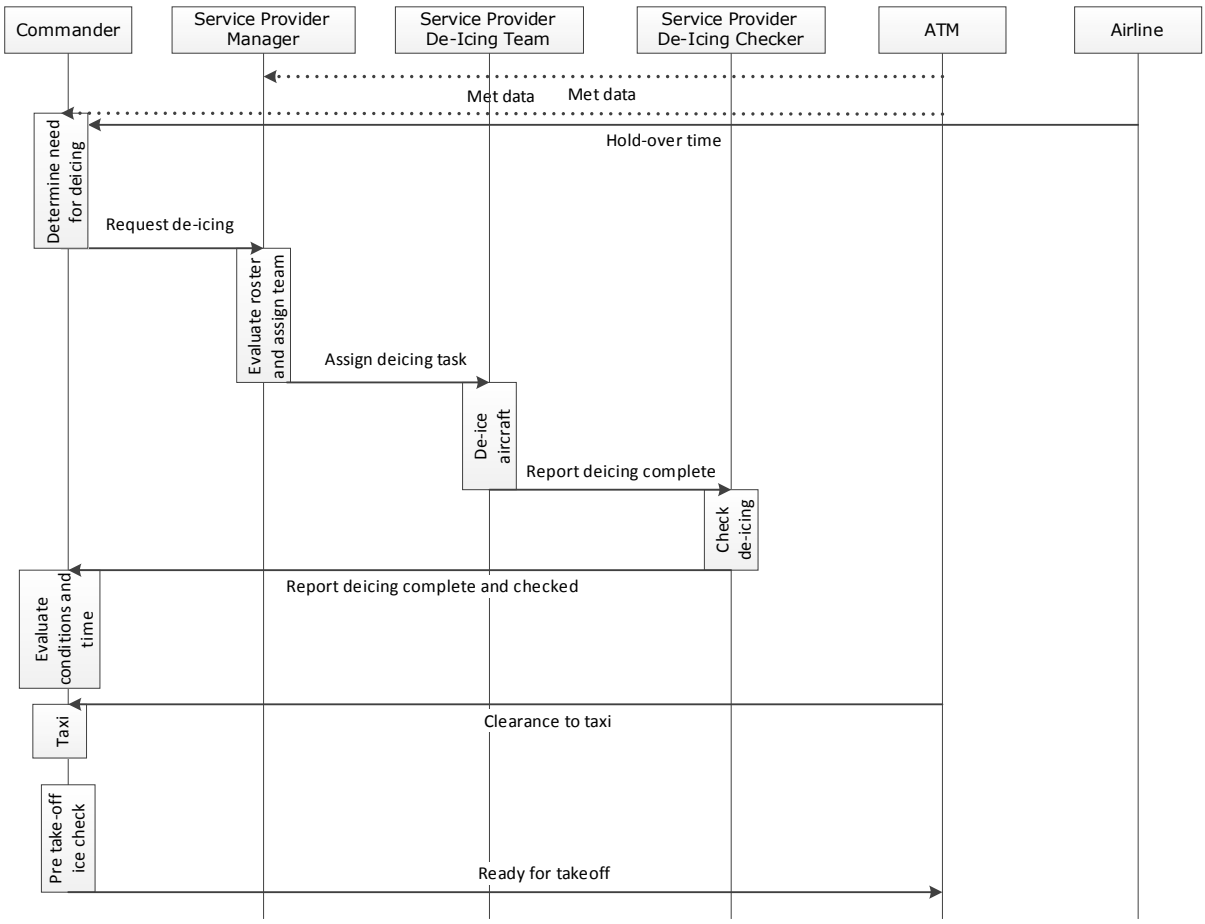

Figure 9-1: Illustration of a sequence diagram for de-icing/anti-icing

An overview of the high-level safety requirements from Stage 4 is as follows:

HSR1. The need for ground de-icing and anti-icing shall be determined, taking into account the expected weather conditions and holdover time.

HSR2. If there is a need, ground de-icing and anti-icing shall be performed.

HSR3. After ground de-icing/anti-icing, a post de-icing / anti-icing check shall be performed.

HSR4. After ground de-icing/anti-icing, the aircraft shall be checked for contamination as part of the pre-take-off check.

HSR5. The de-icing/anti-icing operation shall satisfy the selected target level(s) of safety.

HSR6. The de-icing/anti-icing service provider shall have an SMS.

HSR7. High-level safety requirements HSR1 through HSR6 shall also apply in scenarios 2 and 3.

HSR8. The probability that ice adversely affects the performance or controllability of an aircraft in take-off in such a way that it leads to catastrophic consequences shall not be higher than $1.88 \cdot 10^{-8}$ per flight.

After analysis of the interactions between the elements, Design Safety Requirements may be allocated as follows:

- HSR1 through HSR4 consider actions to be performed. These may be decomposed into Design Safety Requirements for individual elements by specifying the required action for these actions for each actor, including pre-conditions et cetera. This may take the form of process descriptions. An example design requirement could be: "The aircraft commander shall request a weather report and check that it is not older than 30 minutes."
- HSR5 requires the de-icing/anti-icing operation as a whole to satisfy the selected target level(s) of safety. It is understood that this is partly realised via HSR8*, and partly via further analysis in this Stage 5.
- HSR6 requires the de-icing/anti-icing service provider to have an SMS. This may be decomposed into Design Safety Requirements for individual elements by specifying the required processes, and responsibilities.
- HSR7 requires that high-level safety requirements HSR1 through HSR6 shall also apply in the alternative scenarios 2 and 3. Design Safety Requirements can be obtained from this by requiring that the Design Safety Requirements that result from HSR1 through HSR6 are also valid in scenarios 2 and 3.
- HSR8 requires that the probability that ice adversely affects the performance or controllability of an aircraft in take-off in such a way that it leads to catastrophic consequences shall not be higher than $1.88 \cdot 10^{-8}$ per flight. This is in line with the adopted risk acceptance criteria (cf. Section 4.2. Assumption A6) that the safety risks may not increase. A straightforward way to identify Design Safety Requirements at a lower level from this, would be to check the ASCOS risk assessment tool, and adopt the numeric values used in the event sequence diagrams and supporting fault trees in that tool as maximum frequencies. This is not possible since:
    - In the event sequence diagrams of the safety risk assessment tool, the end states have been quantified but the intermediate events and underlying faults have not been quantified.
    - The events in the event sequence diagrams of the safety risk assessment tool and the underlying faults are generally not at the level of the logical elements. E.g., the tool considers faults as "Stall Unavoidable", but does not distinguish the underlying causes.

  To a certain extent it may be possible to use qualitative relative design requirements, such as: the frequency by which de-icing does not remove all ice shall not be higher than in current operations. It is however far from straightforward to define such design safety requirement in a way that makes it both specific and measurable.

The main questions arising in step 2 of the guidance for Stage 5 are:

- How can a safety requirement regarding the target level of safety be decomposed into Design Safety Requirements for individual elements?
- How exactly can the safety risk assessment tool assist in identifying Design Safety Requirements, specifically considering that:
    - The events and faults in the tool are generally at a different level than the logical elements at which the Design Safety Requirements need to be identified.
    - In the event sequence diagrams of the safety risk assessment tool, the end states have been quantified but the intermediate events and underlying faults have not been quantified.
- How exactly does the analysis of interactions using a sequence diagram lead to Design Safety Requirements?
- It is unclear to what level the sequence diagrams need to be decomposed to assess how the various stakeholders work together to satisfy the high level safety requirements.

9.2.3 Assessment of failures

The guidance for Stage 5 [17] proposes as third step the assessment of what could fail within each of the logical elements, and in the interfaces between them. It proposes to do this by considering the causes of the failures identified in Stage 4, considering other ways in which the logical elements could fail, and identifying associated additional Design Safety Requirements.

The hazard focused upon in Stage 4 was the one related to ice adversely affecting the performance or controllability of an aircraft in take-off (hazard 60), since this is the hazard the de-icing/anti-icing process aims to mitigate. In this step, all the causes of this hazard are to be taken into account, but also all other ways in which the de-icing/anti-icing process could fail. In short, this means that all hazards included in the list in Appendix B can play a role. This also includes:

- Hazards related to collisions between a de-icing vehicle and the aircraft (e.g., aircraft allowed to taxi out before de-icing vehicles have been removed from the aircraft);
- Hazards related to the functioning of the Safety Management System that the service provider has to establish according to the assumed regulations (e.g., de-icing service provider not aware of new changes to regulations, earlier identified safety problem not solved due to poor SMS).

This also means that other event sequence diagrams of the safety risk assessment tool [14] will play a role here than just ESD ASC-6 (scenario in which ice adversely affects the performance or controllability of an aircraft in take-off). A review of the tool shows the following:

- Collisions between a de-icing vehicle and the aircraft currently are covered in the tool in ESD ASC-36 “Conflict on taxiway or apron”. Review of ASCOS D3.2 shows that this event sequence diagram includes collisions of aircraft on the taxiway or apron with other aircraft, vehicles, GPUs, lamp posts, et cetera. Hence, this also includes collisions between a de-icing vehicle and aircraft.

- Hazards related to the functioning of the Safety Management System that the service provider has to establish cannot explicitly be addressed by the tool.

From the safety target that the probability of catastrophic consequences shall not be higher than in current operations, a high-level safety requirement can now be, e.g.,

HSR9. The probability of a collision between a de-icing vehicle and the aircraft is not higher than in current operations

Section 9.2.2 considers how design safety requirements may be identified using ESD ASC-6. A similar consideration would be valid for identifying complementary design safety requirements using ESD ASC-03; this is expected to provide the same type of feedback as obtained in Section 9.2.2, and hence not considered further.

The feedback from step 2 of the guidance for Stage 5 is also valid for stage 3. Complementary feedback for Stage 5 is as follows:

- How can the effect of changing safety management be taken into account in the approach?

9.2.4 Assessment of needed development assurance levels

The guidance for Stage 5 [17] proposes as fourth step the assessment of the levels of development assurance that are needed to ensure that the mitigating requirements are successful in making the system sufficiently safe. It is understood that the "mitigating requirements" are the design safety requirements resulting from step 3.

It is at this point not clear how the development assurance levels are defined, in which way they are different from the design safety requirements, and how they can be determined.

The main questions arising for step 4 of the guidance for Stage 5 are:

- What are the development assurance levels, and how are they different from the design safety requirements?
- How are the development assurance levels determined from the design safety requirements?

9.2.5 Confirmation of meeting the requirements

The guidance for Stage 5 [17] proposes as fifth step the confirmation that the system as designed will meet the requirements, including the required level of safety performance.

It is at this point not clear how it can be confirmed in Stage 2 that the system will meet the requirements, since its further development is considered in following stages.

The main questions arising for step 5 of the guidance for Stage 5 are:

- How can one confirm in Stage 2 that the design will meet the requirements?

9.3 Evaluation

Completion of Stage 5 of the proposed certification process using the available guidance [17] seems difficult. The main questions arising are:

- How should the argument structure of Stage 2 drive this process?
- What are the exact scope and the exact depth that are required in this stage of the process?
- How exactly can the safety risk assessment tool assist in identifying Design Safety Requirements, specifically considering that:
    - The events and faults in the tool are generally at a different level than the logical elements at which the Design Safety Requirements need to be identified.
    - In the event sequence diagrams of the safety risk assessment tool, the end states have been quantified but the intermediate events and underlying faults have not been quantified.
    - It is unclear how the changes in safety management can be taken into account in the tool.
- How exactly does the analysis of interactions play a role, e.g., via identification of internal and external elements (the reference for these terms is not clear), and using analysis of a sequence diagram.
- It is not so clear what the last two of the five steps proposed aim to do, and how they should be conducted. These consider the identification of development assurance levels, and the confirmation that the design will meet the requirements?
- Stage 4 focuses on the consequences of those hazards that the function under consideration is designed to mitigate. Stage 5 also considers their causes, and also the hazards associated to failures of the function under consideration itself. These stages are supported by a safety risk assessment tool that makes use of chronological descriptions of series of events leading up to an accident, and supporting fault trees. It is questioned whether this type of development process and safety analysis process are appropriate for changes with a strong socio-technical character such as considered in this study. E.g., Leveson [38] (p.28) puts forward that "In general, event-based models are poor at representing systemic accident factors such as structural deficiencies in the organization, management decision making, and flaws in the safety culture of the company or industry.".

10 Conclusions and recommendations

This case study has tested and evaluated the certification approach proposed in ASCOS D1.3 [9] and the supporting safety tools, by the practical application to the certification of an organisation. The feasibility of this practical application has been studied, and feedback has been collected for improvement.

The certification approach of ASCOS D1.3 [9], the ASCOS tool for safety risk assessment [14][12], and the Area of Change list from FAST [34] were tested by considering the certification of a hypothetical de-icing/anti-icing service provider. Currently, such service providers operate under the AOC of the air operator they are part of, and/ or the air operators to which they provide their services. The case study assumed a hypothetical situation in which this is no longer the case, and in which the de-icing/anti-icing service provider is responsible and accountable for their safe operations in compliance with assumed novel regulations.

Practical feasibility

Several issues arose in applying the D1.3 approach and supporting safety tools to the certification of a de-icing / anti-icing service provider. Example issues are that it was difficult to determine the scope of the change to focus on, how to develop an appropriate argument structure, and when and how to take into account changes in safety management.

The identified issues indicate that use of the D1.3 approach and supporting safety tools may not be optimal for certifying a de-icing/anti-icing service provider. Certifying such provider should be rather straightforward, and less laborious and complex then it appeared to be in this case study. The main complexities of certifying such provider are of an organizational nature, with for example shifted responsibilities. The D1.3 approach and the supporting safety tools appeared to deliver limited added value in that area. Furthermore, the approach appeared to be rather 'heavy' when compared to the technical complexity of the subject of certification.

There are also other causes of the identified issues that arose. Notably, the practical application suffered from the hypothetical character of this case study, which considered a certification process for which no regulation is yet available. Furthermore, the guidance available for the approach was of limited detail and had a preliminary character.

Feedback regarding D1.3 approach

The core of this document has provided detailed feedback regarding the D1.3 approach. The main identified areas of improvement are summarised:

Argument approach: The key innovation of the D1.3 approach is that an overall top level claim of an acceptably safe change to the TAS is decomposed into supporting claims that are aligned with individual aviation domains, such that the approach dovetails with the individual certification approaches existing within those domains. The main comments from this case study to this argument approach are:

- The added value of the argument approach did not become clear. In the decomposition of the claims, the lower claims are not very different from the higher claims. Most stages of the certification approach were conducted without being driven by the argument.
- It was difficult to determine how to develop the arguments for the considered claims, and to understand what these claims should entail.
- The wording of the arguments is such that it may be difficult for applicants to grasp the exact meaning of the claims (e.g., use of terms as functional specification and logical design).

Development and safety analysis of organisational changes: The certification approach is divided into eleven stages, of which Stage 1 through 3 were evaluated in some detail, and Stages 4 and 5 in a more exploratory way. Stage 4 focuses on the consequences of those hazards that the function under consideration is designed to mitigate. Stage 5 also considers their causes, and also the hazards associated to failures of the function under consideration itself. These stages are supported by a safety risk assessment tool that makes use of chronological descriptions of series of events leading up to an accident, and supporting fault trees. It is questioned whether this type of development process and safety analysis process are appropriate for changes with a strong socio-technical character such as considered in this study, since event-based models are generally poor at representing systemic accident factors such as structural deficiencies in the organization.

Defining requirements against which to certify: D1.3 describes how to take into address existing regulations in certification. It became apparent that potentially the D1.3 approach might also be used for the development of the regulatory requirements against which to certify the product, but it is not clear from D1.3 how this should be done.

Scope and level of detail: A recurring issue in the case study was the exact scope and level of detail to be considered in the various stages of the certification process. Example questions that arose were:

- Why does Stage 1 focus on defining a 'change' rather than on defining the 'subject of certification' or the 'scope of the certificate'?
- What is the scope of functional requirements and safety requirements that may be identified per stage? E.g., for which stakeholders are they identified, and should they be limited to the technical and operational level, or also consider items as safety management and the required level of safety?
- What is the scope and level of detail to be considered as 'logical design' in Stage 5 of the process, and which elements are considered as 'internal' and which as 'external'?

Risk acceptance criteria: The proposed certification approach does not aim to replace or adapt the existing certification regimes in the individual aviation domains, but merely to provide structure to the certification of the overall change in the TAS. As such, the risk acceptance criteria or safety targets applied currently in safety assessment in the individual domains remain applicable. It is not well understood whether additional risk acceptance criteria or safety targets need to apply at the overall TAS level, for use in combination with the ASCOS tool for safety risk assessment, and how such criteria should be defined. Associated questions are whether such additional risk acceptance criteria form an additional hurdle for introducing safe changes, and

whether the approach should accommodate introducing changes in which safety in one domain increases considerably but at the cost of a slight decrease in safety in another domain.

Feedback regarding the supporting safety tools

ASCOS tool for safety risk assessment: In line with the adopted study focus, the evaluation of the ASCOS tool for safety risk assessment [14][12] had an exploratory character. The tool includes two event sequence diagrams of relevance for this case study, which could be used for identifying high level safety requirements. It was unclear how to use the tool for specification of safety requirements at a lower level. One cause for this is that it is not clear how to take into account changes in safety management using this tool. Another main cause is that it is not clear how to identify requirements for individual design elements, because 1) events and faults in the tool are generally not at the level at which the safety requirements need to be identified, and 2) the tool does not include quantification of intermediate events and underlying faults.

Area of Change list from FAST: The Area of Change list was used in the definition of the change (Stage 1). It was well possible to determine the subset of Areas of Change that may be relevant for the certification of the service provider. This resulted however in a quite large subset of potentially relevant areas, which were not further used in the study. This is due to the exploratory character of the main Stages 4 and 5 in this case study, and to lack of clarity on how these Areas of Change should be used.

Recommendations

It is recommended to take into account the identified feedback in the further development of a novel certification approach for use in the TAS. The certification approach of ASCOS D1.3 [9] and the supporting tools may be improved using the feedback from this case study, or alternative certification approaches may be considered.

This case does not draw firm conclusions about the effects on safety of certifying a de-icing/anti-icing service provider. It is recommended to be reluctant in drawing conclusions on this matter from this case study.

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Appendix A Relevance of Areas of Change

Table A-1: Areas of change, and relevance for de-icing and anti-icing in the time frame considered

#	Area of Change	Relevance for de-icing and anti-icing in the time frame considered
1	Introduction of new aircraft aerodynamic and propulsion configurations	Yes: Expected new configurations may require a different de-icing/anti-icing strategy.
3	Changes in design roles and responsibilities among manufacturing organizations	No effect on de-icing/anti-icing identified.
5	Introduction of new runway-independent aircraft concepts	No runway-independent aircraft concepts expected in the considered time frame.
6	New supersonic and hypersonic transport aircraft	Yes: Adaptation of de-icing activities to new supersonic and hypersonic transport aircraft
9	Accelerating scientific and technological advances enabling improved performance, decreased fuel burn, and reduced noise	No effect on de-icing/anti-icing identified.
11	Air traffic composed of a mix of aircraft and capabilities	Yes: De-icers need to adapt the de-icing method to the shape and the requirement of each type of aircraft
13	Reliance on automation supporting a complex air transportation system	No effect on de-icing/anti-icing identified.
14	Advanced vehicle health management systems	No effect on de-icing/anti-icing identified.
18	New cockpit and cabin surveillance and recording systems	No effect on de-icing/anti-icing identified.
19	Emergence of high-energy propulsion, power, and control systems	Yes: potential modification on the de-icing method (new shape)
21	Advanced supplementary weather information systems	Yes: improve on the identification of de-icing necessity
...	New cockpit warning and alert systems	No effect on de-icing/anti-icing identified.
27	Next-generation in-flight entertainment and business systems	No effect on de-icing/anti-icing identified.
31	New glass-cockpit designs in general aviation aircraft	No effect on de-icing/anti-icing identified.
33	Entry into service of Very Light Jets	Yes: Increase on demand of de-icing service
36	Increasing implementation of Electronic Flight Bag (EFB) for efficient and safe operations	No effect on de-icing/anti-icing identified.
39	Increasing use of composite structural materials	No effect on de-icing/anti-icing identified.
41	Ongoing electronic component miniaturization	No effect on de-icing/anti-icing identified.
43	Highly-integrated, interdependent	No effect on de-icing/anti-icing identified.

	aircraft systems	
47	Changing human factors assumptions for implementing technology	No effect on de-icing/anti-icing identified.
51	Delegation of responsibility from the regulating authority to the manufacturing, operating or maintaining organization	Yes: Potential decrease on service quality. Potential increase on erroneous de-icing.
53	Trend toward privatization of government ATC systems and airports	Yes: Potential decrease on service quality. Potential increase on erroneous de-icing.
58	Shift toward performance-based solutions and regulations	Yes: De-icing activities regulated by a performance based approach
64	Remote Virtual Tower (RVT) operational concepts	No effect on de-icing/anti-icing identified.
66	Societal pressure to find individuals and organizations criminally liable for errors in design and operations	Yes: Increase pressure on maintenance staff.
67	Economic incentives to form partnerships and outsource organizational activities	Yes: Potential decrease on service quality. Potential increase on erroneous de-icing.
68	Global organizational models	Yes: Mayor global organization tries to control small de-icing companies, modification in the policy of the de-icing company. Impact on the staff
69	Evolution in lines of authority, command and responsibilities within the air transport system	Yes: unclear line of command, who and when asks for de-icing.
73	Increasing complexities within future air transportation systems	Yes: Different regulations or regulation incoherent. De-icing regulation, and airline regulation.
78	Increasing size of maintenance, ATM, and operations databases	Yes: De-icing activity as part of the maintenance is part of the database.
80	Reduction in numbers of aviation personnel familiar with previous generation technology and practices	Yes: Potential decrease of de-icing know-how
82	Technologies and procedures enabling reduced separation	No effect on de-icing/anti-icing identified.
86	Evolution in the type and quantity of information used by ATM personnel	Yes: potential improvement or decrease on the quality of the management of de-icing activities
87	Changing design, operational, and maintenance expertise involving air navigation system (ANS) equipment	Yes: Potential decrease on service quality. Potential increase on erroneous de-icing.
89	Increasing heterogeneity of hardware and software within the ANS system	No effect on de-icing/anti-icing identified.
93	Increasing reliance on satellite-based systems for Communications, Navigations, and Surveillance (CNS)	No effect on de-icing/anti-icing identified.

	Air Traffic Management functions	
95	Changing approaches to ATM warning and alert systems	No effect on de-icing/anti-icing identified.
96	Increasing interactions between highly-automated ground-based and aircraft-based systems	No effect on de-icing/anti-icing identified.
97	Introduction of artificial intelligence in ATM systems	No effect on de-icing/anti-icing identified.
99	Increasing dependence on in-flight electronic databases	No effect on de-icing/anti-icing identified.
100	Increasing operations of military and civilian unmanned aerial systems in shared military, civilian, and special use airspace	Yes: Increasing demand of de-icing service and potential modification of de-icing provider structure to support UAV (where there is not any pilot to perform a final check before departure)
101	Redesigned or dynamically reconfigured airspace	No effect on de-icing/anti-icing identified.
109	Increasing utilization of RNAV/RNP departures and approaches by smaller aircraft	No effect on de-icing/anti-icing identified.
114	Increasing operations of cargo aircraft	Yes: Increasing demand of de-icing service
117	Very long-range operations, polar operations, and ETOPS flights.	Yes Potential modification of the de-icing activates for the long flight and the polar flight
118	Emerging alternate operational models in addition to hub-and-spoke concepts	Yes Adaption of the de-icing activates to the hub configuration.
119	Increasing numbers of Light Sport Aircraft	Yes: Increasing demand of de-icing service
122	Accelerated transition of pilots from simple to complex aircraft	No effect on de-icing/anti-icing identified.
125	Operation of low-cost airlines	No effect on de-icing/anti-icing identified.
129	Growth in aviation system throughput	Yes: Pressure on personnel to perform de-icing in shorter times. Potential lack of performance
133	Assessment of user fees within the aviation system to recover costs of operation	No effect on de-icing/anti-icing identified.
136	Increasing use of Commercial Off The Shelf (COTS) products in aviation	No effect on de-icing/anti-icing identified.
138	Increased need to monitor incident and accident precursor trends	Yes: Incorrect/loss of de-icing or incorrect/loss of identification of de-icing need can be a precursor
139	Increasingly stringent noise and emissions constraints on aviation operations	No effect on de-icing/anti-icing identified.
141	Changes in aviation fuel composition	No effect on de-icing/anti-icing identified.
142	Language barriers in aviation	No effect on de-icing/anti-icing identified.
144	Changing management and labor relationships in aviation	No effect on de-icing/anti-icing identified.
148	Increasing frequency of hostile acts	Yes: It is possible to imagine an attack by adulterating the de-

	against the aviation system	icing liquid. Organizations in charge of de-icing need to follow a process of security to ensure that nobody have access to the de-icing materials.
161	Increasing numbers of (migratory) birds near airports	No effect on de-icing/anti-icing identified.
170	Increasing manufacturer sales price incentives due to expanding competitive environment	No effect on de-icing/anti-icing identified.
174	New surface traffic flow management technologies	Yes: a difficulty is assigning taxiways might imply a late arrival to the de-icing installations. De-icers maybe will need to cope with long queue, maybe new de-icing strategies are required
184	Increasing amount of information available to flight crew	No effect on de-icing/anti-icing identified.
185	Introduction of Non-Deterministic Approaches (NDA) and artificial intelligence (self-learning) in aviation systems	No effect on de-icing/anti-icing identified.
187	Shift in responsibility for separation assurance from ATC to flight crew	Yes: Increasing demand of de-icing service
188	Introduction of new training methodologies for operation of advanced aircraft	Yes: Increasing demand of de-icing service
189	Shifting demographics from military to civilian trained pilots	No effect on de-icing/anti-icing identified.
200	Increased dependence on synthetic training in lieu of full-realism simulators	No effect on de-icing/anti-icing identified.
202	Shortened and compressed type rating training for self-sponsored pilot candidates	No effect on de-icing/anti-icing identified.
205	Operational tempo and economic considerations affecting flight crew alertness	No effect on de-icing/anti-icing identified.
218	Supplementary passenger protection and restraint systems	No effect on de-icing/anti-icing identified.
220	Increasing functionality and use of personal electronic devices by passengers and flight crew	No effect on de-icing/anti-icing identified.
221	Introduction of sub-orbital commercial vehicles	Yes: Increasing demand of de-icing service
222	Standards and certification requirements for sub-orbital vehicles	Yes: Increasing demand of de-icing service
223	Increasing frequency of commercial and government space vehicle traffic	Yes: Increasing demand of de-icing service
225	Entry into service of commercial, space-tourism passenger vehicles	Yes: Increasing demand of de-icing service
226	Changes in the qualifications of	Yes: Considering the de-icing as part of the maintenance, then

	maintenance personnel	increase qualification implies a improvement of the service
230	Paradigm shift from paper based to electronic based maintenance records and databases	No effect on de-icing/anti-icing identified.
236	Increasing use of virtual mock-ups for maintenance training and for evaluation of requirements	No effect on de-icing/anti-icing identified.
241	Operational tempo and economic considerations affecting fatigue among maintenance personnel	Yes: It might impact on the performance of de-icers (if considered as maintenance personnel)
242	Increasing single-engine taxi operations or taxi on only inboard engines of 4-engine aircraft	No effect on de-icing/anti-icing identified.
243	Novel technologies to move aircraft from gate-to-runway and runway-to-gate	Yes: It might imply the localization of the de-icing installation, maybe foster “mobile” de-icing equipment.
244	High-density passenger cabin configurations	No effect on de-icing/anti-icing identified.
245	Worldwide implementation of SMS	Yes: De-icing identified procedures for safety
246	Worldwide climate change trending towards warmer temperatures	Yes: Airport not equipped with de-icing equipment. A non-expected cold wave make airport to collapse, local authorities look for fast rather for efficient solutions.
247	New aircraft recovery systems in general aviation and commercial aircraft	No effect on de-icing/anti-icing identified.
249	Increasing demands for limited radio frequency bandwidth	No effect on de-icing/anti-icing identified.
250	Shortage of rare-earth elements	No effect on de-icing/anti-icing identified.
251	Introduction of new training methodologies for maintenance staff	Yes: Increase of decrease of performance of maintenance staff
252	Smaller organizations and owners operating aging aircraft	Yes: Potential decrease on the awareness of the necessity of the de-icing.
254	Aging maintenance workforce	Yes: Increase of decrease of performance of maintenance staff
255	New pilot licensing standards	No effect on de-icing/anti-icing identified.
256	Decreasing availability of qualified maintenance staff at stations other than home base of operation	Yes: Increase of decrease of performance of maintenance staff
257	Reluctance among operators to implement voluntary proactive safety mitigations	Yes: Avoid identification of erroneous de-icing procedures
259	Shift in the demographics of newly-hired air traffic controllers compared with retiree skills and interests	No effect on de-icing/anti-icing identified.
260	Increasing use of Controller Pilot Data Link Communication (CPDLC) for weather information and advisories/clearances	No effect on de-icing/anti-icing identified.
261	Operational tempo and economic	No effect on de-icing/anti-icing identified.

	considerations affecting air traffic controller alertness	
262	Potential pilot shortages	No effect on de-icing/anti-icing identified.
263	Shift from clearance-based to trajectory-based air traffic control	Yes: It might imply time objective for the de-icing activity
265	Socio-economic and political crises affecting aviation	Yes: Potential modification of hiring rules for de-icier staff (low trained staff) Modification of law for de-icing equipment, less restrictive laws;
266	Single-pilot cockpits for large commercial transports	No effect on de-icing/anti-icing identified.
267	Increasing adoption of software defined radio systems in commercial aviation	No effect on de-icing/anti-icing identified.
268	Decrease in turboprop fleets and operations	No effect on de-icing/anti-icing identified.
269	Proliferation of voluntarily-submitted safety information	Yes: administrative procedures to be achieved by the de-icing staff in order to inform about a missing de-icing.
270	Initiation of collaborative air traffic management	No effect on de-icing/anti-icing identified.
271	Improved surface operations technologies and procedures	Yes: De-icing activities are part of the surface procedure management
272	Increased traffic flows involving closely-spaced parallel, converging, and intersecting runway operations	Yes: complexity in runways implies complexity on taxiway management. It might impact the time schedule for de-icing and the performance of the de-icing
273	Increased throughput utilizing improved vertical flight profiles and aids to low-visibility operations	No effect on de-icing/anti-icing identified.
274	Widespread deployment of System Wide Information Management (SWIM) on-demand NAS information services	No effect on de-icing/anti-icing identified. (A priori no effect, but de-icing can be part of SWIM data, for example it is not clear if the data about de-icing times required for each type of aircraft will be part of the SWIM inputs to calculate ETOT)

Appendix B List of identified hazards

The following table provides a list of hazards identified for the de-icing/anti-icing operation. Where necessary, the hazards from the original source have been generalised for the purpose of this study (e.g., in this study it is not known ex ante who is responsible for a contamination check).

#	Hazard	Source
1.	Contamination check forgotten	[42]
2.	Contamination check not considered necessary	[42]
3.	Contamination check not performed due to pressure to reach departure slot	[42]
4.	Weather deterioration between gate and take-off; anti-icing should have been done	[42]
5.	Weather forecast too optimistic	[42]
6.	Contamination not detected during pre-flight check	[42]
7.	De-icing crew not available	[42]
8.	De-icing equipment for contamination check not available	[42]
9.	Only visual inspection performed, not tactile	[42]
10.	Poor visibility conditions	[42]
11.	Contamination check performed by unqualified person	[42]
12.	Insufficient training winter operations flight crew	[42]
13.	Insufficient training winter operations de-icing operator	[42]
14.	Wrong de-icing procedure chosen (one step / two step)	[42]
15.	Wrong fluids used by de-icing crew	[42]
16.	De-icing procedure not applied well (e.g. a/c type specific spray or non-spray areas)	[42]
17.	Aircraft parts/surfaces forgotten to de-ice	[42]
18.	De-icing equipment fails	[42]
19.	Insufficient resources (personnel, equipment, fluids)	[42]
20.	Coordination problems when working with several de-icing teams	[42]
21.	Insufficient monitoring of de-icing	[42]
22.	Communication problems between de-icing coordinator and de-icing crew	[42]
23.	Communication problems between flight crew and de-icing coordinator/ crew	[42]
24.	No use of standard phraseology in the communication between the ground staff and the flight crew	[42]
25.	Time pressure for de-icing crew, due to other aircraft to be de-iced	[42]
26.	Time pressure for de-icing crew, due departure slot of aircraft	[42]
27.	De-icing crew not well trained / qualified	[42]
28.	Final check not performed	[42]
29.	Final check performed but contamination not detected	[42]
30.	Holdovertime exceeded but flight crew continues take-off (erroneously or on purpose)	[42]
31.	De-icing takes longer than expected	[42]
32.	Longer taxi times due to taxiway conditions.	[42]
33.	Flight crew takes more time to taxi to the runway than expected	[42]
34.	No holdover timetable used for estimating holdover time	[42]
35.	Wrong holdover timetable used (wrong brand, wrong fluid type)	[42]
36.	Holdover timetable erroneously interpreted	[42]
37.	ATC delay during taxiing and line-up	[42]
38.	Fluid performance affected by weather conditions	[42]
39.	Pre take-off check not performed	[42]
40.	Pre take-off check performed, but contamination not detected	[42]
41.	Pre take-off contamination check not performed	[42]

42.	Pre take-off contamination check performed, but contamination not detected	[42]
43.	Flight crew does not detect the contamination of aircraft parts after starting the take-off roll	[42]
44.	Flight crew detects contamination after reaching V1 during take-off roll	[42]
45.	Flight crew does not notice engine problems during take-off	[42]
46.	Aircraft systems failure such that engine failure is not shown/sounded	[42]
47.	Aircraft is uncontrollable	[42]
48.	Lack of control by the flight crew	[42]
49.	Incorrect control by the flight crew	[42]
50.	Insufficient control by the flight crew	[42]
51.	Insufficient runway length available to avoid a runway overrun	[42]
52.	Maximum braking not applied by the pilot	[42]
53.	Brake system failure	[42]
54.	Pilot ignores stickshaker	[42]
55.	Stickshaker failure	[42]
56.	Stall angle of attack too low	[42]
57.	Pilot does not reject take-off	[42]
58.	Pilot rejects take-off above V1	[42]
59.	Aircraft allowed to taxi out before de-icing vehicles has been removed from aircraft	ASCOS
60.	Ice adversely affects the performance or controllability of an aircraft in take-off.	ASCOS
61.	Disruption of ground flows (due to taking an aircraft out of the departure sequence if ice is detected)	ASCOS
62.	De-icing service provider not aware of new changes to regulations	ASCOS
63.	Safety management system not functioning well: problem identified earlier is not solved.	ASCOS