Resilience 2050

**Resilience2050.eu**

**New design principles fostering safety, agility and resilience for ATM**


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# D4.2 Balanced concept considering safety, productivity and resilience


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# 1 INTRODUCTION

## 1.1 Purpose of the Document

In contrast to the material foreseen in description of work, this report describes a proposed approach to derive resilient design principles by the means of simulation as one solution. The work of deriving resilient design principles from elements of the ATM system which are identified as critical to the resilience of the system was intended in the former deliverable D3.3.

D3.3 did not deliver these results so far, due to the fact that it was found that the conditions for the contingency plan in Work package 3, as described in the DoW, are met. The risks described in work package 3 affect the work in D3.3.

Deliverable D4.2 itself depends also on D3.3. Due to this relation this report cannot address the work as demanded in the DoW. Instead, an approach is presented to meet the demands required in D3.3 and thus enabling D4.2. This is being done by using material already available through the work in WP4 and by adapting to the DoW accordingly. Deliverable D3.3 already presented an outlook of that approach.

The proposed approach is adapted from the work structure of the DoW. That is, the approach incorporates work to be developed subsequently to this deliverable. It can be said, that for parts of the DoW a reversed procedure is applied.

This deliverable will firstly describe the alignment with other deliverables as formerly intended by the DoW. Afterwards a working plan will be presented as one proposal for the remaining part of the project concerning the use of simulation.

Finally, for the sake of demonstrating the plausibility of the presented approach, elements of the proposed approach will be presented in more detail concerning the work according to the simulation done in WP4 so far. The according relationship to the particular tasks of the DoW is provided as well.

## 1.2 Alignment with other deliverables, tasks and WPs of the project

In this chapter the relations of deliverable D4.2 with the tasks of the project is presented. For a more detailed overview with respect to deliverables of former work packages, the reader is kindly referred to chapter 1.2 of deliverable D3.3v2 submitted at the 27.02.2015. Deliverable D4.2 aims to create a new concept for the ATM system that provides resilient properties and incorporates a balance between resilience and efficiency. To fulfill the first point, resilient design principles, intended to be developed in deliverable D3.3, are incorporated into the description of the current ATM system. To assess the effectiveness of the resilient measure by means of simulation in the following work package 5, an implementation of the holistic model has to be conducted. As preparatory step for that implementation, an abstraction of the elements of the ATM system and their interrelations has to be conducted. This is done in task 4.1. The resilient design principles gained in D3.3 are then to be incorporated into that abstraction of the ATM system[1]. The resilience metrics developed in D3.2 have to be taken into consideration as well. For a more detailed description of the interdependencies between D3.2 and D3.3 the reader is kindly referred to the deliverable D3.3v2.

[1] "[...] a balance between resilience and efficiency is implemented into the new concept. For that purpose the design principles described in task 3.3 are incorporated into the abstraction found in task 4.1, bearing in mind the resilience metrics for the European ATM System (task 3.2).", page 26, DoW

The second aspect of the deliverable D4.2 addresses the balance between efficiency and resilience. Here, the description of a system that is optimized for efficiency considering a time horizon beyond the year 2050 and carried out in task 4.2, serves as input. Afterwards a balance between the resilient measures, applied on the description of the current system, and the efficient measures, derived in D4.2 is to be introduced.

The influence of the human is represented in task 4.4. The roles of the different operators and their interactions as well as performance issues are assessed from a multi-agent perspective. Furthermore safety related aspects are taken into consideration. The implementation of the balanced concept is intended in task 4.6, whereas in task 4.5 the respective simulation environment is created. This environment has to provide the means for fast time simulation and stochastic influences in order to represent the dynamic of the system. The verification of the systems behavior with respect to the effects found in D2.2 has to be performed. After implementing the balanced concept the reaction to disturbances is investigated on a qualitative and quantitative level.

In work package 5, the implemented concept is being validated with respect to efficiency on the one and resilience on the other hand (task 5.3). Disturbances are introduced by the means of appropriate scenarios (task 5.2) which are based on stress test. The stress tests provide a set of different kinds of disturbances which can be applied on the traffic prediction for the year 2050 (task 5.1).

Figure 1 from page 34 of the DoW illustrates the connection between the deliverable D4.2, that is represented by the task 4.1 and the other tasks of the project.

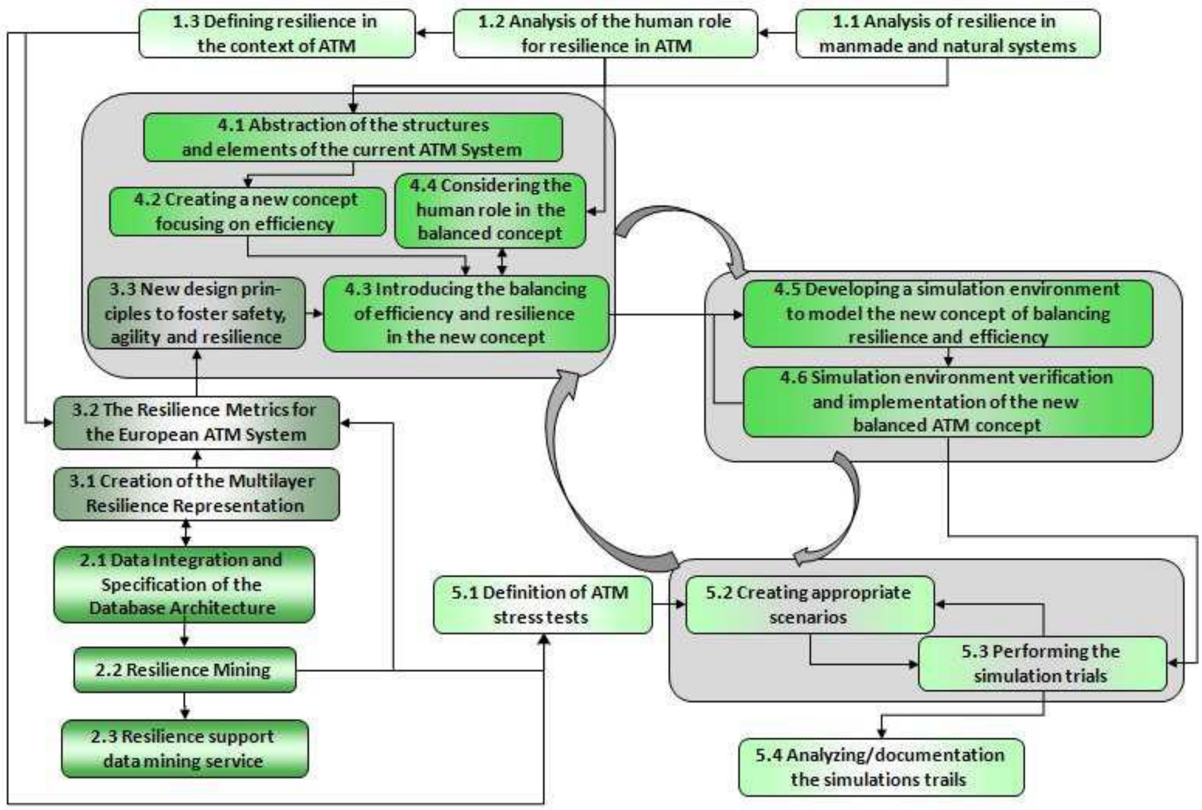



**Figure 1**
**Interdependencies between tasks in the project Resilience2050**

# 2 Working plan

## 2.1 Introduction

Only an adapted D4.2 can be delivered at the 20.03.2015, considering the findings in D3.3 version 2, which was sent to the EC at the 27.02.2015.

To overcome the problems concerning the identification of “resilient design principles”, see D3.3, basically two different approaches are thinkable. The first approach addresses an increased data analysis, the second addresses the use of the simulation developed in WP 4. In the following an approach is presented considering the application of simulation means to derive a data basis to identify “resilient design patterns”.

Due to the fact that deliverable D4.2 depends on deliverable D3.3 and within the latter, the results could not be achieved as intended in the DoW (shown in D3.3v2). This document therefor refers to the alternate approach presented in D3.3 that aims to derive resilient design principles by means of simulation. That approach adapts the DoW by incorporating the work of work package 4 in order to provide the opportunity to detect bottlenecks in the ATM system by means of simulation instead of data analysis. Simulation is being viewed as a feasible approach to gain insights into the causes responsible for decreasing the resilience of the system. Data to feed the simulation are gained from flight schedules as well as from different sourced related to operational procedures such as the turnaround.

## 2.2 Elements of the proposed working plan

As introduced in deliverable D3.3v2, a two parted simulation[2] is intended to be used to detect bottlenecks of the current ATM system as a preparation to derive new design principles. On the one

[2] “A first modelling approach was proposed in deliverable D1.3. It was developed in conjunction with a generic algorithm developed to investigate resilience. Important aspects of that algorithm represent the level of detail that is needed to investigate the implications of a particular disturbance or the horizon of time during which the systems reaction is being analysed. The modelling approach presented in D1.3, derived from the algorithm to investigate resilience, considers also the importance of the human role with respect to resilience. Due to the socio-technical character of the ATM system, the human operator is of pivotal importance and has to be reflected.
Results of the dynamic analysis of the macro part in deliverables D2.2 revealed that besides the TMA, the turnaround is responsible for generation of delay. It was suggested in D2.2 to focus on operational aspects of the turnaround phase due to their impact on the systems dynamic at that phase. The turnaround also influences the dynamic of the network by affecting capacities at the particular airports. Since both, the network related affects, which show influences on a greater, macroscopic scale, as well as the influences on capacity during the turnaround phase, which apply on a more microscopic scale, have to be considered, the proposed modelling incorporates them both. It has to be stressed that the modelling approach presented here consists of different levels of detail. This relates to the generic algorithm of D1.3, where the definition of the level of detail has to be chosen according to the disturbances whose implications are investigated. In other words, the propagation of smaller disruptions will be observed in the microscopic part, reflecting the turnaround, whilst larger disturbances can be applied to the macroscopic part of the en-route phase. Though, one has to consider that smaller disturbances on the ground may have a wider effect on the system too, due to the connection with the capacity of the airport. To a specific extent, the capacity of an airport is determined by the turnaround process. On the other hand, disturbances occurring on a lower level in the hierarchy of the system, i.e, occurring on a microscopic level of detail, can be absorbed in a higher level of hierarchy. The degree of insight at the higher level is lower, since particular reactions of the system are bound to be viewed as properties, inherent to the system inherent.”, page 25, D3.3v2

hand, a flow based macro model aims to depict the propagation of delay in the network due to weather related disturbances and capacities decreases, whereas a microscopic model addresses disturbances on a lower level and focuses on the processes during the turnaround. To incorporate safety related aspects in conjunction with the human operator, the deicing process was chosen. The development of the simulation environment and the implementation of the current system address the tasks 4.1, 4.4, 4.5 and 4.6 of the DoW. The next paragraph will illustrate the current status of the work on those deliverables with respect to the DoW. It will also present a coordinated working plan among the partners NLR, ITU and DHMI for the proposal of deriving new design principles as intended in D3.3 by the DoW based on a simulation approach.

## 2.3 Description of the working plan

The following Table 1 summarizes the status of the work as intended in the DoW, showing the relation to the particular tasks. Tasks that relate directly to deliverables that were approved before are omitted. This affects Task 4.2 (related to D4.2) and Task 5.1 (related to D5.1).

**Table 1: current status of the available material related to the particular tasks of the DoW**

| Task | Results demanded by the DoW: available | Results demanded by the DoW: available in parts | Results demanded by the DoW: to be done |
|---|---|---|---|
| Task 4.1 | Abstraction of the structures and elements [of the system] such as entities attributes and buffers (available for taxi in, turnaround, taxi out, deicing, enroute, TMA) | | |
| Task 4.4 | -Influence of the human, agent based perspective, -interactions of human operators, -safety related aspects | -performance of human operators | -[To set] In context of the balanced concept |
| Task 4.5 | fast time simulation environment that covers the representation of dynamic and stochastic influences at the same level of detail for all elements of the ATM system | to complete adaption to one level of detail of<br>- taxiing<br>- turnaround<br>- TMA,<br>- En-route | |
| Task 4.6 | | verification of the system behavior to disruptions | New balanced concept (task 4.3+4.4) is implemented into the simulation environment. |
| Task 5.2 | | specification of a range of disruptions, including small | |

| | | | |
|---|---|---|---|
| | | disturbance up to the level of large crises, e.g. a volcano ash cloud case | |

As explained above, only an adapted D4.2 can be delivered at the 20.03.2015, considering the findings in D3.3 version 2, which was sent to the EC at the 27.02.2015.

In order to achieve the results demanded for D3.3 in the DoW and because of deficiencies in D3.3, we propose an altered procedure, as shown in Table 2 based on a simulation approach. The related tasks and deliverables of the DoW are depicted as well. The dates of the different threads are created under the assumption of an extension of the project by 6 months. The relation to deliverable D3.3 is shown, though it has to be noted, that this deliverable was already sent to the EC.
The material already available as shown in Table 1 will be used in the proposed plan, shown in Table 2.

This proposal is coordinated between ITU, NLR and DLR. It aims to create results for the remaining work of the project, i.e. WP4 and WP5 concerning a simulation approach.

Table 2: preliminary work plan, based on the assumption of the extension of the project by 6 months

| **thread** | **goal** | **Related Task of DoW** | **Related Deliverable of DoW** | **Begin at** | **Due at** | **Partner** |
|---|---|---|---|---|---|---|
| Micro model | To consider the influence of the human, also to consider safety related aspects | Task 4.4<br>Task 4.5<br>Task 4.6 | D4.2 | immediately | Mid of May | NLR,DLR |
| Coupling of the macro micro model | Interface between the two models, DLR provides two options for an interface [an s-function of the Macro model to be executed in the Simevents/Simulink model and a mySQL connection] | Task 4.5 | D4.2 | Meeting early April ITU/DLR | Mid of April | DLR, ITU |
| Coupling of the macro micro model | Verified simulation of hookup of the Macro and Micro model for a cluster of airports, first examples of reproducing qualitatively correct network effects (PRISME historic data will be used) | Task 4.6 | D4.2 | Mid of April | Mid of May | DLR, ITU |
| Meeting INX NLR ITU DLR | To discuss the content for the report, to present the current combined model of macro and micro | - | D4.2 | | Mid of May | INX, ITU, NLR, DLR |

| | | | | | | |
|---|---|---|---|---|---|---|
| Writing of the report new D4.2 | Selection of tackled aspects:<br>-Simulation as a way to create results, describing the approach for a more resilient system (Resource management, adaptation, model as a mean to investigate resilience)<br>-Description of mechanisms as strategies, small examples in order to show the functionality of investigating different strategies<br>-Create expectation of the kind of results - that is we do a description here and provide in D5.3 the quantitative results<br>- Relation to the framework in D1.3, Relation to the approach suggested for D3.3<br>-human influences | - | D4.2 | immediately | Mid of June | DLR, NLR, ITU |
| Review of the report new D4.2 | | - | D4.2 | Mid of June | End of June | INX, ITU, NLR |
| Presentation of the model functionalities | Demonstration of the functionality of the model to get input from the EC, meeting in Brussels | - | D4.3 | | End of June | Depends on availability of partners |
| Update of report new D4.2, delivering of D4.2 | Considering the inputs of the presentation, Milestone | - | D4.2 | End of June | Mid of July | DLR |
| Delivering of D4.3 | | - | D4.3 | | Mid of July | DLR |
| Validation of the whole model [micro and macro] | Possible qualitative reproduction of the effects of delay propagation and delay generation found in the PRISME data | Task 4.6<br>Task 5.3<br>Task 5.4 | D5.3 | Begin of August | Mid of September | DLR, ITU |
| Scenario creation | | Task 5.2 | D5.2 | Begin of August | Mid of September | DLR, ITU |

| | | | | | | |
|---|---|---|---|---|---|---|
| Findings of bottlenecks in the current ATM system | Originally intended to be the result of D3.3, this was proposed as an alternate procedure in the new D3.3, sent to the EC at the 27.02.2015<br>(by comparing the dynamics of the system with the respective involved elements possible deductions with regard to critical elements are investigated and subsequently new design principles are derived) | Task 3.3 | **D3.3** | Mid of September | End of October | DLR, ITU, NLR |
| New measures are investigated by means of the simulation, subsequently new strategies are implemented in the model | Parameter study of new strategies applied on found bottlenecks,<br>-Different disturbances will be applied, the resilience will be investigated and the new strategies will be assessed therefor | Task 3.3<br>Task 5.3 | **D3.3** | Mid of September | End of October | DLR, ITU |
| Writing of the report D5.3 | -Final results achieved by using the model,<br>To show the added value of the approach for the analysis of resilience with the respect to the dynamic of the system<br>- The general application of the approach will be discussed, examples are provided (deicing, turnaround) | Task 5.4 | D5.3 | Mid of September | End of October | DLR |
| Demonstration of the model at EC | To present the model with the applied scenarios and the results gained, to get input from the EC | - | D5.3 | | Begin of November | INX , DLR, NLR, ITU |
| Review of the report D5.3 | | - | D5.3 | End of October | Mid of November | INX ,ITU,NLR |
| Update of report, delivering report | Milestone / End of project | - | D5.3 | | End of November | DLR |
| Demonstration of the model | At SESAR innovation days | - | Whole project | | Begin of December | All partners |

A more detailed description of a selection of aspects of the tasks related to the modeling aspects (task 4.5 and 4.5 as well as task 4.4 which addresses human influences) can be found in Annex part 1. The basis for the implementation of the current model was a detailed process description which was introduced in D1.3 and subsequently developed further. A selection of processes and according dependencies can be found in Annex part 2. Annex part 3 presents a small exemplary case study of aspects of the deicing process such as demand for deicing, resource availability and generated delay for particular aircraft.

The feasibility of the presented approach is intended to be emphasized by the more detailed description in the Annex, also presenting a selection of results of the work carried out already.

# 3 Conclusion

To overcome the problem of identifying “resilient design patterns” there are basically two solutions thinkable. The first one addresses a deeper data analysis, the second addresses a generic data creation, based on simulation.

Considering the Annex, it seems plausible to use a combination of a macro and micro simulation to create data to derive “resilient design principles”. The possibility to relate the observed effects of disturbances, which are affecting resources and processes, and can be expressed by key performance parameters, creates a basis to introduce resilient modifications on the particular level of detail.

A baseline, which constitutes a system not optimized for resilience, and the resilient system, can be investigated by the simulation in order to enable a quantitative assessment of the identified modifications, concerning processes and resources, with respect to the resilience of the system.

In this way it assumed to be a feasible approach to fulfill the demands of D3.3 and hence D4.2 can be created.

# 4 Annexes

## 4.1 Annex 1: Micro and Macro model description

The macro model as discussed in D3.3v2 aims to represent delay propagation on a network wide level as well as to investigate the implications of changes in the capacity at the airport[3]. The dynamic of the system is hereby being researched by a flow model. The macro model will be presented in the form a short summary. The related task are 4.5 and 4.6.

### 4.1.1 Macro simulation model summary

Understanding the delay generation and propagation mechanisms across air traffic networks is crucial in identifying and designing resilience enhancing ATM features against disturbances such as severe weather, airspace closures and strikes. Towards this goal, as a part of D4.2, a data analytic methodology for macro simulation modeling of the European air traffic flow network is developed.

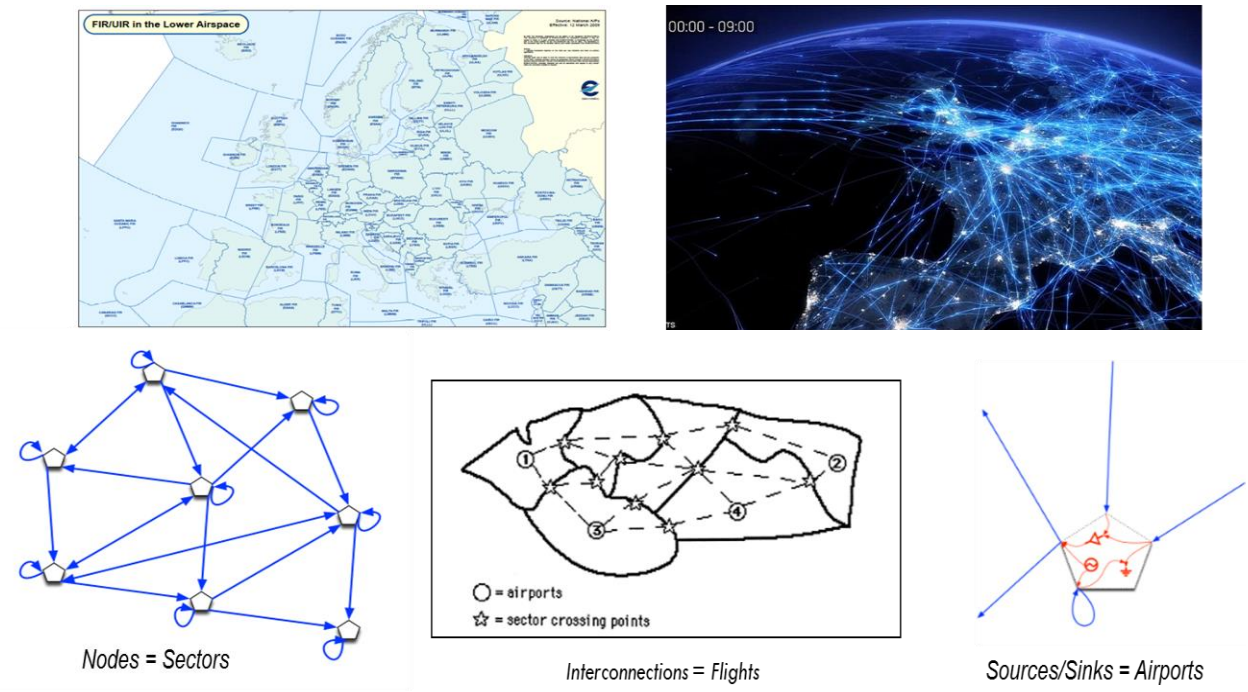



Figure 2. The fundamentals of the Macro Model

The macro model provides a basic air traffic network flow model (as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**) which consists of an interconnected network of departure and arrival queues of European airports and other continental airports connected to Europe through intercontinental flights. The connections between airports are represented through scheduled and

[3] “The macroscopic part of the modelling approach represents a network flow model with interconnected airports. The airports constitute queues, whereas FIFO queues are assumed for the arrival and departure capacities. A simplified network wide slot management algorithm across the queues is implemented. Thus, implications of capacity alterations at an airport during the arrival or the departure can be analysed with respect to the network. Since the macroscopic model comprises of all European airports which schedule times are available from the PRISME data, the delay propagation across Europe can be investigated, whereas the quality of the analysis is limited by the completeness of the available data. Elements that absorb or amplify delay can be detected.”, page 25, D3.3v2

unscheduled flights, whereas the serving rate of the queues is denoted through arrival and departure capacity declarations. In this model, the effect of any disturbance can be represented through either capacity changes on arrival/departure queues, or individual delays/cancelations for each (or a group of) flights. This is presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

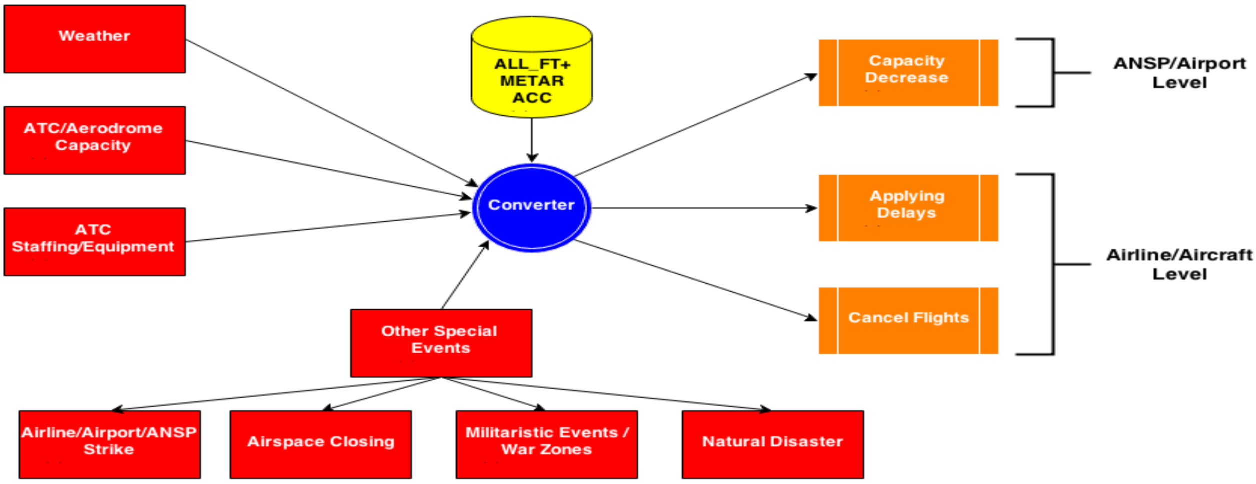



Figure 3. Translational of all delay generating events into three specific events in the macro model

Using the PRISME data (Eurocontrol ALL_FT and DDR data for 9 months in 2011), we have identified the scheduled flights, typical unscheduled flights and the actual arrival and departure capacities of each of the European airports. Through a basic arrival/departure slot allocation model that uses a FIFO and flight time consistent sequencing model as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**, the basal delay state of the European air traffic flow network for a generic week is generated. Comparing this basal delay state with actual data, the effects of the disturbances on each of the airports and how they are propagated to other airports that are connected via flights are analyzed.

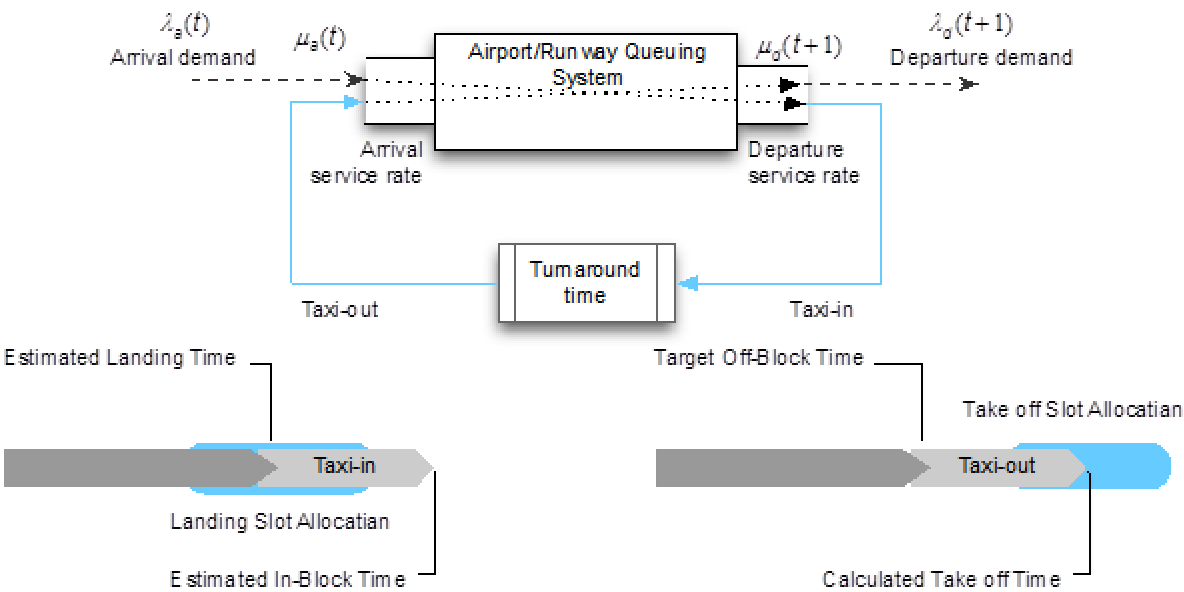



Figure 4. Basic FIFO model of airports in the macro model

The analysis indicate that the wave operations of the airlines especially across strongly connected hubs can result in a knock-knock effect in which a disturbance is magnified into multiple timeframes in which wave operations are conducted. This is illustrated in **Fehler! Verweisquelle konnte nicht gefunden werden.**. In addition, the data analysis shows that the actual capacity of arrival and departure operations at key European airports can be considerably higher than the declared values. Through this, the airports provide the much needed resilience enhancing feature in face of delays that result in increased size of arrival and departure waiting queues.

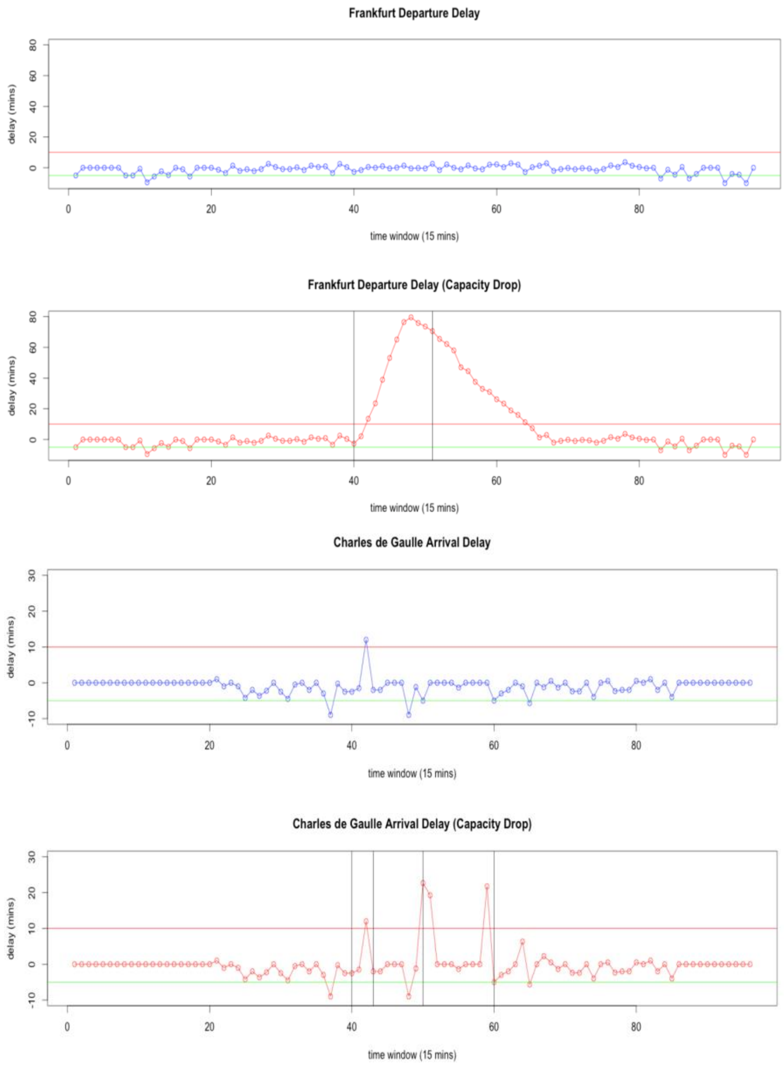



Figure 5. Effect of Capacity Decrease at Frankfurt Airport to Charles de Gaulle Airport as calculated through macro simulation model

### 4.1.2 Micro Model

After addressing aspects of the macro model, the micro model is intended to be presented in more detail. It has to be noted, that both models are to be coupled in order to investigate the dynamics of the system. The description of the processes stakeholders and interactions, which constitutes the basis of the implementation of the current system, can be found in Annex 2.

Firstly, in chapter 4.1.2.1, measures gained from operational experience related the turnaround phase are discussed. That addresses aspects of D3.3, since it follows a different approach of work, based on heuristics to derive resilient design principles. This approach will not be discussed in this document since during exchange with partners of the consortium; simulation of data was assessed as the most feasible approach.

Mathworks Simevents was chosen as a suitable environment to incorporate the human role with respect from an agent bases modelling perspective[4] and to allow simulating processes and interactions in more detail. Aspect of that perspective will be discussed in 4.1.2.2, addressing task 4.4 and 4.5. Subsequently aspects of a chosen example of the deicing process are discussed in 4.1.3 (task 4.6). Examples of the implementation which is based of the descriptions shown in Annex 2 are provided in 4.2 (task 4.6). A case study of the deicing process is presented in Annex3.

#### 4.1.2.1 Examples of resilient measures based on heuristics in Turnaround

The turnaround process itself is an overall term for a group of sub-processes, in detail on-block actions (setting the chocks, ground power supply, stairs / jet bridge positioning), de-boarding, de-loading, refueling, potable water, cleaning, catering, loading, boarding and off-block actions (removing stairs / jet bridge, cutting the ground power supply, removing the chocks and push-back).

The following page shows examples of total turnaround times for several passenger aircraft. Unfortunately this data is only available for manufacturers Airbus and Boeing [TAT 2014].

[4] This transaction based discrete event environment delivers an easy transformation of the information in the depiction of this report (please see [Gray 2007], [Mathworks 2014]. An element such as servers, generators, queues, gates, switches or timers, to name a few, can be assigned to the elements of the UML descriptions.

## Table 3: Examples of turn-around times for several airbus aircraft

| producer | aircraft type | model | aircraft ICAO designator ICAO DOC 8643 | category (according to Fraport) | ICAO category | basic conditions | | | | | | | | | | standard turnaround times (min) | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | kind of service | transport of Freight and/or Passengers | passenger amount | doors open | percentage of passenger movement | percentage of refuelling | passenger flow rate deplaning (pax/door) | passenger flow rate boarding (pax/door) | APU running | Percentage of unload-load | Position pax bridge and open doors | passengers movement deboarding | passengers movement boarding | remove pax bridge and close doors | headcounting | position equipment for cargo loading | cargo unloading | baggage and cargo movement | cargo loading | remove equipment for cargo loading | position equipment for cleaning | clean cabin | remove equipment for cleaning | position equipment for refreshing potable water | (service toilet and) water replenishment | remove equipment for refreshing potable water | position equipment for lavatory service | toilet servicing | remove equipment for lavatory service | position equipment for catering | catering | remove equipment for catering | position equipment for refuelling | refuelling | remove equipment for refuelling | walk around check | start engines | disconnections | total turnaround time |
| Airbus | A300 | C4 | A30B | E | D | Full Servicing | Freight/Passengers | 145 | 1 | 100 | 80 | 18 | 16 | yes | 100 | 2 | 8 | 9 | 1,5 | | 3 | | 21 | | 2 | | 7 | | | 7 | | | | | | 6 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | C4 | A30B | E | D | Full Servicing | Freight/Passengers | 75 | 1 | 100 | 80 | 18 | 16 | yes | 100 | 2 | 4 | 5 | 1,5 | | 3 | | 21 | | 2 | | 4 | | | 4 | | | | | | 5 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B2 | A30B | E | D | Full Servicing | Passengers | 281 | 2 | 100 | 80 | 18 | 16 | yes | | 2 | 8 | 9 | 1,5 | | 3 | | 21 | | 2 | | 10 | | | 10 | | | | | | 10 | | | 24 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B4 | A30B | E | D | Full Servicing | Passengers | 281 | 2 | 100 | 80 | 18 | 16 | yes | | 2 | 8 | 9 | 1,5 | | 3 | | 21 | | 2 | | 10 | | | 10 | | | | | | 10 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | C4 | A30B | E | D | Full Servicing | Passengers | 281 | 2 | 100 | 80 | 18 | 16 | yes | | 2 | 8 | 9 | 1,5 | | 3 | | 21 | | 2 | | 10 | | | 10 | | | | | | 10 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B2 | A30B | E | D | Full Servicing | Passengers | 281 | 3 | 100 | 80 | 18 | 16 | yes | | 2 | 6 | 6,5 | 1,5 | | 3 | | 21 | | 2 | | 15 | | | 10 | | | | | | 12 | | | 24 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B4 | A30B | E | D | Full Servicing | Passengers | 281 | 3 | 100 | 80 | 18 | 16 | yes | | 2,5 | 6 | 6,5 | 1,5 | | 3 | | 21 | | 2 | | 15 | | | 10 | | | | | | 12 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | C4 | A30B | E | D | Full Servicing | Passengers | 281 | 3 | 100 | 80 | 18 | 16 | yes | | 2,5 | 6 | 6,5 | 1,5 | | 3 | | 21 | | 2 | | 15 | | | 10 | | | | | | 12 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | C4 | A30B | E | D | Full Servicing | Freight | | | | 80 | | | yes | 100 | 2 | | | | | 3 | | 21 | | 2 | | | | | 4 | | | | | | | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B2 | A30B | E | D | Transit | Passengers | 281 | 3 | 60 | 30 | 18 | 16 | yes | | 3 | 5 | 6 | 2 | | 4,5 | | 18 | | 3 | | | | | 15 | | | | | | 12 | | | 18,5 | | 22,5 | 3 | 1 | 20 |
| Airbus | A300 | B4 | A30B | E | D | Transit | Passengers | 282 | 3 | 60 | 30 | 18 | 16 | yes | | 3 | 5 | 6 | 2 | | 4,5 | | 18 | | 3 | | | | | 15 | | | | | | 12 | | | 22 | | 22,5 | 3 | 1 | 20 |
| Airbus | A300 | C4 | A30B | E | D | Transit | Passengers | 282 | 3 | 60 | 30 | 18 | 16 | yes | | 3 | 5 | 6 | 2 | | 4,5 | | 18 | | 3 | | | | | 15 | | | | | | 12 | | | 22 | | 22,5 | 3 | 1 | 20 |
| Airbus | A300 | B4-600 | A306 | E | D | Full Servicing | Passengers | 285 | 2 | 100 | 80 | 18 | 16 | yes | | 2 | 8 | 9 | 1,5 | | 3 | | 21 | | 2 | | 10 | | | 10 | | | | | | 10 | | | 26,5 | | 25 | 2 | 1 | 30 |
| Airbus | A300 | B4-600 | A306 | E | D | Transit | Freight | | | | 80 | | | yes | 100 | 2 | | | 1,5 | | 3 | | 26,5 | | 2 | | | | | 5 | | | | | | | | | 26,5 | | 25 | 2 | 1 | 35 |
| Airbus | A300 | F4-600 | A306 | E | D | Transit | Freight | | | | 80 | | | yes | 100 | 2 | | | 1,5 | | 3 | | 26 | | 2 | | | | | 5 | | | | | | | | | 26 | | 25 | 2 | 1 | 35 |
| Airbus | A310 | 200 | A310 | D | D | Transit | Passengers | 237 | | | 0 | 22 | 18 | yes | | 2 | 10 | 13 | 2 | | 2 | 10 | | 10 | 2 | | | | | 7 | | | 7 | | | | | | | | | | | 30 |
| Airbus | A310 | 300 | A310 | D | D | Transit | Passengers | 237 | | | 0 | 22 | 18 | yes | | 2 | 10 | 13 | 2 | | 2 | 10 | | 10 | 2 | | | | | 7 | | | 7 | | | | | | | | | | | 30 |
| Airbus | A310 | 200 | A310 | D | D | Full Servicing | Passengers | 237 | | | 72 | 22 | 18 | yes | | 2 | 10 | 13 | 2 | | 2 | 10 | | 10 | 2 | | 11,5 | | | 7 | | | 7 | | | 15 | | 4 | 13,5 | 4 | | | | 45 |
| Airbus | A310 | 300 | A310 | D | D | Full Servicing | Passengers | 237 | | | 53 | 22 | 18 | yes | | 2 | 10 | 13 | 2 | | 2 | 10 | | 10 | 2 | | 11,5 | | | 7 | | | 7 | | | 15 | | 4 | 13,5 | 4 | | | | 45 |
| Airbus | A310 | 200 | A310 | D | D | Full Servicing | Passengers | 237 | | | 100 | 22 | 18 | yes | | 2 | 10 | 13 | 3,5 | | 2,5 | 8 | | 12,5 | 3,5 | | 20,5 | | | 7 | | | 8,5 | | | 31 | | 4 | 17,5 | 3,5 | | | | 90 |
| Airbus | A310 | 300 | A310 | D | D | Full Servicing | Passengers | 237 | | | 70 | 22 | 18 | yes | | 2 | 10 | 13 | 3,5 | | 2,5 | 8 | | 12,5 | 3,5 | | 20,5 | | | 7 | | | 8,5 | | | 31 | | 4 | 17,5 | 3,5 | | | | 90 |
| Airbus | A310 | 310F | A310 | D | D | Transit | Freight | | | | | | | yes | 100 | 2 | | | 1,5 | | 3 | | 19,5 | | 2 | | | | | 5 | | | | | | | | | 22 | | 22,5 | 2 | 1 | 28 |
| Airbus | A318 | 100 | A318 | C | C | Full Servicing | Passengers | 107 | 1 | 100 | | 20 | 12 | yes | | 2 | 5,5 | 9 | 1,5 | 2 | 2 | 6,5 | | 8,5 | 1,5 | | 15 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 9 | 3 | 2,5 | 16 | 2,5 | | | | 35 |
| Airbus | A318 | 100 | A318 | C | C | Outstation | Passengers | 132 | 2 | 100 | | 18 | 12 | yes | 100 | 2 | 3,5 | 5,5 | 1,5 | 2 | 2 | 6,5 | | 8,5 | 1,5 | | 6,5 | | | | | | | | 2 | 6,5 | 1,5 | | | | | | | 21 |
| Airbus | A319 | 100 | A319 | C | C | Full Servicing | Passengers | 124 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 6,5 | 10,5 | 1,5 | 2 | 2 | 3 | | 3 | 1,5 | | 15 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 9 | 3 | 2,5 | 15,5 | 2,5 | | | | 37 |
| Airbus | A319 | neo | A319 | C | C | Full Servicing | Passengers | 124 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 6,5 | 10,5 | 1,5 | 2 | 2 | 3 | | 3 | 1,5 | | 15 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 9 | 3 | 2,5 | 15,5 | 2,5 | | | | 37 |
| Airbus | A319 | 100 | A319 | C | C | Outstation | Passengers | 156 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 4,5 | 7,5 | 1,5 | 2 | 2 | 3 | | 3 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1 | | | | | | | 21 |
| Airbus | A319 | neo | A319 | C | C | Outstation | Passengers | 156 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 4,5 | 7,5 | 1,5 | 2 | 2 | 3 | | 3 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1 | | | | | | | 21 |
| Airbus | A320 | 200 | A320 | C | C | Full Servicing | Passengers | 150 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 7,5 | 12,5 | 1,5 | 2 | 2 | 6 | | 6 | 1,5 | | 18,5 | | 2 | 3,5 | 1 | 2 | 6,5 | 1 | 5 | 13,5 | 3 | 2,5 | 16 | 2,5 | | | | 44 |
| Airbus | A320 | neo | A320 | C | C | Full Servicing | Passengers | 150 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 7,5 | 12,5 | 1,5 | 2 | 2 | 6 | | 6 | 1,5 | | 18,5 | | 2 | 3,5 | 1 | 2 | 6,5 | 1 | 5 | 13,5 | 3 | 2,5 | 16 | 2,5 | | | | 44 |
| Airbus | A320 | 200 | A320 | C | C | Outstation | Passengers | 180 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 5 | 7,5 | 1,5 | 2 | 2 | 6 | | 6 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1,5 | | | | | | | 22 |
| Airbus | A320 | neo | A320 | C | C | Outstation | Passengers | 180 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 5 | 7,5 | 1,5 | 2 | 2 | 6 | | 6 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1,5 | | | | | | | 22 |
| Airbus | A321 | 100 | A321 | C | C | Full Servicing | Passengers | 185 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 9,5 | 15,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 22 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 17 | 3 | 2,5 | 14 | 2 | | | | 52 |
| Airbus | A321 | 200 | A321 | C | C | Full Servicing | Passengers | 185 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 9,5 | 15,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 22 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 17 | 3 | 2,5 | 14 | 2 | | | | 52 |
| Airbus | A321 | neo | A321 | C | C | Full Servicing | Passengers | 185 | 1 | 100 | | 20 | 12 | yes | 100 | 2 | 9,5 | 15,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 22 | | 2 | 4 | 1 | 2 | 5 | 1 | 5 | 17 | 3 | 2,5 | 14 | 2 | | | | 52 |
| Airbus | A321 | 100 | A321 | C | C | Outstation | Passengers | 220 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 6 | 7,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1,5 | | | | | | | 23 |
| Airbus | A321 | 200 | A321 | C | C | Outstation | Passengers | 220 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 6 | 7,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1,5 | | | | | | | 23 |
| Airbus | A321 | neo | A321 | C | C | Outstation | Passengers | 220 | 2 | 100 | 0 | 18 | 12 | yes | 100 | 2 | 6 | 7,5 | 1,5 | 2 | 2 | 7,5 | | 7,5 | 1,5 | | 4 | | | | | | | | 2 | 4 | 1,5 | | | | | | | 23 |
| Airbus | A330 | | A330 | F | E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Airbus | A330 | 300 | A333 | F | E | Full Servicing | Passengers | 300 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 6 | 10 | 2,5 | 4 | 2,5 | 21,5 | | 25 | 2,5 | 2 | 33 | 2 | 2 | 11,5 | 2 | 2 | 11 | 2 | 5 | 33 | 3 | 5 | 26,5 | 5 | | | | 59 |
| Airbus | A330 | 200 | A332 | F | E | Full Servicing | Passengers | 246 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 5 | 8,5 | 3 | 4 | 2,5 | 16,5 | | 19,5 | 2,5 | 2 | 29,5 | 2 | 2 | 11,5 | 2 | 2 | 11 | 2 | 5 | 29,5 | 3 | 5 | 32 | 5 | | | | 53 |
| Airbus | A330 | 200F | A332 | F | E | Full Servicing | Freight | | | | | | | yes | 100 | 2,5 | 0,5 | 0,5 | 3 | | 5 | 24 | | 28 | 3 | | | | 2 | 3 | 2 | 2 | 6 | 2 | | | | 5 | 32,5 | 5 | | | | 63 |
| Airbus | A330 | 300 | A333 | F | E | Transit | Passengers | 300 | 1 | 50 | 0 | 20 | 15 | yes | 50 | 3 | 6 | 10 | 3 | 4 | 2,5 | 8,5 | | 9,5 | 2,5 | 2 | 8 | 2 | | | | | | | 5 | 8 | 3 | | | | | | | 34 |
| Airbus | A330 | 200 | A332 | F | E | Transit | Passengers | 246 | 1 | 50 | 0 | 25 | 15 | yes | 50 | 3 | 5 | 8 | 3 | 4 | 2,5 | 7,5 | | 8,5 | 2,5 | 2 | 8 | 2 | | | | | | | 5 | 8 | 3 | | | | | | | 31 |
| Airbus | A340 | | A340 | F | E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Airbus | A340 | 300 | A343 | F | E | Full Servicing | Passengers | 270 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 5,5 | 9 | 3 | 4 | 2,5 | 19 | | 22,5 | 2,5 | 2 | 38,5 | 2 | 2 | 11,5 | 2 | 2 | 11 | 2 | 5 | 37,5 | 3 | 5 | 34,5 | 5 | | | | 62 |
| Airbus | A340 | 200 | A342 | F | E | Full Servicing | Passengers | 231 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 4,5 | 8 | 3 | 4 | 2,5 | 14,5 | | 17 | 2,5 | 2 | 29,5 | 2 | 2 | 12 | 2 | 2 | 11,5 | 2 | 5 | 29,5 | 3 | 5 | 34 | 5 | | | | 52 |
| Airbus | A340 | 300 | A343 | F | E | Transit | Passengers | 270 | 1 | 50 | 30 | 25 | 15 | yes | 50 | 3 | 5,5 | 9 | 3 | 4 | 2,5 | 5 | | 5,5 | 2,5 | 2 | 9 | 2 | | | | | | | 5 | 9 | 3 | 5 | 15,5 | 5 | | | | 33 |
| Airbus | A340 | 200 | A342 | F | E | Transit | Passengers | 231 | 1 | 50 | 30 | 25 | 15 | yes | 50 | 3 | 4,5 | 7,5 | 3 | 4 | 2,5 | 5 | | 5,5 | 2,5 | 2 | 9 | 2 | | | | | | | 5 | 9 | 3 | 5 | 15,5 | 5 | | | | 31 |
| Airbus | A340 | 600 | A346 | G | E | Full Servicing | Passengers | 319 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 6,5 | 11 | 3 | 4 | 2,5 | 24 | | 28 | 2 | 2 | 41 | 2 | 2 | 18 | 2 | 2 | 21 | 2 | 5 | 41 | 3 | 5 | 28,5 | 5 | | | | 68 |
| Airbus | A340 | 500 | A345 | G | E | Full Servicing | Passengers | 246 | 2 | 100 | | 25 | 15 | yes | 100 | 3 | 5 | 8,5 | 3 | 4 | 2,5 | 19 | | 22,5 | 2,5 | 2 | 33 | 2 | 2 | 11,5 | 2 | 2 | 21 | 2 | 5 | 33 | 3 | 5 | 29,5 | 5 | | | | 56 |
| Airbus | A340 | 600 | A346 | G | E | Transit | Passengers | 319 | 1 | 50 | 30 | 25 | 15 | yes | 50 | 3 | 6,5 | 10,5 | 3 | 4 | 2,5 | 7,5 | | 8,5 | 2,5 | 2 | 7 | 2 | | | | | | | 5 | 7 | 3 | 5 | 18 | 5 | | | | 34 |
| Airbus | A340 | 500 | A345 | G | E | Transit | Passengers | 246 | 1 | 50 | 30 | 25 | 15 | yes | 50 | 3 | 5 | 8 | 3 | 4 | 2,5 | 5 | | 5,5 | 2,5 | 2 | 9,5 | 2 | | | | | | | 5 | 9,5 | 3 | 5 | 17,5 | 5 | | | | 32 |

The following table shows examples of disturbances that might occur during the turnaround process. Implications and possible countermeasures are also listed. [Förster 2014] This was done in order to investigate possible measure suitable to enhance the resilience using operational experience. Methods that might enhance resilience were discussed[5]. These alternative measures are depicted in the process description of the turnaround in Annex2 in the form of magenta dyed elements.

**Table 4: Examples of disturbances, implications and resilient measures during turn-around**

| *Type of disturbance* | *Implications* | *Possible countermeasures* |
|---|---|---|
| Delayed arriving aircraft | Delay might not be compensated if normal operation are applied | Different procedures are proposed like<br>- Additional personnel<br>- Shortened cleaning process (transit cleaning vs. deep cleaning)<br>- Omit fueling (if possible) |
| Gate occupied by other aircraft | As consequence of the gate change, passengers have to be informed, some are missing the updated gate and arrived delayed at the gate. The boarding process is delayed. | early re-planning of gate position and information of passengers |
| Passenger unable to deboard/board due to missing stairs or bus | Delay of deboarding/boarding process | - |
| Delayed fuel truck | Delayed boarding, or in case of boarding with fire service on site higher costs occur | In case the existing fuel is sufficient, fueling is carried out at the next flight leg |
| Amount of block fuel was not communicated on time to fuel truck or fueling company | Delay of boarding | - |
| Catering personnel not on time at the aircraft | Delayed boarding, or boarding is interrupted | Omitting catering, in case existing amount is sufficient |

[5] "The most important method applied today, to deal with the problems connected with the turnaround process is A-CDM. It proved its usefulness at different airports in Europa already. The main aspect of information sharing (Milestone approach) and binding target times (the target off block time has to be communicated by the airline to the airport/ATC) enhances the predictability of push back times and provides a better integration of the turnaround process into the network. Besides improved departure sequence, also the traffic flow management can be enhanced.
As a new design principle reaching beyond the year 2050, highly automated operations on airports are suggested. A plan that determines all operations at the airport and which is deducted from demand and capacity constraints, seems not likely to be applicable due to the different particular interests and the element of competition. As a feasibly implementation of the idea, the collaborative decision making was proposed by the total airport management in 2006. Potential solutions (in the case of disturbances) are assessed by this methodology together by all involved stakeholders by means of what of probing. This aims to enable a faster return of the airport system to its reference point. Again the reader should be aware that this implies a commonly agreed reference point (please see D1.3 for the importance of the reference state) which poses a significant obstacle to reach, as discussed in D4.1.", page 15, D3.3

| | | |
|---|---|---|
| | | |
| Cleaning personnel not on time at the aircraft (due to tied up resources, see Air Berlin and TUI) | Delayed boarding | Reducing cleaning quality (transit vs deep) |
| Prolonged cleaning due to increased contamination | Delayed, catering and boarding | - |
| Passengers not on time at the gate due to shortage at security | Delayed boarding | Providing an additional „Fast Lane" at security for a particular flight<br><br>Passengers are checked out |
| Passengers delayed, baggage already checked in | Waiting for passengers for a distinct amount of time | Passengers are checked out |
| Delayed cargo | Flight is delayed | Loading of cargo with additional personnel |
| Due to thunderstorm/lightning/ strong winds, flight cannot be dispatched | Flight is delayed | - |
| Technical failure at aircraft (for example changing of a tire adds 30 minutes) | Flight is delayed | |
| Strike of ground handler (mostly security) | Delay or cancellation of flight | If applicable, federal police steps in, in case of security strikes |
| Pushback truck not available on time | Flight is delayed | |

#### 4.1.2.2 Agent-based modelling and simulation

Section **Fehler! Verweisquelle konnte nicht gefunden werden.** introduces agent-based modelling and simulation (ABMS) for studying resilience in ATM. Section **Fehler! Verweisquelle konnte nicht gefunden werden.** provides a concise overview of literature on ABMS applications in air transport. Section **Fehler! Verweisquelle konnte nicht gefunden werden.** describes steps of ABMS of sociotechnical systems, based on (Nikolic et al., 2013). Section **Fehler! Verweisquelle konnte nicht gefunden werden.** presents steps in ABMS for safety analysis in ATM.

#### 4.1.2.2.1 ABMS for studying resilience in ATM

Agent-based modelling and simulation (ABMS) is an approach for modelling complex systems by describing the behaviour and interactions of a collection of autonomous decision-making entities, called agents (Bonabeau, 2002; Macal and North, 2010; Van Dam et al., 2013). The overall system behaviour emerges as a result of the individual agent processes and their interactions. ABMS provides a highly modular and transparent way of structuring a model, thus supporting systematic analysis, both conceptually and computationally. ABMS has been used in a wide range of application fields, including molecular physics, cell biology, ecology, epidemiology, social sciences, economy, market analysis, archaeology, and anthropology (Macal and North, 2010). Also for transport and traffic studies the value of ABMS and multi-agent technology has been well realized, as follows from overviews in (Burmeister et al., 1997; Chen and Cheng, 2010; Davidsson et al., 2005). Examples of ABMS applications in the ATM domain include analysis of controller workload and traffic flows during arrival operations (Shah et al., 2005), competitive decision making of airlines (Niedringhaus, 2004), traffic flow management (Tumer and Agogino, 2007), ATM network delays (Grether et al., 2013), runway incursion risk (Stroeve et al., 2013a), and safety of airborne self-separation (Blom and Bakker, 2012). The latter two studies are focused on assessment of rare safety occurrences and they explicitly include a range of hazards in the ABMS, i.e. conditions, events or circumstances which could contribute to the occurrence of an accident, such as system failures, misunderstandings, or bad weather. Building on the recognized assets of ABMS for transport and traffic studies, including ATM, and the emergent results that can be obtained by ABMS, it is a promising candidate for studying resilience in the sociotechnical ATM system.

Studying resilience by ABMS means analysing the capability of the sociotechnical system to deal with disturbances and performance variability. The disturbances may reflect a wide range of events, conditions or circumstances, and they may be internal to the sociotechnical system, i.e. stem from particular human operators or technical systems, or they may be external, i.e. reflect phenomena in the environment of the sociotechnical system. Human operators and technical systems can express a large variety of behavioural patterns, which are influenced by processes and characteristics of the agent considered (e.g. cognitive and affective aspects), and which depend on interactions between the agents. Disturbances and performance variability can be represented by model constructs in ABMS, which describe behaviour, events and circumstances of human operators, technical systems and their environment (**Fehler! Verweisquelle konnte nicht gefunden werden.**). To study resilience in sociotechnical systems by ABMS a sufficiently broad set of model constructs should be available, such that a broad variety of disturbances and performance variability can be represented.

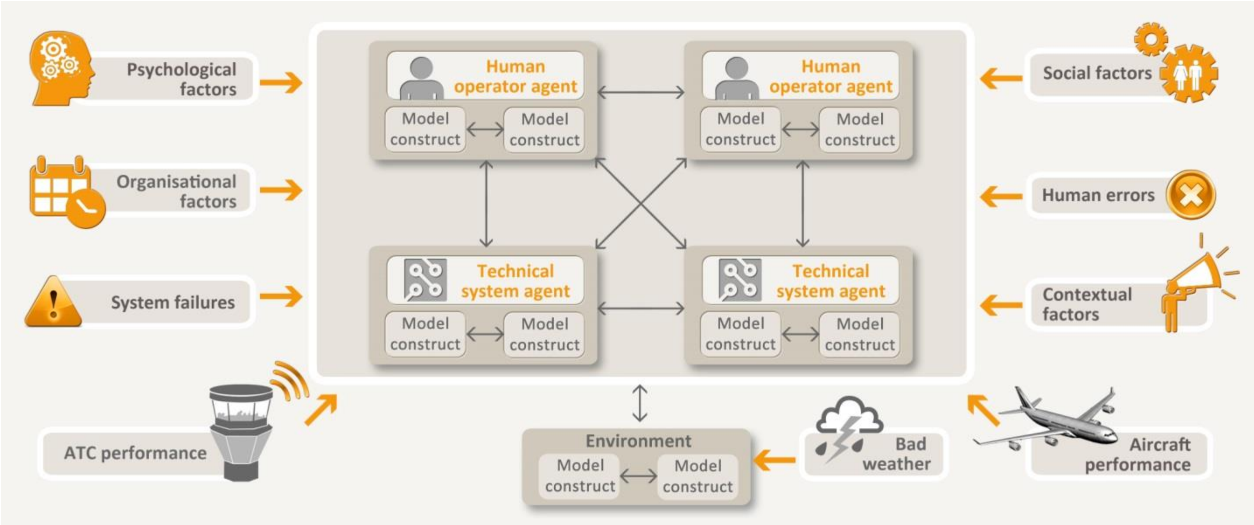



Figure 6. Generic overview of an agent-based model consisting of human operators and technical systems in an environment. Agents are represented by a combination of model constructs that depict aspects of the agents' behaviour and interactions.

Using a broad set of hazards that may occur in ATM, a library consisting of 38 model constructs was developed in (Stroeve et al., 2013b). A list of these model constructs and an indication of the frequency of their use for modelling of the set of hazards are listed in **Fehler! Verweisquelle konnte nicht gefunden werden.**. For instance, it shows that the model constructs Multi-agent situation awareness, System mode, and Human error are used most often to model hazards in ATM.

Table 5. Model constructs for agent-based modelling in ATM. The frequency of use indicates the number of hazards in ATM that can be modelled using each model construct (Stroeve et al., 2013b).

| Rank | Model construct | | Frequency of use | |
|---|---|---|---|---|
| | | | No. | Perc. |
| 1 | C2 | Multi-agent situation awareness | 219 | 41.7% |
| 2 | C10 | System mode | 118 | 22.5% |
| 3 | C8 | Human error | 117 | 22.3% |
| 4 | C1 | Human information processing | 95 | 18.1% |
| 5 | C5 | Task execution | 57 | 10.9% |
| 6 | C11 | Dynamic variability | 53 | 10.1% |
| 7 | MC6 | Situation awareness with complex beliefs | 50 | 9.5% |
| 8 | MC3 | Operator functional state | 49 | 9.3% |
| 9 | C12 | Stochastic variability | 48 | 9.1% |
| 10 | C13 | Contextual condition | 48 | 9.1% |
| 11 | MC2 | Experience-based decision making | 40 | 7.6% |
| 12 | MC8 | Formal organisation | 37 | 7.0% |
| 13 | C4 | Task scheduling | 31 | 5.9% |
| 14 | MC7 | Trust | 31 | 5.9% |
| 15 | NM14 | Confusion / Surprise (A) | 28 | 5.3% |
| 16 | C9 | Decision making | 27 | 5.1% |
| 17 | C3 | Task identification | 25 | 4.8% |
| 18 | C6 | Cognitive control mode | 24 | 4.6% |
| 19 | C7 | Task load | 23 | 4.4% |
| 20 | NM33 | Bad weather | 18 | 3.4% |

| | | | | |
|---|---|---|---|---|
| 21 | MC1 | Object-oriented attention | 16 | 3.0% |
| 22 | MC9 | Learning / adaptivity | 15 | 2.9% |
| 23 | MC5 | Safety culture | 10 | 1.9% |
| 24 | NM15 | Confusion / Surprise (B) | 10 | 1.9% |
| 25 | MC4 | Information presentation | 9 | 1.7% |
| 26 | MC11 | Extended mind | 8 | 1.5% |
| 27 | NM7 | Group emotion | 5 | 1.0% |
| 28 | NM21 | Deciding when to take action | 5 | 1.0% |
| 29 | NM34 | Weather forecast wrong | 4 | 0.8% |
| 30 | NM31 | Access rights | 3 | 0.6% |
| 31 | MC10 | Goal-oriented attention | 2 | 0.4% |
| 32 | NM2 | Approach | 2 | 0.4% |
| 33 | NM35 | Turbulence | 2 | 0.4% |
| 34 | NM36 | Icing | 2 | 0.4% |
| 35 | NM38 | Influence of many agents on flight planning | 2 | 0.4% |
| 36 | NM3 | Handling Inconsistent Information | 1 | 0.2% |
| 37 | NM32 | Merging or splitting ATC sectors | 1 | 0.2% |
| 38 | NM40 | Uncontrolled aircraft | 1 | 0.2% |

The model constructs of **Fehler! Verweisquelle konnte nicht gefunden werden.** refer to the modelling semantics. Syntactically, they may be implemented in various ways. For instance, in the context of (Stroeve et al., 2013b), the Stochastically and Dynamically Coloured Petri Net (SDCPN) syntax and the LEADSTO syntax have been applied. In general, the syntax needed to represent the model constructs of **Fehler! Verweisquelle konnte nicht gefunden werden.** should be sufficiently broad to describe stochastic and dynamic non-linear processes with continuous as well as discrete timed events in a multi-agent sociotechnical system.

#### 4.1.2.2.2 Concise review of ABMS applications in air transport

The paper (Davidsson et al., 2005) provides an analysis of research in the years 1992-2005 on agent-based approaches to transportation and traffic management, including air, road, rail, sea and intermodal modalities. It is concluded that many of the logistic problems studied can be well addressed by agent-based systems, but that the maturity of the research was low and few systems were deployed.

A review (2010) of the applications of agent technology in traffic and transportation systems is provided in (Chen and Cheng, 2010). The review shows that multi-agent methods and techniques have been applied to many aspects of traffic and transportation systems. This includes, on the one hand, multi-agent technology in systems for dynamic routing and congestion management, and intelligent traffic control, and on the other hand, agent-based modelling and simulation of traffic scenarios. The emphasis has been on the latter, few real-world applications have yet been implemented and deployed.

A literature review of agent-based approaches for airport performance modelling is included in (Bouarfa, 2012). It describes a number of agent-based model and simulation environments for air traffic management, including the Traffic Organization and Perturbation AnalyZer (TOPAZ) of NLR, the agent-based Reconfigurable Flight Simulator (RFS) of Georgia Institute of Technology, the

Jet:Wise model of MITRE, the Airspace Concept evaluation System (ACES) of NASA, and the Optimal Aircraft Sequencing using Intelligent Scheduling (OASIS) of the Australian Intelligence Institute.

In (Lee et al., 2007) agent-based modelling and simulation was demonstrated for analysis of aircraft arrivals into Los Angeles International airport (LAX) using various spacing techniques. The agent models of human operators (pilots and air traffic controllers) herein are based on the Air-MIDAS model. The study was done using the agent-based Reconfigurable Flight Simulator (RFS) modelling and simulation framework. This simulation platform was constructed in C++ and is described in (Shah, 2006).

An agent-based model for analyzing control policies and the dynamic service-time performance of a capacity-constrained air traffic management facility is reported in (Conway, 2006). The model is implemented in Repast. The model emulates commercial airline demand at a busy airport with a simplified huband-spoke route structure. The model includes primitive representations of system capacity, demand, airline schedules and strategy, and aircraft capability. The agent-based simulations reveal the interdependences between these system attributes. The model does not include human performance models or aircraft dynamics models.

Agent-based modelling using Repast was done for planning of the location of intermodal freight hubs in (Van Dam et al., 2007). The paper presents the initial design of the model and does not provide results. More details of modelling sociotechnical systems by ABMS are in the PhD-thesis (Van Dam, 2009) and book (Van Dam et al., 2013).

In the SESAR WP-E project CASSIOPEIA (http://www.complexworld.eu/projects/cassiopeia/) an open platform for ATM multi-agent simulation software has been developed. The CASSIOPEIA consortium includes Innaxis and the Technical University of Madrid. The CASSIOPEIA framework started by using the multi-agent tools Repast and JADE (Java Agent Development Framework) (Innaxis Cassiopeia team and Universidad Politecnica de Madrid, 2012). The main objective of using the JADE framework in CASSIOPEIA was to provide a set of services that simplify the development while ensuring standard compliance in agent-oriented programming. Repast-provided GUIs could help developers to rapidly construct simulation prototypes. At a later stage, CASSIOPEIA decided to use JADEX to implement agent-based models due to a series of modelling issues, but mainly because of its flexible BDI engine and FIPA compliant communication infrastructure. In using JADEX certain problems, such as partial documentation and a number of execution errors, were encountered that should be solved in more mature versions of JADEX.

Agent-based modelling and simulation of air traffic by the MATSim framework is presented in (Grether et al., 2013). MATSim is a framework to implement large-scale agent-based transport simulations.

The Jet:Wise agent-based model (Niedringhaus, 2004) models competitive decision making of airlines with respect to aspects such as fleet mix, itineraries, schedules and fares in the context of delays and missed connections. No developments after 2004 have been found for this model.

An application of the Future ATM Concepts Evaluation Tool (FACET) is presented in (Tumer and Agogino, 2007). FACET is presented in (Bilimoria et al., 2001), (Bilimoria et al., 2000).

The development of the Airspace Concept Evaluation System (ACES) is presented in (Meyn et al., 2006). ACES is still being developed. The company Intelligent Automation, Inc. (IAI) is contributing to this development using its CybelePro agent infrastructure to simulate and assess the performance of the National Airspace System (NAS).

#### 4.1.2.2.3 Steps for developing and using an agent-based model

This section provides a summary of steps for creating and using an agent-based model of a socio-technical system, as presented in (Nikolic et al., 2013), and it provides some notes on the the relevance for the modelling in the Resilience2050 project. The following ten steps are presented in (Nikolic et al., 2013):

- Step 1: Problem formulation and actor identification;
- Step 2: System identification and decomposition;
- Step 3: Concept formalisation;
- Step 4: Model formalisation;
- Step 5: Software implementation;
- Step 6: Model verification;
- Step 7: Experimentation;
- Step 8: Data analysis;
- Step 9: Model validation;
- Step 10: Model use.

**Step 1: Problem formulation and actor identification**

Step 1 forms the starting point of the modelling and simulation process. It defines the problem that is addressed by the modelling, describing a particular knowledge gap or initial hypotheses on emergent patterns. It describes the stakeholder(s) of the problem and other actors relevant for the problem considered.

**Step 2: System identification and decomposition**

The objective of Step 2 is to identify the system composition and its boundaries. It consists of an inventory phase and a structuring phase. In the inventory phase information about the sociotechnical system is gathered by various means, such as data collection, surveys, interviews and brainstorm sessions with domain experts and stakeholders. The information gathered includes system boundaries (in time and space), relevant concepts, actors, objects, behaviours, interactions, states and properties. In the structuring phase, the information achieved in the inventory phase is used to identify agents, states and behaviours of agents, interactions between agents, and the environment. Several iterations may be needed to obtain a consistent and complete structuring of the information on the sociotechnical system.

**Step 3: Concept formalisation**

The objective of Step 3 is to formalise the concept of the sociotechnical system under study. Although the concept obtained in Step 2 may seem well-structured to the stakeholders, they may well be context-dependent and not sufficiently specific for formal modelling and computer implementation. Methods for concept formalisation include (1) listing of software data structures and (2) developing of a formal ontology. A software data structure describe classes, objects and variables of agents' data. An ontology represents knowledge as a hierarchy of concepts within a domain, including types, properties and interrelationships of those concepts. Software tools such as Protégé support ontology development.

**Step 4: Model formalisation**

Extending on the what and who is in the model, as identified in Step 3, the objective of Step 4 is defining who does what and when. This model formalisation consists of two tasks: (1) creation of a model narrative, and (2) expression of this narrative in pseudo-code. The model narrative describes the behaviour of each agent by expressing which agent does what with whom and when. The pseudo code uses mathematical and logical descriptions of what and how agents are supposed to behave to combine the model narrative and the formalised concepts resulting from Step 3. Pseudo code includes computation and assignment, iterations and loop, conditions, and input/output operations. An alternative to pseudo code is Unified Modelling Language (UML).

**Step 5: Software implementation**

In Step 5 the model is implemented in a modelling or programming environment. There are many agent-based modelling platforms and modelling environments. In (Van Dam et al., 2013) Netlogo, Repast and custom code development are concisely discussed as options. Furthermore, a number of good programming practices are discussed with regard to version control, documentation, standardisation, task distribution, and bug tracking.

**Step 6: Model verification**

Step 6 considers model verification: has the model been correctly implemented in the software? Agent-based models can be verified in 4 phases: (1) recording and tracking agent behaviour, in which relevant metrics are identified and recorded; (2) single-agent testing, in which the behaviour of a single agent is verified; (3) interaction testing limited to a minimal model, in which the interaction between agents is tested; (4) multi-agent testing, in which the emergent behaviour of multiple agents is examined.

**Step 7: Experimentation**

In Step 7 experiments are performed that may provide insights into the nature of the macroscopic regularity of interest described in Step 1. Two main types of hypotheses can be tested in an “in-silico” experiment. The first hypothesis type is that under specified conditions, a particular macroscopic regularity emerges from the agent-based model. This type of hypothesis may be confirmed or falsified. The second hypothesis type specifies that a range of emergent behaviours and regularities can be identified by the agent-based model. Type 2 hypotheses are oriented towards exploration of the sociotechnical system.

Simulations for type 1 hypotheses are typically linked to specific scenarios, which can be understood as a set of real-world situations. For these scenarios it may be possible to indicate the time frame in which an emergent pattern may arise, thus providing a basis for selecting appropriate simulation times. Simulations for type 2 hypotheses are usually characterised by parameter sweep experiments with a (large) number of experimental model runs at varying combinations of parameters, without a priori knowledge about the duration for the arising of emergent patterns.

Experiments may use various types of parameter sweeps:

- Full factorial design, where each experiment is a point in a multidimensional parameter space. This is only feasible for models with small number of parameters.
- Parameters chosen randomly from uniform distributions.
- Latin Hypercube Sampling (LHS), which guarantees uniform sampling of a scenario space given a parameter space and a number of experiments. Unlike random parameters, which are chosen by considering only one parameter at a time, LHS considers the entire set of parameters and finds where in the parameter space we should perform the predetermined number of experiments to get the most representative subset of the space.
- Monte Carlo experiments, with parameters chosen from specific probability distributions.

**Step 8: Data analysis**

Data analysis means trying to understand the results of the experiments. It is one of the most difficult parts of the modelling cycle, especially for poorly known emergent patterns. Tools for data analysis include Excel, R (open source and free de-facto standard in the statistics community), SPSS (commercial statistical software), and Matlab. Emergent patterns may be related to states of single agents , to interactions between agents, or to the collective behaviour of agents. Emergent patterns may be manifested by dynamic behaviour (e.g. cyclical, exponential increase), attractor changes (sudden jumps in the model behaviour), metastable behaviour (resulting in different clusters), or lack of patterns (i.e. noise). Patterns that are recognized should be interpreted and explained by the analyst, i.e. it should be explained what interactions and conditions have lead to the observed patterns. Next, it may be needed to perform iterations with other experiments in Step 7.

**Step 9: Model validation**

Model validation addresses questions whether we designed and build what is needed to answer the questions of the problem owner, and whether the outcomes are convincing. For agent-based modelling validation may be different from traditional views on validation, such as comparing experimental results and real-world data. Methods for validation include

- Historic replay of real-world situations. Problems with this approach include lack of knowledge of the states of the actors in the historic situation and the potential sensitivity of the results for unknown or partially known conditions.
- Face validation through expert consultation. This usually includes structured interviews with individuals or workshops with groups of experts, wherein model assumptions, mechanisms and outcomes are discussed. Problems with this approach are that experts may may rely on biased and flawed internal models of system behaviour to estimate possible futures, and they may not well understand (complex) models.
- Validation by literature comparison. This entails comparing the conclusions attained by the ABMS with those by other approaches reported in the literature.
- Validation by model replication. Herein a second agent-based model is developed with a different system decomposition and the results of both models are compared.

**Step 10: Model use**

Step 10 in the ABMS approach of (Nikolic et al., 2013) considers the presentation of model results to stakeholders, the raising of new questions on the basis of the model results, long term stakeholder engament and support, educating stakeholders in what models can and cannot do.

#### 4.1.2.2.4 Steps in ABMS for air traffic safety assessment

ABMS is used as part of the TOPAZ safety risk assessment methodology. An overview of the steps in a TOPAZ safety risk assessment cycle is given in Figure 2. In step 0, the objective of the assessment is determined, as well as the safety context, the scope and the level of detail of the assessment. Step 1 serves to obtain a complete overview of the operation. Next, hazards associated with the operation are identified (step 2), and aggregated into safety relevant scenarios (step 3). Using severity and frequency assessments (steps 4 and 5), the safety risk associated with each safety relevant scenario is classified (step 6). For each safety relevant scenario with a (possibly) unacceptable safety risk, the main sources contributing to the lack of safety (safety bottlenecks) are identified (step 7). A more detailed discussion of the processes in these steps is provided in (Blom et al., 2006).

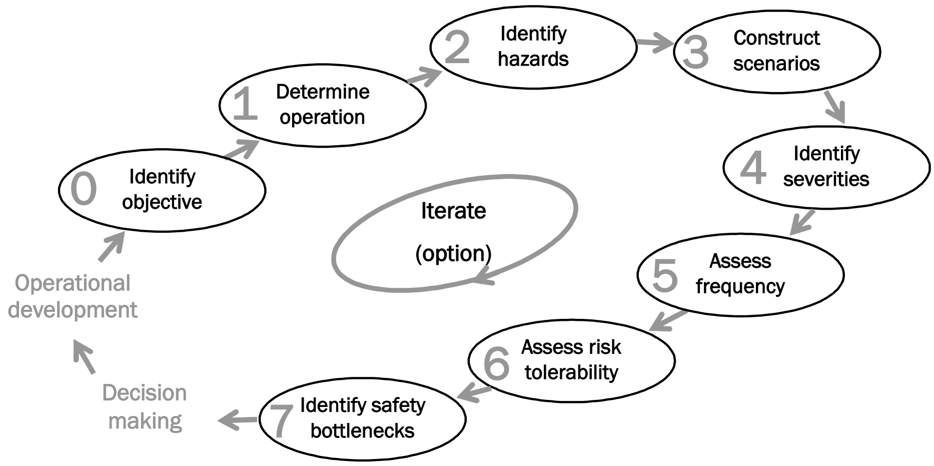



Figure 7. Overview of steps in TOPAZ safety risk assessment cycle (Blom et al., 2006).

ABMS is mainly used in Step 5 of the safety risk assessment cycle to assess the probabilities of rare safety occurreces, such as aircraft collisions. In this context, ABMS is referred to as agent-based dynamic risk modelling (DRM). In a recent White Paper (Eurocontrol / FAA AP15 Safety, 2014), it is explained that agent-based DRM uses the following substeps:

A. Deciding who are the agents;
B. Modelling hazards;
C. Developing a stochastic dynamic model for each agent, and modelling their interactions;
D. Rare event Monte Carlo simulation;
E. Evaluating the differences between the model and the real operation.

Next, we concisely explain these steps. More details and references to related papers can be found in (Eurocontrol / FAA AP15 Safety, 2014).

**A. Deciding who are the agents**

The first step in agent-based DRM is identifying the agents in the operation. Each agent is an autonomous entity in the operation that is able to perceive its environment, including other agents, and that is able to act upon and interact with this environment. Agents can be human operators, technical systems, or complete organisations. The result of this step is an overview of the agents and the connections between the agents.

**B. Modelling hazards**

The second step is to identify the agent-based hazard model constructs required to capture the hazards applicable to the operation. Each such model construct is an abstraction of one aspect in an agent. Through a recent study, a rather complete library of 38 model constructs has been developed for application in air traffic management (Stroeve et al., 2013b). The study has also shown that this library addresses some 95% of all potential hazards in ATM. Many of the model constructs in the library are human performance related.

**C. Developing a stochastic dynamic model for each agent, and modelling their interactions**

The next step is to develop a stochastic dynamic model for each agent in the operation, and to model their interactions. For this, the formalism of *stochastically and dynamically coloured Petri net (SDCPN)* is used, since it has many important strengths. The SDCPN formalism was obtained through extensions (Everdij, 2010) of ordinary Petri Nets. These extensions maintain the graphical elements and key properties of ordinary Petri nets, and add the notions of time, continuous-valued processes, various types of stochastics, and hierarchical modelling.

The process to develop an SDCPN-based model proceeds in several substeps. The first substep is to develop a local SDCPN-based model for each agent entity identified for the ATM operation, by specifying all SDCPN elements, and how they work together. This uses the results of Step B. Next, the entities within one agent are coupled by modelling the interactions within each agent. Subsequently, all agent models are coupled by modelling the interactions between agents. Normally, there are iterations and loops between all substeps. Finally, all parameters are given a value. An example of a SDCPN of a short term conflict alert system is provided in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

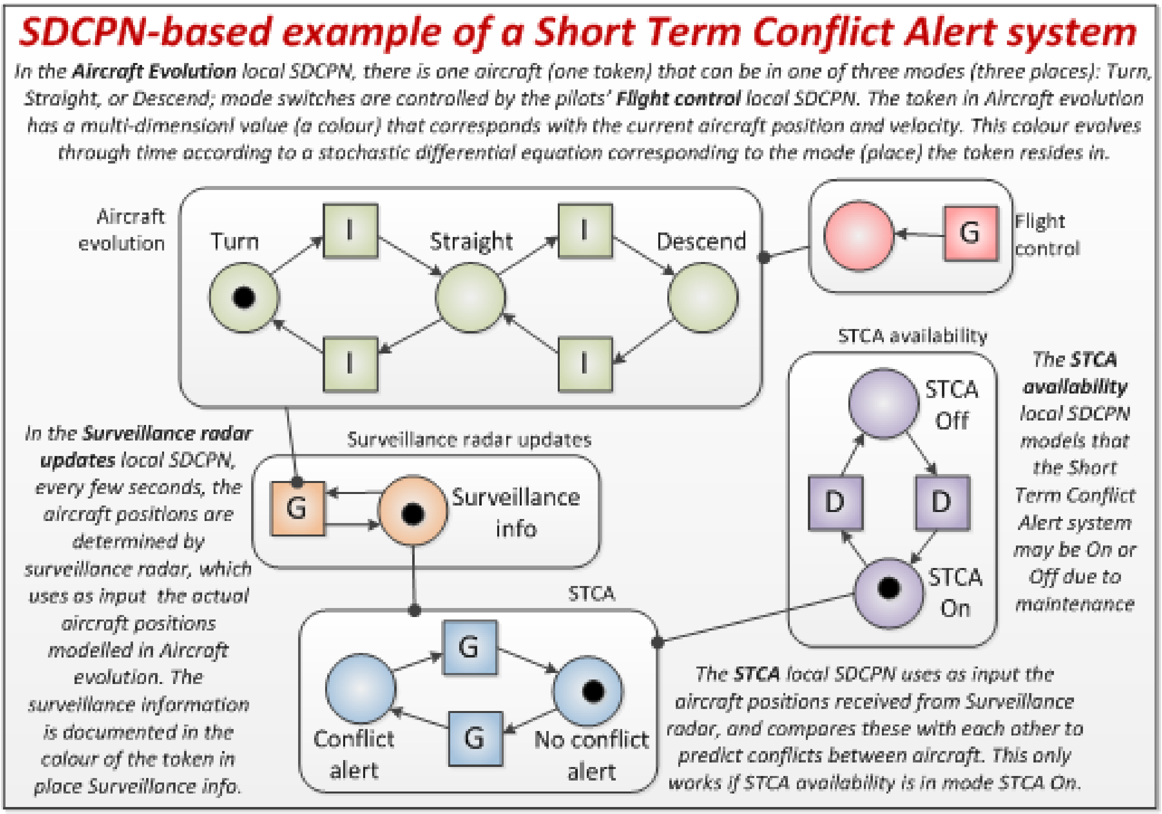



Figure 8. Example of an SDCPN of a short term conflict alert system (Eurocontrol / FAA AP15 Safety, 2014).

**D. Rare event Monte Carlo simulation**

Once the SDCPN-based model for the operation is completed, it is implemented in a software environment for Monte Carlo simulation. This implementation includes verification to assure that the software components all perform as specified by the formal SDCPN model. The Monte Carlo simulation software enables to simulate an operations many millions of times under varying conditions and to record safety-relevant events. In the context of ATM safety assessments acceleration techniques are needed for the Monte Carlo simulations to properly assess the very low probabilities of severe safety events. These acceleration techniques include risk decomposition, and particle swarm approaches.

**E. Evaluating the differences between the model and the real operation**

By the very nature of any model, there are differences between a real operation and a model of the operation. Assessment of the effects of these differences on the risk results is an approach towards validation of the risk assessment. In an agent-based DRM-based risk assessment, this is pursued by identifying all potential differences between the SDCPN based model and reality, and by systematically assessing the 'bias and uncertainty' in the risk that is expected to be inferred by those differences (Everdij et al., 2006). The bias and uncertainty assessment approach includes sensitivity analysis of parameter values and it typically involves obtaining feedback from operational experts about assumptions adoipted in the model.

The bias and uncertainty assessment not only provides a value for the model-based safety risk compensated for all differences between model and reality, it also has other important results:

- It provides a complete list of differences between model and reality, including all assumptions adopted in the modelling. This list is provided in words, hence is readable also to those who are not willing or able to read the SDCPN-based model. This way, the model is made transparent to a large group of experts.
- The bias and uncertainty assessment process helps to provide further insight into the model and the safety risk results. The sensitivity analysis helps to better understand how the output reacts to changes in the input, and helps to better understand where the risk is coming from.
- It identifies those differences that have the highest impact on risk, in terms of bias, uncertainty, sensitivity or combinations of these. These differences can be used to find elements in the operation that are most efficiently improved, hence provide effective feedback to the designers of the ATM operational concept.

The results of the agent-based DRM approach obtained in substeps A to E are used to evaluate the risk tolerability and safety bottlenecks in the safety risk assessment approach of **Fehler! Verweisquelle konnte nicht gefunden werden.**.

### 4.1.3 Example De-icing

After discussing ABM aspects, the example of the deicing process, which besides the turnaround process was implemented in the micro part, shall be presented.
The deicing process was chosen in order to investigate safety related aspects besides, the influence of the human and the available resources on the dynamic of the system. Different operational aspects of the deicing process such as involved operators resources and safety related issues are discussed in 4.1.3.1. Assumptions concerning the implementation of the deicing process are presented in 4.1.3.2. Safety aspects with regard to the deicing process are discussed in 4.1.3.3.

#### 4.1.3.1 Ground de-icing / anti-icing operation

##### 4.1.3.1.1 Introduction

The ‘clean aircraft concept’ requires an aircraft to begin its flight with its critical surfaces free of frozen or semi-frozen moisture. Therefore, it is sometimes necessary to perform aircraft ground de-icing / anti-icing. Aircraft ground de-icing / anti-icing procedures serve three purposes:

- removal of any frozen or semi-frozen moisture from critical external surfaces of an aircraft on the ground prior to flight; and/or,
- protection of those surfaces from the effects of such contaminant for the period between treatment and becoming airborne; and/or,
- removal of any frozen or semi-frozen moisture from engine intakes and fan blades and protection of external surfaces from subsequent contamination prior to takeoff.

In this chapter, a general ground de-icing / anti-icing operation is described. This operation could be different per airport, depending on environmental conditions, de-icing locations on the airport, the number of movements, et cetera. The focus is on the roles and responsibilities of the human operators involved, in particular on those human operators deciding that ground de-icing/anti-icing is required, performing ground de-icing/anti-icing and executing supervision and checks. Relevant human operators are identified in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**. After that, a general de-icing/anti-icing operation is described in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

The information in this chapter is derived from documents from the Association of European Airlines (AEA, 2013a, 2013b) and from Transport Canada (Transport Canada, 2005). If more detailed information is required for a better understanding of the de-icing/anti-icing operation, the reader is referred to these documents.

##### 4.1.3.1.2 Human operators

It is essential that every human operator involved in each step of the de-icing/anti-icing operation must be properly trained and qualified. AEA suggests a structure for levels of qualifications for persons involved in de-icing/anti-icing (AEA, 2013b). One person may be trained on several levels. The following levels are distinguished:

- De-icing operator – This includes the contamination check, performance of de-icing/anti-icing and post de-icing/anti-icing check and includes the qualification level of the vehicle driver and the de-icing/anti-icing supervision.
- De-icing vehicle driver – This includes manoeuvring the vehicle and performing communication procedures.
- Supervision of de-icing/anti-icing – This includes the performance of the performance of the post de-icing/anti-icing check and the vehicle driver and de-icing operator levels.
- Pre-/Post de-icing/anti-icing inspector – This includes the determination of the need for de-icing/anti-icing and the pre/post de-icing/anti-icing check.
- De-icing instructor – Person who conducts de-icing/anti-icing training. This person, having competence in the de-icing subjects and training skills, should have received the training for the de-icing operator qualification level.
- De-icing coordinator – Person who coordinates and manages the de-icing operation and/or work as a team leader in the de-icing, mainly when de-icing is performed at remote sites.
- Fluid Quality Inspector – This covers performing quality control of fluids.

- Head of de-icing training – Person responsible for the de-icing training program.
- Flight Crew (winter operations) – The flight crew should have knowledge of the de-icing/anti-icing processes
- Cabin Crew – Cabin crew should be aware of the effects of frozen surface contaminants and the needs to inform the flight crew of any observed contamination.

(Transport Canada, 2005) also mentions individuals with de-icing/anti-icing responsibilities. These are, but are not limited to:

- The Pilot-in-Command;
- The cabin crew;
- Flight dispatchers, flight followers;
- De-icing operators;
- Maintenance crew;
- Management team; and
- Local ATC.

A clear and brief definition of these roles is not provided in (Transport Canada, 2005).

### 4.1.3.1.3 Ground de-icing/anti-icing operation

AEA provides recommendations for ground de-icing/anti-icing (AEA, 2013a) as well as relevant background information (AEA, 2013b). From this, we derive a general ground de-icing/anti-icing operation in which we distinguish the following phases:

- Pre de-icing/anti-icing;
- De-icing/anti-icing;
- Post de-icing/anti-icing;
- Pre-takeoff check; and
- Pre-takeoff contamination check.

These phases are elaborated in the following subsections, by using the material from (AEA, 2013a, 2013b). The information is taken from various parts in the AEA document and grouped and summarized in each of the proposed de-icing phases. In the description of AEA, the human operators as presented in Section **Fehler! Verweisquelle konnte nicht gefunden werden.** are not always used explicitly, e.g. de-icing coordination, supervisor, and inspector. As much as possible, the AEA terminology is used. However, here the term “flight crew” is used instead of “commander” and “aircraft” instead of “aeroplane”.

#### 4.1.3.1.3.1 Pre de-icing/anti-icing

Prior to departure, a contamination check (a check for the need to de-ice) of the aircraft surfaces is performed by trained and qualified ground crew or the flight crew. If there is a need to de-ice the aircraft, the operation includes the following:

- After checking relevant aircraft parts, a decision of de-icing procedures is made. When surfaces are contaminated by frozen moisture, they shall be de-iced prior to dispatch. When there is a risk of contamination of the surface at the time of dispatch, surfaces shall be anti-iced. The flight crew has the final responsibility about the de-icing procedures. The proper de-icing/anti-icing procedure shall be communicated and verified with all parties involved (ground crew, flight crew, de-ice crew).
- Requests for de-icing/anti-icing shall specifiy the aircraft parts to be treated. Aspects to consider are e.g. specific aircraft requirements, the location of the de-icing (at gate or

remote), the ability of the aircraft to taxi to the remote area, etc. Gate de-icing/anti-icing is more straightforward than remote de-icing/anti-icing since engines are not running and the a/c is easier to configure for de-icing. The remote procedures may need some extra verification before the start of the de-icing operation.

#### 4.1.3.1.3.2 De-icing/anti-icing

After verification of the de-icing/anti-icing procedure, the actual de-icing/anti-icing is performed by the de-icing operator:

- The flight crew configures the aircraft before the start of the ground de-icing/anti-icing procedure. The flight crew gives the de-icing operator a "go-ahead" and considers when they will be able to depart;
- The aircraft is treated on the relevant aircraft areas, using one or two appropriate de-icing/anti-icing steps, dependent on weather conditions, fluids etc.. For details of the de-icing/anti-icing itself, e.g. the techniques that are used, specific aircraft areas requiring specific treatment etc, we refer to the AEA documentation (AEA, 2013b).
- De-icing/anti-icing can be performed at the gate or off-gate (e.g. a centralised area, a remote de-icing area). Differences with de-icing and anti-icing at the gate are that aircraft engines are running, added communication, safety area and positioning, coordination control, multiple vehicle de-icing etc. In case of off-gate de-icing:
    - ATC directs the aircraft to a predetermined position close to the remote area from where the de-icing coordinator will take control. The coordinator is responsible for the movement of the aircraft and ground vehicles on the remote pad and no movement shall be made without clearance.
    - A two-way communication between pilot and de-icing/anti-icing operator/supervisor shall be established prior to the de-icing/anti-icing treatment. As important as the communication between the flight crew and the de-icing crew, so is the communication between the de-icing crews themselves and the de-icing coordinator.
    - Vehicles stand in a safety area before and after de-icing/anti-icing. This area shall be of sufficient size and placed where there is no risk of interfering with nearby aircraft moving to and from the pad. All movements around the aircraft must be coordinated.

#### 4.1.3.1.3.3 Post de-icing/anti-icing

After finishing the actual de-icing/anti-icing of the aircraft, the remaining operational steps are as follows:

- The de-icing operator verifies that the aircraft surfaces are clean (post de-icing/anti-icing check). This can be done either visual or tactile. If contamination has been found, this has to be removed. This cycle repeats until the aircraft is clean;
- The flight crew is notified of the type of de-icing/anti-icing operation performed. The flight anti-icing code is provided to the flight crew;
- The flight crew estimates the expected holdover time under the prevailing weather conditions. This holdover time (HOT) is the estimated time for which an anti-icing fluid will prevent the formation of frost or ice and the accumulation of snow on the protected surfaces of an aeroplane, under specified weather conditions (AEA, 2013a). Holdover time begins at the start of the anti- icing operation. If a two-step operation is used, then it begins at the start of the final (anti-icing) step.

- The aircraft is dispatched for departure;
- The aircraft is reconfigured (if necessary) and ready to taxi to the runway.

#### 4.1.3.1.3.4 Pre-takeoff check

After the performed de-icing/anti-icing treatment, the flight crew taxies the aircraft to the runway for departure. The flight crew shall continually monitor the weather conditions. Prior to takeoff the flight crew 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.

#### 4.1.3.1.3.5 Pre-takeoff contamination check

The pre-takeoff contamination check 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-takeoff 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-takeoff contamination check is a complete de-icing/anti-icing re-treatment of the aircraft.

### 4.1.3.1.4 Holdover time

The holdover time is an important property of ground de-icing/anti-icing. As described in (AEA, 2013a), the holdover time is obtained by anti-icing fluids remaining on the aeroplane surfaces. With a one-step deicing/ anti-icing operation the holdover time begins at the start of the operation and with a two-step operation at the start of the final (anti-icing) step. Holdover time will have effectively run out when frozen deposits start to form/accumulate on treated aeroplane surfaces.

To estimate the holdover time, timetables can be used (AEA, 2013b). Timetables exist for generic fluids (developed using the lowest holdover times, attained from the certified fluids) and brandname fluids (attained for one particular fluid and cannot be used for any other fluids), as well as for various types of fluids (Type I, II, III, IV). Type I fluids provide limited holdover time, especially in conditions of freezing precipitation. With this type of fluid no additional holdover time would be provided by increasing the concentration of the fluid in the fluid/water mix. Type II, III and type IV fluids provide a longer holdover time especially in conditions of freezing precipitation. With this type of fluid additional holdover time will be provided by increasing the concentration of the fluid in the fluid/water mix, with maximum holdover time available from undiluted fluid.

**Fehler! Verweisquelle konnte nicht gefunden werden.** presents an example of (AEA, 2013b) of a Type-I generic holdover timetable. The lower limit of the published time span is used to indicate the estimated time of protection during moderate precipitation and the upper limit indicates the estimated time of protection during light precipitation. Type I Fluid / Water Mixture is selected so that the Freezing Point of the mixture is at least 10 °C (18 °F) below actual Outside Air Temperature (OAT). It is up to the captain to decide on which time is usable. If the de-icing crew is asked to give this information to the flight crew, it is essential to give the time span (e.g. 2-5 min.).

| OAT | | Approximate Holdover Times Under Various Weather Conditions (hours : minutes) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| °C | °F | Active Frost | Freezing Fog | Snow/ Snow Grains/ Snow Pellets (1) | Freezing Drizzle (2) | Light Freezing Rain | Rain on Cold Soaked Wing | Other (3) |
| -3 and above | 27 and above | (5) | 0:09 - 0:16 | 0:03 - 0:06 | 0:08 - 0:13 | 0:02 - 0:05 | 0:01 - 0:05 (4) | CAUTION: No Holdover time Guidelines exist |
| below -3 to -6 | below 27 to 21 | (5) | 0:06 - 0:08 | 0:02 - 0:05 | 0:05 - 0:09 | 0:02 - 0:05 | | |
| below -6 to -10 | below 21 to 14 | (5) | 0:04 - 0:08 | 0:02 - 0:05 | 0:04 - 0:07 | 0:02 - 0:05 | | |
| below -10 | below 14 | (5) | 0:04 - 0:07 | 0:02 - 0:04 | | | | |

Figure 9. Example holdover timetable for a Type I fluid (AEA, 2013b).

Holdover times may be reduced below the lowest time stated in the range due to the conditions such as heavy precipitation rates, high moisture content, high wind velocity, jet blast, or when aeroplane skin temperature is lower than Outside Air Temperature (OAT). Therefore, the indicated times should be used only in conjunction with a pre-takeoff check.

Two more example holdover timetables are presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden.**. These tables show that holdover times can be quite different for each fluid type.

| OAT | | SAE Type IV Fluid Concentration Neat-Fluid/Water (Vol %/Vol %) | Approximate Holdover Times under Various Weather Conditions (hours : minutes) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| °C | °F | | Active Frost | Freezing Fog | Snow/ Snow Grains/ Snow Pellets (1) | Freezing Drizzle (2) | Light Freezing Rain | Rain on Cold Soaked Wing | Other (3) |
| –3 and above | 27 and above | 100/0 | (6) | 1:15-2:30 | 0:35-1:15 | 0:40-1:10 | 0:25-0:40 | 0:10-1:05 (4) | |
| | | 75/25 | (6) | 1:00-1:45 | 0:20-0:55 | 0:35-0:50 | 0:15-0:30 | 0:05-0:40 (4) | |
| | | 50/50 | (6) | 0:15-0:35 | 0:05-0:15 | 0:10-0:20 | 0:05-0:10 | | |
| below -3 to -14 | below 27 to 7 | 100/0 | (6) | 0:20-1:20 | 0:20-0:40 | 0:20-0:45 (5) | 0:10-0:25 (5) | CAUTION: | |
| | | 75/25 | (6) | 0:25-0:50 | 0:15-0:35 | 0:15-0:30 (5) | 0:10-0:20 (5) | No holdover time | |
| below -14 to -25 or LOUT | below 7 to -13 or LOUT | 100/0 | (6) | 0:15-0:40 | 0:15-0:30 | | | guidelines exist | |

Figure 10. Example holdover timetable for a type IV fluid (AEA, 2013b).

| OAT | | Type II, III and IV Fluid<br>Concentration Neat Fluid/Water Vol % / Vol % | Approximate Holdover Times Under Various Weather Conditions (hours : minutes) | | | |
|---|---|---|---|---|---|---|
| | | | Active Frost | | | |
| °C | °F | | Type I (1) (2) | Type II | Type III | Type IV |
| -1 and above | 30 and above | 100/0 | | 8:00 | 2:00 | 12:00 |
| | | 75/25 | | 5:00 | 1:00 | 5:00 |
| | | 50/50 | | 3:00 | 0:30 | 3:00 |
| below -1 to -3 | below 30 to 27 | 100/0 | | 8:00 | 2:00 | 12:00 |
| | | 75/25 | | 5:00 | 1:00 | 5:00 |
| | | 50/50 | | 1:30 | 0:30 | 3:00 |
| below -3 to -10 | below 27 to 14 | 100/0 | 0:35 | 8:00 | 2:00 | 10:00 |
| | | 75/25 | | 5:00 | 1:00 | 5:00 |
| below -10 to -14 | below 14 to 7 | 100/00 | | 6:00 | 2:00 | 6:00 |
| | | 75/25 | | 1:00 | 1:00 | 1:00 |
| below -14 to -21 | below 7 to -6 | 100/0 | | 6:00 | 2:00 | 6:00 |
| below -21 to -25 | below -6 to -13 | 100/0 | | 2:00 | 2:00 | 4:00 |

Figure 11. Example Active Frost holdover timetable for type I/II/III/IV fluids (AEA, 2013b).

#### 4.1.3.2 Assumptions made in the model

This chapter discussed the assumptions made for the current implementation of the deicing process. The remote de-icing process is implemented in MATLAB Simulink/Simevents. It is based on the model of the process description. Several assumptions are made in the model, which will be addressed in this chapter.

This chapter will use the following terms:

De-icing is a process where the aircraft is cleared of ice and snow contamination. This document only describes the process where external equipment is used to clear the aircraft and not the de-icing devices on plane (like heating elements or de-icing boots).

Anti-icing is a process where the aircraft gets protected from new contamination with ice and snow. A fluid will be sprayed on the aircraft, which prevents the accumulation of frozen moisture for a limited amount of time (see section “Determination of HOT”).

For the processes mentioned above as well as for the processes “Post-De-/Anti-icing-checks” and “Generation of Anti-icing code” no distinct durations are available.

The processes are modelled as a single overall process; total durations are obtainable and will hereinafter be referred to as de-icing times.

#### 4.1.3.2.1 Determination of de-icing time

##### 4.1.3.2.1.1 One or two step method

When the aircraft is contaminated with frozen moisture, it has to be de-iced (see also the relevant Visio diagrams).

If there is a risk of contamination by frozen moisture before the aircraft has taken off, the aircraft shall be anti-iced.

Aircraft can be de-iced and anti-iced using a one or two-step procedure:

> One-step procedure: the de-icing fluid can be used for de-icing as well as anti-icing simultaneously.
>
> Two-step procedure: aircraft are first de-iced with a specific fluid and thereafter anti-iced with a different fluid and has to be done within less than three minutes.

According to [KADEN 2013], the one-step procedure is used when the aircraft is light contaminated and there is no precipitation expected. This also includes active frost conditions as well as freezing fog (see next section). The two-step procedure is used when the aircraft is contaminated with (large) amounts of frozen moisture and/or precipitation is present or expected (rain or drizzle on aircraft surface at sub-zero temperatures or all other precipitations at any temperatures).

The model uses the METAR data to decide at several points in time (before contacting aircraft de-icing center and during waiting for de-icing), whether de-icing is needed and if the one or two-step procedure is used. The decision is made on basis of the following parameters:

**Table 6: Source of parameters that are used in order to decide whether the one- or two-step method will be applied**

| Parameter | Decision |
|---|---|
| **contaminated** | SN, IC, GR, UP, SG, PL or GS in METAR |
| **precipitation exists** | SN, IC, GR, UP, SG, PL, GS, RA or DZ in METAR |
| **OAT** | Outside Air Temperature in METAR |
| **one-step** | Active frost conditions or freezing fog without precipitation and not contaminated |
| **two-step** | contaminated or (Rain/drizzle under active frost conditions or other precipitations at any temperature) |

##### 4.1.3.2.1.2 Duration of de-icing

The time it takes to de-ice the aircraft depends on various factors, like the amount of steps, the aircraft category or stand versus remote. Several sources are used to determine the de-icing time. **Fehler! Verweisquelle konnte nicht gefunden werden.** gives an overview of the estimated time needed to de-ice an aircraft in Frankfurt Airport (EDDF).

Table 7: De-icing time in minutes per aircraft category. The aircraft categories are not ICAO conform. Source: [Fraport 2011]

| Aircraft Category | one-step | | two-step | |
|---|---|---|---|---|
| | remote | position | remote | position |
| **A (aircraft < 5.7 MTOW)** | 10 | 11 | 13 | 14 |
| **B (AT42/72, DH8A/B/C/D, E135 to E195, F50, RJ1H, RJ70, RJ85, etc.)** | 10 | 11 | 22 | 24 |
| **C (A318 to A321, B727, B737, F70, F100, MD80, MD90, etc.)** | 11 | 13 | 23 | 25 |
| **D (A310, B757, DC8, T154, etc.)** | 13 | 14 | 24 | 26 |
| **E (A300, B767, IL76, IL86, etc.)** | 13 | 14 | 28 | 31 |
| **F (A330, A342/3, B772, MD11, etc.)** | 14 | 15 | 22 | 24 |
| **G (A346, B747, B773, etc.)** | 16 | 18 | 30 | 32 |
| **H (A380, etc.)** | 18 | 19 | 43 | 47 |

The source [Fraport 2011] does not mention whether this de-icing procedure is done with 1 or multiple vehicles. According to [ACI 2011], it takes 10 to 25 minutes to de-ice a narrow body aircraft. These times correspond to the values of aircraft category C.

The values for the 2 step procedure on a remote stand for category G and H are very large. A lot of Holdover Times (HOTs) will be exceeded [AEA 2013a]. According to [KLM 2014] (see **Fehler! Verweisquelle konnte nicht gefunden werden.**), a B747 or A380 can be de-iced and anti-iced in 10 minutes at Amsterdam Airport Schiphol. These aircraft are de-iced with 4 to 6 vehicles simultaneously.

Table 8: De-icing at Stuttgart (EDDS) in minutes per aircraft on remote stands. The aircraft categories are conform ICAO Annex 14. Source: [KADEN 2013]

| Aircraft Category | one-step | two-step |
|---|---|---|
| **B** | 8 | 10 |
| **C (A320, B737, etc.)** | 10 | 12 |
| **D (B757, B767, MD11, etc.)** | 13 | 16 |
| **E (A330, A340, B747, etc.)** | 17 | 20 |

**Fehler! Verweisquelle konnte nicht gefunden werden.** shows the de-icing times of Stuttgart. They are more realistic and correspond to the values given by [KLM 2014]. The difference between remote and position for the one-step procedure in **Fehler! Verweisquelle konnte nicht gefunden werden.** is on average 1 minute. For the two-step procedure it is 2 minutes. These values are added to **Fehler! Verweisquelle konnte nicht gefunden werden.** and are shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

Table 9: De-icing times used in the model.

| Aircraft Category | one-step | | two-step | |
|---|---|---|---|---|
| | remote | position | remote | position |
| **B** | 8 | 9 | 10 | 12 |
| **C (A320, B737, etc.)** | 10 | 11 | 12 | 14 |
| **D (B757, B767, MD11, etc.)** | 13 | 14 | 16 | 18 |
| **E (A330, A340, B747, etc.)** | 17 | 18 | 20 | 22 |

Information was available only about total times of de-icing and anti-icing combined. Therefore it is not possible to simulate both processes separately. To distinguish between one-step and two-step procedure the model uses different total times shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. In this way the time between the end of de-icing and the start of anti-icing is not known. So, the start of the holdover time (which begins with the anti-icing process) cannot be determined exactly. For modelling it is assumed that it starts with the de-icing process.

#### 4.1.3.2.2 Determination of Holdover time (HOT)

Aircraft are "protected" for a limited time after the de/anti-ice procedure has been applied. The protection time is called Holdover Time (HOT). The HOT depends on the weather conditions, type of fluid and other conditions. The HOT can be found in tables. The cockpit crew has the final responsibility to determine the HOT. Therefore, the model tries to simulate the behavior of the cockpit crew as realistic as possible, but still several assumptions are made.

The cockpit crew has to check regularly if the HOT changes due to alterations in weather conditions. It is assumed, that this check is performed every five minutes. In the simulation the check will be started at the begin of the de-icing process and will be performed every 5 minutes until the aircraft reaches the end of the simulation, which in this case is the waiting position to taxi to the threshold.

The weather conditions have a large influence on the HOT. Pilots can make use of the following sources (page 25-26 of [AEA 2013b]):

1. ATIS
2. METAR
3. TAF
4. Pre-Take off Contamination Check (looking outside of the window or visual inspection outside the aircraft)
5. Other (i.e. weather charts, weather radar)

The historical data of METARs and TAFs are widely available and easily accessible. To simplify the model, only the METAR data are used. As a possible future improvement of the model, the use of TAFs is suggested.

The HOT tables contain a lower and upper HOT value for several weather phenomena. The lower value corresponds to moderate conditions, whereas the upper value is valid in light conditions. According to [AEA 2013b], the final decision whether the lower or upper value is chosen, has to be taken by the pilot in command. Therefore, the next sections describe the assumptions of what kind of selection the pilot in command would make, in case only the METAR data are available. No scientific research has been done to analyze these assumptions. The assumptions made are open for discussion.

The next sections will discuss how the METAR data are correlated to the HOT tables for modelling.

#### 4.1.3.2.2.1 Active Frost

The definition of active frost is (page 23 of [AEA 2013b]):

> *Active frost is a condition when frost is forming. Active frost occurs when aeroplane surface temperature is at or below 0°C (32°F) and at or below dew point.*

According to that, the surface temperature of the aircraft would have to be modelled. The surface temperature lags behind the outside air temperature, but it remains unknown to which degree. A lower surface temperature of the aircraft depends on several factors like the aircraft staying on the ground overnight or the wings are filled with cold fuel (see the section about cold soaked wings).

Active frost is modelled as follows:
The aircraft stayed on the ground over the last hour (or longer)

The surface temperature of the aircraft "lags" 1 hour behind the outside air temperature. Note: no information was found on the change in aircraft temperature compared to the outside air temperature (OAT), therefore another value as 1 hour could have been chosen as well.

- $T_{aircraft} \leq T_{dew\ point} \leq 0°C$

Note: when the OAT has the same value as the dew point temperature, it does not automatically mean that there is fog (=FG) or mist (=BR), e.g. in case of moderate or strong wind.

#### 4.1.3.2.2.2 Freezing Fog

The definition of freezing fog is (page 24 of [AEA 2013b]):

> *A suspension of numerous minute water droplets which freeze upon impact with ground or other exposed objects, generally reducing the horizontal visibility at the earth's surface to less than 1 km (5/8 mile).*

Fog and freezing fog can be identified in a METAR by:

The descriptor code FZ (=freezing) in combination with the obscuration code FG (=fog) which means freezing fog. In a METAR the code for fog is never being used in combination with the intensity symbols + or – to distinguish between different weather conditions (light, moderate, heavy). It is unknown, in which cases pilots use the corresponding lower HOT or upper HOT value. Prior to model start it can be chosen whether the conservative value (i.e. the lower value) will be used or not.

Note: when the OAT has the same value as the dew point temperature, it does not automatically mean that there is fog (=FG) or mist (=BR) , e.g. in case of moderate or strong wind.

#### 4.1.3.2.2.3 Snow/Snow Grains/Snow Pellets

The definitions are (page 25 of [AEA 2013b]):

*Snow:*
*Precipitation of ice crystals, most of which are branched, star-shaped or mixed with unbranched crystals. At temperatures higher than -5°C (23°F), the crystals are generally agglomerated into snowflakes.*

*Snow grains:*
*Precipitation of very small white and opaque particles of ice that are fairly flat or elongated with a diameter of less than 1 mm (0.04 in.). When snow grains hit hard ground, they do not bounce or shatter.*

*Snow pellets:*
*Precipitation of white, opaque particles of ice. The particles are round or sometimes conical; their diameter range from about 2-5 mm (0.08-0.2 in.). Snow pellets are brittle, easily crushed; they do bounce and may break on hard ground.*

The codes for the precipitations used in METAR are:

- SN: snow
- SG: snow grains
- GS: snow pellets

If the intensity symbol – is used, the upper HOT value will be taken for modelling. If the METAR has no intensity symbol, the lowest HOT value will be taken.

According to the notes attached below the HOT tables [AEA 2013a], heavy snow is covered by the category “Other” and there are no holdover time guidelines (see also section Heavy snow).

#### 4.1.3.2.2.4 Freezing Drizzle

The definition of freezing drizzle is (page 23 of [AEA 2013b]):

*Fairly uniform precipitation composed exclusively of fine droplets (diameter less than 0.5 mm (0.02 in)) very close together which freezes upon impact with the ground or other exposed objects.*

Drizzle and freezing drizzle can be identified in a METAR by:

> The descriptor code FZ (=freezing) in combination with the precipitation code DZ (=drizzle) means freezing drizzle. If the intensity symbol – is used, the upper HOT value will be taken. If no intensity symbol is used, the lowest HOT value will be taken.
>
> Aircraft surface temperatures below 0°C together with the code DZ will be treated like light freezing drizzle and the upper HOT will be taken.

#### 4.1.3.2.2.5 Light Freezing Rain

The definition of light freezing rain is (page 24 of [AEA 2013b]):

> *Precipitation of liquid water particles which freezes upon impact with the ground or other exposed objects, either in the form of drops of more than 0.5 mm (0.02 inch) or smaller drops which, in contrast to drizzle, are widely separated. Measured intensity of liquid water particles is up to 2.5 mm/hour (0.10 inch/hour) or 25 grams/dm2/hour with a maximum of 0.25-mm (0.01 inch) in 6 minutes.*

The definition for moderate or heavy freezing rain is the same as for light, except for the last sentence:

> *Measured intensity of liquid water particles is more than 2.5 mm/hour (0.10 inch/hour) or 25 grams/dm2/hour.*

Light freezing rain can be identified in a METAR by:

> The descriptor code FZ (=freezing) in combination with the precipitation code RA (=rain) and intensity symbol "–" means light freezing rain. There is a lower and upper HOT limit given which are normally used to make a difference between light and moderate conditions. The upper value may not be used for moderate freezing rain, because that is covered by the column "Other". For modelling it can be choosen before start whether the most conservative value will be used (i.e. the lower HOT value) or not.

#### 4.1.3.2.2.6 Rain on Cold Soaked Wing

The definition of cold-soaked effect is (page 23 of [AEA 2013b]):

> *The wings of aeroplane are said to be "cold-soaked" when they contain very cold fuel as a result of having just landed after a flight at high altitude or from having been re-fuelled with very cold fuel. Whenever precipitation falls on a cold-soaked aeroplane when on the ground, clear icing may occur. Even in ambient temperatures between -2°C and +15°C, ice or frost can form in the presence of visible moisture or high humidity if the aeroplane structure remains at 0°C or below. Clear ice is very difficult to be detected visually and may break loose during or after take-off. The following factors contribute to cold-soaking: temperature and quantity of fuel in fuel cells, type and location of fuel cells, length of time at high altitude flights, temperature of re-fuelled fuel and time since re-fuelling.*

Whether the wings are cold-soaked or not depends on factors like:

The altitude and duration of the previous flight.

Amount of fuel remaining after the previous flight.

Amount of warmer fuel added to the wing tanks for the next flight.

The model does not have this kind of information. Several airlines restrict the amount of tankering[6] fuel to reduce the risk of cold soaked wings. It is not known how often cold soaked wings take place and in what kind of distribution. It is assumed that airlines try to prevent the phenomena and therefore rain on Cold Soaked Wings is only modelled in case of rain that falls on aircraft surfaces with temperatures below zero degrees.

#### 4.1.3.2.2.7 Heavy snow

The FAA gives guidelines that can be used in heavy snow conditions (see page 57 of [FAA 2014]). The guideline allows take-offs within 5 minutes after de-/anti-icing.

The model covers mostly European airlines and they do not have this FAA guideline. Therefore, it is assumed that no aircraft can take-off when there are heavy snow conditions.

#### 4.1.3.2.2.8 Other

Other conditions are heavy snow (+SN), ice pellets (PL), hail (GR), moderate (FZRA) and heavy freezing rain (+FZRA). No holdover time guidelines are given for these weather conditions. The model assumes a holdover time of zero minutes, so no take-off is possible.

In case of composed precipitation information, like for sleet (SNRA), the de-icing process (selection of one step or two step procedure) will be geared towards the precipitation with the highest impact. In the example mentioned above it would be snow (SN). The lowest HOT will be selected accordingly.

#### 4.1.3.2.2.9 Summary

The following table gives a summary of how METAR entries are correlated to the weather conditions that are given in the HOT tables.

**Table 10: Summary of the assumptions made in the model to simulate the holdover times**

| Weather condition in HOT table | Lower value | Upper Value |
|---|---|---|
| **Active frost** | $T_{aircraft\ surface} \leq T_{dew\ point} \leq 0°C$ | |
| **Freezing Fog** | will be set in regard to input variable ("worst case value" = safety) or "optimistic value" | |
| **Snow / Snow Grains / Snow Pellets** | SN or SG or GS | -SN or -SG or -GS |

[6] The flight crew can decide to take extra fuel on board. If it is done for economic reasons (i.e. fuel at the destination airport is much more expensive than on departure airport) or operational reasons (e.g. there is a fuel shortage expected at the destination), it will be called "tankering fuel".

| | | |
|---|---|---|
| **Freezing Drizzle** | FZDZ | -FZDZ |
| **Light Freezing Rain** | will be set in regard to input variable ("worst case value" = safety) or "optimistic value" | |
| **Rain on Cold Soaked Wing** | (DZ or RA) & $T_{aircraft\ surface} \leq 0°C$ | (-DZ or –RA) & $T_{aircraft\ surface} \leq 0°C$ |
| **Other** | +SN or PL or GR or FZRA or +FZRA | |

Because changes on weather conditions have an impact, the pilots have to check the HOT regularly. An algorithm for this HOT check was implemented in the model which determines the HOT under the current weather conditions and with the information about fluid type and fluid concentration. In this respect the following assumptions are made:

HOT check every 5 minutes by the pilot

If the aircraft is already on the de-icing pad and the de-icing process hasn't started yet and if the expected HOT is smaller than the duration of the de-icing process, the process won't start and the aircraft has to wait for better weather conditions resulting in a HOT longer than the de-icing time.

If the HOT is extended or reduced due to changing weather conditions, the new HOT will be used and reduced by the elapsed part of the old HOT. Should the aircraft still be on a de-icing pad while the HOT elapsed completely, the aircraft will remain on the pad without the de-icing process performed to the end. It has to wait on the pad for better weather conditions and subsequently the de-icing process restarts.

If weather conditions change in a way that de-icing is no longer required and the aircraft is still in the de-icing process, than the process will be terminated.

The HOT also depends on the choice of the de-icing fluid. Every fluid gives a protection for a specific time at the given weather conditions and has a lowest operational use temperature (LOUT). If the outside air temperature (OAT) is lower than this LOUT, then the corresponding fluid is not permitted to be used.

### 4.1.3.3 Safety related aspects in ground de-icing/anti-icing

#### 4.1.3.3.1 Introduction

De-icing/anti-icing is a process applied in air transport to deal resiliently with the disturbance of icing conditions. The organization of the process has impact on various key performance areas in ATM, including safety and capacity/delays. An analysis of safety effects is provided in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**.; an analysis of effects on capacity/delays is provided in Section **Fehler! Verweisquelle konnte nicht gefunden werden.**.

#### 4.1.3.3.2 Safety effects

Safety is an issue concerning everyone involved in the ground de-icing/anti-icing operation. Some examples of accidents and incidents resulting from airframe icing and problems with anti-icing fluids include the following [Skybrary, 2014]:

> C208, vicinity Pelee Island Canada, 2004 – On 17 January, 2004 a Cessna 208 Caravan operated by Georgian Express, took off from Pelee Island, Ontario, Canada, at a weight significantly greater than maximum permitted and with ice visible on the airframe. Shortly after take off, the pilot lost control of the aircraft and it crashed into a frozen lake.
>
> C208, Helsinki Finland, 2005 – On 31 January 2005, a Cessna 208 stalled and crashed on take off from Helsinki-Vantaa following failure to properly de-ice the aircraft.
>
> MD81, vicinity Stockholm Sweden, 1991 – On 27 December 1991, after take-off from Arlanda Airport, Stockholm, an MD-81 operated by Scandinavian Airlines System (SAS), experienced a failure of both engines following the ingestion of clear ice detaching from the wings. Subsequently, the crew executed a successful forced landing.

These examples relate to flight safety, incidents and accidents that occur after commencing take-off . Other incidents/accidents relate to operational safety, occurring while the aircraft is still on the ground preparing for flight. AEA describes operational safety as the proper performance of de-icing operations around/close to aeroplane, equipment and de-icing fluid filling station procedures, airport operations in general, knowledge of aeroplane movements at the apron, danger of jet blast etc. [AEA, 2013b].

Therefore the following incident/accident types can be distinguished:

> Flight safety, e.g.
>
> Aircraft controllability problems after take-off due to contaminated wings or aircraft flight controls;
>
> Engine failure during take-off due to ingestion of ice, snow, slush;
>
> Operational safety, e.g.
>
> Collisions between aircraft and de-icing vehicles (at the gate, or on the de-icing apron);
>
> Aircraft jet blast versus de-icing operators and vehicles; and
>
> Engine inlet of de-icing personnel on the de-icing apron.

Hazards are events that may lead to a dangerous situation. In Section **Fehler! Verweisquelle konnte nicht gefunden werden.**, a preliminary list of hazards related to flight safety is identified. In Section **Fehler! Verweisquelle konnte nicht gefunden werden.**, a preliminary list of hazards related to operational safety is identified.

#### 4.1.3.3.2.1 Flight safety hazards

A preliminary list of hazards is provided in this section, which is the result of a small brainstorm, based on the operation description of Section **Fehler! Verweisquelle konnte nicht gefunden werden.**. To be more complete, a hazard brainstorm with operational experts should be organized.

The root causes for the flight safety occurrences are related to the fact that an aircraft takes off while being contaminated.

Flight safety hazards may be:

- Flight crew does not assess the need for a check for contamination
- Pressure on flight crew to reach CTOT
- Contamination not detected during pre-flight check
- Weather deterioration between gate and take-off; anti-icing should have been done
- De-icing equipment not available
- Only visual inspection performed, not tactile
- Bad visibility conditions
- Check performed by person without the right qualification
- Insufficient training
- Coordination problems when working with several de-icing teams
- Communication problems between de-icing coordinator and de-icing crew
- Communication problems between flight crew and de-icing crew
- Time pressure for de-icing crew
- More aircraft to de-ice
- CTOT pressure for one aircraft
- De-icing crew not well trained / qualified
- Wrong fluids used by de-icing crew
- Wrong de-icing procedure chosen (e.g. no anti-icing)
- De-icing procedure not applied well (e.g. aircraft type specific spray or non-spray areas)
- Incomplete de-icing
- Failure of de-icing equipment
- Shortage of de-icing resources
- Holdover time exceeded
- Longer taxi times due to taxiway conditions.
- Winter operation in harsh climates is bound to affect the punctuality of any airline. Not only ground operations are impaired; snow and ice on apron, taxiway and runway areas affect aircraft operations as well. However, there is no short cut to a safe de-icing/anti-icing procedure on ground. Flights are, irrespective of season, in some cases restricted with a certain take-off time (CTOT). This “window” of departure causes undue pressure for the completion of ground procedures but this shall not cause any diversions in normal and safe de-icing/anti-icing procedures [AEA, 2013b].
- ATC delay during taxiing
- Fluid performance affected by weather conditions.
- Holdover time calculated incorrectly
- Pre take-off check not performed
- Pre take-off check performed but contamination not detected

These root hazards could lead to different types of incidents or accidents:
Collision with the ground after take-off - The aircraft, after being airborne, becomes uncontrollable and crashes;
Engine failure during take-off due to ingestion of ice, snow, slush - Ice, snow and slush can cause engine failures and structural damage. Mainly fuselage aft-mounted engines are susceptible for this FOD (Foreign Object Damage). Ice can be present on any part of the aircraft and when it breaks off there is some probability that it could go into the engine, also in case of wing-mounted engines.

## 4.2 Examples of the implementation

This chapter illustrates part of the implementation in the micro part in the discrete event simulation environment of Simevents. The environment was extended by different functions in order to provide the functionalities which were derived from the process descriptions.
This for example encompasses functions for resource allocations or the determination of hold over times.
In this chapter, the turnaround process will be presented in an overview, whereas the deicing process is depicted in more detail. Aspects of the different elements of the implementation are discussed shortly.

### 4.2.1 Deicing on remote

The simulation model consists of two dimensions: Dimension one depicts the communication respectively the information flow between the different actors and systems involved in the deicing process while dimension two represents the movement of the aircraft.

The background colors of the areas of responsibilities in dimension one are matched with the colors of the areas of responsibilities of the MS Visio diagrams. Furthermore for a better recognition value all elements are blue colored, which also exist in the Visio diagram.

Both dimensions interact among each other, whereby each aircraft starts in dimension two: for every simulated aircraft an entity will be created at a specific timestamp based on its scheduled offblock time (SOBT) and will be leaded through the elements of dimension two. At several points of dimension two the arrival of each entity will start an interaction between the two dimensions. For example simulates the entity the arrival of the corresponding aircraft at a waiting position and the next action is the transmission of its aircraft_id to dimension one which will start a process that represents the communication of the pilot, who wants to inform the aircraft deicing center about the arrival. After the communication process the aircraft_id will be transmitted back again to dimension two so that the entity can proceed.

Whether an aircraft needs deicing or not is investigated by several functions which analyze the simulated weather. If deicing is needed, the aircraft will be guided to one of the six deicing pads. Which one, depends on which one is free and on its pad_id (smallest id first). Should all pads be occupied, then the aircraft has to wait in a queue until the next pad will be released. Then the other process associated with deicing will be performed – all this happens again in interaction with communication process of dimension one. If no deicing is needed, the aircraft will be lead past the deicing pads to a merging point, where the paths from all pads join together again. After this, each aircraft has to wait for clearance to runway threshold.

To show the complexity of the simulation model and the corresponding effort to build up the model, the procedure of the deicing process will be described exemplary. The process spreads over thre level. At the first level the process only consists only of a single block with some signal receivers and senders to communicate with other blocks (Figure 12).


Figure 12. Deicing process, level 1.

At the second level the complexity becomes visible easily (see Figure 13, pages 49f). The arriving entity starts the execution of a function to investigate the holdover time (HOT) under the weather conditions for this point of simulation time. The value returned by this function is the base for decision making, which way the entity has to take:

HOT == -1 … no deicing needed: entity leaves the deicing block

HOT == 0 … deicing required, but due to worse weather conditions no HOT is available: the entity will be hold in a waiting loop until the weather is good enough (according to the aircraft which waits on the deicing pad without deicing performed)

HOT > 1 and HOT < deicing duration … deicing required, but due to worse weather conditions the deicing is temporarily not reasonable because the deicing duration would be bigger than the HOT: the entity will be hold in a waiting loop until the weather is good enough (according to the aircraft which waits on the deicing pad without deicing performed)

HOT > 0 and HOT > deicing duration … deicing needed and reasonable: the entity will be lead into the actual deicing process

Due to changes in weather conditions, it is possible that the HOT can change during the deicing process. Therefore it is required to check the HOT regurlarly. Due to technical reasons it is needed to create a “virtual” entity in order to simulate the deicing process and perform the regular HOT check simultaneously.

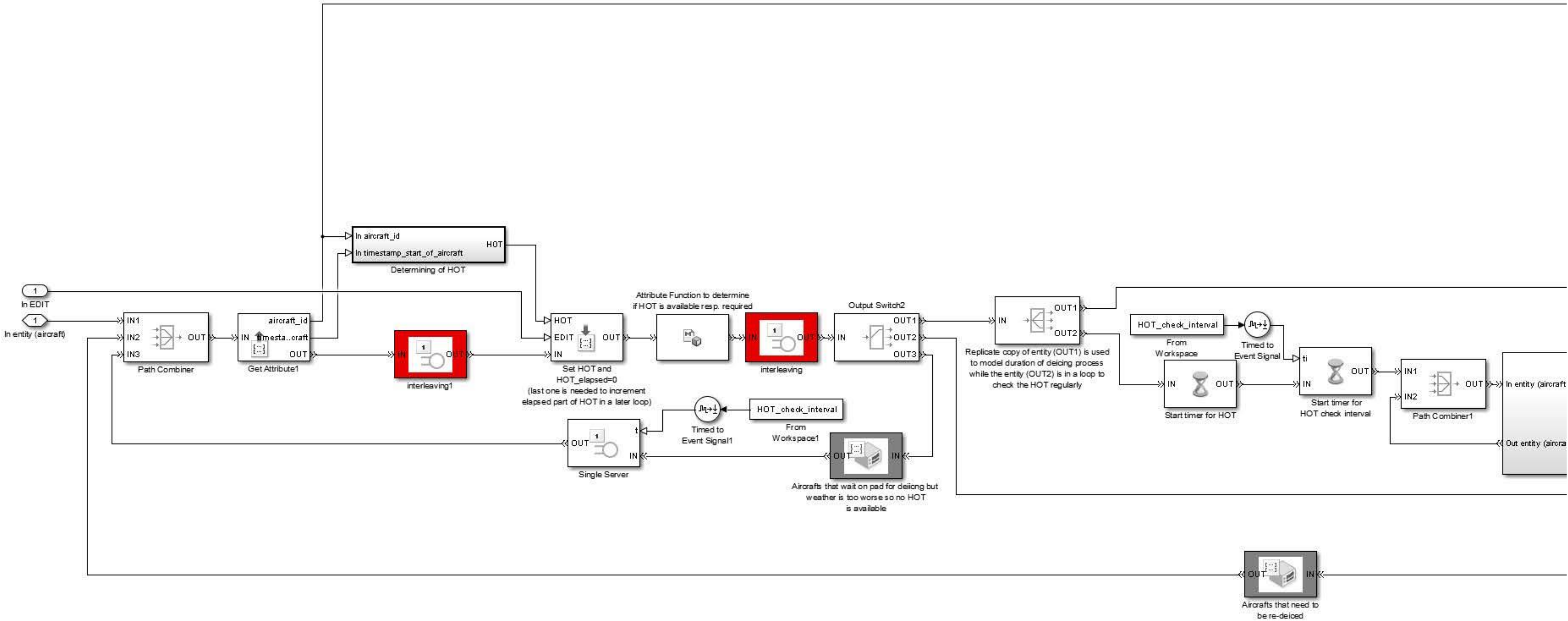
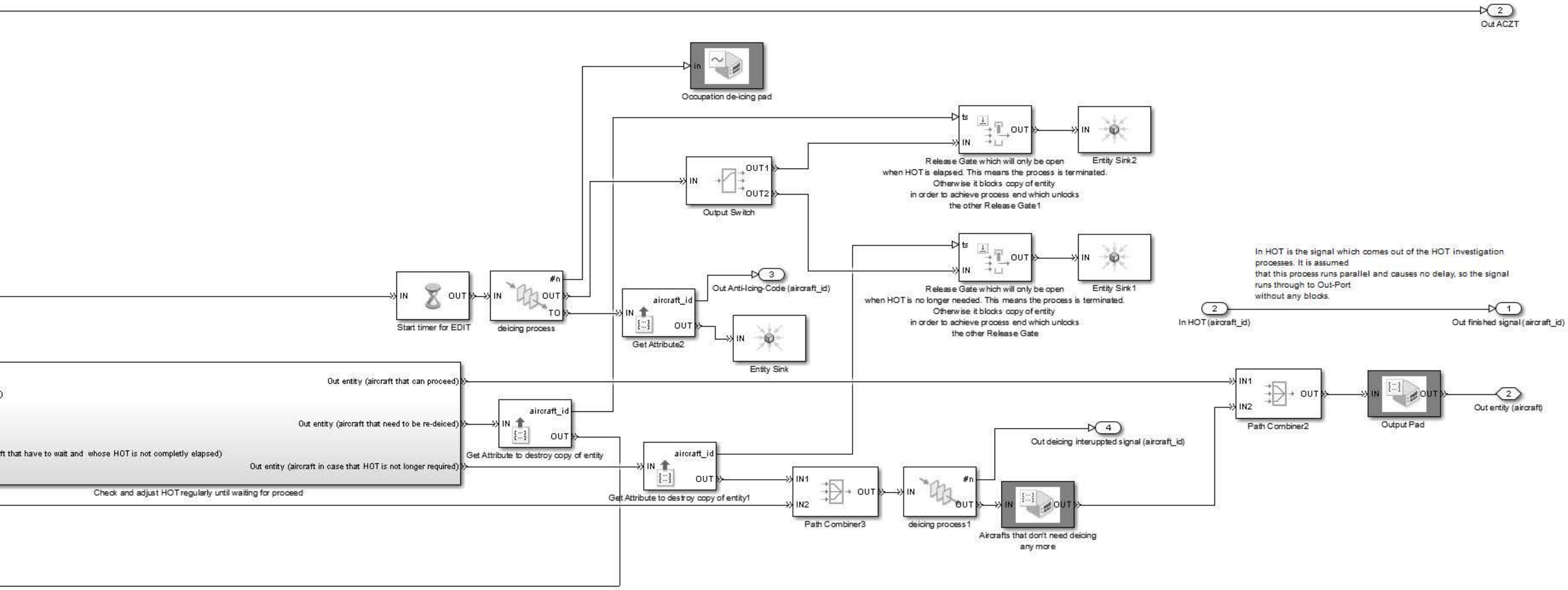



**Figure 13. Deicing process, level 2.**



2
Out ACZT
in
Occupation de-icing pad
ts
IN
OUT
Release Gate which will only be open
when HOT is elapsed. This means the process is terminated.
Otherwise it blocks copy of entity
in order to achieve process end which unlocks
the other Release Gate1
IN
Entity Sink2
IN
OUT1
OUT2
Output Switch
ts
IN
OUT
Release Gate which will only be open
when HOT is no longer needed. This means the process is terminated.
Otherwise it blocks copy of entity
in order to achieve process end which unlocks
the other Release Gate
IN
Entity Sink1
In HOT is the signal which comes out of the HOT investigation
processes. It is assumed
that this process runs parallel and causes no delay, so the signal
runs through to Out-Port
without any blocks.
2
In HOT (aircraft_id)
1
Out finished signal (aircraft_id)
IN
OUT
Start timer for EDIT
IN
#n
OUT
TO
deicing process
aircraft_id
IN
OUT
Get Attribute2
3
Out Anti-Icing-Code (aircraft_id)
IN
Entity Sink
Out entity (aircraft that can proceed)
Out entity (aircraft that need to be re-deiced)
ft that have to wait and whose HOT is not completly elapsed)
Out entity (aircraft in case that HOT is not longer required)
Check and adjust HOT regularly until waiting for proceed
aircraft_id
IN
OUT
Get Attribute to destroy copy of entity
aircraft_id
IN
OUT
Get Attribute to destroy copy of entity1
IN1
IN2
OUT
Path Combiner3
IN
#n
OUT
deicing process1
4
Out deicing interupped signal (aircraft_id)
IN
OUT
Aircrafts that don't need deicing
any more
IN1
IN2
OUT
Path Combiner2
IN
OUT
Output Pad
2
Out entity (aircraft)

The HOT check is a very complex technique. Therfore it was summarized to a separate block, which depicts a third level (see Figure 14, pp. 53f).

The entity runs through this check in a fix interval until the deicing process had been finished or interrupted. Within the check the new HOT will be investigated corresponding to the weather conditions at the point of simulation time and then set off against the part of the old HOT which already elapsed. Thereby the results mentioned above are possible and the entity will be forwarded accordingly (waiting loop in level 2, leave the deicing block prematurely or orderly after end of deicing).

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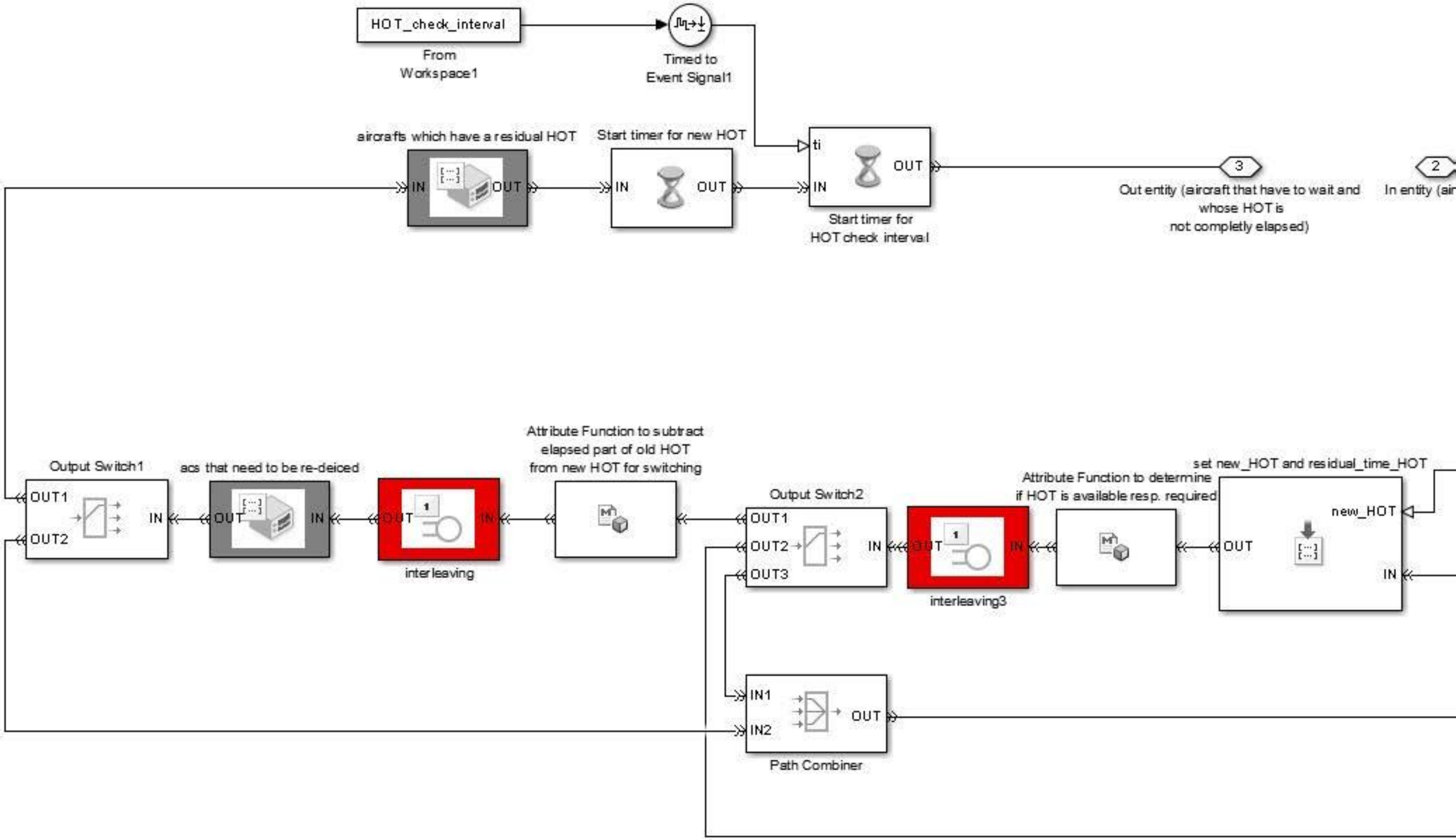
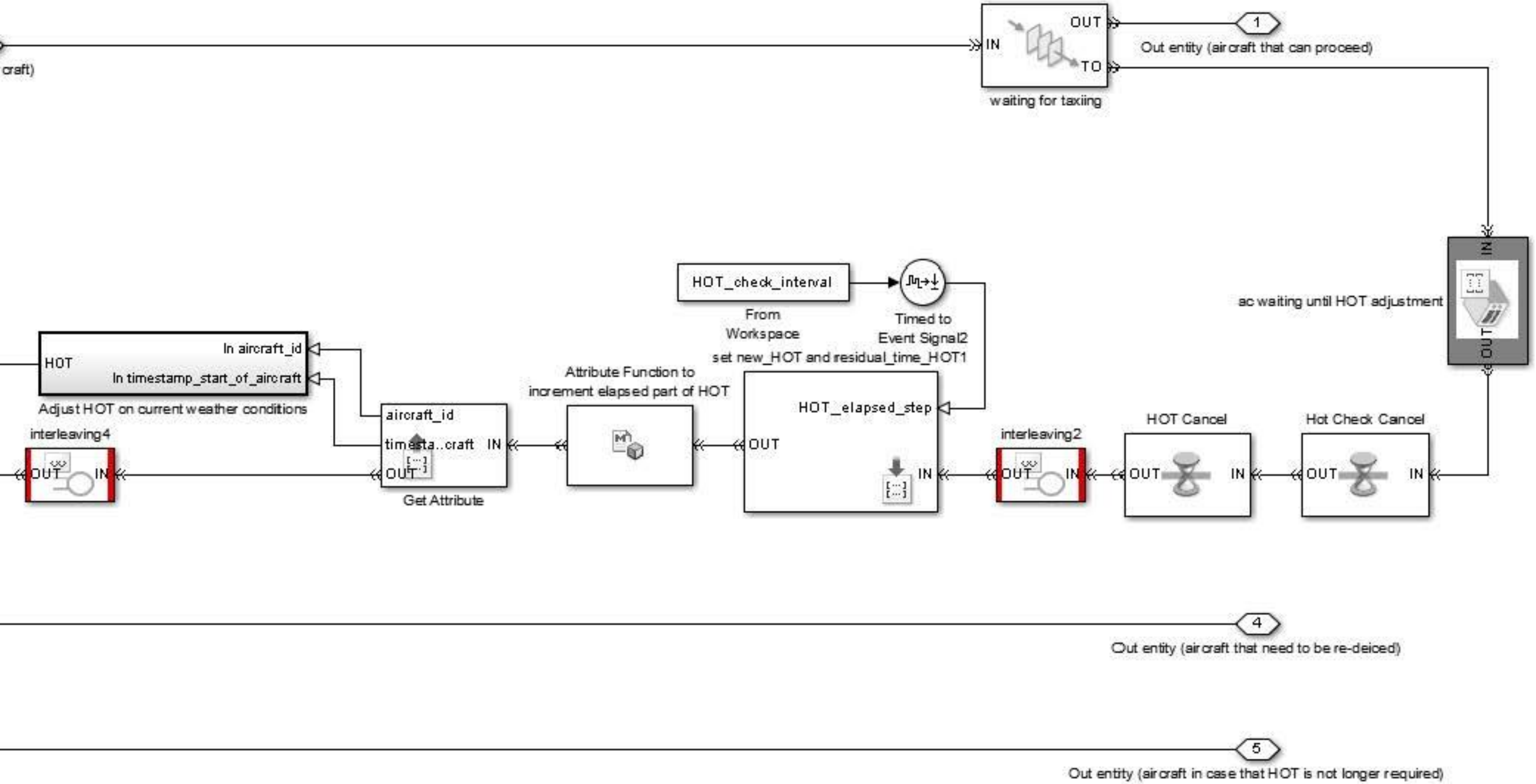



**Figure 14. Deicing process, level 3.**



craft)
IN
OUT
TO
waiting for taxiing
1
Out entity (aircraft that can proceed)
IN
OUT
ac waiting until HOT adjustment
HOT_check_interval
From
Workspace
Timed to
Event Signal2
set new_HOT and residual_time_HOT1
HOT_elapsed_step
OUT
IN
HOT
In aircraft_id
In timestamp_start_of_aircraft
Adjust HOT on current weather conditions
interleaving4
OUT
IN
aircraft_id
timesta..craft
IN
OUT
Get Attribute
Attribute Function to
increment elapsed part of HOT
interleaving2
OUT
IN
HOT Cancel
OUT
IN
Hot Check Cancel
OUT
IN
4
Out entity (aircraft that need to be re-deiced)
5
Out entity (aircraft in case that HOT is not longer required)

### 4.2.2 Turnaround

As mentioned before in the description of the deicing model the turnaround model also exists of the two dimensions for signal flow and aircraft movement. But in this model the entity representing the aircraft moves only a short way within the simulation, because most of the time it has to wait until all the processes of dimension one are performed

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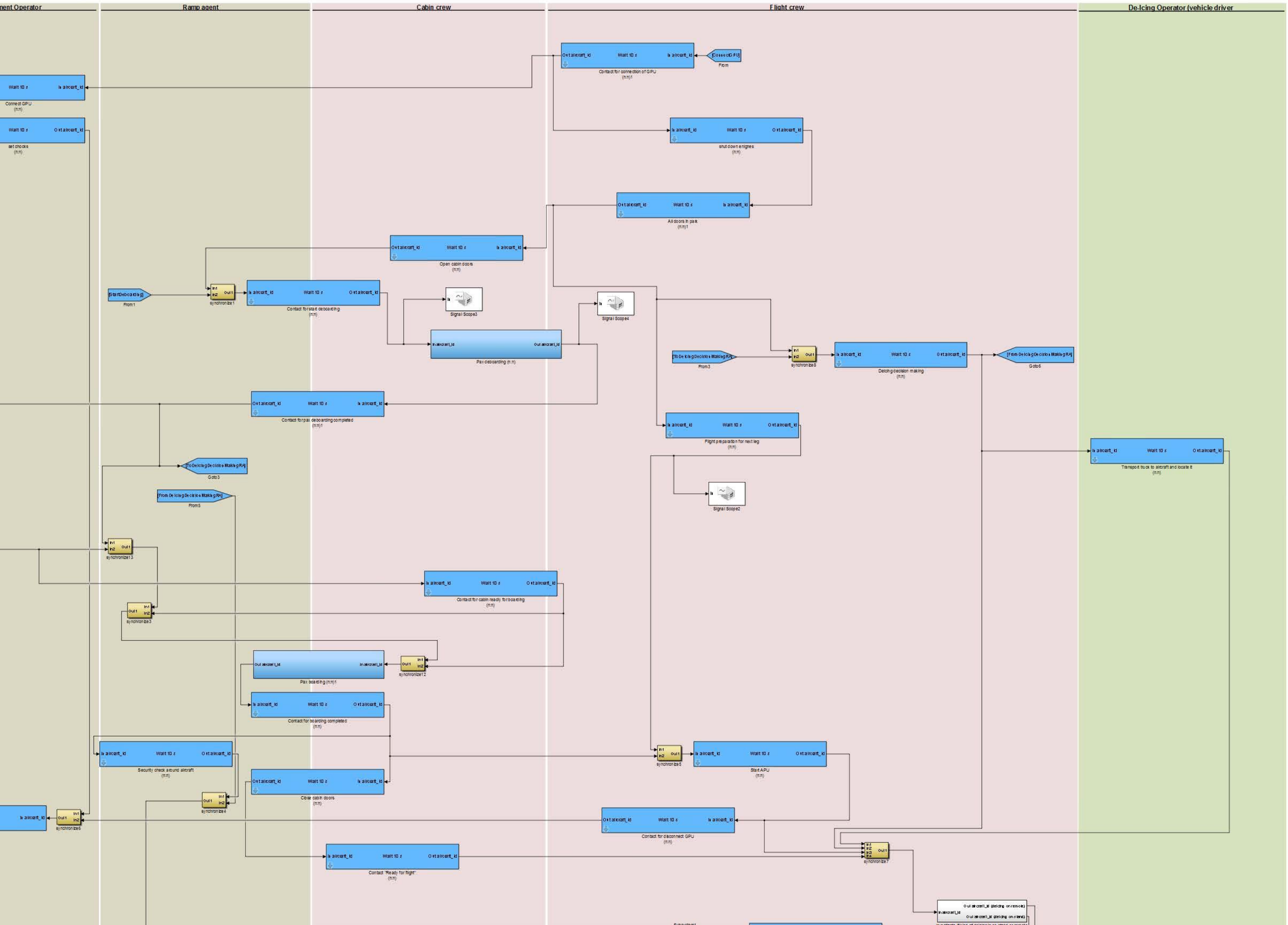
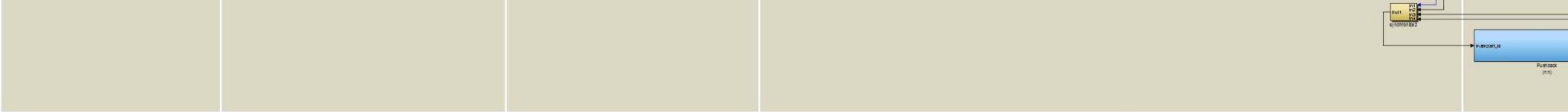
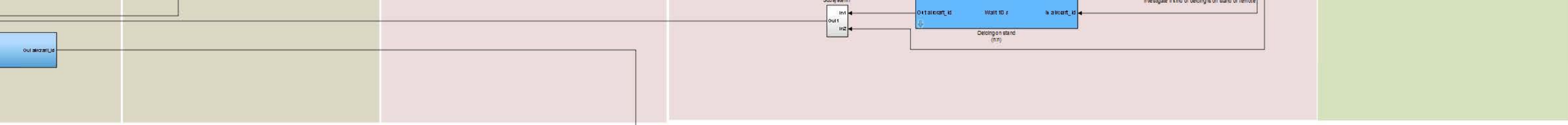
Figure 15. Turnaround, dimensions 1 and 2



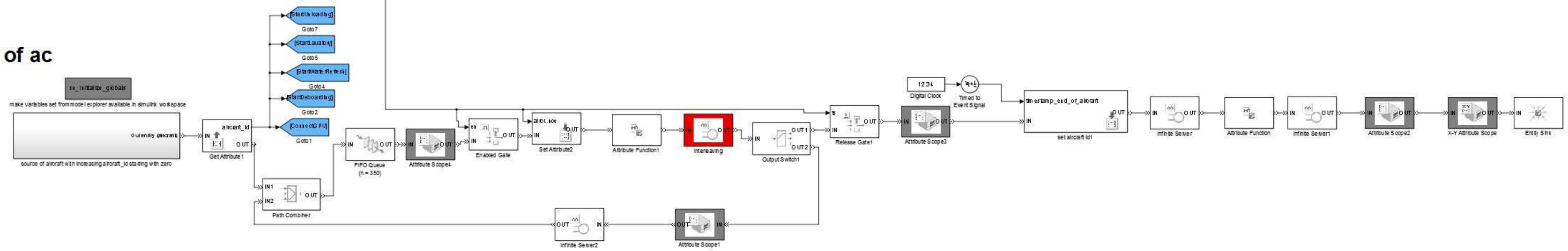
ment Operator
Ramp agent
Cabin crew
Flight crew
De-Icing Operator (vehicle driver
Contact for connection of GPU (n:n)1
From
Connect GPU (n:n)
set chocks (n:n)
shut down enignes (n:n)
All doors in park (n:n)1
Open cabin doors (n:n)
From1
synchronize1
Contact for start deboarding (n:n)
Signal Scope3
Signal Scope4
Pax deboarding (n:n)
From3
synchronize8
Deicing decision making (n:n)
Goto6
Contact for pax deboarding completed (n:n)1
Flight preparation for next leg (n:n)
Goto3
From5
Transport truck to aircraft and locate it (n:n)
Signal Scope2
synchronize13
Contact for cabin ready for boarding (n:n)
synchronize3
Pax boarding (n:n)1
synchronize12
Contact for boarding completed (n:n)
Security check around aircraft (n:n)
synchronize5
Start APU (n:n)
Close cabin doors (n:n)
synchronize4
synchronize6
Contact for disconnect GPU (n:n)
synchronize7
Contact "Ready for flight" (n:n)



Out1
In1
In2
In3
In4
Pushback




## DIM2 movement of ac



## 4.3 Annex 2: Process description

The detailed process description depicts common processes, participants and resources during all phases of flight, especially turnaround, taxi operations, de-icing, departure, enroute, approach and ATFM including sub-processes. It constitutes the basis for the investigation of the current system with respect to the micro part. A UML2 description was chosen to allow an easier transfer to the model[7].

Since some selected process are distributed over several pages for a better resolution, it is suggested for a better viewing experience to enable the 4 window option in the adobe reader.

### 4.3.1 Annex 2.1: Flow diagram of the turn-around process model

The following four pages show parts of the flow diagram related to the turn-around process model described in this document. These pages can be assembled in a 4-page-view.

This diagram is divided into columns, each representing the involved persons of the ground crew (brown background colour), air crew (light red background colour) and de-icing crew (light green background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this person. Sub-processes with underlined titles have already been modelled, e.g. the push-back sub-process model is depicted in chapter 4.3.8.

Concave and convex polygons represent communication between participants with direction of communication.

---

[7] Besides the requirements of the implementation phase, a suitable method of formalizing should be employed during the phase of analysing as the step before. Here, one should be enabled to compare both concepts with respect to the different roles of actors, technical functionalities and interdependencies in a suitable manner. Since the (complex) information about procedures, responsibilities and respective interdependencies are available in writing, workflows seem to be an appropriate form of representation.

To satisfy the requirements of analysis and implementation, the standard of the unified modelling language UML appears as a reasonable method of description. UML has proven its wide applicability in software development [Kecher 2009] and shows characteristics similar to discrete event formalization [Spiteri Staines 2008]. As a consequence of the first description of the system in D1.3, UML was being used in form of activity diagrams of the UML2 standard during the project. Since UML activity diagrams are another way of portraying workflows by abstracting the interdependencies into a graphical representation, they provide the aspect of synchronization, choice, sequence and concurrency of actions and processes. Areas of responsibility, exception handling and hierarchical modelling can be represented. The figure 1 in annex 1 shows an example of the abstracted description of the ATM system by applying UML2 activity diagrams. Here, the overview of the turnaround process, as carried out in the current ATM system is given. Different sub processes, like the cleaning process, are integrated at a lower hierarchical level in the diagram. The depicted workflow incorporates different elements such as decisions, actions, parallel processes or elements of communications like sending and receiving. The abstraction of the workflows, which were mainly drawn from literature and interviews of actors such as pilots, airport operators, controllers and ground handlers have to pave the way for an easy adoption into the modelling environment. Due to the character of UML2 activity diagrams, the process of transfer to a discrete event environment is feasible.

Black bars represent points, where the process flow splits up into several parallel sub-flows. Following flow merging points are also represented as a black bar.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

Elements drawn in pink colour represent possible short-cuts to expedite the turn-around process.

This model is mainly derived from [Ashford 2012] and [TAT 2014] and was supplemented with operational know-how of ground handling personnel, airliner pilots and air traffic controllers.

A-CDM has been modelled separately and is depicted in chapter 4.3.9.

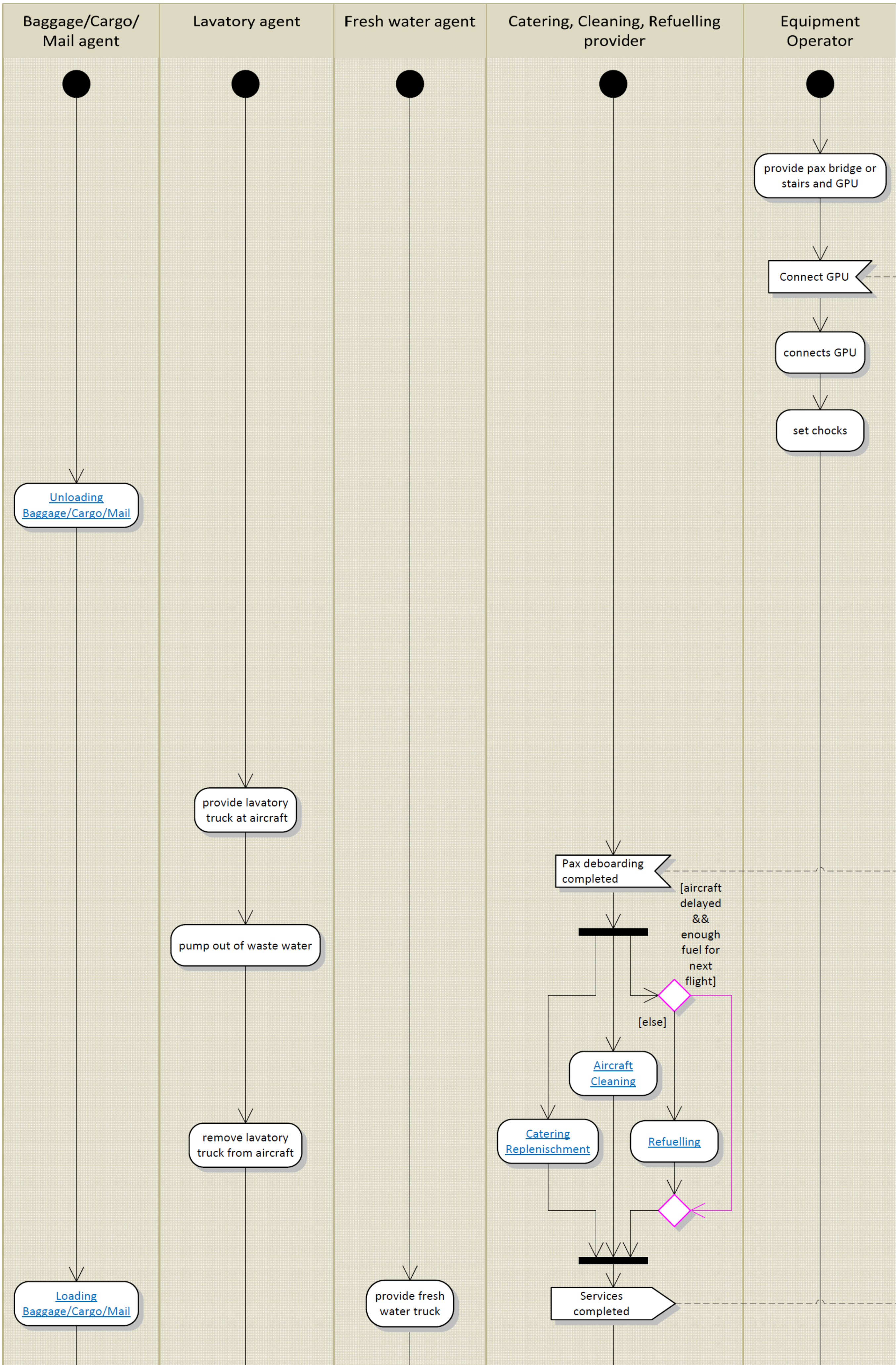
**Following pages:**

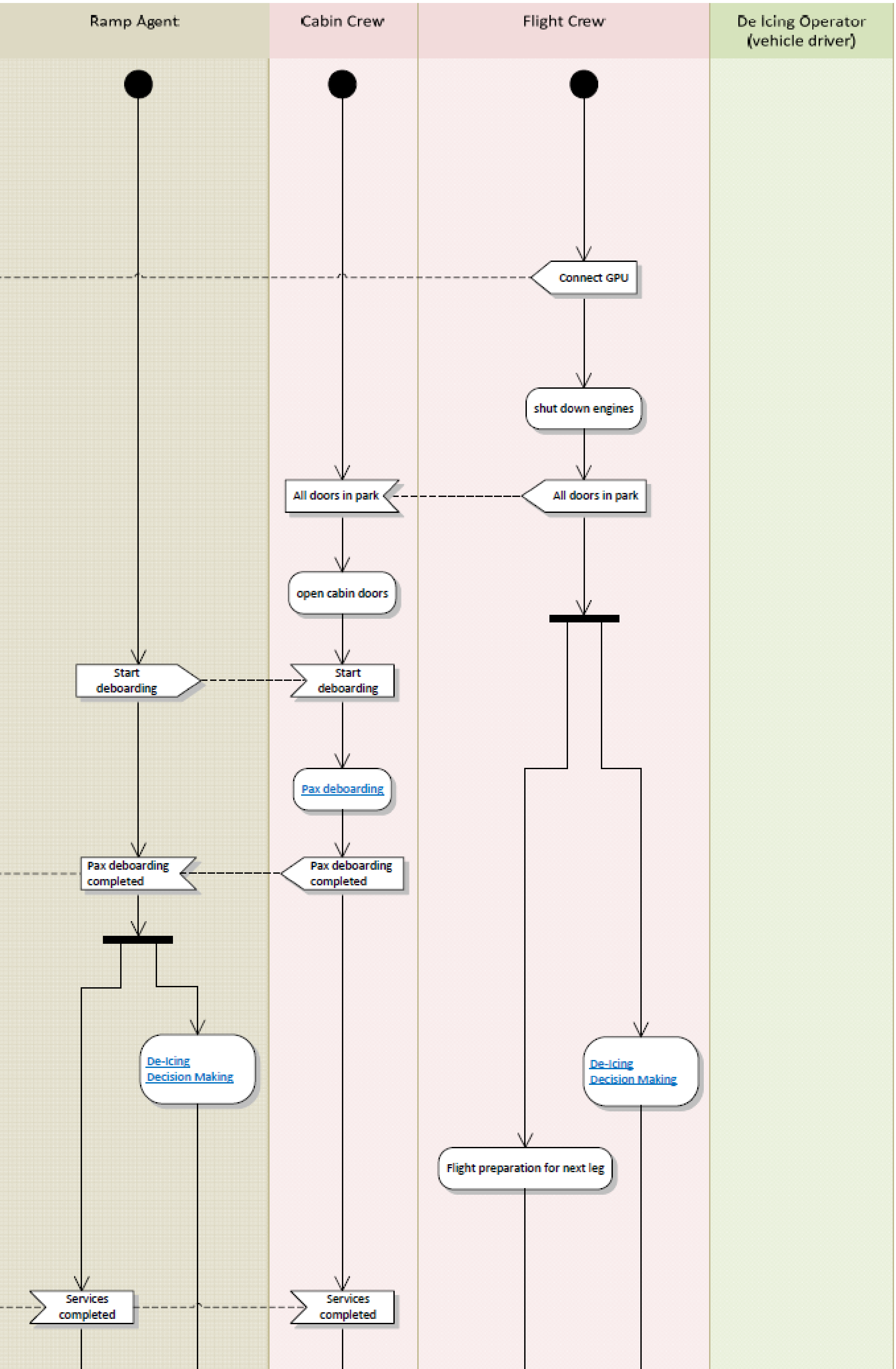
**Figure 16. Flow diagram of the turn-around model (1/4), upper left part**

**Figure 17. Flow diagram of the turn-around model (2/4), upper right part**

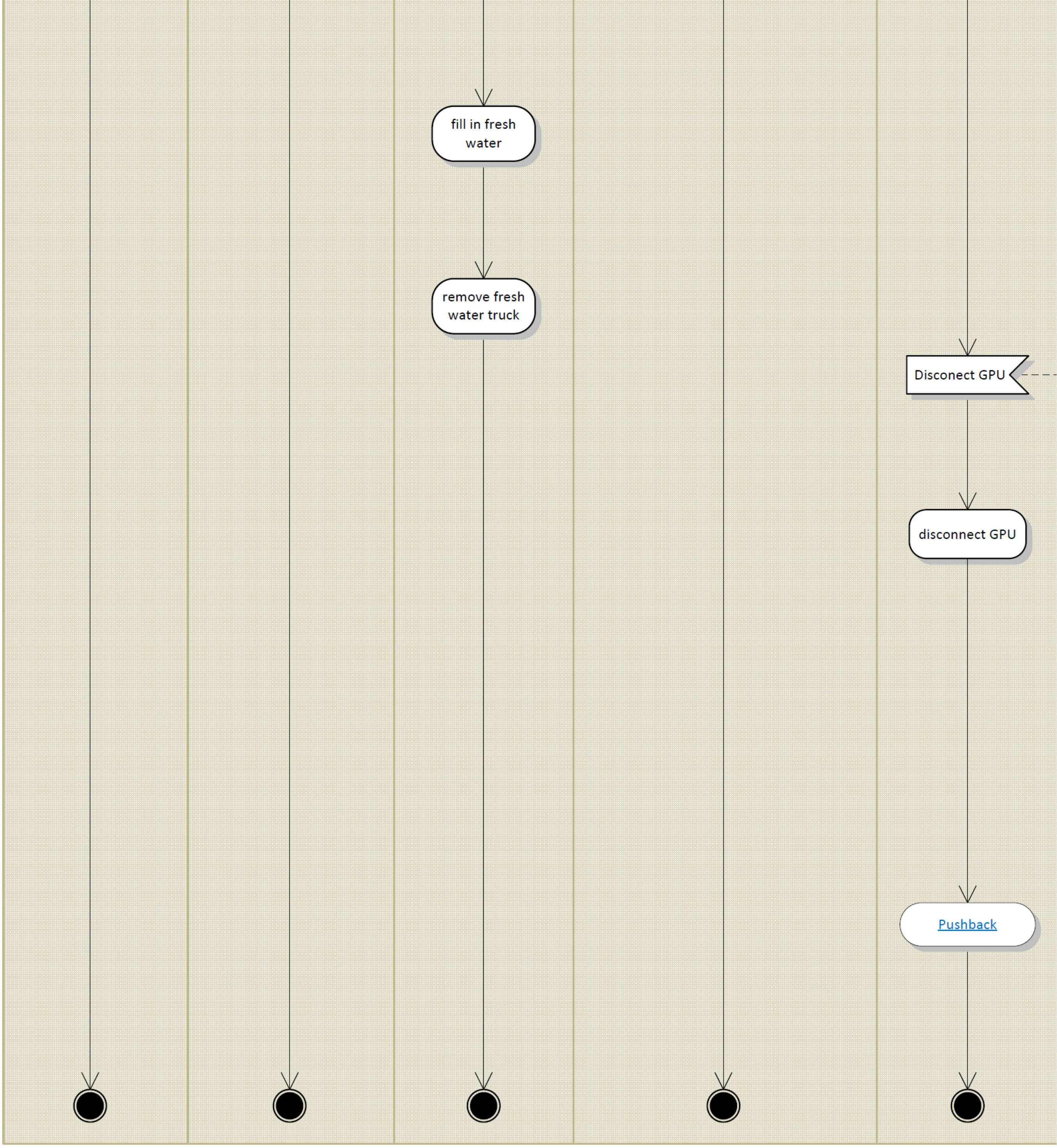
**Figure 18. Flow diagram of the turn-around model (3/4), lower left part**

**Figure 19. Flow diagram of the turn-around model (4/4), lower right part**

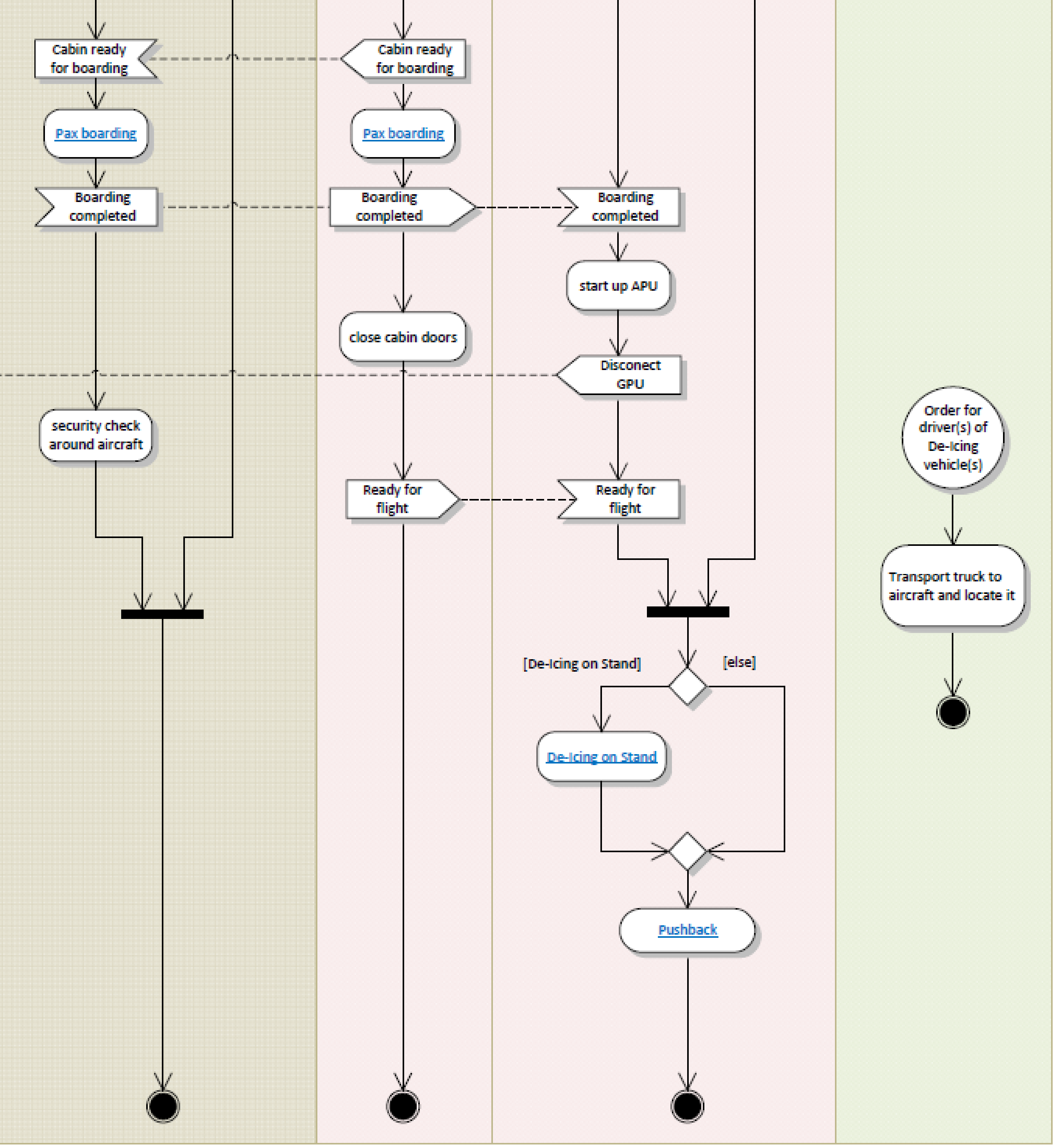

Baggage/Cargo/ Mail agent
Lavatory agent
Fresh water agent
Catering, Cleaning, Refuelling provider
Equipment Operator
provide pax bridge or stairs and GPU
Connect GPU
connects GPU
set chocks
Unloading Baggage/Cargo/Mail
provide lavatory truck at aircraft
Pax deboarding completed
[aircraft delayed && enough fuel for next flight]
pump out of waste water
[else]
Aircraft Cleaning
Catering Replenischment
Refuelling
remove lavatory truck from aircraft
Loading Baggage/Cargo/Mail
provide fresh water truck
Services completed



Ramp Agent
Cabin Crew
Flight Crew
De Icing Operator (vehicle driver)
Connect GPU
shut down engines
All doors in park
All doors in park
open cabin doors
Start deboarding
Start deboarding
Pax deboarding
Pax deboarding completed
Pax deboarding completed
De-Icing Decision Making
De-Icing Decision Making
Flight preparation for next leg
Services completed
Services completed



fill in fresh water
remove fresh water truck
Disconect GPU
disconnect GPU
Pushback



Cabin ready for boarding
Cabin ready for boarding
Pax boarding
Pax boarding
Boarding completed
Boarding completed
Boarding completed
start up APU
close cabin doors
Disconect GPU
security check around aircraft
Order for driver(s) of De-Icing vehicle(s)
Ready for flight
Ready for flight
Transport truck to aircraft and locate it
[De-Icing on Stand]
[else]
De-Icing on Stand
Pushback

### 4.3.2 Annex 2.2: Flow diagram of the de-icing process model (remote de-icing pad)

The following four pages show parts of the flow diagram related to the de-icing process model described in this document. These pages can be assembled in a 4-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): A-CDM (light green background colour), ATC (light blue background colour), aircraft de-icing center (light green background colour), flight crew (light red background colour) and de-icing operator (light green background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant. Sub-processes with underlined titles have already been modelled.

Concave and convex polygons represent communication between participants with direction of communication.

Black bars represent points, where the process flow splits up into several parallel sub-flows. Following flow merging points are also represented as a black bar.

Diamond represents a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

Blocks with dashed borderlines represent a more complex program structure; relations are indicated.

This model is derived from [Ashford 2012], [EUROCONTROL L 2012] [HAHN 2011], [KADEN 2013], [KLM 2014], [MUC 2014], [NORACON 2011], [Fraport 2011], [ACI 2011], [AEA 2013a] and [AEA 2013b].

**Following pages:**

**Figure 20. Flow diagram of the de-icing process model (1/4), upper left part**

**Figure 21. Flow diagram of the de-icing process model (2/4), upper right part**

**Figure 22. Flow diagram of the de-icing process model (3/4), lower left part**

**Figure 23. Flow diagram of the de-icing process model (4/4), lower right part**

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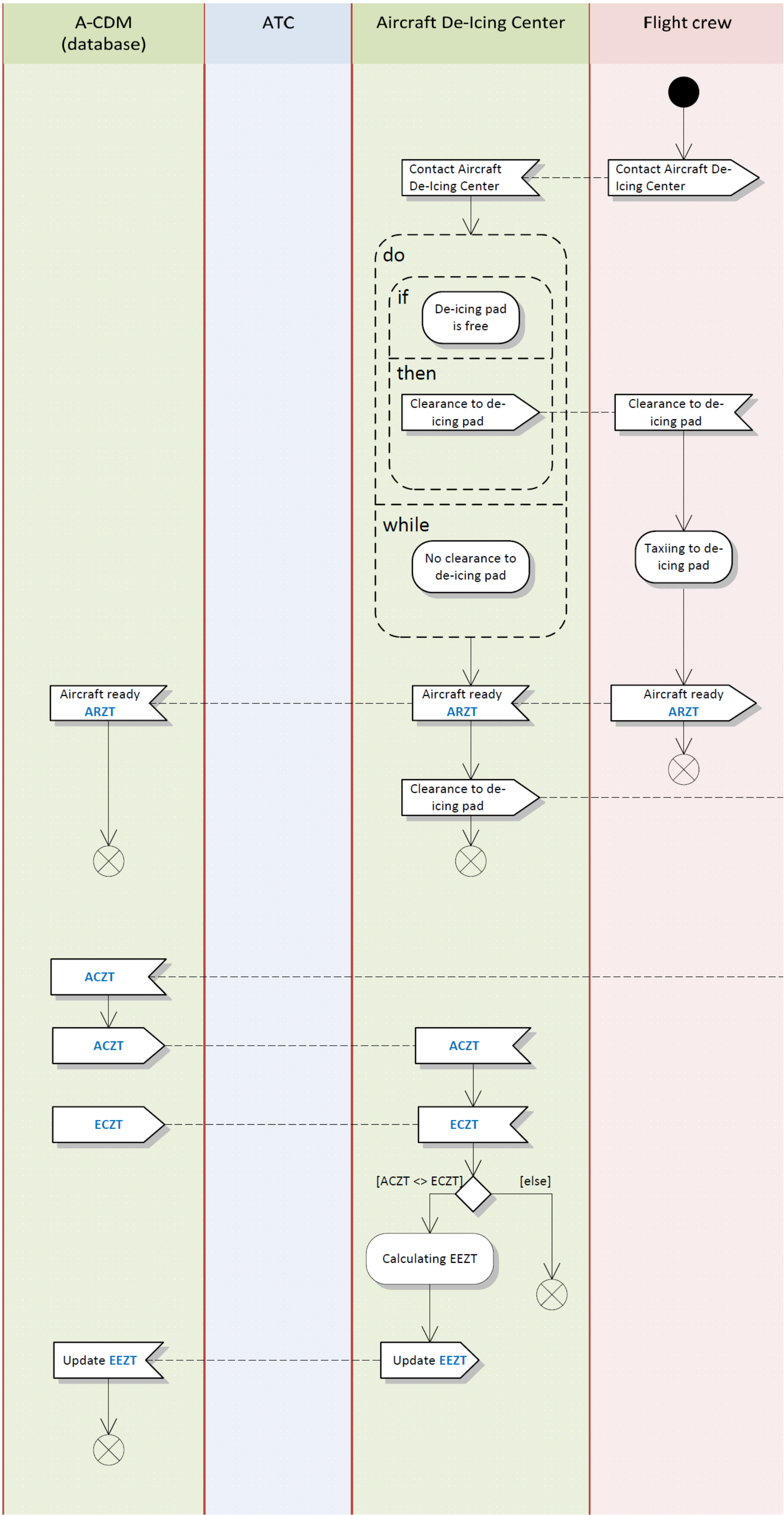
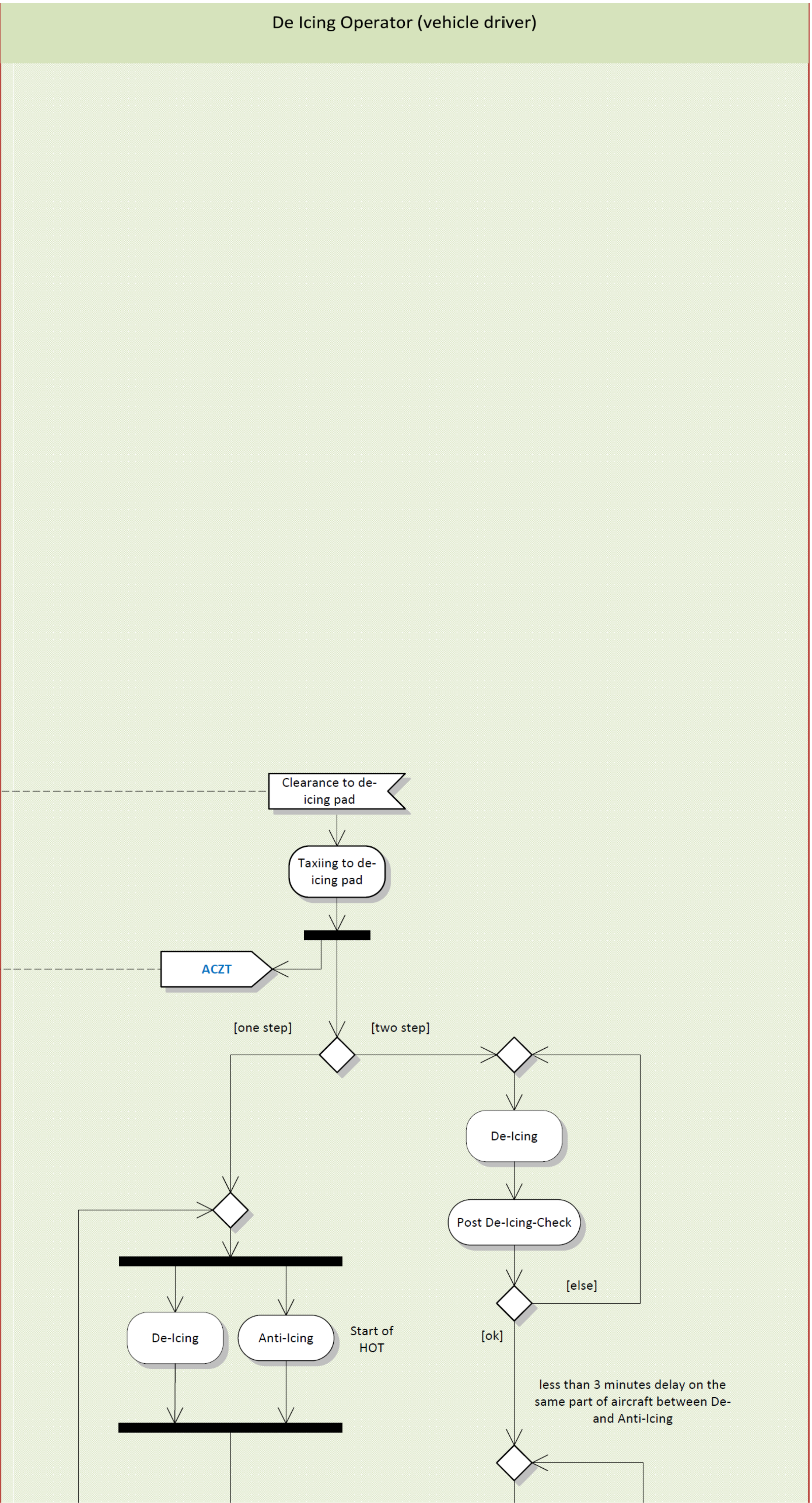
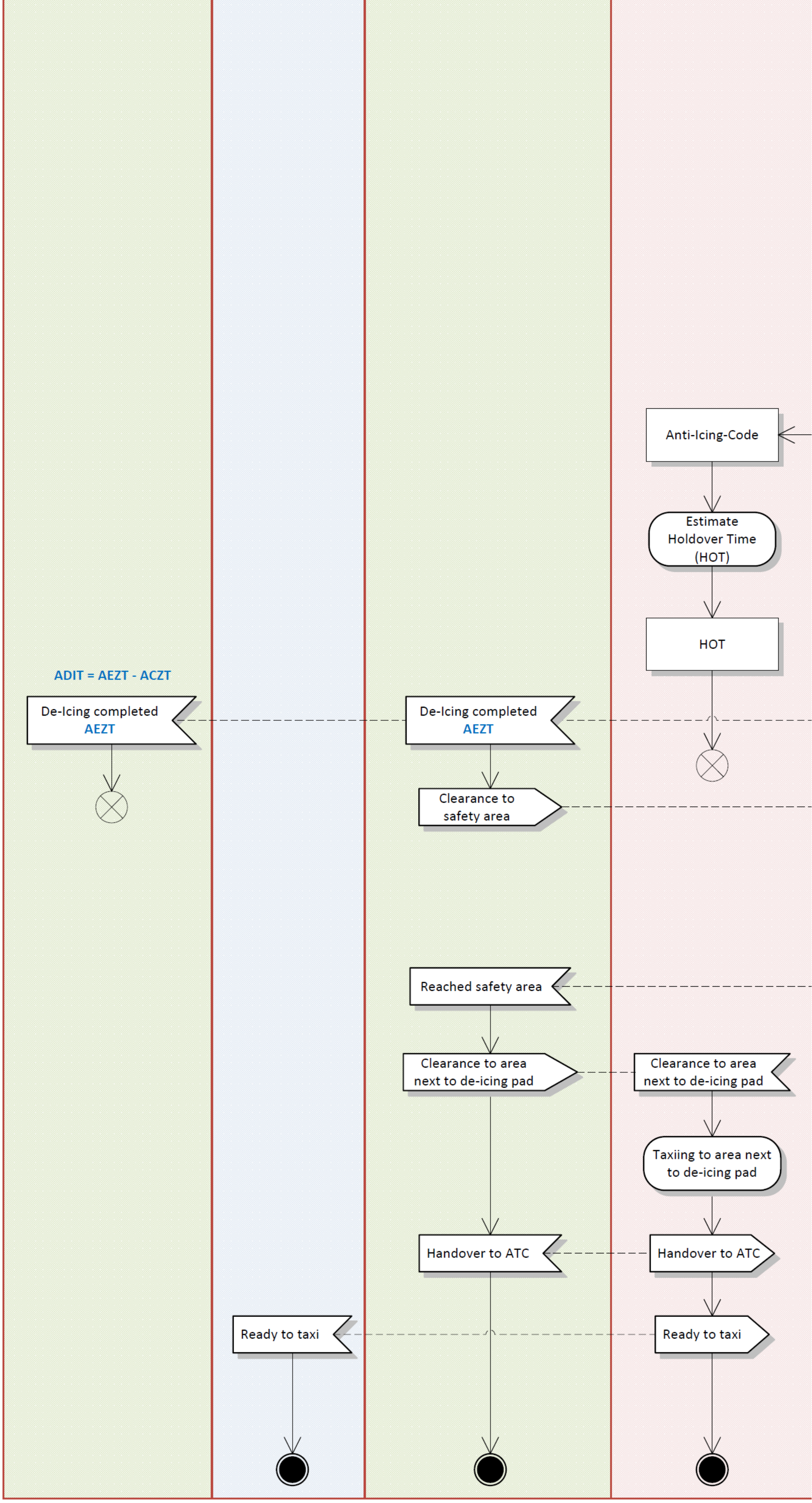
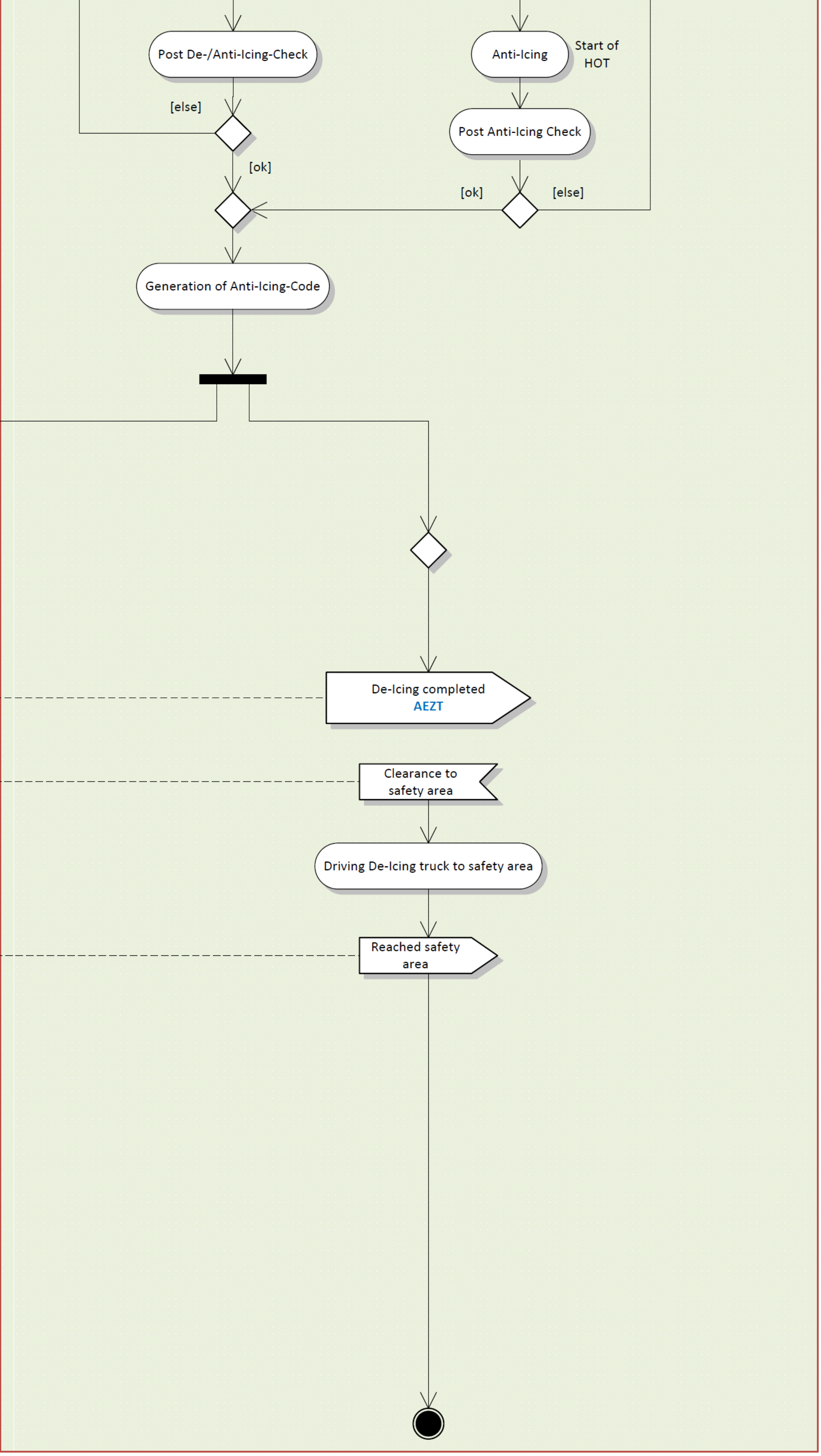

A-CDM
(database)
ATC
Aircraft De-Icing Center
Flight crew
Contact Aircraft De-Icing Center
Contact Aircraft De-Icing Center
do
if
De-icing pad is free
then
Clearance to de-icing pad
Clearance to de-icing pad
while
No clearance to de-icing pad
Taxiing to de-icing pad
Aircraft ready ARZT
Aircraft ready ARZT
Aircraft ready ARZT
Clearance to de-icing pad
ACZT
ACZT
ACZT
ECZT
ECZT
[ACZT <> ECZT]
[else]
Calculating EEZT
Update EEZT
Update EEZT


De Icing Operator (vehicle driver)
Clearance to de-icing pad
Taxiing to de-icing pad
ACZT
[one step]
[two step]
De-Icing
Post De-Icing-Check
[else]
[ok]
De-Icing
Anti-Icing
Start of HOT
less than 3 minutes delay on the same part of aircraft between De- and Anti-Icing



Anti-Icing-Code
Estimate Holdover Time (HOT)
HOT
ADIT = AEZT - ACZT
De-Icing completed AEZT
De-Icing completed AEZT
Clearance to safety area
Reached safety area
Clearance to area next to de-icing pad
Clearance to area next to de-icing pad
Taxiing to area next to de-icing pad
Handover to ATC
Handover to ATC
Ready to taxi
Ready to taxi


Post De-/Anti-Icing-Check
Anti-Icing
Start of HOT
[else]
Post Anti-Icing Check
[ok]
[ok]
[else]
Generation of Anti-Icing-Code
De-Icing completed
AEZT
Clearance to safety area
Driving De-Icing truck to safety area
Reached safety area

### 4.3.3 Annex 2.3: Flow diagram of the Taxi/Take-off process model

The following four pages show parts of the flow diagram related to the modelled Taxi/Take-off process which follows the turnaround. These pages can be assembled in a 4-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): Met Office (light green background colour), De-Icing operator (light green background colour), cockpit crew (light red background colour), Ground controller (light blue background colour), Tower planner (light blue background colour), Tower executive (light blue background colour) and network operations (dark blue background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant. Sub-processes with underlined titles have already been modelled.

Concave and convex polygons represent communication between participants with direction of communication.

Black bars represent points, where the process flow splits up into several parallel sub-flows. Following flow merging points are also represented as a black bar.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

This model is derived from [Ashford 2012], [EUROCONTROL L 2014] and [ICAO 2007] and was supplemented with operational know-how of ground handling personnel, airliner pilots and air traffic controllers.

**Following pages:**

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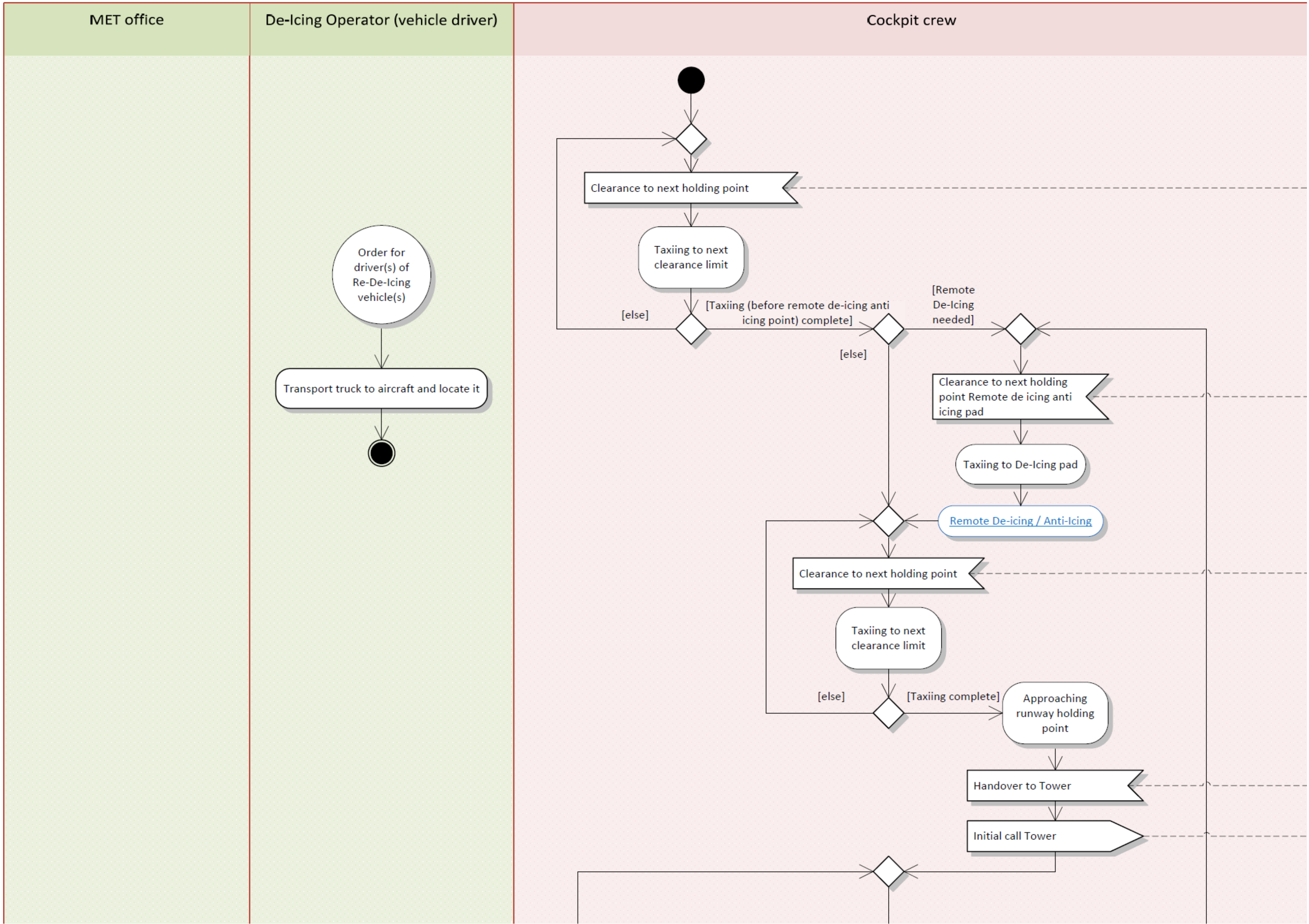
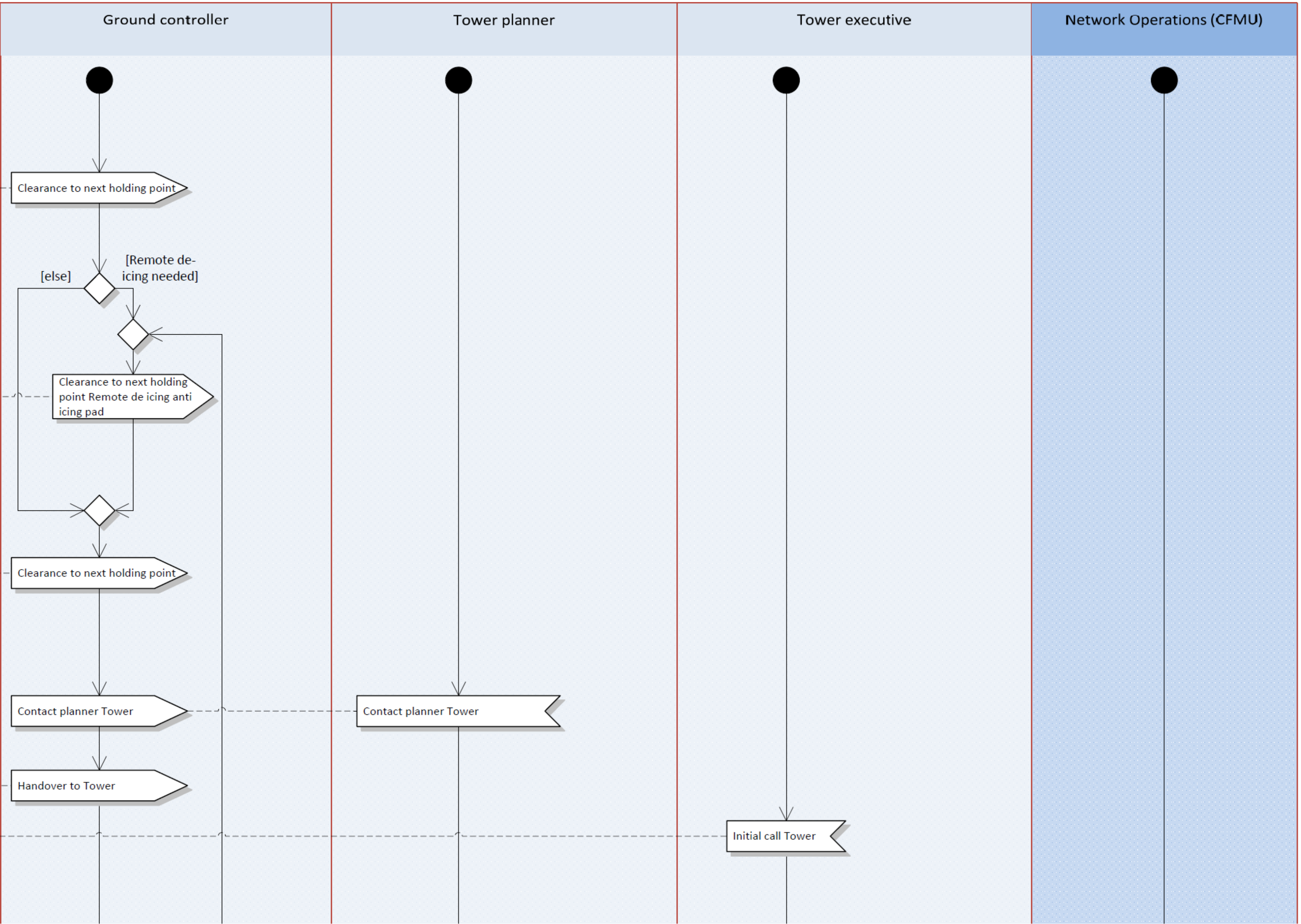
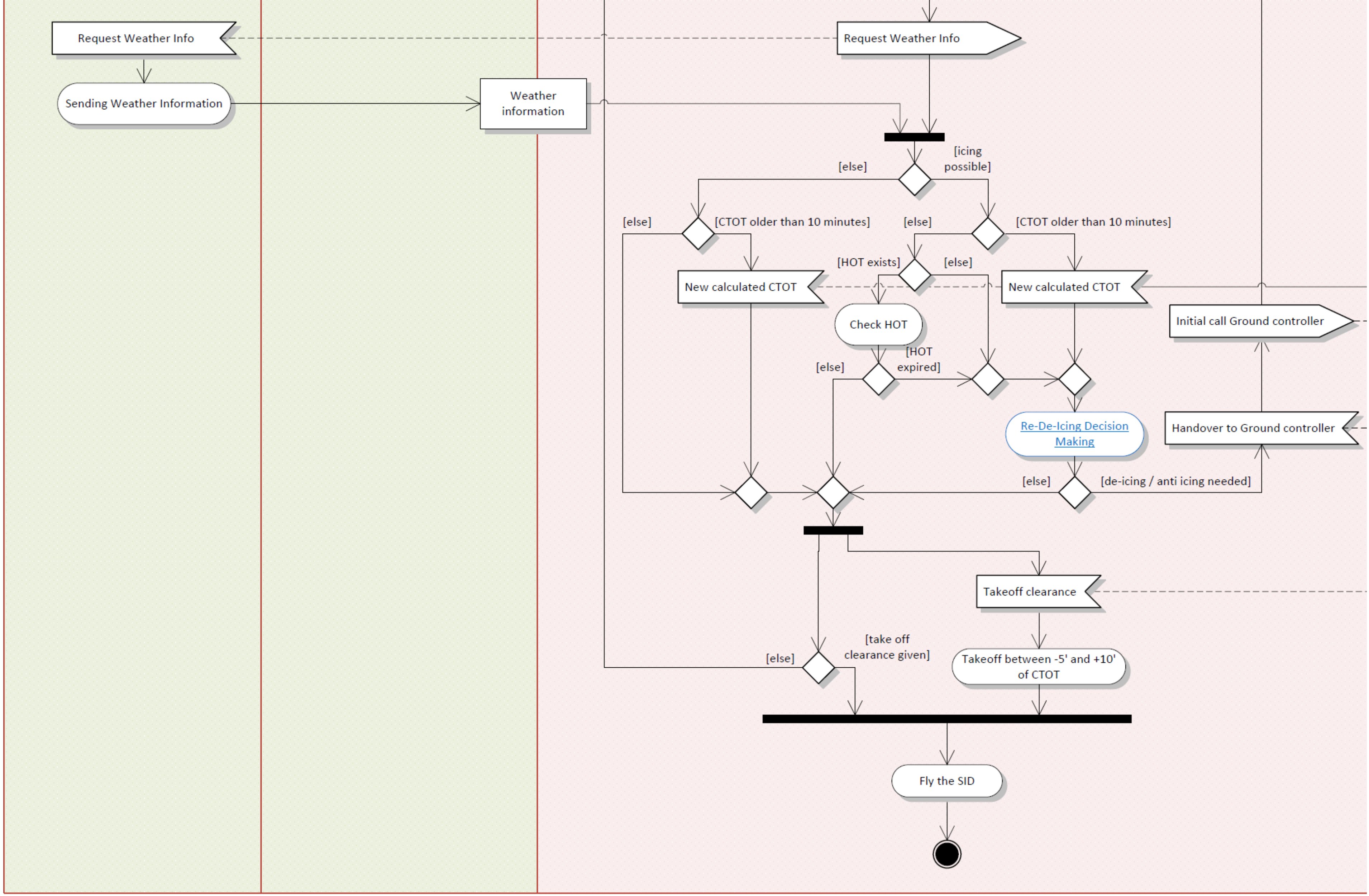
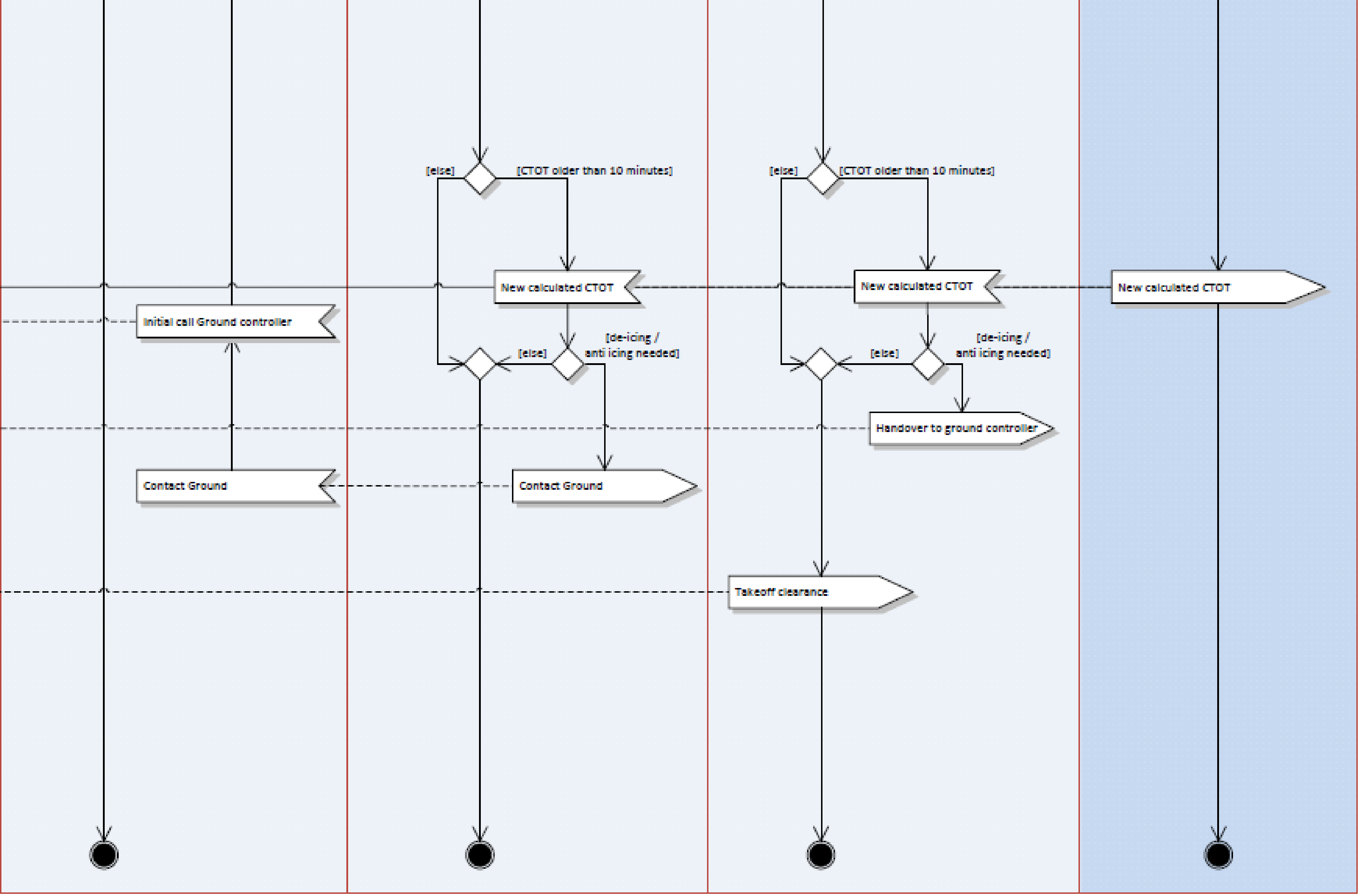


MET office
De-Icing Operator (vehicle driver)
Cockpit crew
Clearance to next holding point
Taxiing to next clearance limit
Order for driver(s) of Re-De-Icing vehicle(s)
[else]
[Taxiing (before remote de-icing anti icing point) complete]
[Remote De-Icing needed]
[else]
Transport truck to aircraft and locate it
Clearance to next holding point Remote de icing anti icing pad
Taxiing to De-Icing pad
Remote De-icing / Anti-Icing
Clearance to next holding point
Taxiing to next clearance limit
[else]
[Taxiing complete]
Approaching runway holding point
Handover to Tower
Initial call Tower


Ground controller
Tower planner
Tower executive
Network Operations (CFMU)
Clearance to next holding point
[Remote de-icing needed]
[else]
Clearance to next holding point Remote de icing anti icing pad
Clearance to next holding point
Contact planner Tower
Contact planner Tower
Handover to Tower
Initial call Tower


Request Weather Info
Sending Weather Information
Weather information
Request Weather Info
[icing possible]
[else]
[else]
[CTOT older than 10 minutes]
[else]
[CTOT older than 10 minutes]
[HOT exists]
[else]
New calculated CTOT
Check HOT
New calculated CTOT
Initial call Ground controller
[else]
[HOT expired]
Re-De-Icing Decision Making
Handover to Ground controller
[else]
[de-icing / anti icing needed]
Takeoff clearance
[else]
[take off clearance given]
Takeoff between -5' and +10' of CTOT
Fly the SID


[else]
[CTOT older than 10 minutes]
[else]
[CTOT older than 10 minutes]
New calculated CTOT
New calculated CTOT
New calculated CTOT
Initial call Ground controller
[else]
[de-icing / anti icing needed]
[else]
[de-icing / anti icing needed]
Handover to ground controller
Contact Ground
Contact Ground
Takeoff clearance

### 4.3.4 Annex 2.4: Flow diagram of the TMAi process model

The figure below shows the flow diagram related to the modelled TMAi process which encompasses departure and climb operations following the take-off.

This diagram is divided into columns, each representing the involved participants / systems (left to right): Cockpit crew (light red background colour), Tower executive (light blue background colour), ACC TMAi DEP (light blue background colour), ACC/lower airspace planner (light blue background colour) and ACC/lower airspace executive (light blue background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant.

Concave and convex polygons represent communication between participants with direction of communication.

This model is derived from [ICAO 2007] and was supplemented with operational know-how of airliner pilots and air traffic controllers.

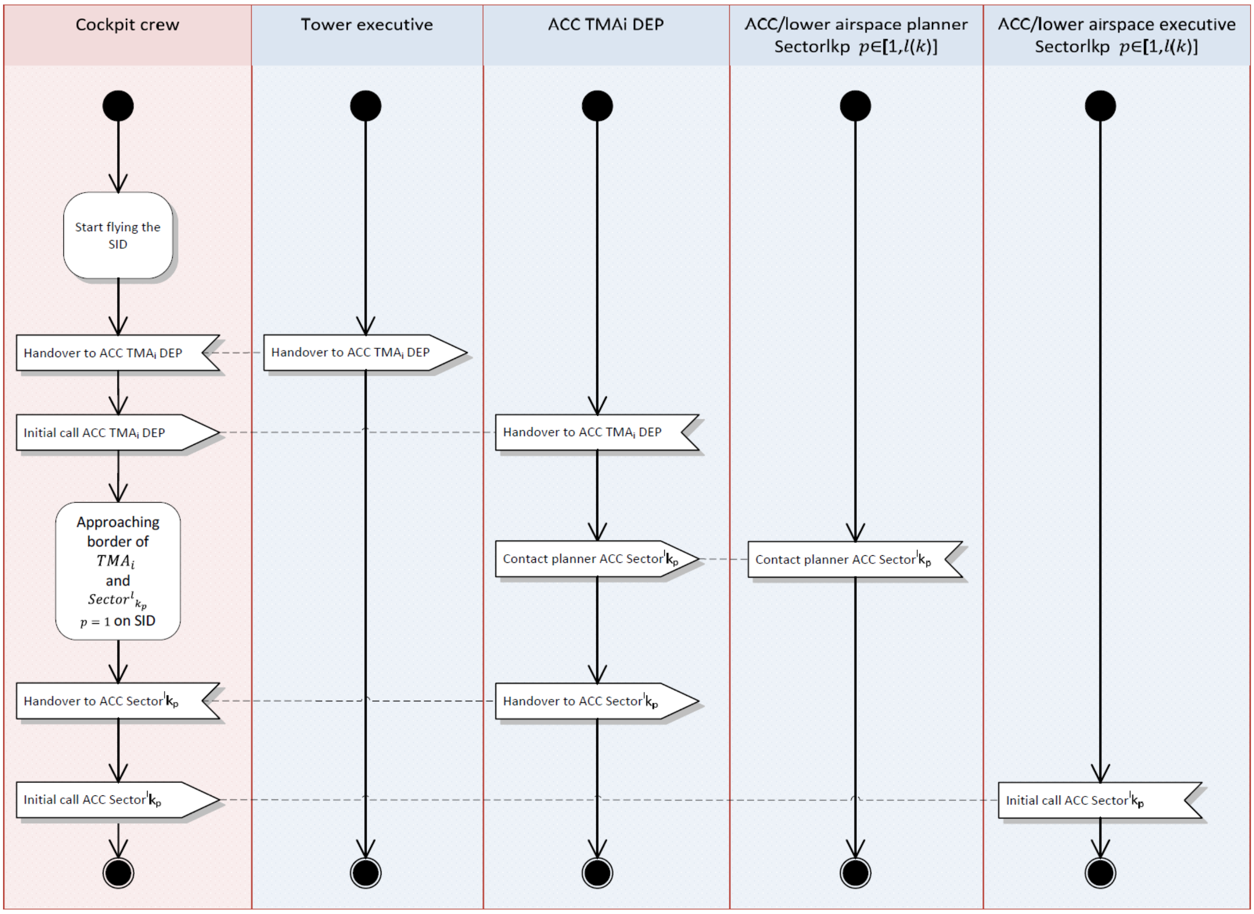



Figure 28. Flow diagram of the TMAi process model

### 4.3.5 Annex 2.5: Flow diagram of the sector process model

The following four pages show parts of the flow diagram related to the sector process model which encompasses climb, enroute and descent operations outside of a TMA. These pages can be assembled in a 4-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): cockpit crew (light red background colour), ACC/lower airspace planner (climb operations, light blue background colour), ACC/lower airspace executive (climb operations, light blue background colour), ACC/upper airspace planner (light blue background colour), ACC/upper airspace executive (light blue background colour), ACC/lower airspace planner (descent for landing, light blue background colour) and ACC/lower airspace executive (descent for landing, light blue background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant. Sub-processes with underlined titles have already been modelled.

Concave and convex polygons represent communication between participants with direction of communication.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Following flow merging points are also represented as a diamond.

This model is derived from [ICAO 2007] and [LVNL 2013] and was supplemented with operational know-how of airliner pilots and air traffic controllers.

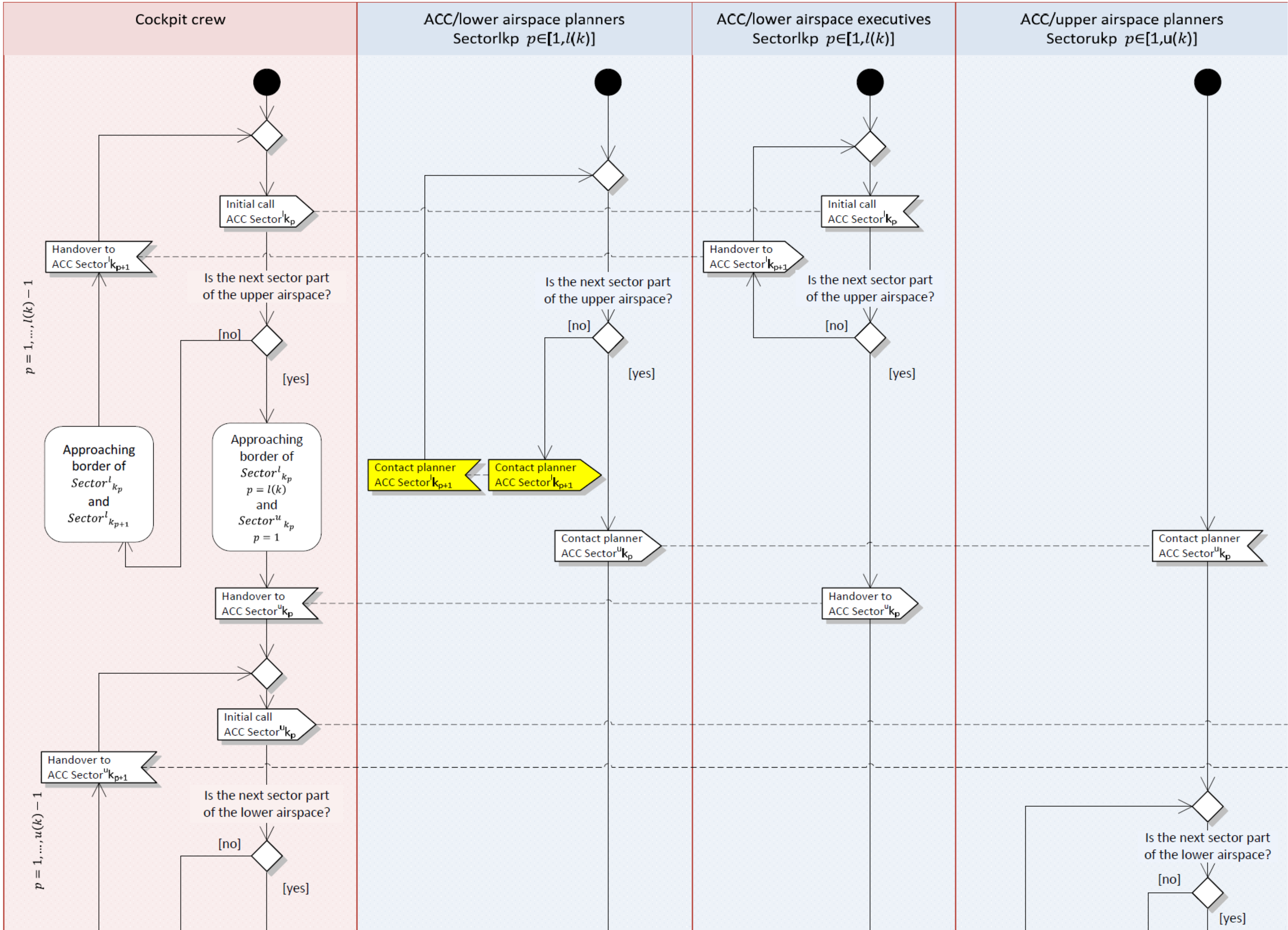
**Following pages:**

**Figure 29. Flow diagram of the sector process model (1/4), upper left part**

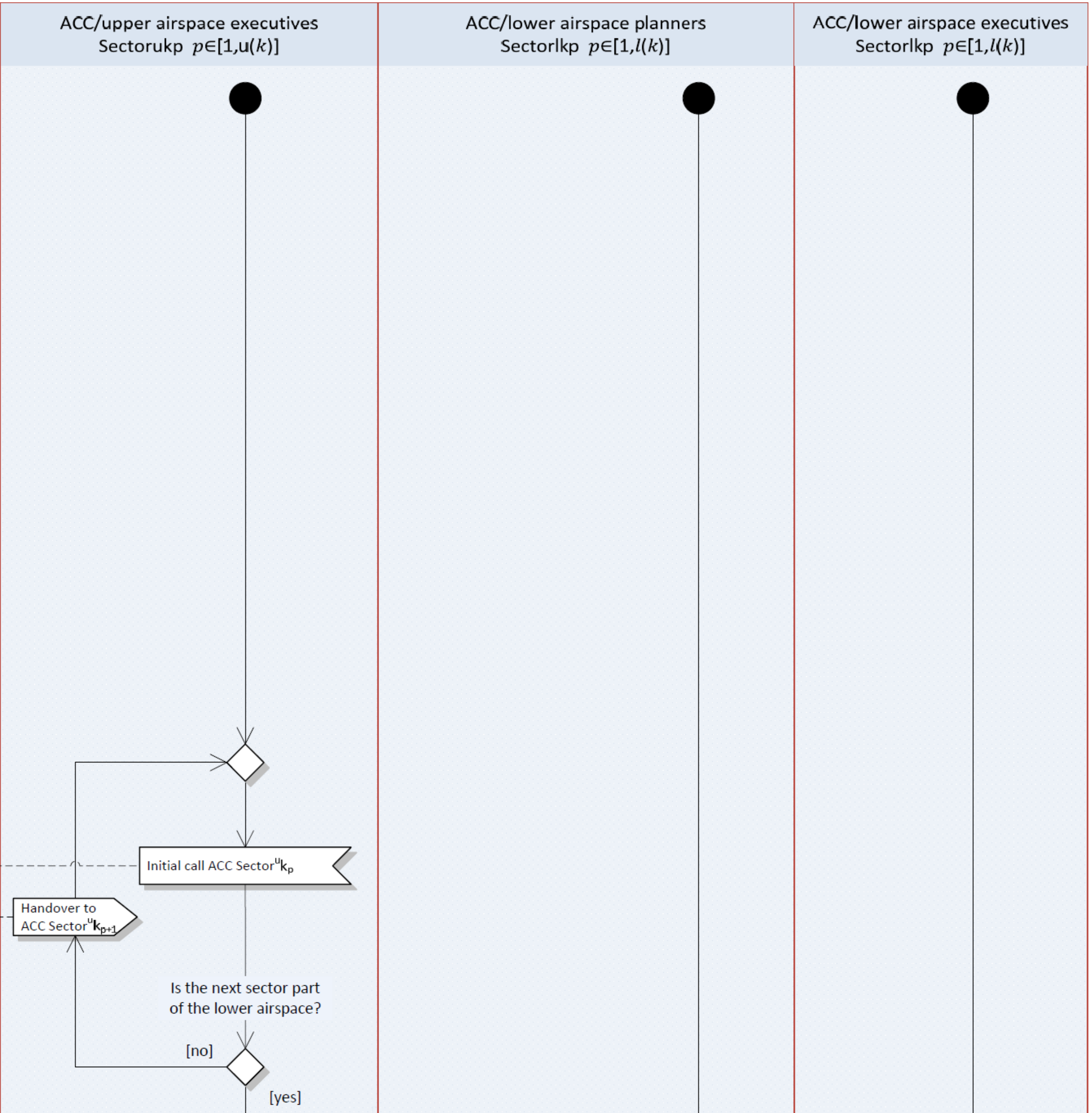
**Figure 30. Flow diagram of the sector process model (2/4), upper right part**

**Figure 31. Flow diagram of the sector process model (3/4), lower left part**

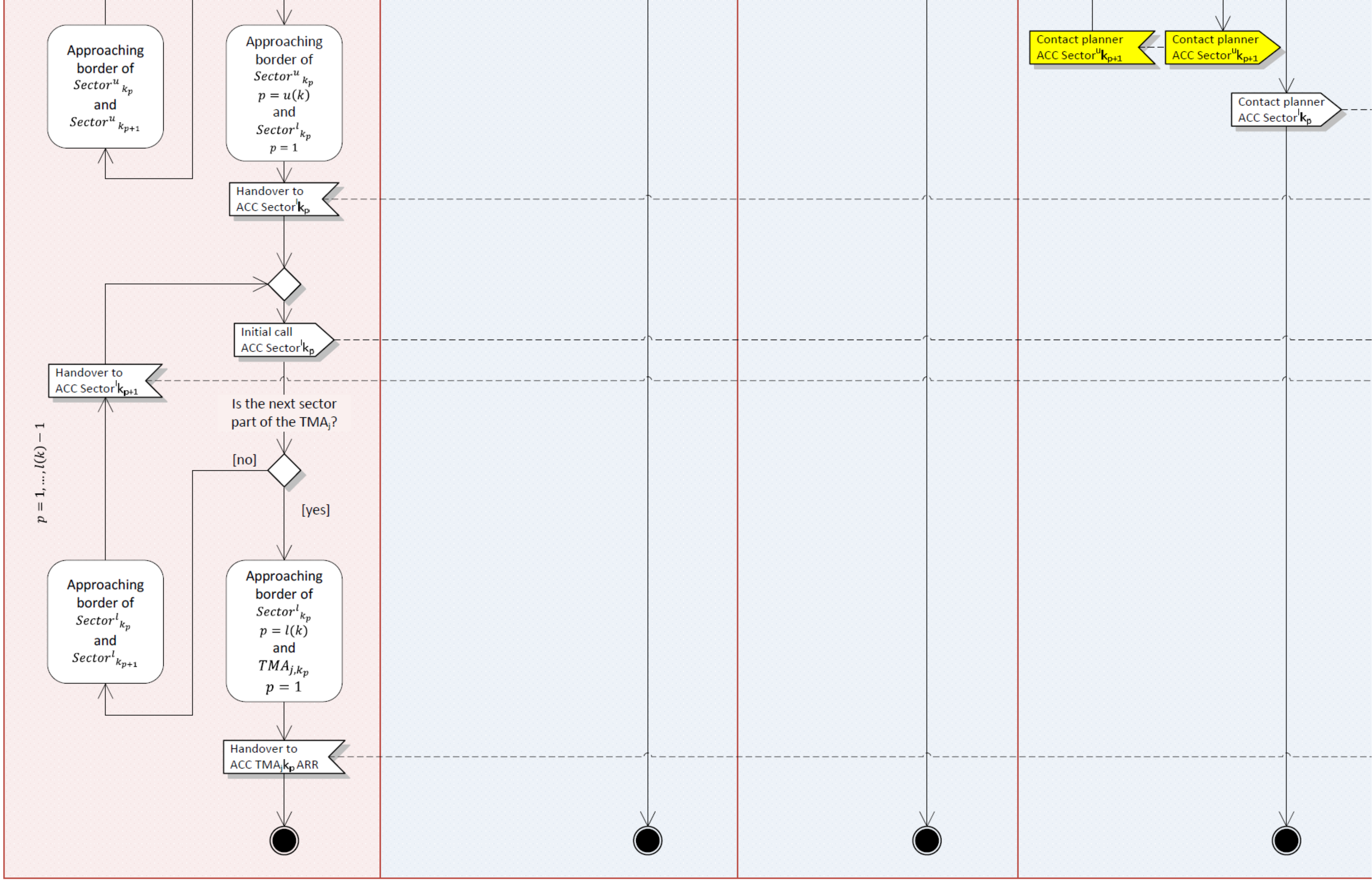
**Figure 32. Flow diagram of the sector process model (4/4), lower right part**



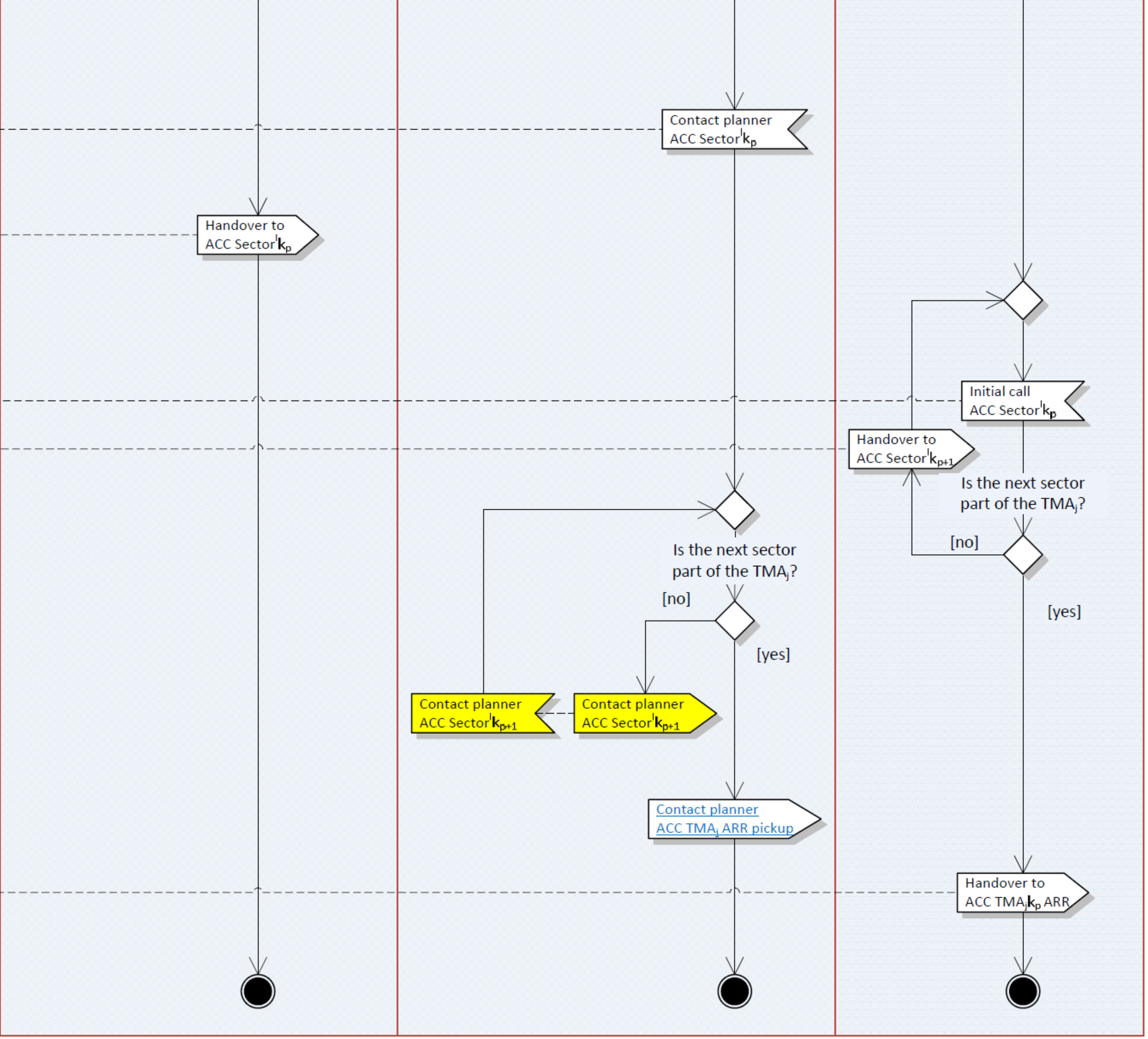
Cockpit crew
ACC/lower airspace planners
Sectorlkp p∈[1,l(k)]
ACC/lower airspace executives
Sectorlkp p∈[1,l(k)]
ACC/upper airspace planners
Sectorukp p∈[1,u(k)]
Initial call
ACC Sector l kp
Handover to
ACC Sector l kp+1
Is the next sector part
of the upper airspace?
[no]
[yes]
Approaching
border of
Sector l kp
and
Sector l kp+1
Approaching
border of
Sector l kp
p = l(k)
and
Sector u kp
p = 1
p = 1, …, l(k) − 1
Contact planner
ACC Sector l kp+1
Contact planner
ACC Sector u kp
Handover to
ACC Sector u kp
Initial call
ACC Sector u kp
Handover to
ACC Sector u kp+1
Is the next sector part
of the lower airspace?
p = 1, …, u(k) − 1



ACC/upper airspace executives
Sectorukp $p\in[1,u(k)]$
ACC/lower airspace planners
Sectorlkp $p\in[1,l(k)]$
ACC/lower airspace executives
Sectorlkp $p\in[1,l(k)]$
Initial call ACC Sector$^{u}k_{p}$
Handover to
ACC Sector$^{u}\mathbf{k}_{p+1}$
Is the next sector part
of the lower airspace?
[no]
[yes]



Approaching border of $Sector^{u}{}_{k_p}$ and $Sector^{u}{}_{k_{p+1}}$
Approaching border of $Sector^{u}{}_{k_p}$ $p = u(k)$ and $Sector^{l}{}_{k_p}$ $p = 1$
Handover to ACC Sector$^{l}$$k_p$
Contact planner ACC Sector$^{u}$$k_{p+1}$
Contact planner ACC Sector$^{u}$$k_{p+1}$
Contact planner ACC Sector$^{l}$$k_p$
Initial call ACC Sector$^{l}$$k_p$
Handover to ACC Sector$^{l}$$k_{p+1}$
Is the next sector part of the TMA$_j$?
[no]
[yes]
$p = 1, \dots, l(k) - 1$
Approaching border of $Sector^{l}{}_{k_p}$ and $Sector^{l}{}_{k_{p+1}}$
Approaching border of $Sector^{l}{}_{k_p}$ $p = l(k)$ and $TMA_{j,k_p}$ $p = 1$
Handover to ACC TMA$_j$$k_p$ ARR



Contact planner ACC Sector k_p
Handover to ACC Sector k_p
Initial call ACC Sector k_p
Handover to ACC Sector k_p+1
Is the next sector part of the TMA_j?
[no]
[yes]
Is the next sector part of the TMA_j?
[no]
[yes]
Contact planner ACC Sector k_p+1
Contact planner ACC Sector k_p+1
Contact planner ACC TMA_j ARR pickup
Handover to ACC TMA_j k_p ARR

### 4.3.6 Annex 2.6: Flow diagram of the TMAj process model

The following four pages show parts of the flow diagram related to the modelled TMAj process which encompasses arrival and descent operations following the enroute flight phase. These pages can be assembled in a 4-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): cockpit crew (light red background colour), ACC/TMAj ARR planners (light blue background colour), ACC/TMAj ARR executives (light blue background colour), ACC/TMAj ARR planners Sectorlkp (light blue background colour), ACC/TMAj ARR executives Sectorlkp (light blue background colour), Tower planner (light blue background colour) and Tower executive (light blue background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant.

Concave and convex polygons represent communication between participants with direction of communication.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Following flow merging points are also represented as a diamond.

This model is derived from [ICAO 2007] and was supplemented with operational know-how of airliner pilots and air traffic controllers.

**Following pages:**

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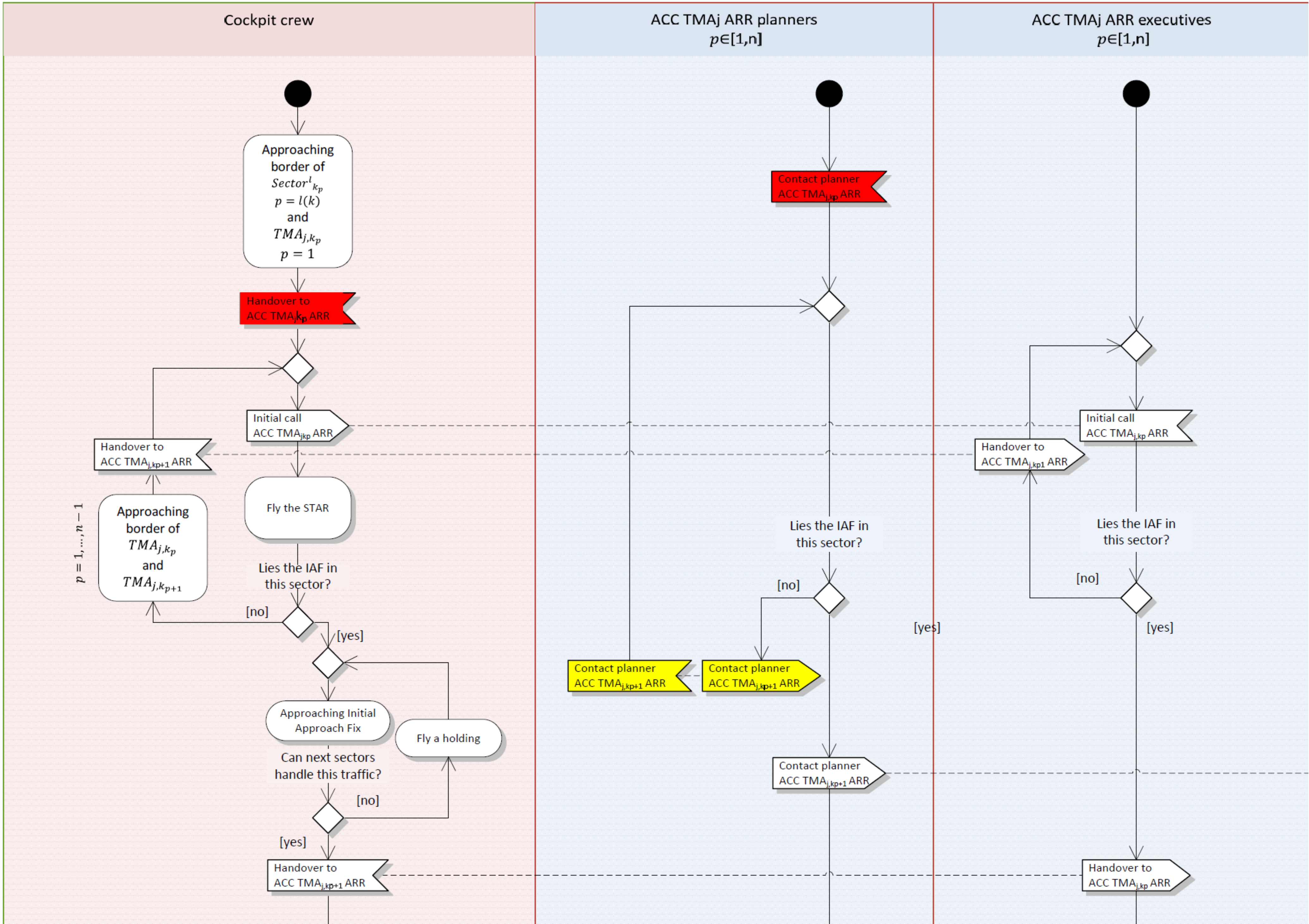
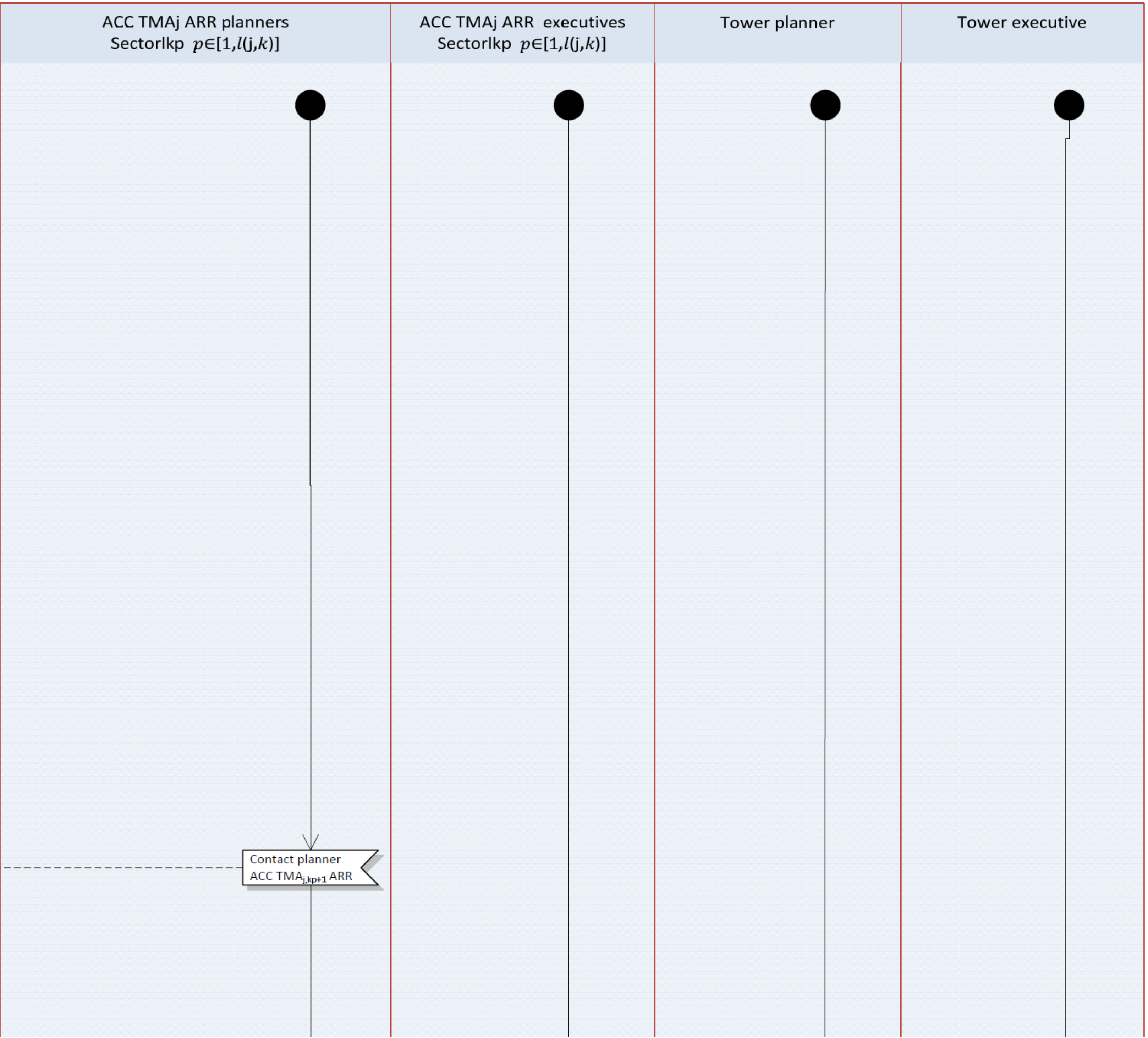
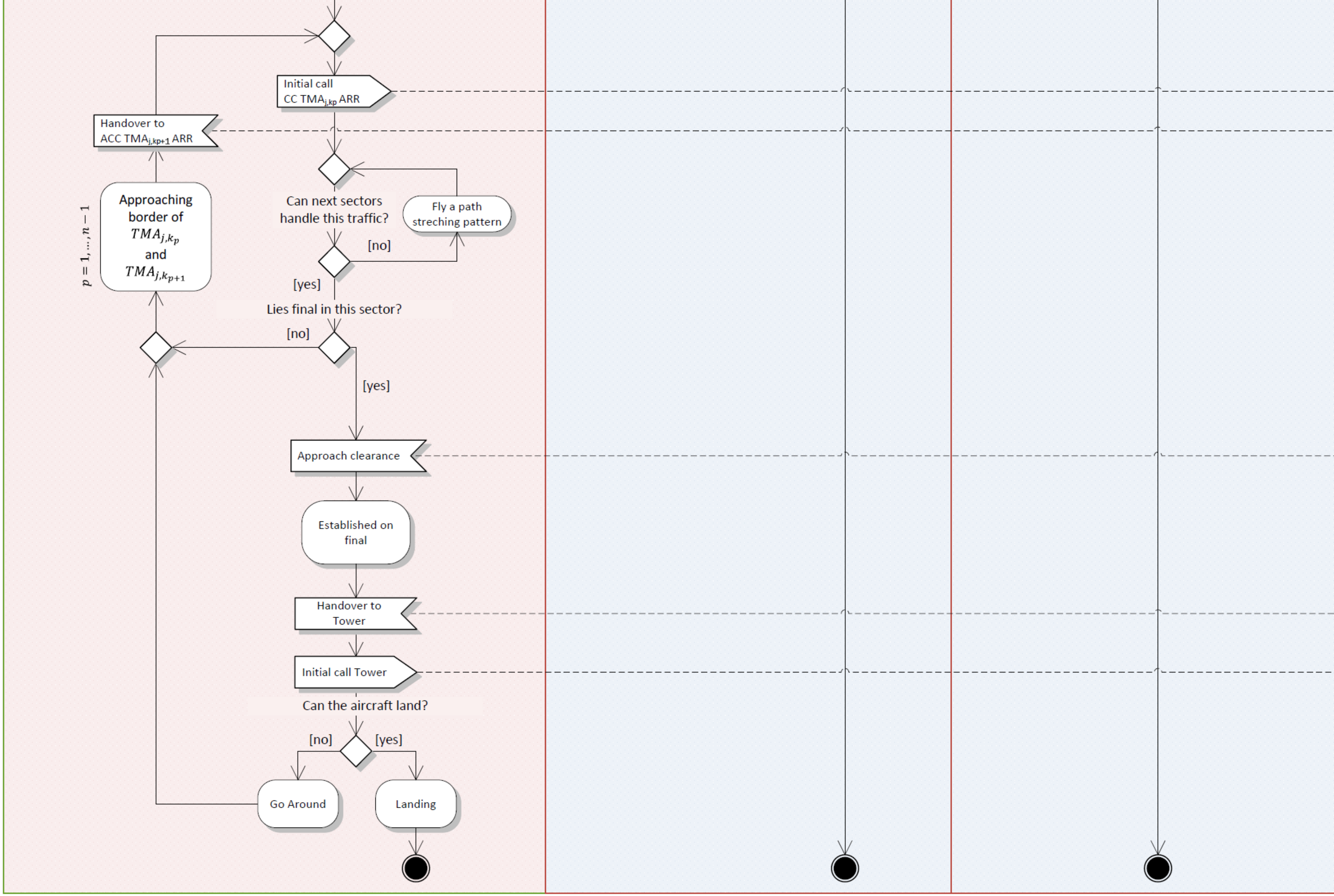
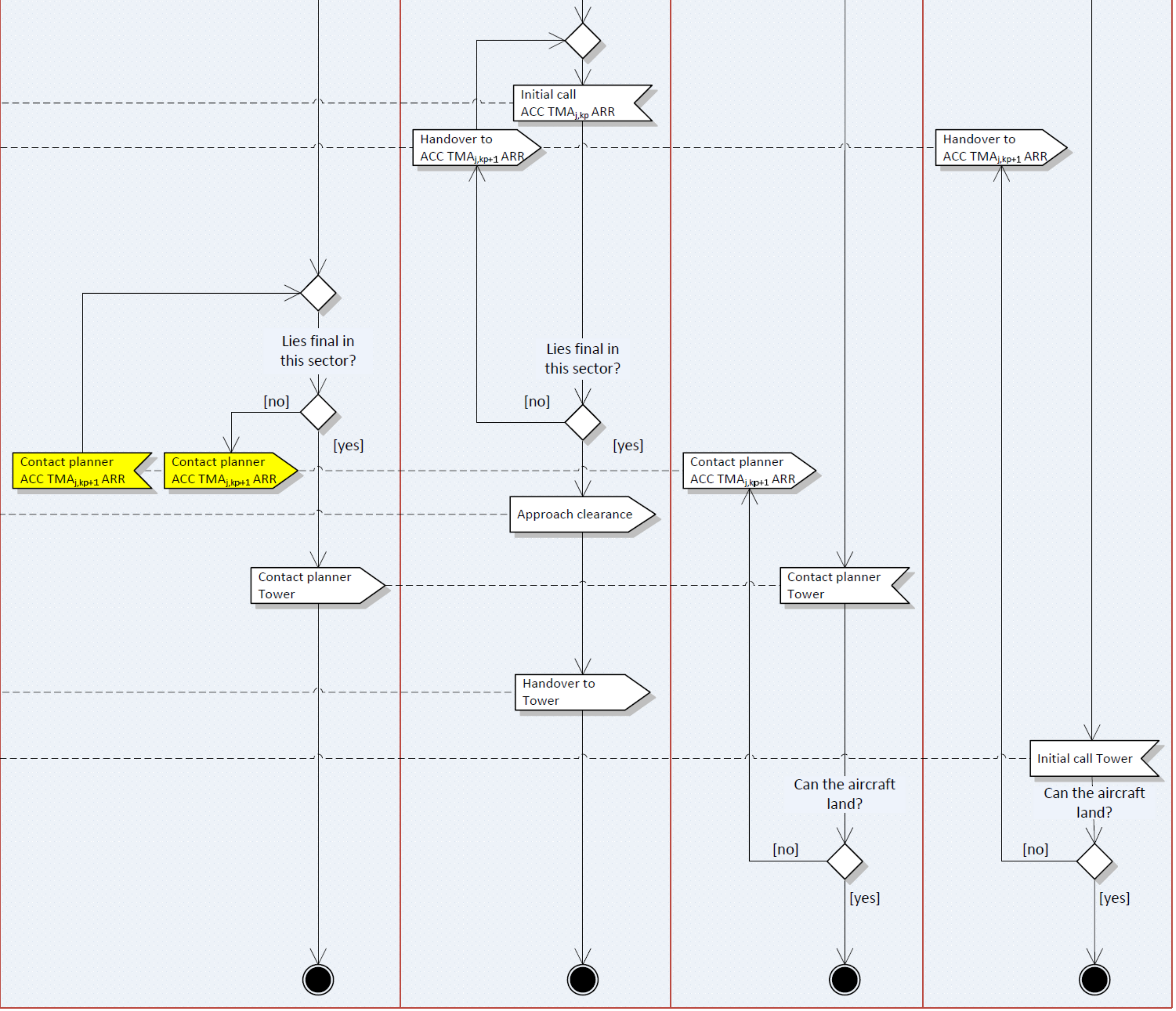

Cockpit crew
ACC TMAj ARR planners
p∈[1,n]
ACC TMAj ARR executives
p∈[1,n]
Approaching border of $Sector^{l}_{k_p}$ $p = l(k)$ and $TMA_{j,k_p}$ $p = 1$
Handover to ACC TMAjkp ARR
Initial call ACC TMAjkp ARR
Handover to ACC TMAj,kp+1 ARR
Fly the STAR
Approaching border of $TMA_{j,k_p}$ and $TMA_{j,k_{p+1}}$
$p = 1, \dots, n-1$
Lies the IAF in this sector?
[no]
[yes]
Approaching Initial Approach Fix
Fly a holding
Can next sectors handle this traffic?
[no]
[yes]
Handover to ACC TMAj,kp+1 ARR
Contact planner ACC TMAj,kp ARR
Lies the IAF in this sector?
[no]
[yes]
Contact planner ACC TMAj,kp+1 ARR
Contact planner ACC TMAj,kp+1 ARR
Contact planner ACC TMAj,kp+1 ARR
Initial call ACC TMAj,kp ARR
Handover to ACC TMAj,kp1 ARR
Lies the IAF in this sector?
[no]
[yes]
Handover to ACC TMAj,kp ARR


ACC TMAj ARR planners
Sectorlkp $p \in [1, l(j,k)]$
ACC TMAj ARR executives
Sectorlkp $p \in [1, l(j,k)]$
Tower planner
Tower executive
Contact planner
ACC $TMA_{j,kp+1}$ ARR



Initial call
CC $TMA_{j,kp}$ ARR
Handover to
ACC $TMA_{j,kp+1}$ ARR
Can next sectors handle this traffic?
Fly a path streching pattern
[no]
[yes]
Approaching border of $TMA_{j,k_p}$ and $TMA_{j,k_{p+1}}$
$p = 1, \ldots, n-1$
Lies final in this sector?
[no]
[yes]
Approach clearance
Established on final
Handover to Tower
Initial call Tower
Can the aircraft land?
[no]
[yes]
Go Around
Landing



Initial call ACC TMA$_{j,kp}$ ARR
Handover to ACC TMA$_{j,kp+1}$ ARR
Handover to ACC TMA$_{j,kp+1}$ ARR
Lies final in this sector?
Lies final in this sector?
[no]
[no]
[yes]
[yes]
Contact planner ACC TMA$_{j,kp+1}$ ARR
Contact planner ACC TMA$_{j,kp+1}$ ARR
Contact planner ACC TMA$_{j,kp+1}$ ARR
Approach clearance
Contact planner Tower
Contact planner Tower
Handover to Tower
Initial call Tower
Can the aircraft land?
Can the aircraft land?
[no]
[no]
[yes]
[yes]

### 4.3.7 Annex 2.7: Flow diagram of the Land/Taxi process model

The following figure shows the flow diagram related to the modelled Land/taxi process which follows the approach flight phase.

This diagram is divided into columns, each representing the involved participants / systems (left to right): cockpit crew (light red background colour) and ground controller (light blue background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant.

Concave and convex polygons represent communication between participants with direction of communication.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

This model is derived from [Ashford 2012], [EUROCONTROL L 2014] and [ICAO 2007] and was supplemented with operational know-how of ground handling personnel, airliner pilots and air traffic controllers.

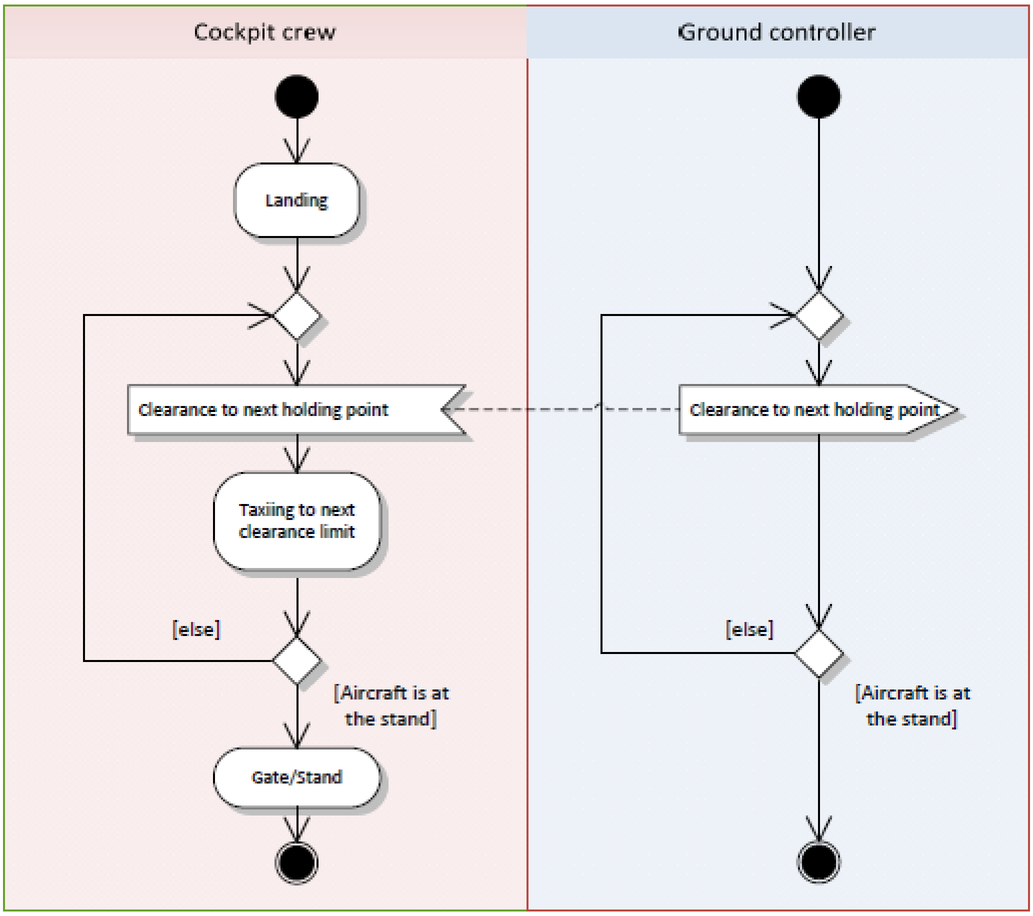



Figure 37. Flow diagram of the land/taxi process model

### 4.3.8 Annex 2.8: Flow diagram of the pushback process model

The following two pages show parts of the flow diagram related to the modelled TMAj process which encompasses arrival and descent operations following the enroute flight phase. These pages can be assembled in a 2-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): OPS controller (brown background colour), Equipment operator (brown background colour), Ramp Agent (brown background colour), cabin crew (light red background colour), cockpit crew (light red background colour), TWR/Delivery controller (light blue background colour), Ground controller (light green background colour), Airport operator (light green background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this participant.

Concave and convex polygons represent communication between participants with direction of communication.

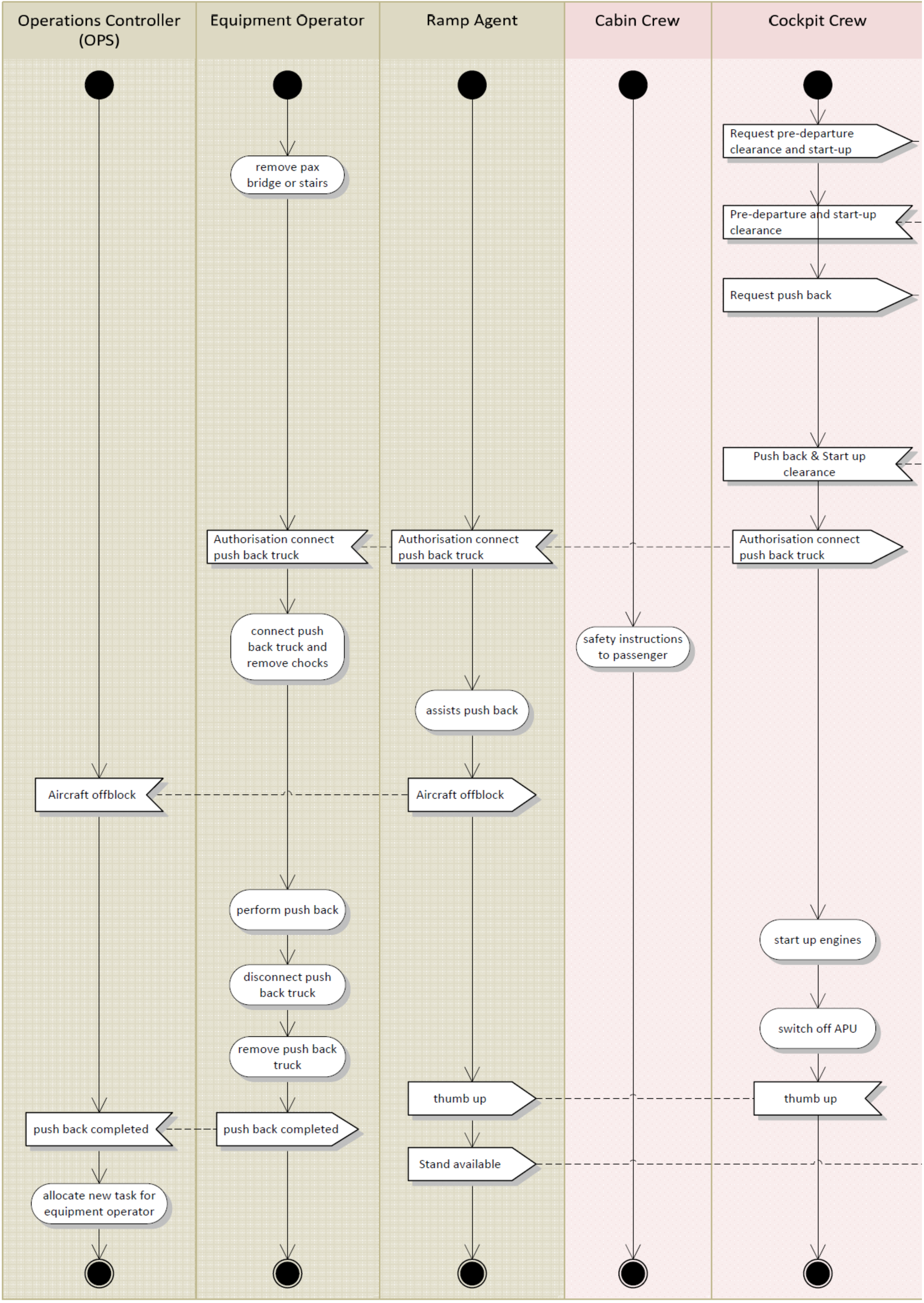
Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

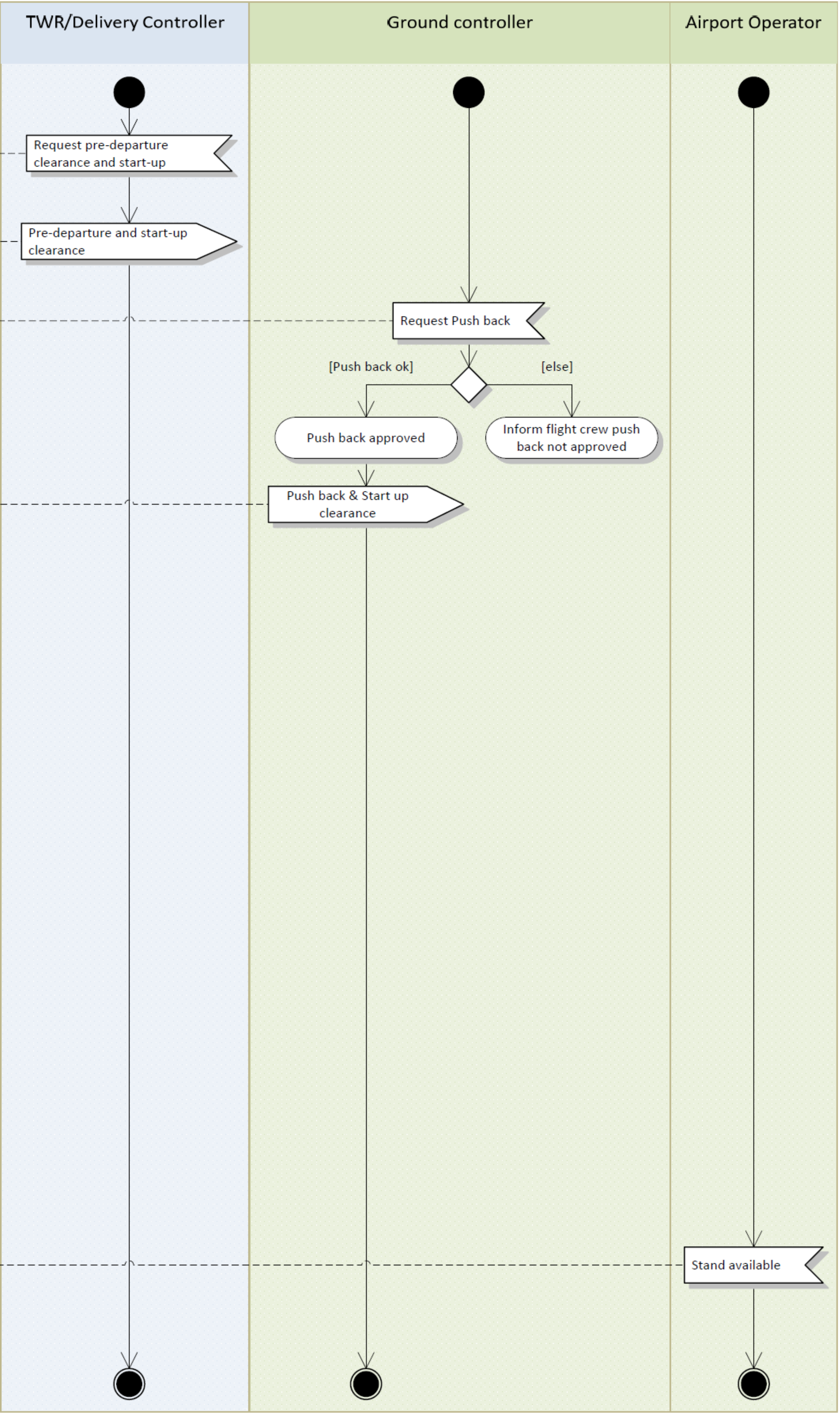
This model is derived from [Ashford 2012] and was supplemented with operational know-how of ground handling personnel, airliner pilots and air traffic controllers.

**Following pages:**

**Figure 38. Flow diagram of the pushback process model (1/2), left part**

**Figure 39. Flow diagram of the pushback process model (2/2), right part**


Operations Controller (OPS)
Equipment Operator
Ramp Agent
Cabin Crew
Cockpit Crew
Request pre-departure clearance and start-up
remove pax bridge or stairs
Pre-departure and start-up clearance
Request push back
Push back & Start up clearance
Authorisation connect push back truck
Authorisation connect push back truck
Authorisation connect push back truck
connect push back truck and remove chocks
safety instructions to passenger
assists push back
Aircraft offblock
Aircraft offblock
perform push back
start up engines
disconnect push back truck
switch off APU
remove push back truck
thumb up
thumb up
push back completed
push back completed
Stand available
allocate new task for equipment operator


TWR/Delivery Controller
Ground controller
Airport Operator
Request pre-departure clearance and start-up
Pre-departure and start-up clearance
Request Push back
[Push back ok]
[else]
Push back approved
Inform flight crew push back not approved
Push back & Start up clearance
Stand available

### 4.3.9 Annex 2.9: Flow diagram of the turn-around A-CDM process model

The following six pages show parts of the flow diagram related to the turn-around A-CDM process model. These pages can be assembled in a multiple-page-view.

This diagram is divided into columns, each representing the involved participants / systems (left to right): A-CDM database (brown background colour), ATC (light blue background colour), CFMU (dark blue background colour), aircraft operator (light red background colour) and ground handler (brown background colour). The process flow starts at the top of the diagram and ends at the bottom.

Each block with rounded edges represents a sub-process executed by this person. Sub-processes with underlined titles have already been modelled.

Concave and convex polygons represent communication between participants with direction of communication.

Black bars represent points, where the process flow splits up into several parallel sub-flows. Following flow merging points are also represented as a black bar.

Diamonds represent a conditional relation, which is programmed as an if-then-else-command. The condition, which must be true to continue on the specific flow track is written down in a label in brackets. Flow tracks that are labelled with the word [else] would be active in case of the condition is false. Following flow merging points are also represented as a diamond.

This model is mainly derived from [EUROCONTROL 2011], [EUROCONTROL 2012.2], [EUROCONTROL 2012.3], [EUROCONTROL 2012], [EUROCONTROL 2013], [EUROCONTROL 2014], [HAHN 2011], [Koolen 2013.2] and [Koolen 2013].

**Following pages:**

**Figure 40. Flow diagram of the turn-around A-CDM model (1/6), upper left part**

**Figure 41. Flow diagram of the turn-around A-CDM model (2/6), upper right part**

**Figure 42. Flow diagram of the turn-around A-CDM model (3/6), mid left part**

**Figure 43. Flow diagram of the turn-around A-CDM model (4/6), mid right part**

**Figure 44. Flow diagram of the turn-around A-CDM model (5/6), lower left part**

**Figure 45. Flow diagram of the turn-around A-CDM model (6/6), lower right part**

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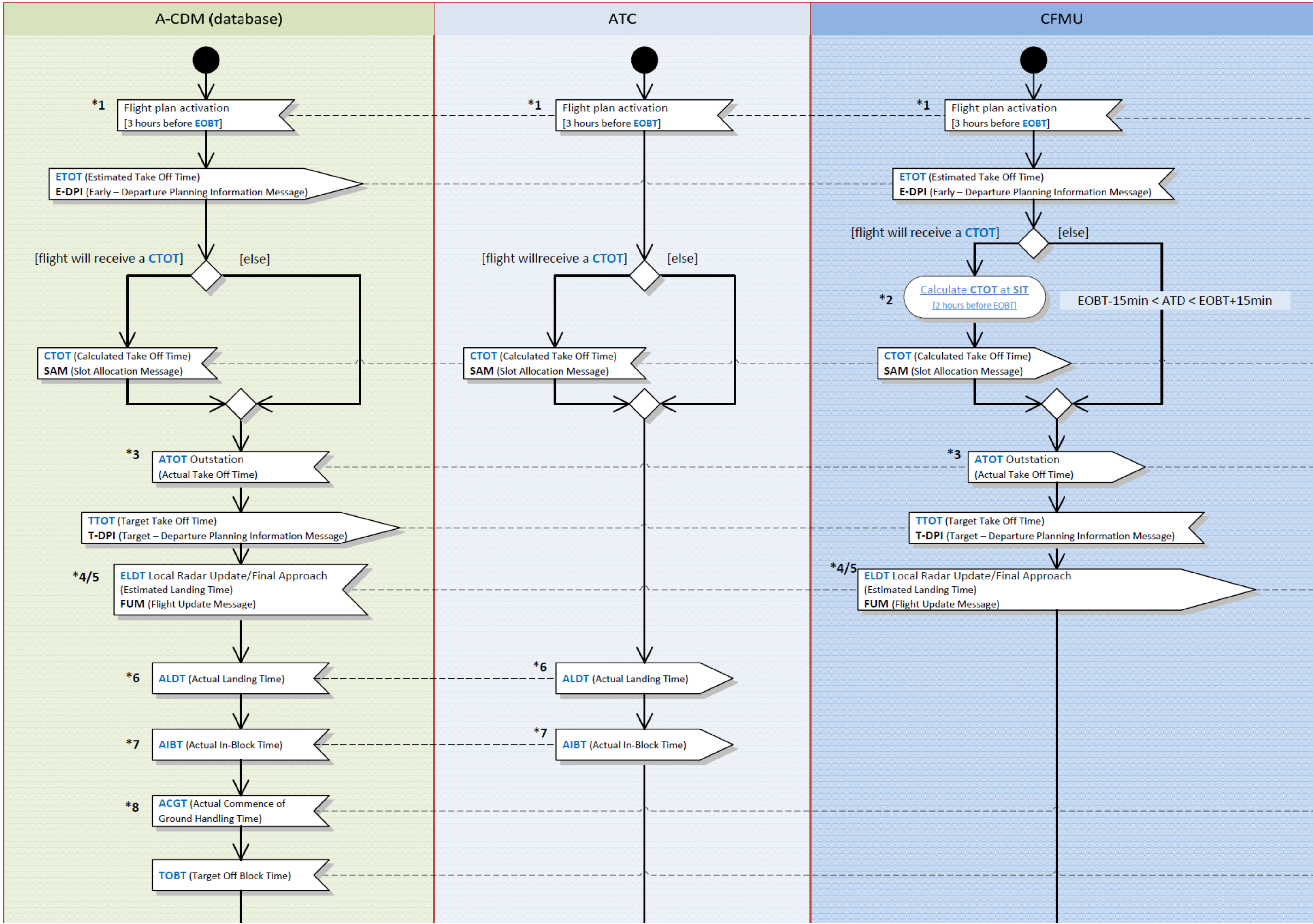
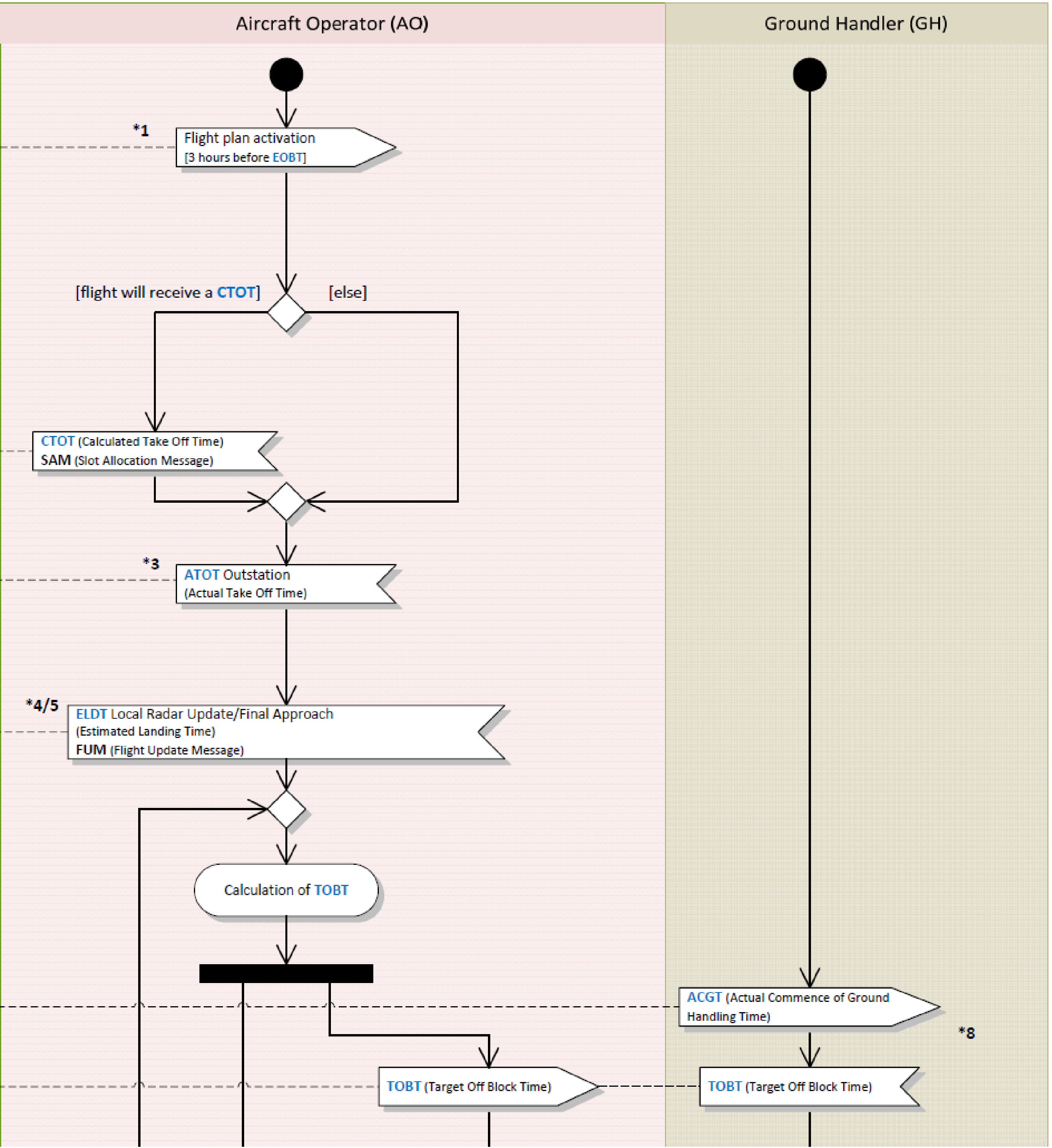
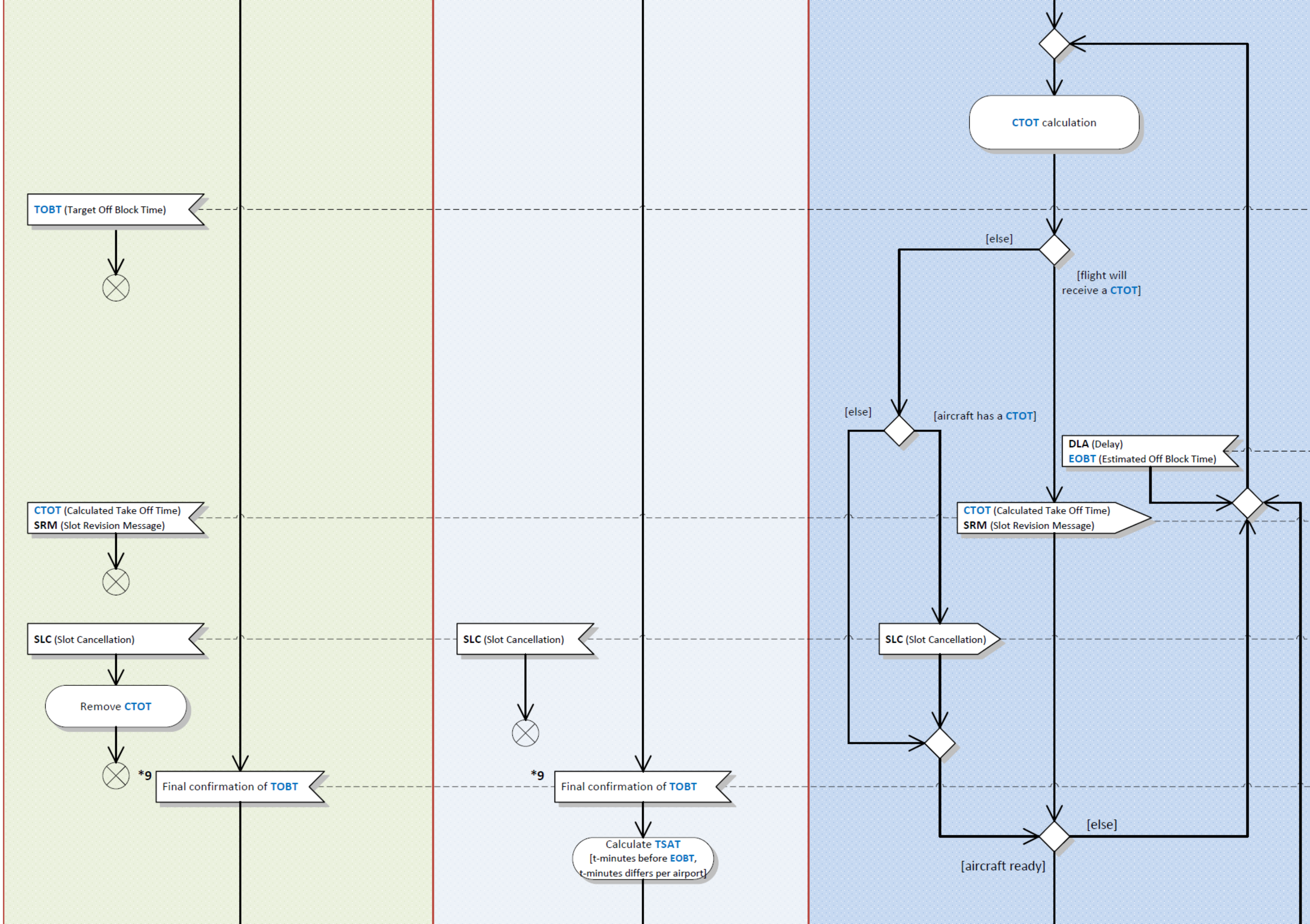


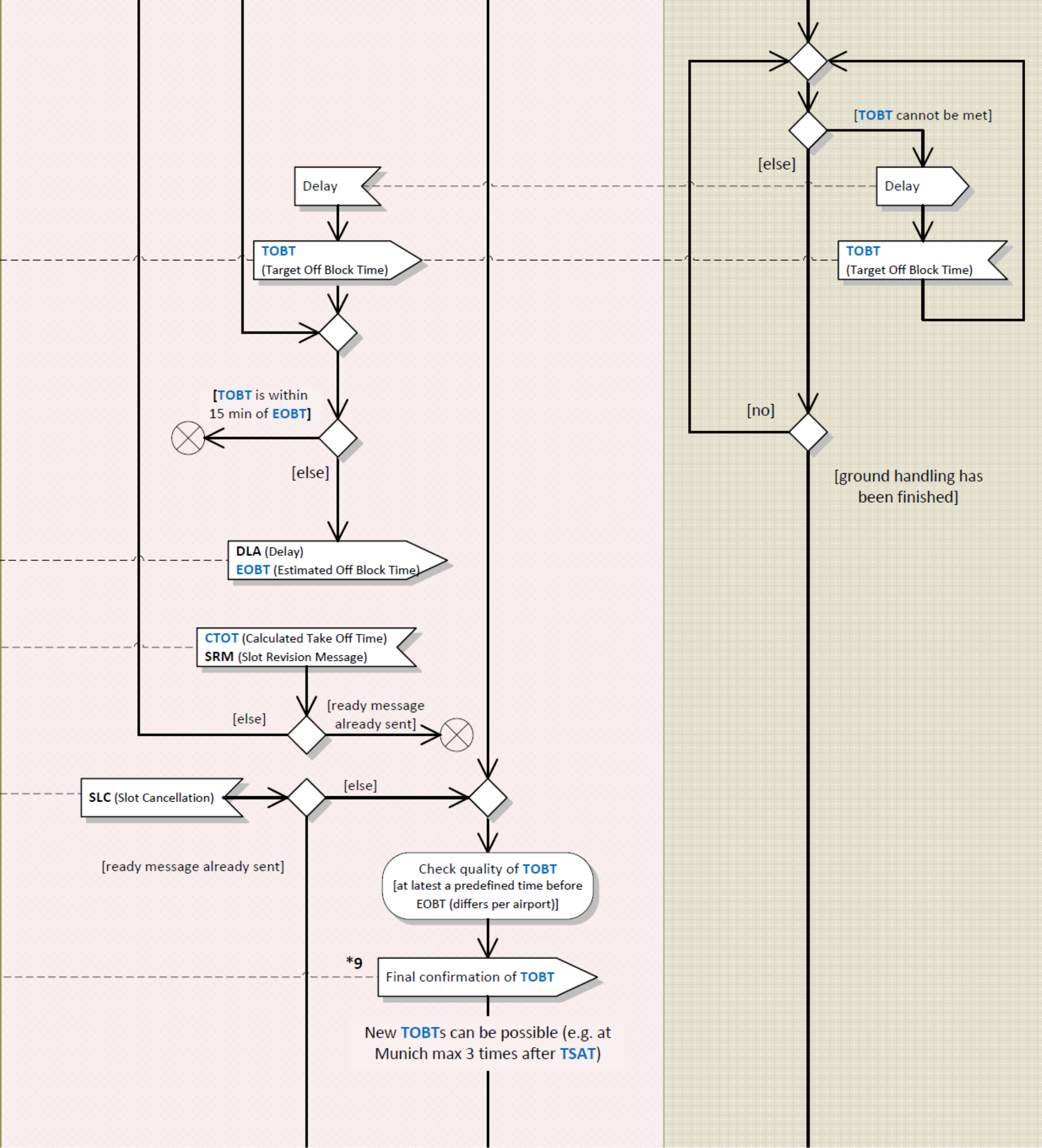
A-CDM (database)
ATC
CFMU
*1
Flight plan activation
[3 hours before EOBT]
ETOT (Estimated Take Off Time)
E-DPI (Early – Departure Planning Information Message)
[flight will receive a CTOT]
[else]
[flight willreceive a CTOT]
*2
Calculate CTOT at SIT
[2 hours before EOBT]
EOBT-15min < ATD < EOBT+15min
CTOT (Calculated Take Off Time)
SAM (Slot Allocation Message)
*3
ATOT Outstation
(Actual Take Off Time)
TTOT (Target Take Off Time)
T-DPI (Target – Departure Planning Information Message)
*4/5
ELDT Local Radar Update/Final Approach
(Estimated Landing Time)
FUM (Flight Update Message)
*6
ALDT (Actual Landing Time)
*7
AIBT (Actual In-Block Time)
*8
ACGT (Actual Commence of
Ground Handling Time)
TOBT (Target Off Block Time)



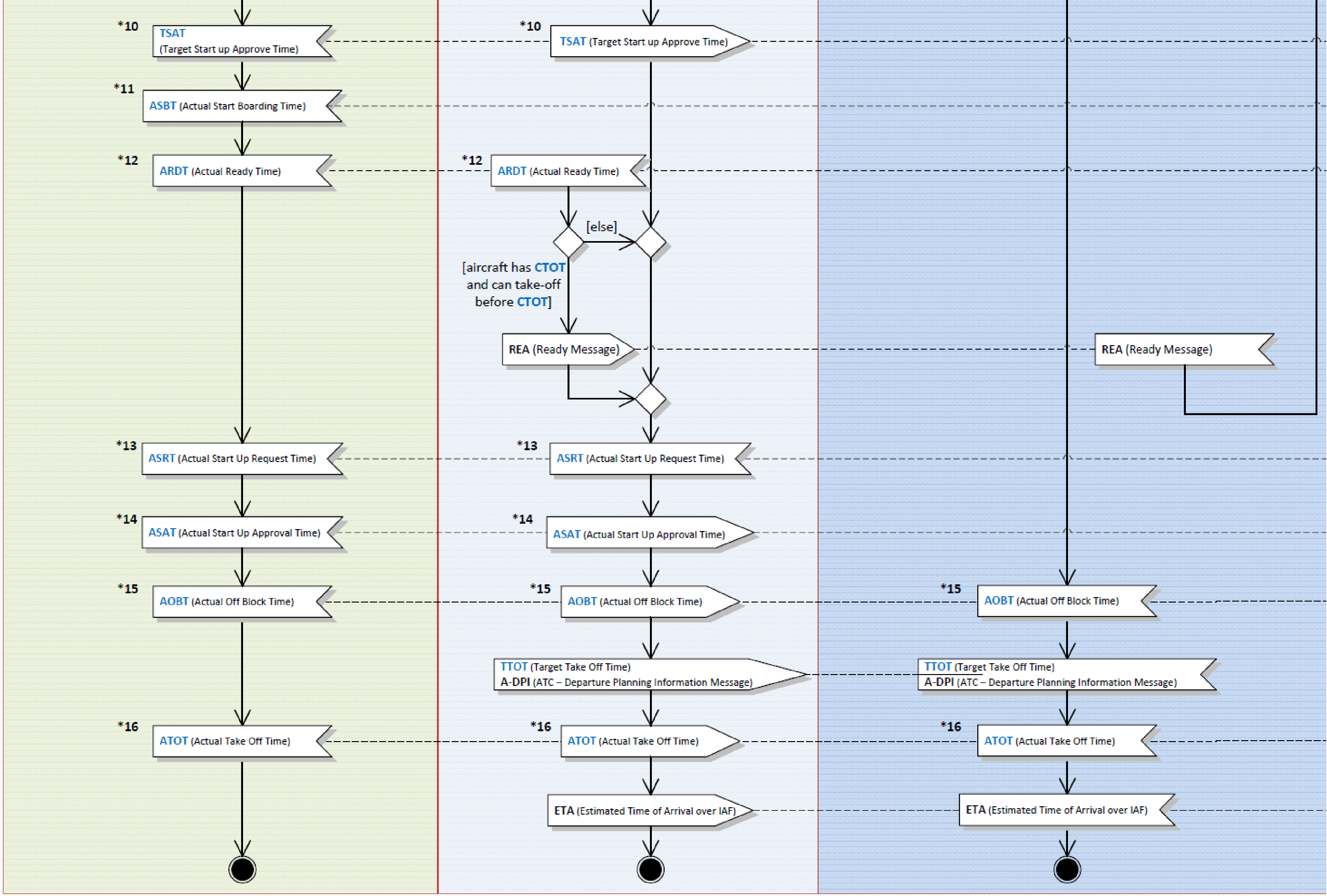
Aircraft Operator (AO)
Ground Handler (GH)
*1
Flight plan activation
[3 hours before EOBT]
[flight will receive a CTOT]
[else]
CTOT (Calculated Take Off Time)
SAM (Slot Allocation Message)
*3
ATOT Outstation
(Actual Take Off Time)
*4/5
ELDT Local Radar Update/Final Approach
(Estimated Landing Time)
FUM (Flight Update Message)
Calculation of TOBT
ACGT (Actual Commence of Ground Handling Time)
*8
TOBT (Target Off Block Time)
TOBT (Target Off Block Time)



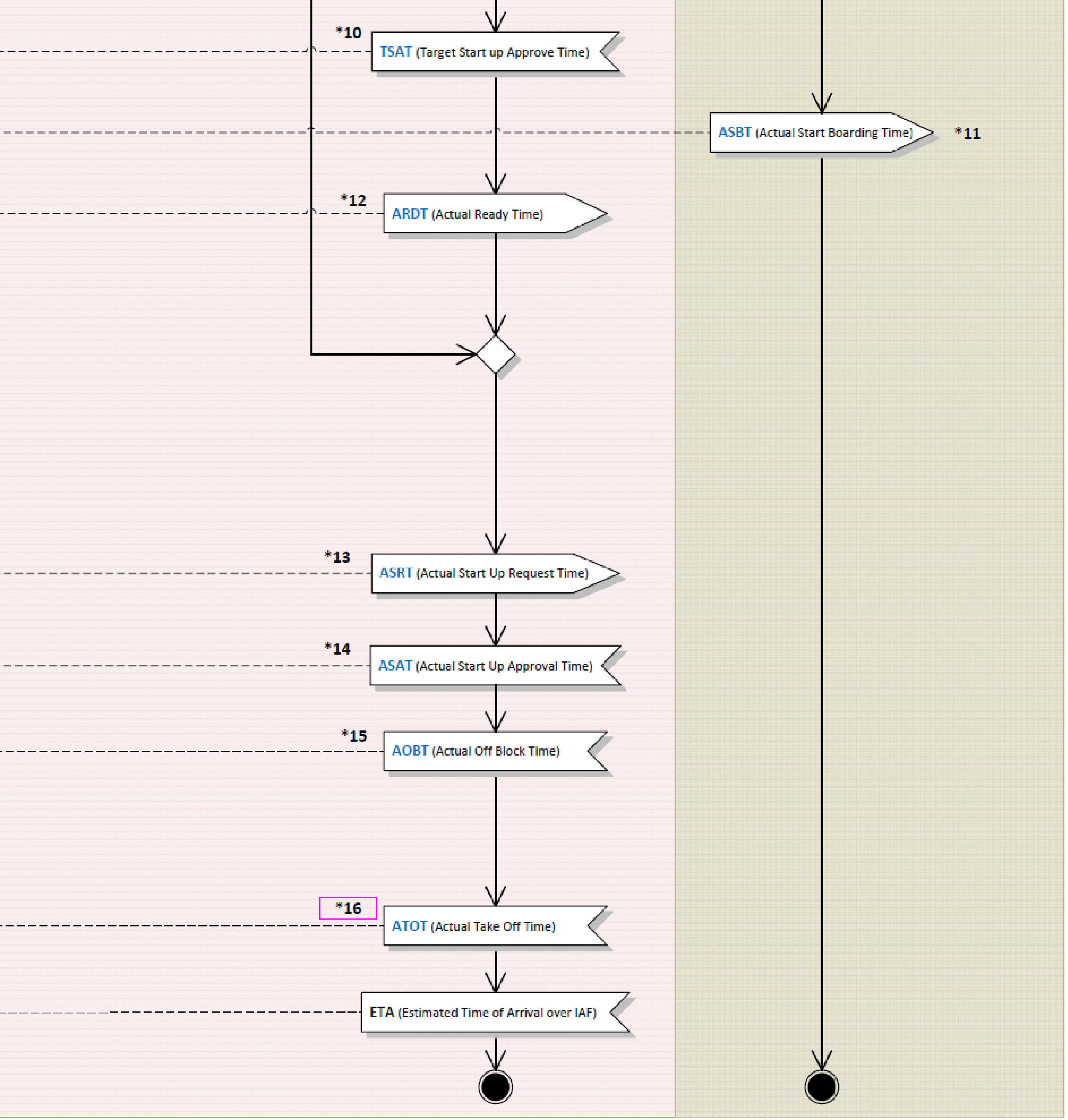
CTOT calculation
TOBT (Target Off Block Time)
[else]
[flight will receive a CTOT]
[else]
[aircraft has a CTOT]
DLA (Delay)
EOBT (Estimated Off Block Time)
CTOT (Calculated Take Off Time)
SRM (Slot Revision Message)
CTOT (Calculated Take Off Time)
SRM (Slot Revision Message)
SLC (Slot Cancellation)
SLC (Slot Cancellation)
SLC (Slot Cancellation)
Remove CTOT
*9
Final confirmation of TOBT
*9
Final confirmation of TOBT
[else]
Calculate TSAT
[t-minutes before EOBT, t-minutes differs per airport]
[aircraft ready]



[TOBT cannot be met]
[else]
Delay
Delay
TOBT
(Target Off Block Time)
TOBT
(Target Off Block Time)
[TOBT is within
15 min of EOBT]
[no]
[else]
[ground handling has
been finished]
DLA (Delay)
EOBT (Estimated Off Block Time)
CTOT (Calculated Take Off Time)
SRM (Slot Revision Message)
[ready message
already sent]
[else]
[else]
SLC (Slot Cancellation)
[ready message already sent]
Check quality of TOBT
[at latest a predefined time before
EOBT (differs per airport)]
*9
Final confirmation of TOBT
New TOBTs can be possible (e.g. at
Munich max 3 times after TSAT)



*10
TSAT (Target Start up Approve Time)
*10
TSAT (Target Start up Approve Time)
*11
ASBT (Actual Start Boarding Time)
*12
ARDT (Actual Ready Time)
*12
ARDT (Actual Ready Time)
[else]
[aircraft has CTOT and can take-off before CTOT]
REA (Ready Message)
REA (Ready Message)
*13
ASRT (Actual Start Up Request Time)
*13
ASRT (Actual Start Up Request Time)
*14
ASAT (Actual Start Up Approval Time)
*14
ASAT (Actual Start Up Approval Time)
*15
AOBT (Actual Off Block Time)
*15
AOBT (Actual Off Block Time)
*15
AOBT (Actual Off Block Time)
TTOT (Target Take Off Time)
A-DPI (ATC – Departure Planning Information Message)
TTOT (Target Take Off Time)
A-DPI (ATC – Departure Planning Information Message)
*16
ATOT (Actual Take Off Time)
*16
ATOT (Actual Take Off Time)
*16
ATOT (Actual Take Off Time)
ETA (Estimated Time of Arrival over IAF)
ETA (Estimated Time of Arrival over IAF)


*10
TSAT (Target Start up Approve Time)
ASBT (Actual Start Boarding Time)
*11
*12
ARDT (Actual Ready Time)
*13
ASRT (Actual Start Up Request Time)
*14
ASAT (Actual Start Up Approval Time)
*15
AOBT (Actual Off Block Time)
*16
ATOT (Actual Take Off Time)
ETA (Estimated Time of Arrival over IAF)

## 4.4 Annex 3: Case study

This chapter will present results generated by the simulation of the remote deicing process. Oslo Gardermoen (ICAO-code: ENGM) is being chosen as airport during the early times of March 2011. Weather data were obtained from METAR and processed to generate the holdover time HOT. Besides the weather conditions, the HOT depends on the used type of deicing fluid and the fluid concentration. In case a fixed fluid type and concentration is assumed, the HOT can serve as an indicator for demand of deicing. Figure 46 to Figure 48 show the distribution of the holdover times for days with different demand for deicing. The HOT itself varies due to different weather conditions. Lower values of the HOT pose a higher workload on the deicing operators since the possibility of a need for re-deicing before the start increases.

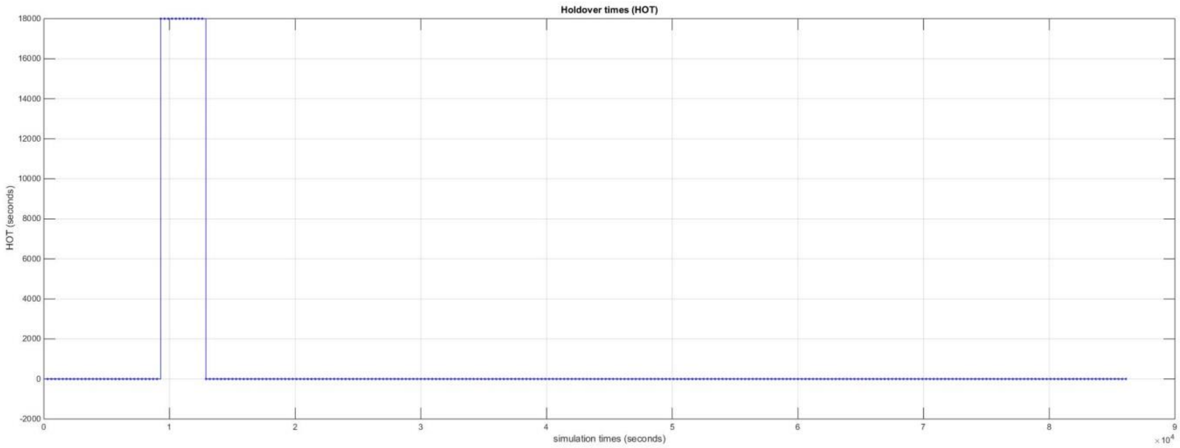



**Figure 46. Distribution of holdover times (HOT) for a day with low work load concerning deicing. Date: 05.03.2011**

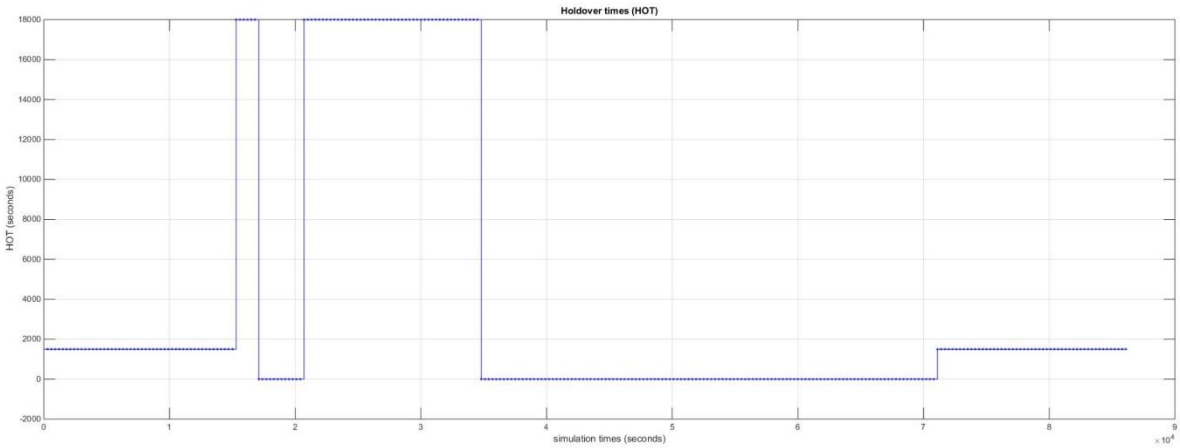



**Figure 47. Distribution of holdover times (HOT) for a day with moderate work load concerning deicing. Date: 01.03.2011**

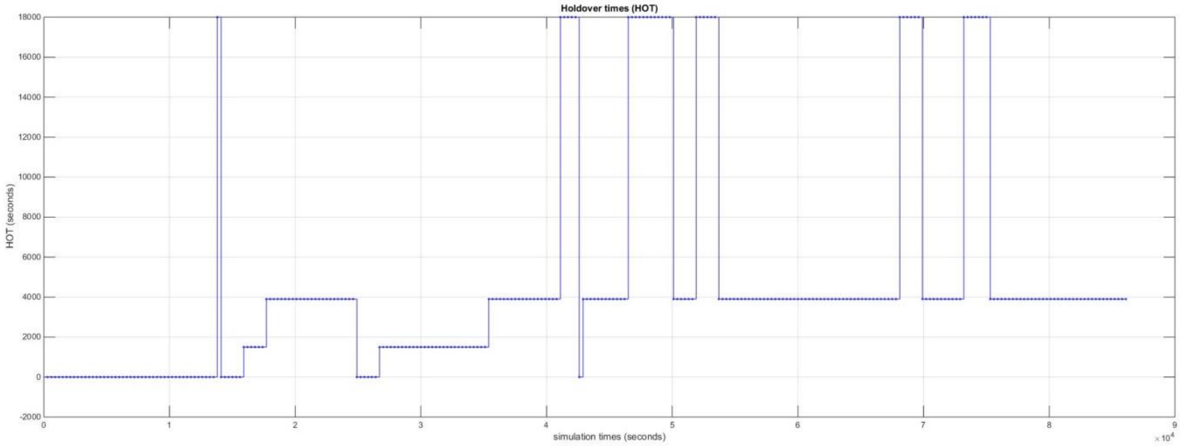



Figure 48. Distribution of holdover times (HOT) for a  day with high work load concerning deicing. Date: 03.03.2011

To investigate the deicing process with respect to generated delay due to limited resources, scheduled off block times were taken from the PRISME data set as input to simulate the demand of deicing. In this example resources are represented by de-icing pads. That is the taxi out process was omitted, as well as possibly interactions between operators concerning the slot allocation.  Since aircraft represent so called entities in the discrete event simulation, they are generated at the beginning of the model and numbered in ascending order. Figure 49 and Figure 50 are representing the entities i.e. the particular aircraft which do not need a deicing or are scheduled for deicing respectively.

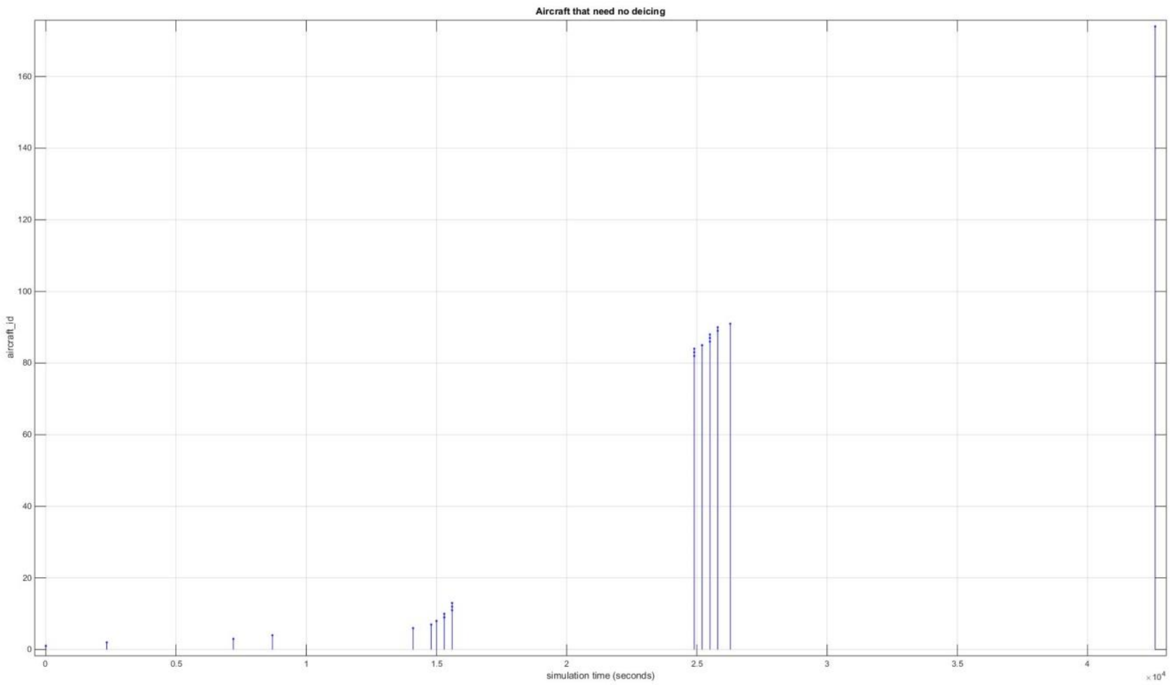



Figure 49. Aircraft that need no deicing. Oslo (ENGM), 03.03.2011

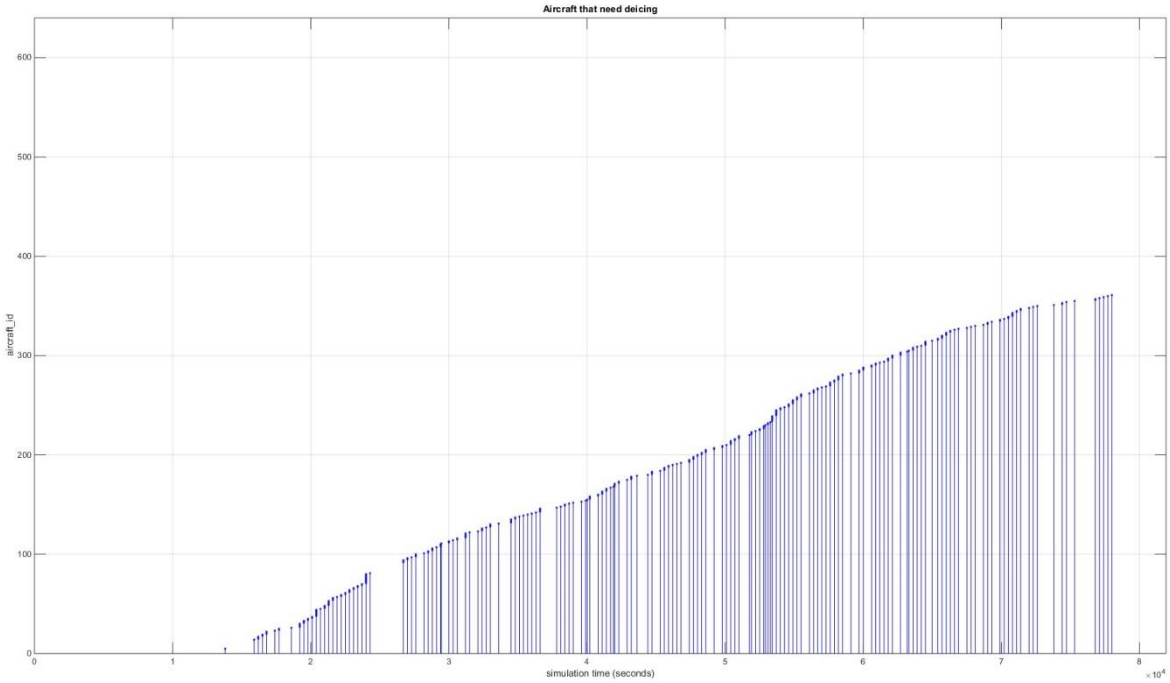



**Figure 50. Aircraft that need deicing. Oslo (ENGM), 03.03.2011, high workload**

The usage of resources, i.e. deicing pads is represented in Figure 51, whereas the resulting queue on the area before the pads is being shown in Figure 52.

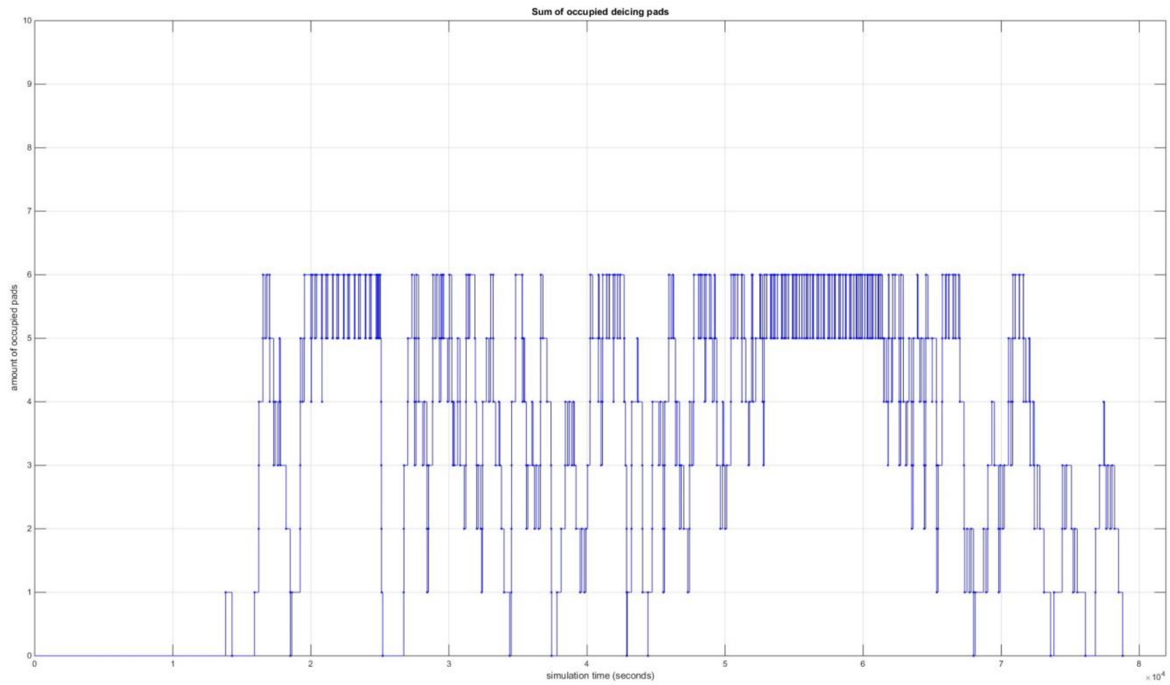



**Figure 51. Number of simultaneously used deicing pads. Oslo (ENGM), 03.03.2011, 6 pads active**

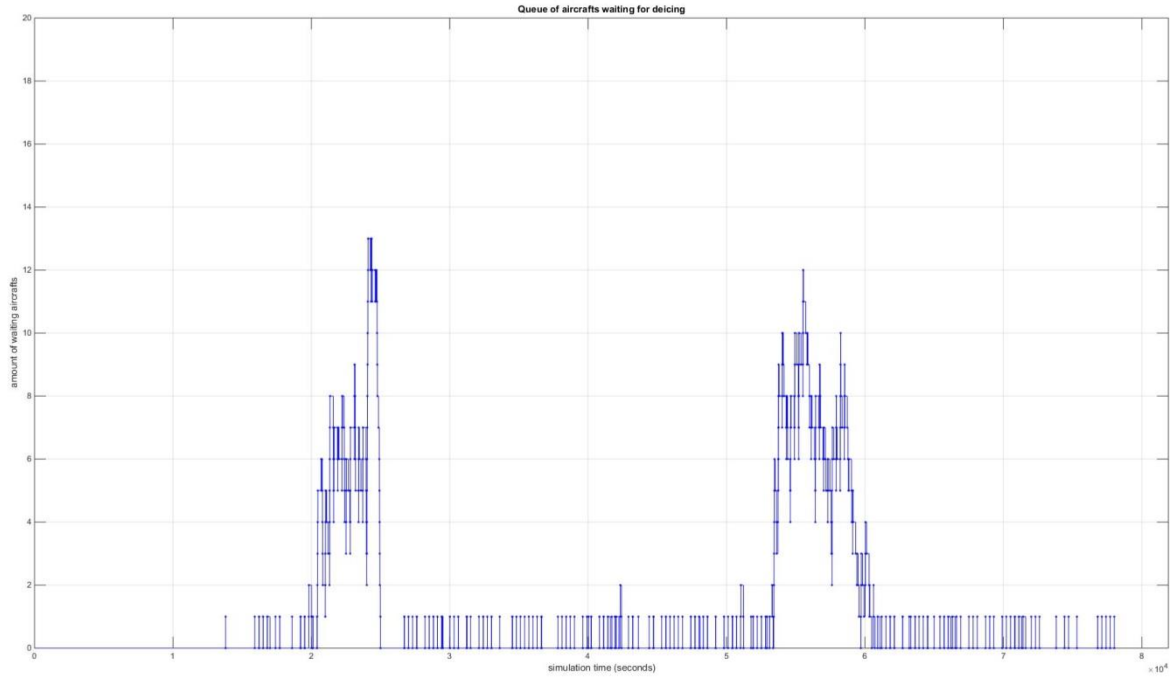



**Figure 52. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 6 pads active**

Figure 53 illustrates the delay of particular aircraft plotted over the time that is induced by the deicing process.

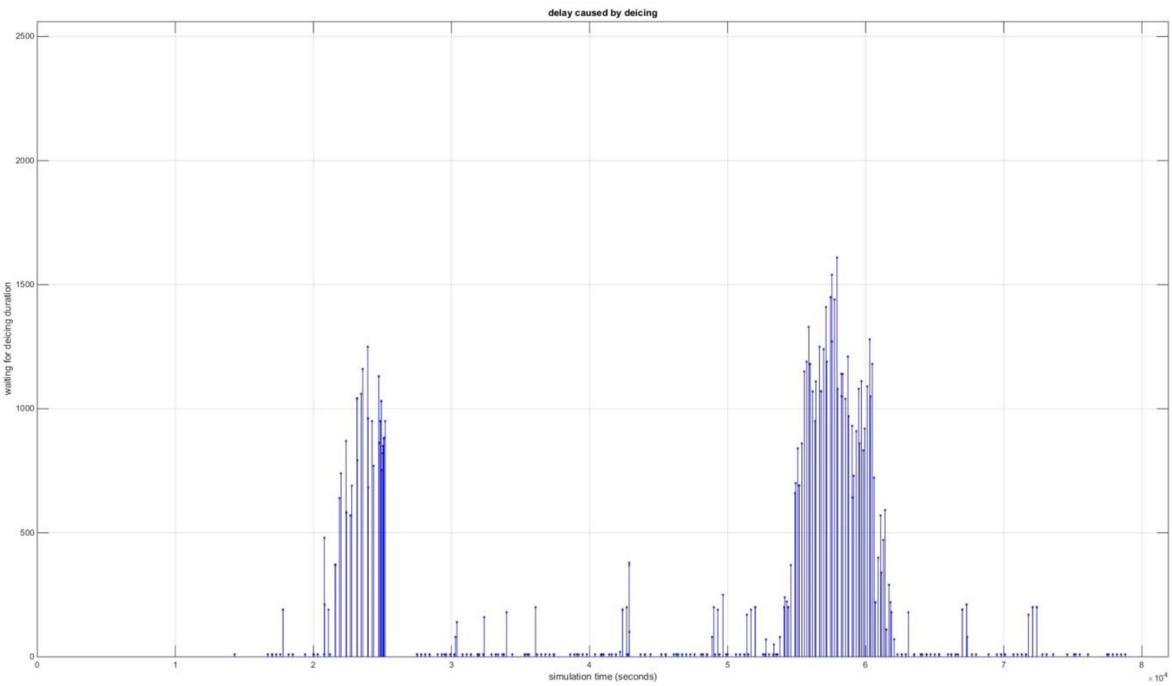



**Figure 53. Delay caused by deicing. Oslo (ENGM), 03.03.2011, 6 pads active**

The following figures show the demand for deicing, the number of used pads, the queue generated at the area before the deicing pads as well the generated delay for different days and available deicing pads. Exemplary it was chosen between 2, 4 and 6 deicing pads.

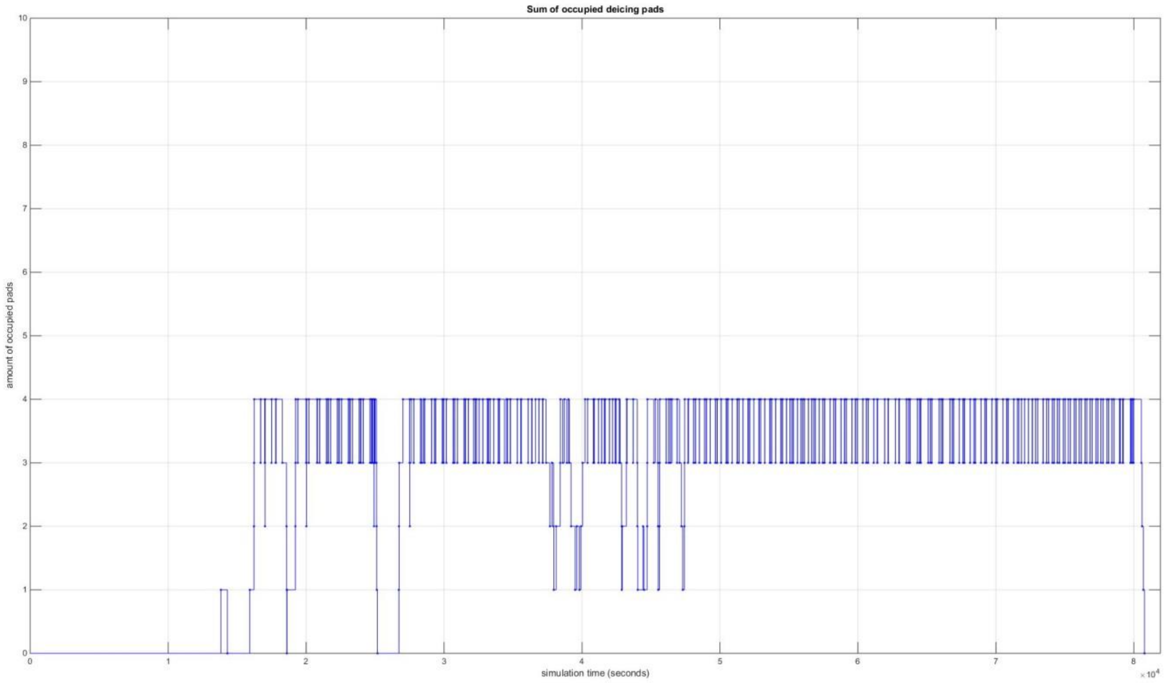



**Figure 54. Number of simultaneously used deicing pads. Oslo (ENGM), 03.03.2011, 4 pads active**

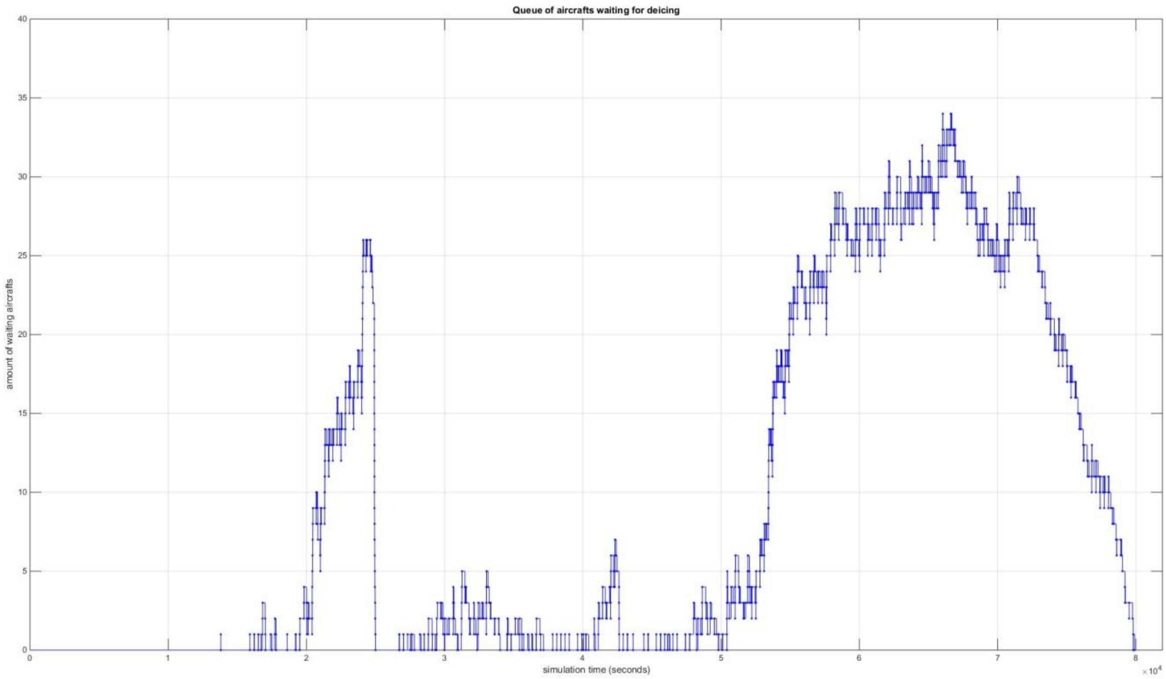



**Figure 55. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 4 pads active**

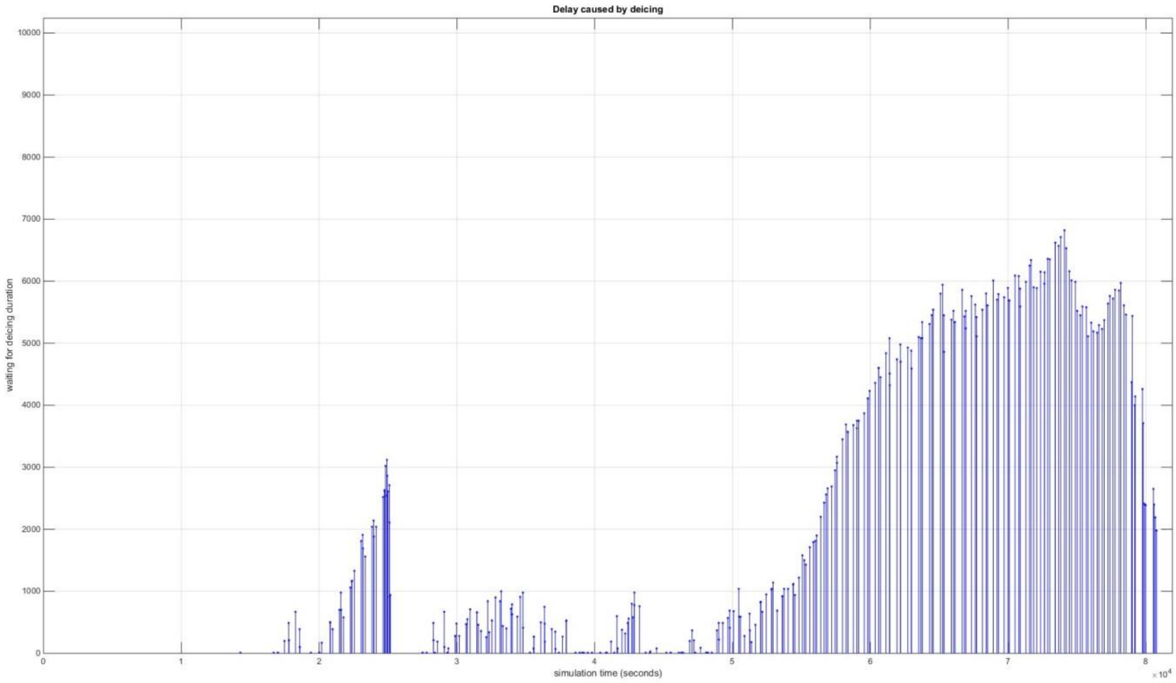



**Figure 56. Delay caused by deicing. Oslo (ENGM), 03.03.2011, 4 pads active**

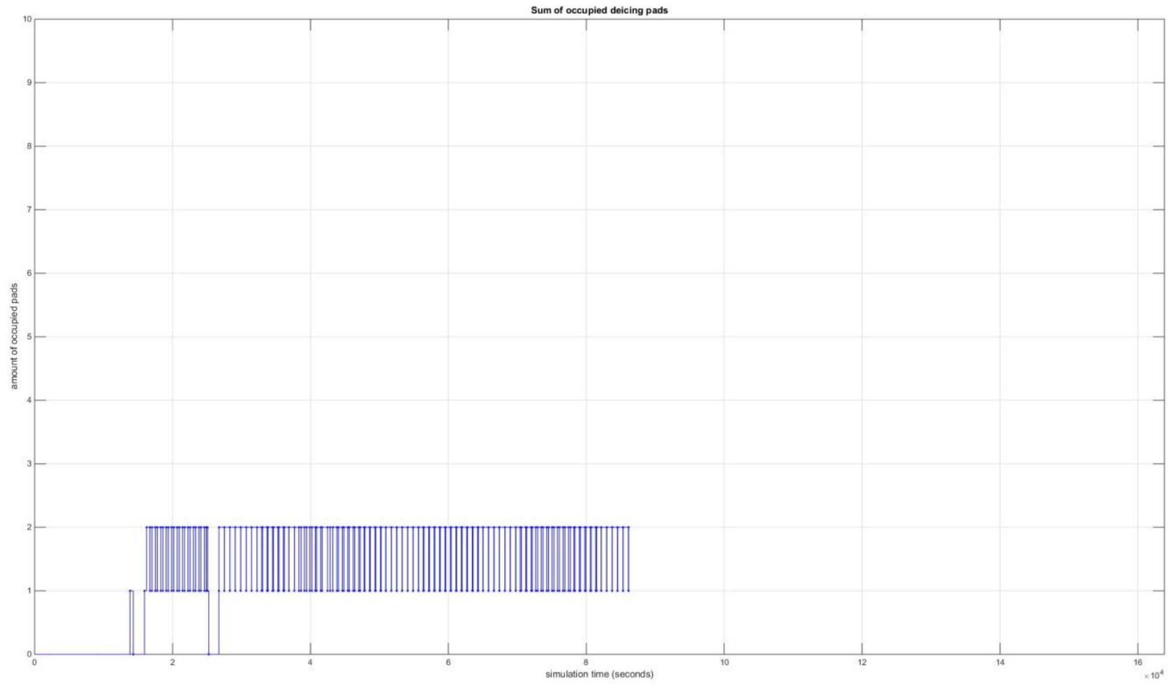



**Figure 57. Number of simultaneously used deicing pads. Oslo (ENGM), 03.03.2011, 2 pads active**

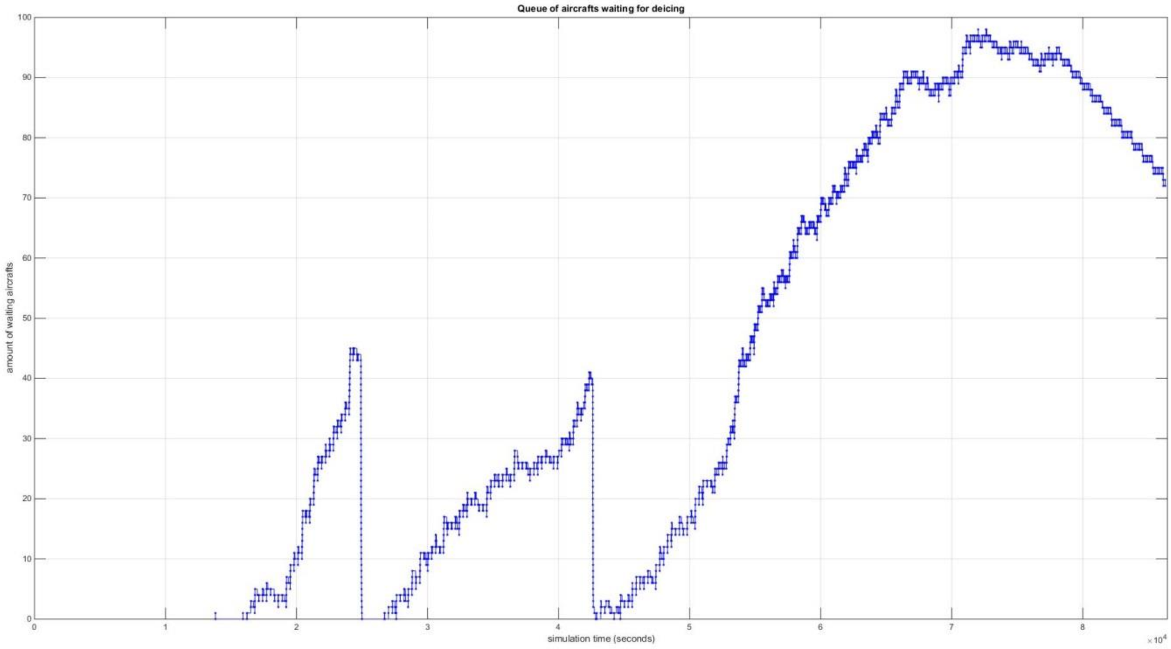



**Figure 58. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 2 pads active**

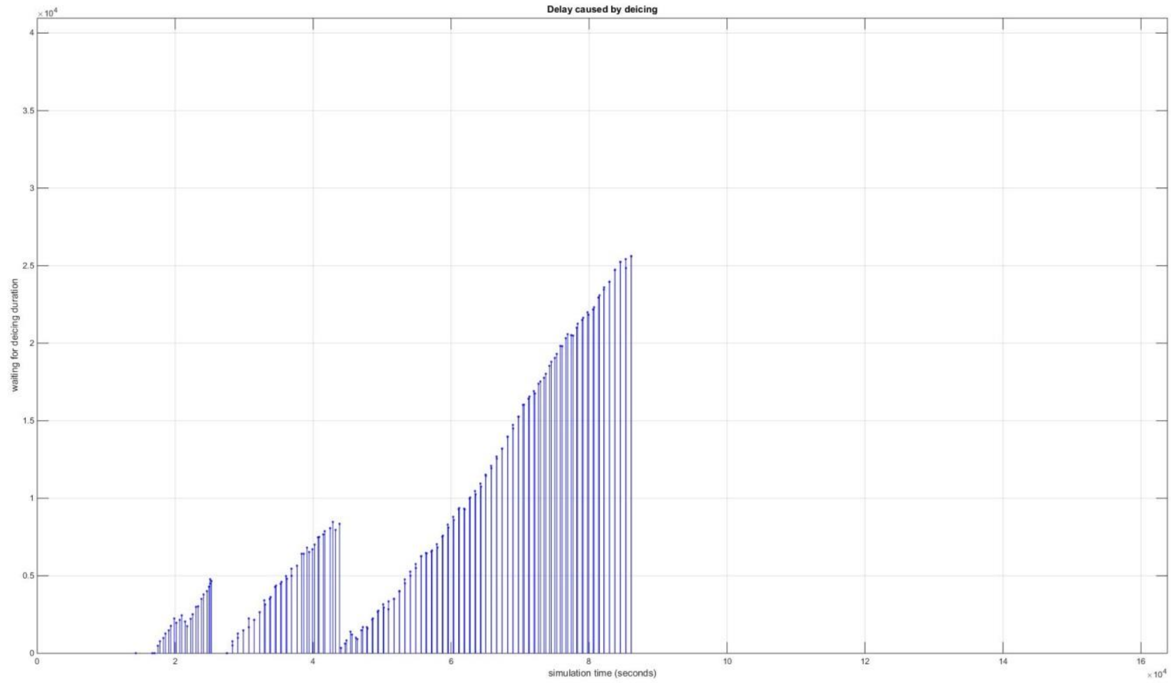



**Figure 59. Delay caused by deicing. Oslo (ENGM), 03.03.2011, 2 pads active**

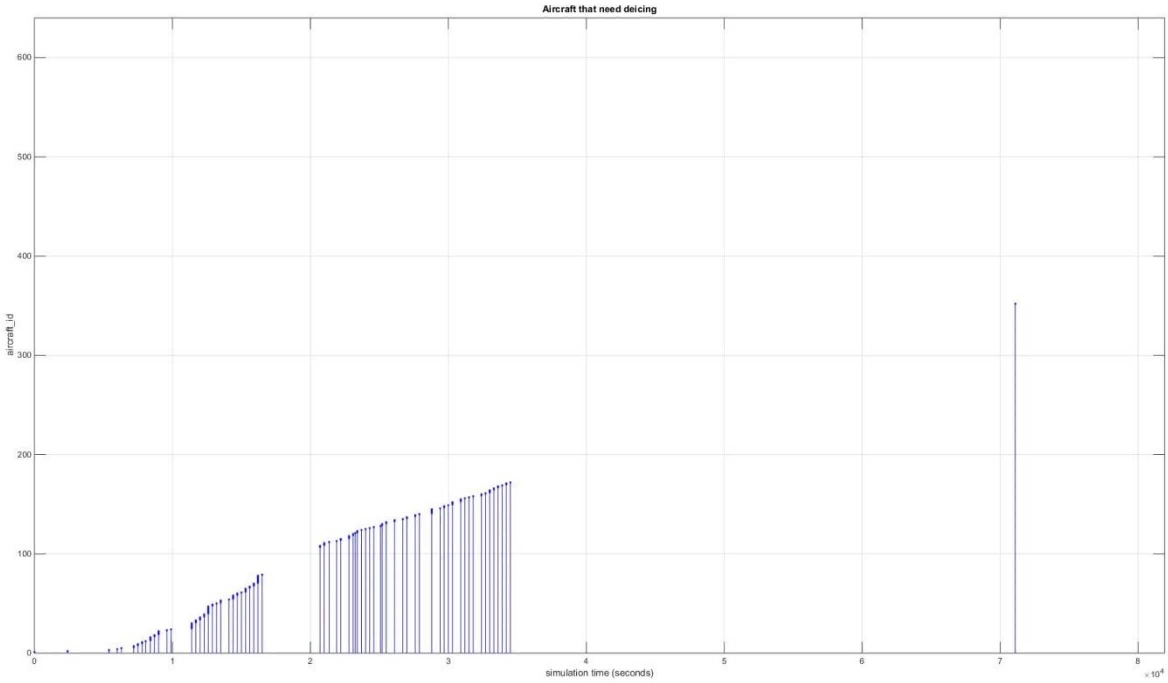



**Figure 60. Aircraft that need deicing. Oslo (ENGM), 01.03.2011, moderate workload**

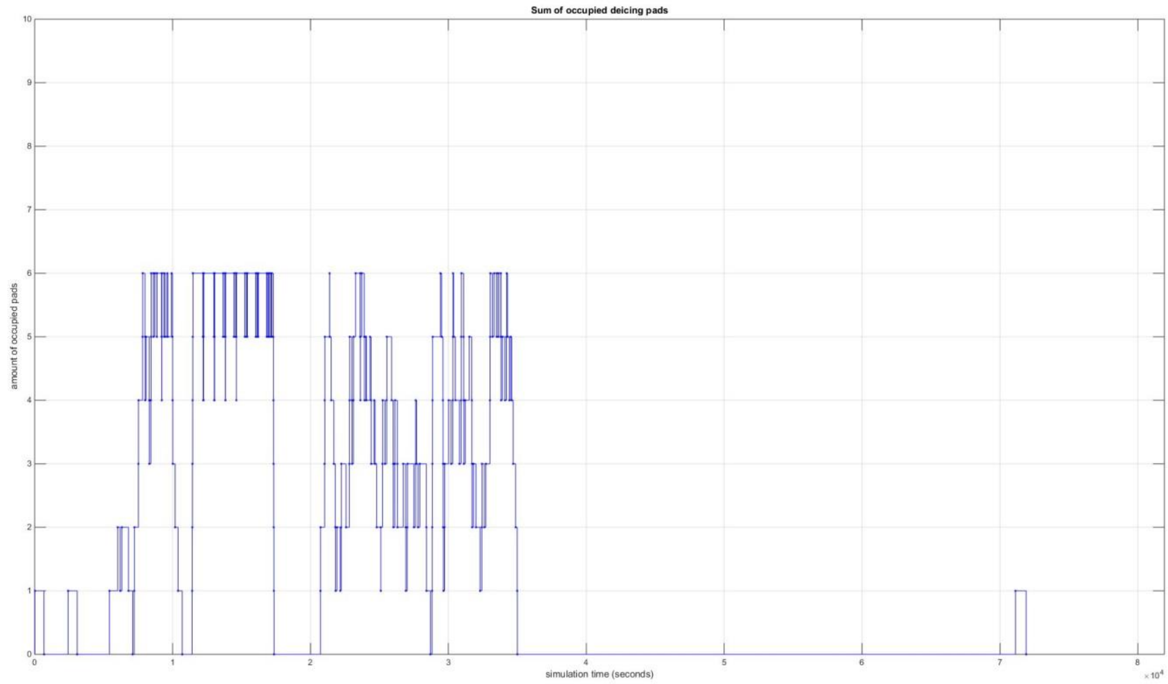



**Figure 61. Number of simultaneously used deicing pads. Oslo (ENGM), 01.03.2011, 6 pads active**

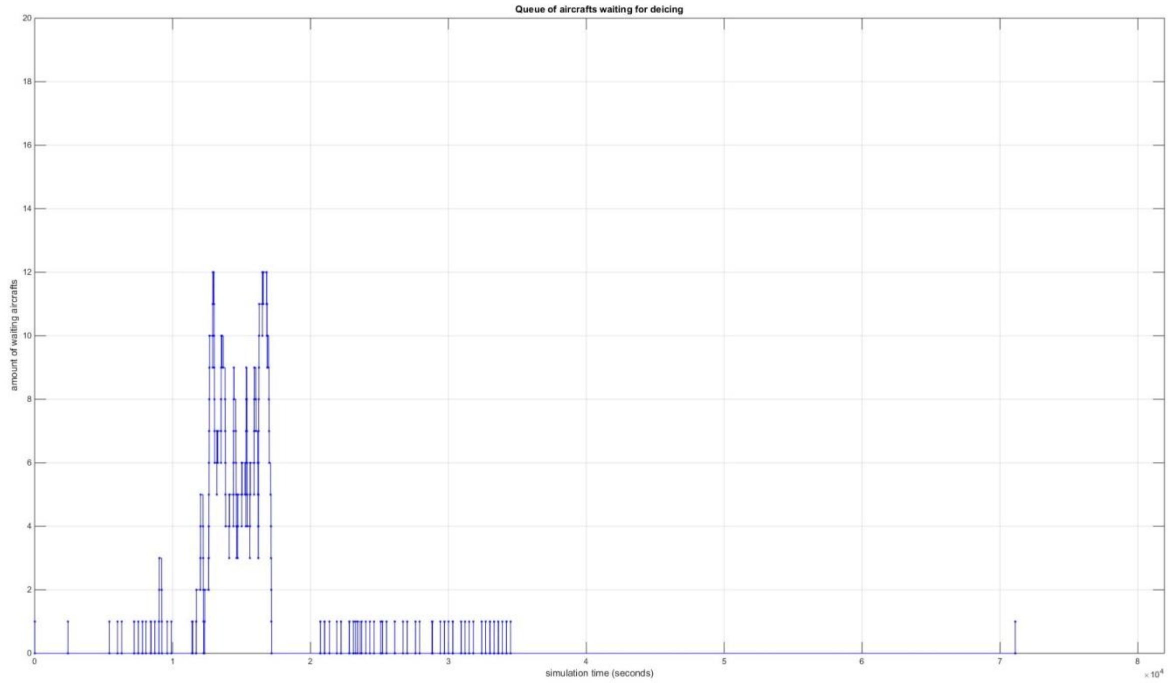



**Figure 62. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 6 pads active**

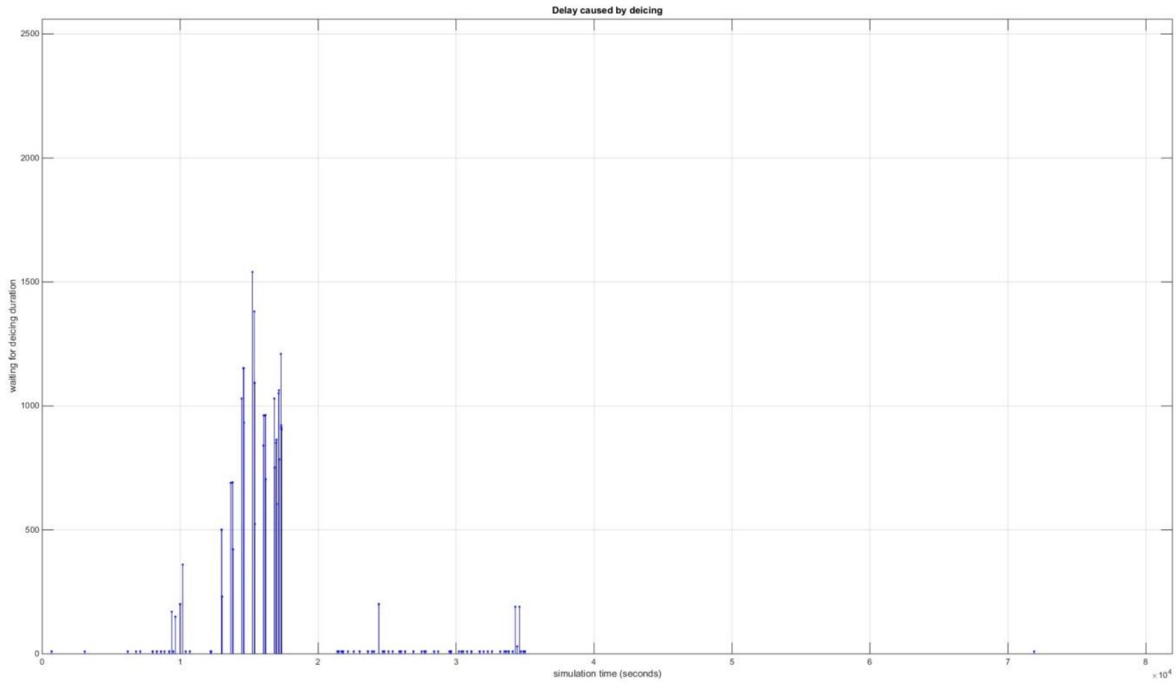



**Figure 63. Delay caused by deicing. Oslo (ENGM), 01.03.2011, 6 pads active**

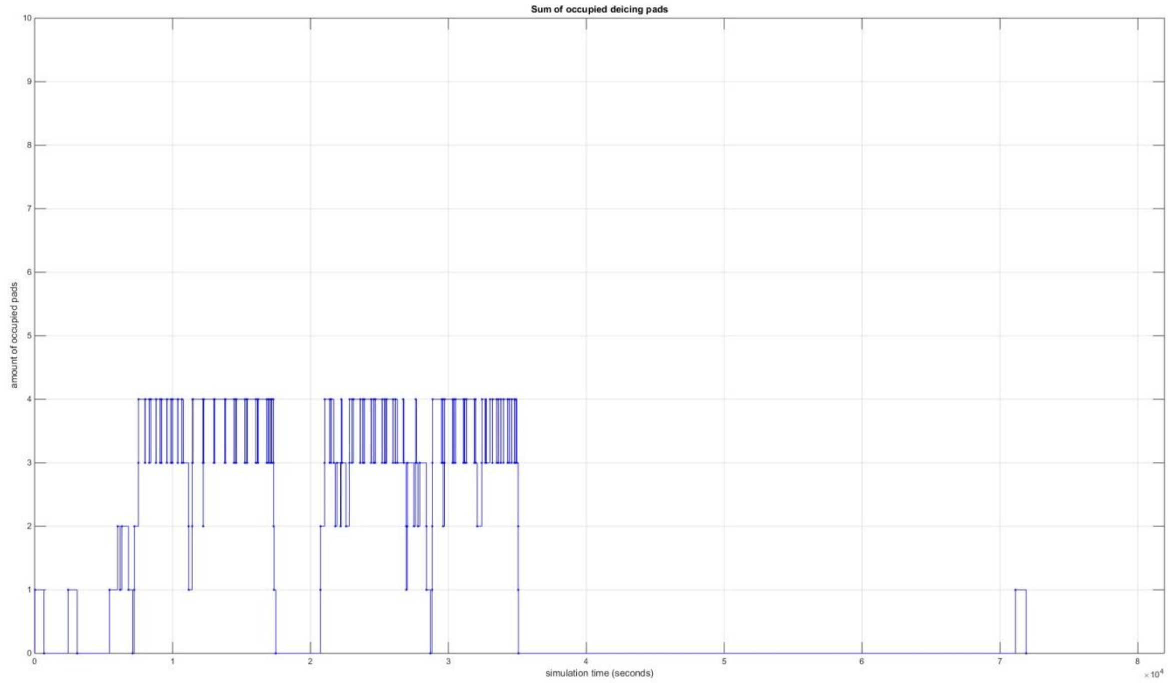



**Figure 64. Number of simultaneously used deicing pads. Oslo (ENGM), 01.03.2011, 4 pads active**

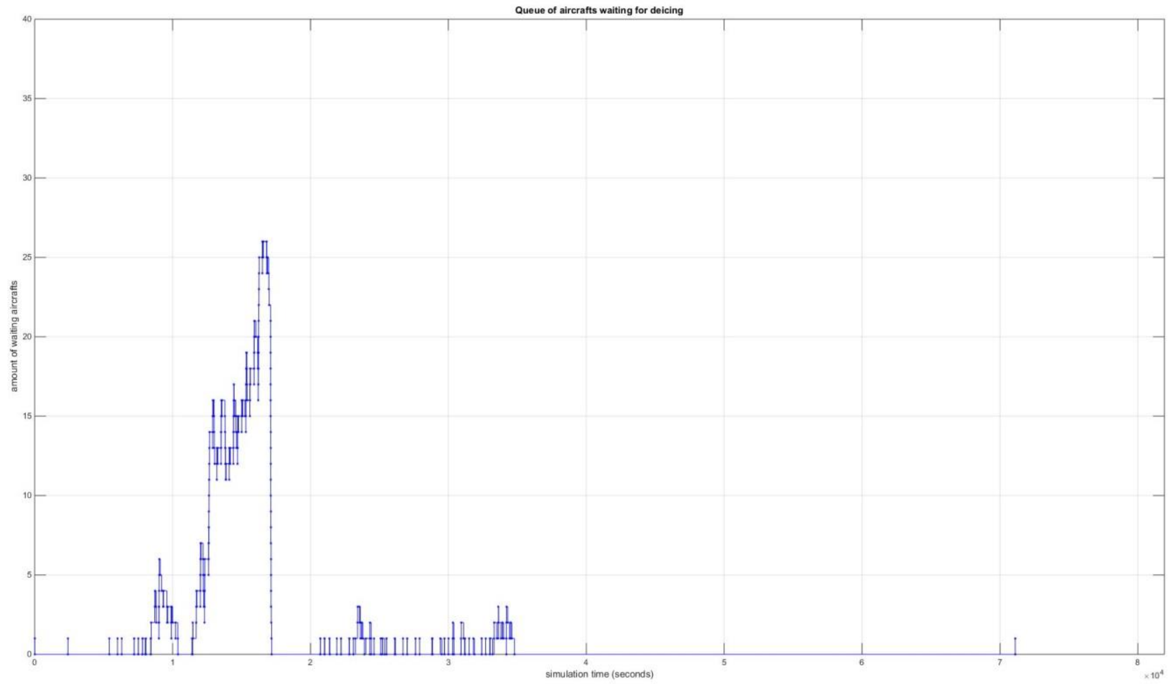



**Figure 65. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 4 pads active**

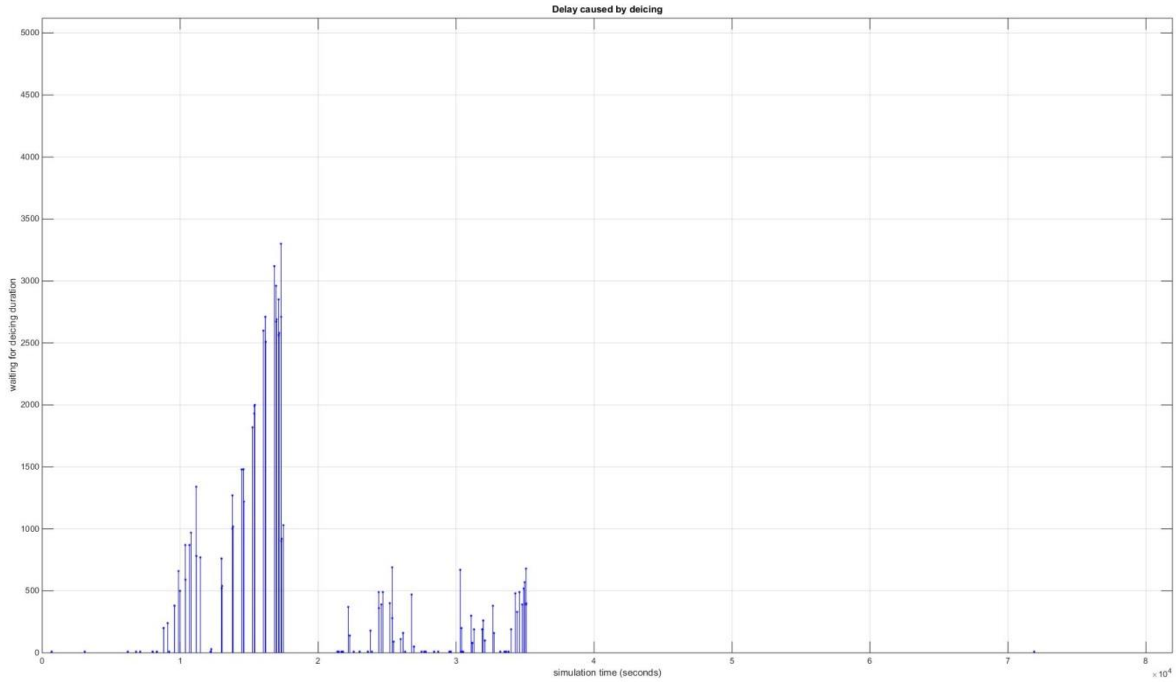



**Figure 66. Delay caused by deicing. Oslo (ENGM), 01.03.2011, 4 pads active**

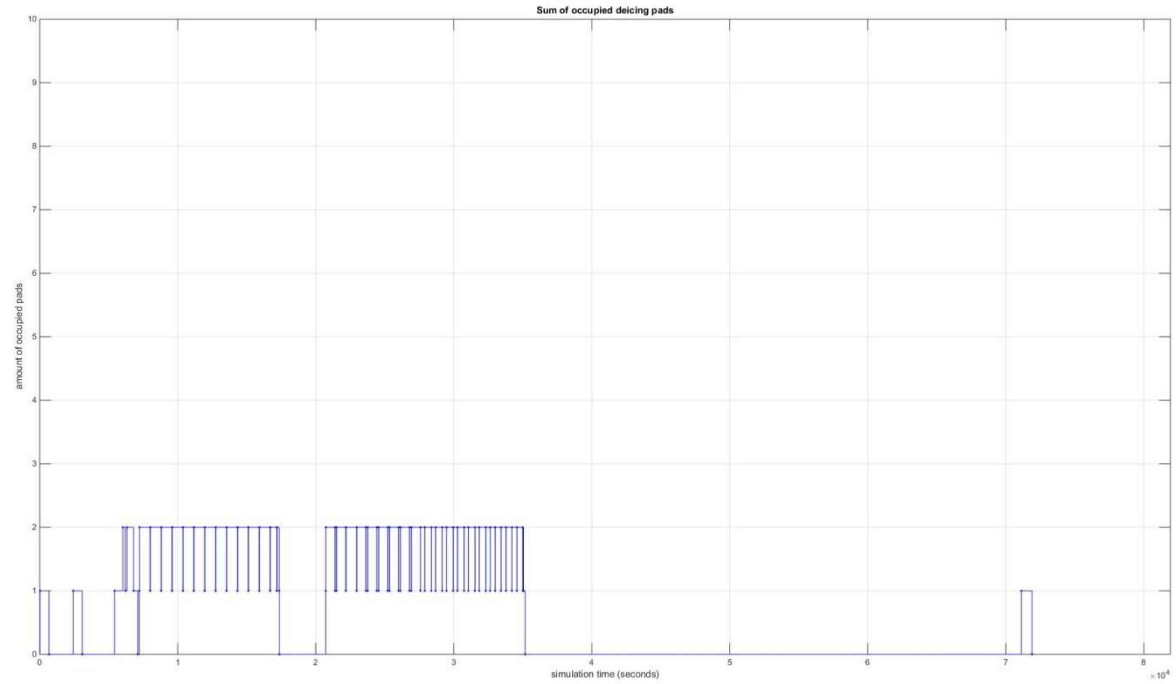



**Figure 67. Number of simultaneously used deicing pads. Oslo (ENGM), 01.03.2011, 2 pads active**

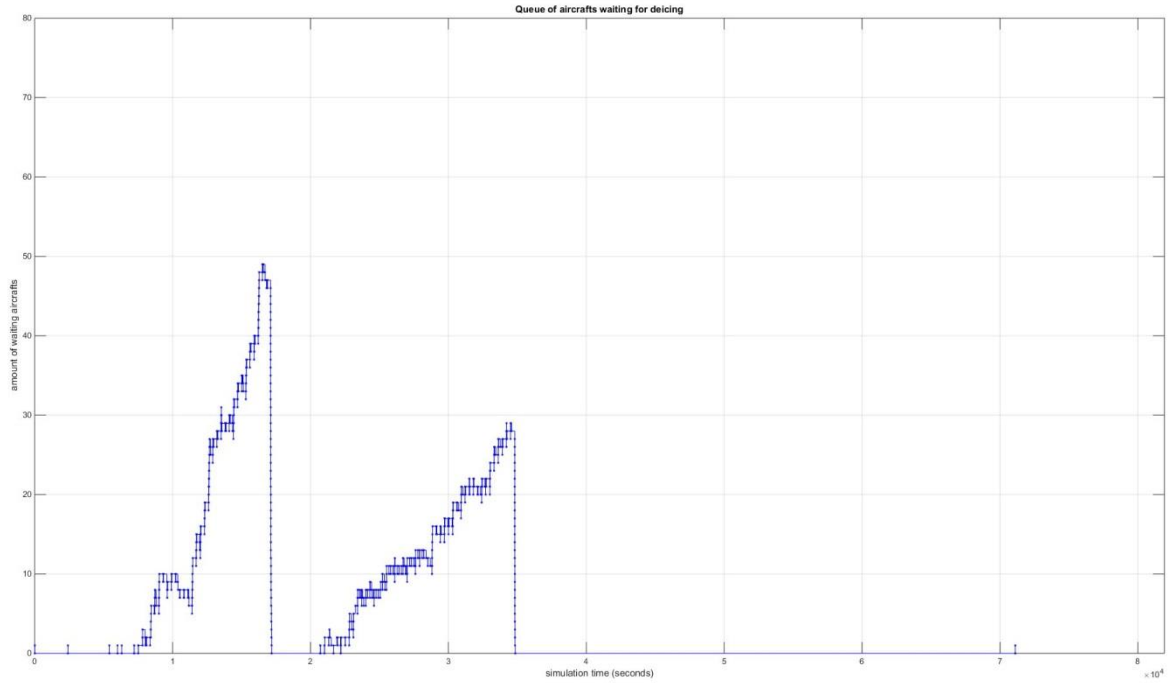



**Figure 68. Queue of aircrafts waiting for deicing. Oslo (ENGM), 03.03.2011, 2 pads active**

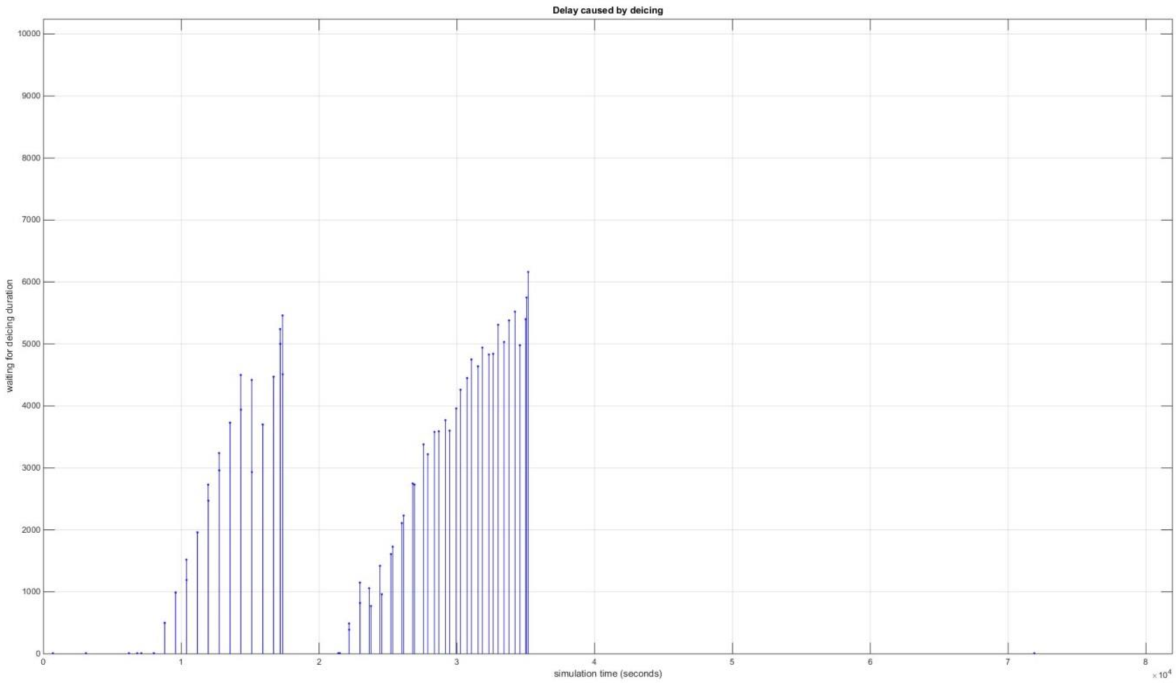



**Figure 69. Delay caused by deicing. Oslo (ENGM), 01.03.2011, 2 pads active**

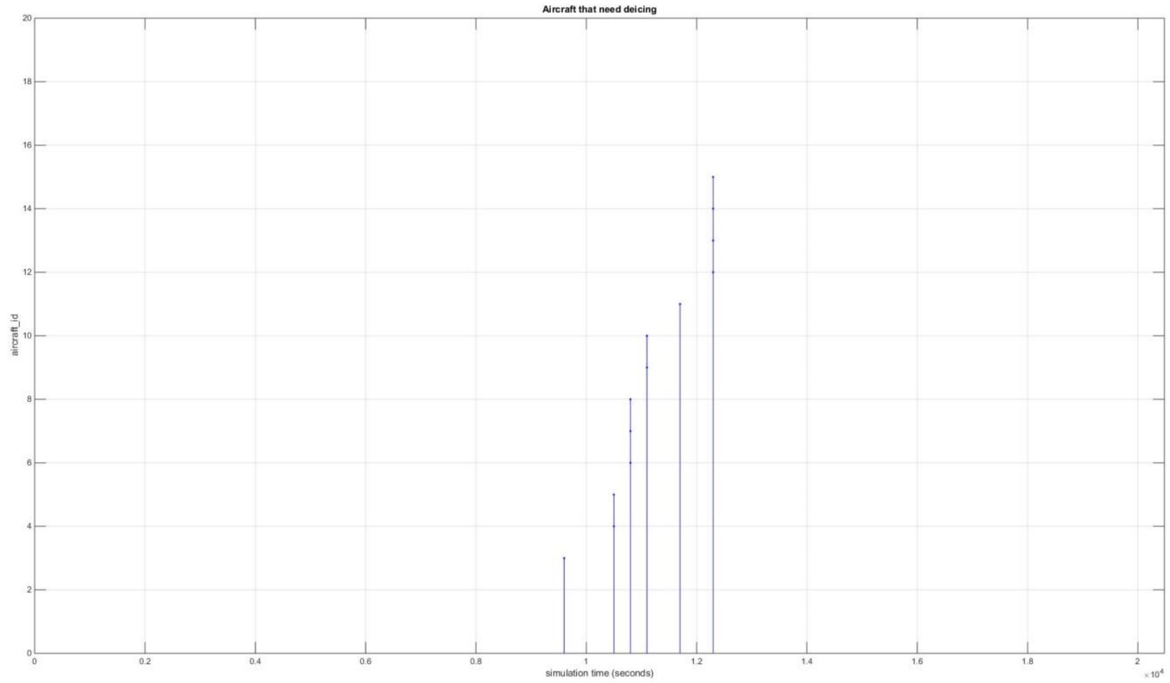



**Figure 70. Aircraft that need deicing. Oslo (ENGM), 05.03.2011, low workload**

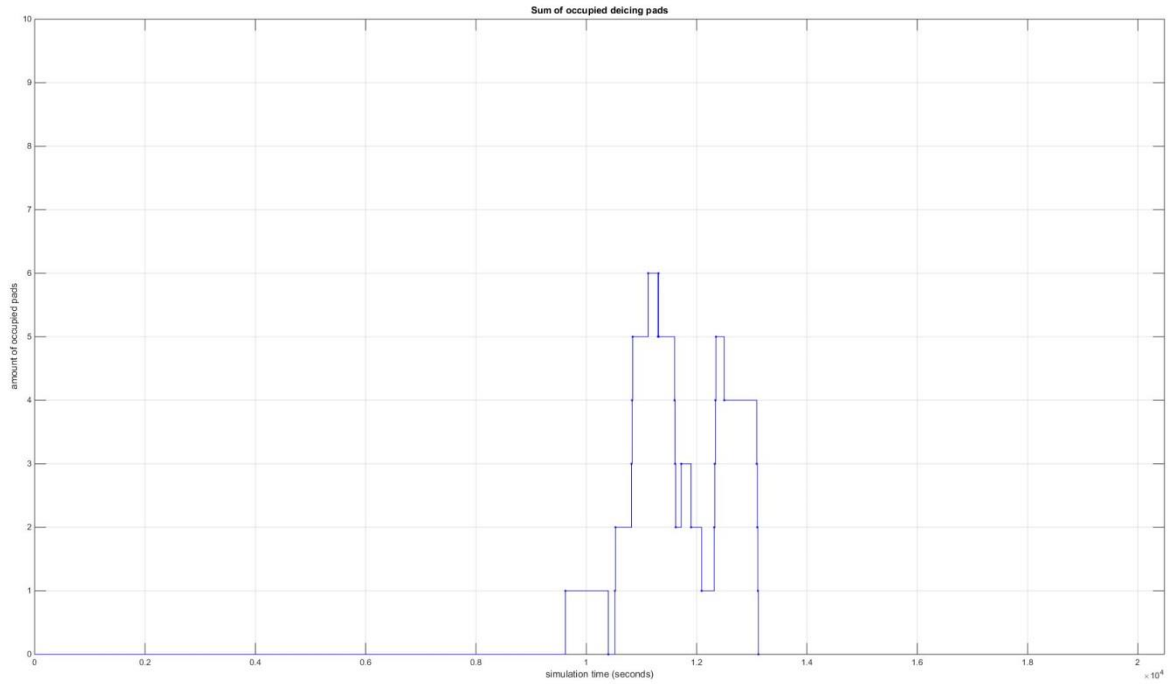



**Figure 71. Number of simultaneously used deicing pads. Oslo (ENGM), 05.03.2011, 6 pads active**

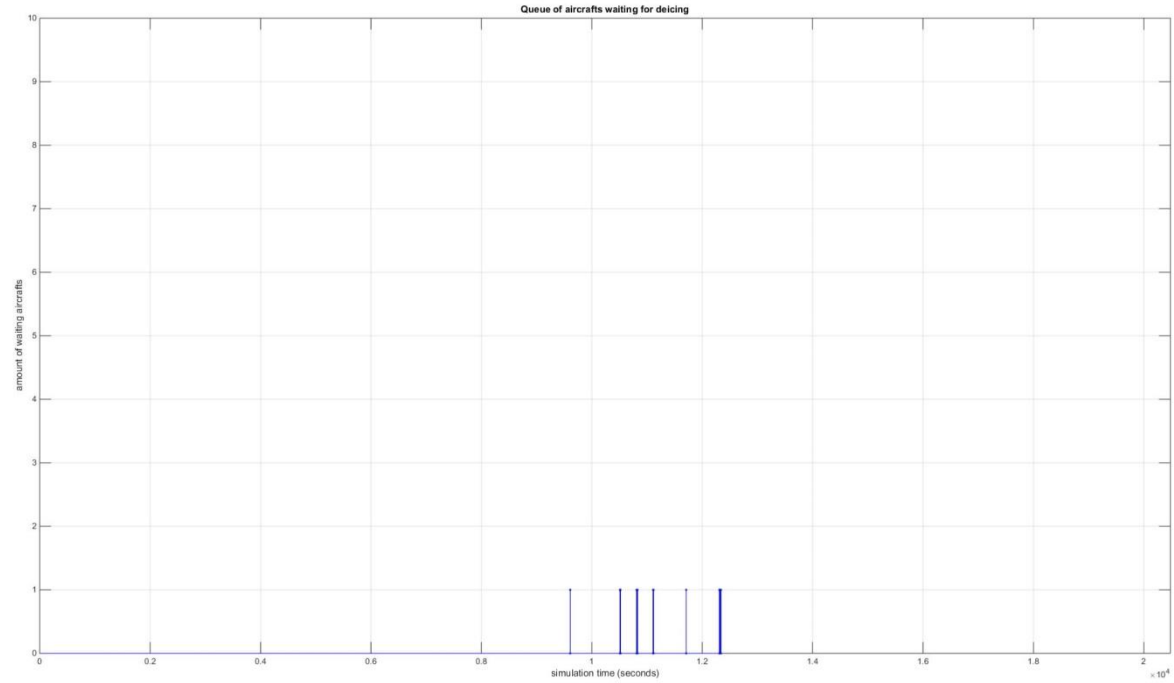



**Figure 72. Queue of aircrafts waiting for deicing. Oslo (ENGM), 05.03.2011, 6 pads active**

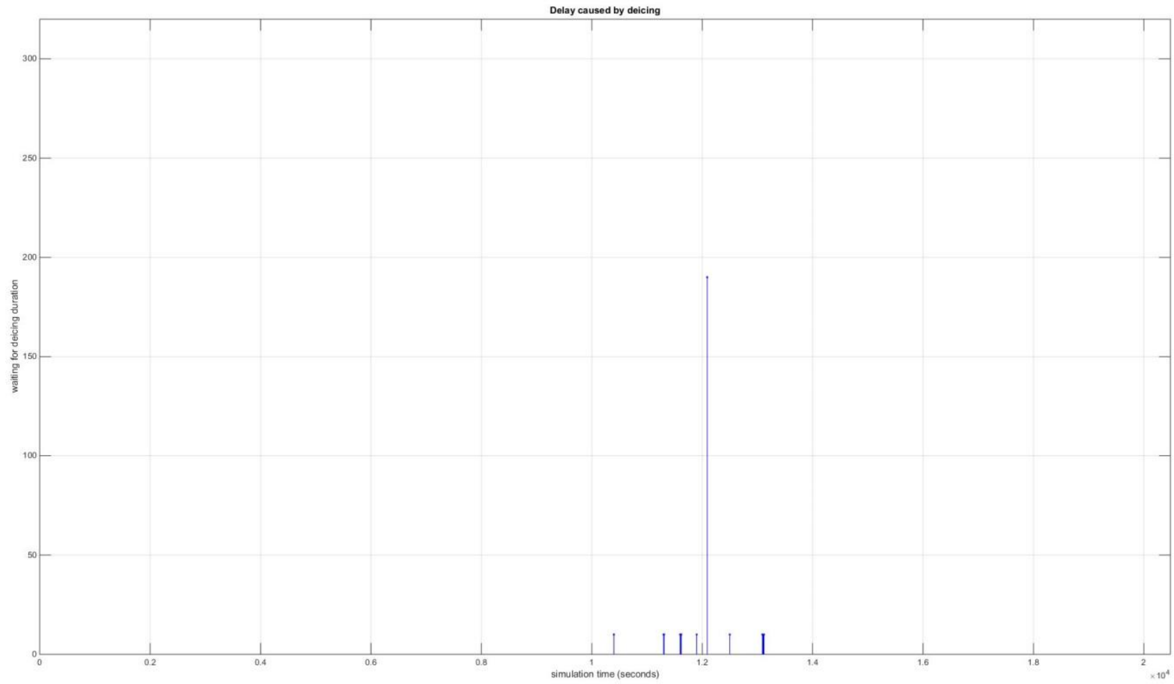



**Figure 73. Delay caused by deicing. Oslo (ENGM), 05.03.2011, 6 pads active**

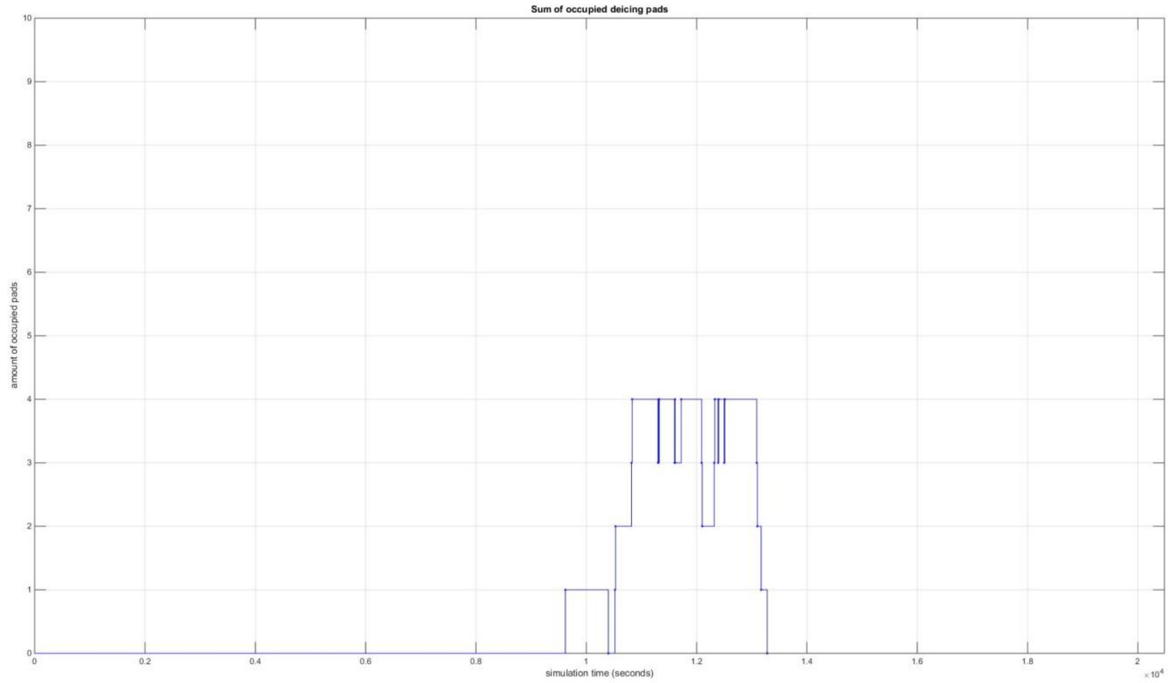



**Figure 74. Number of simultaneously used deicing pads. Oslo (ENGM), 05.03.2011, 4 pads active**

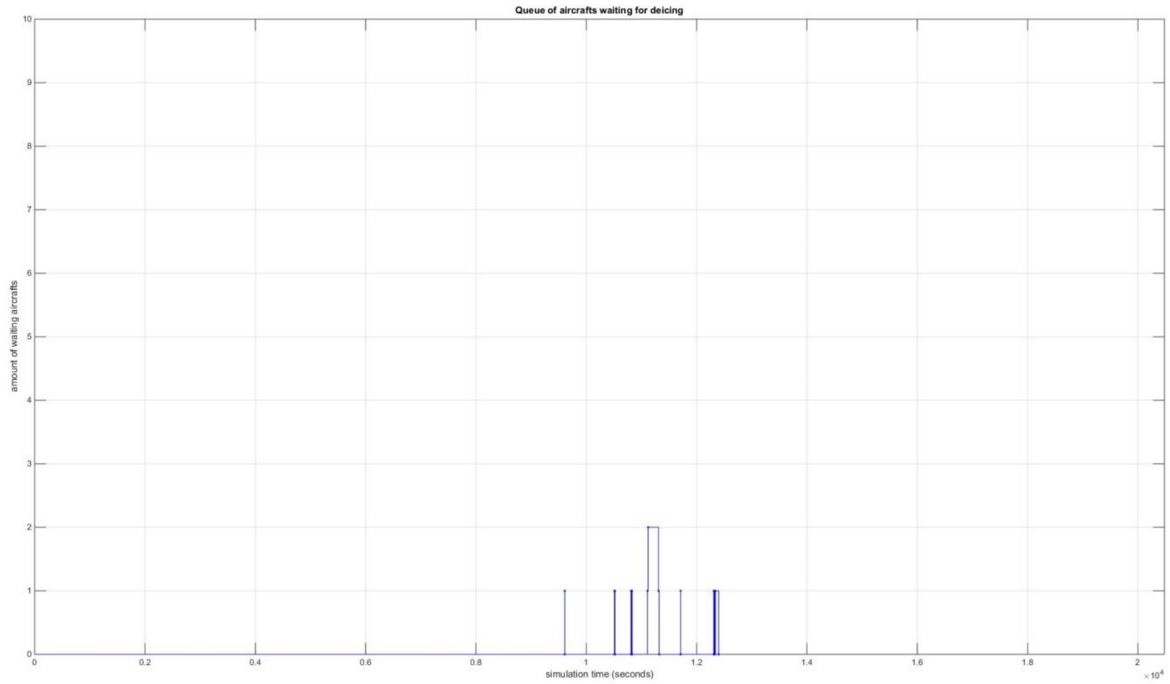



**Figure 75. Queue of aircrafts waiting for deicing. Oslo (ENGM), 05.03.2011, 4 pads active**

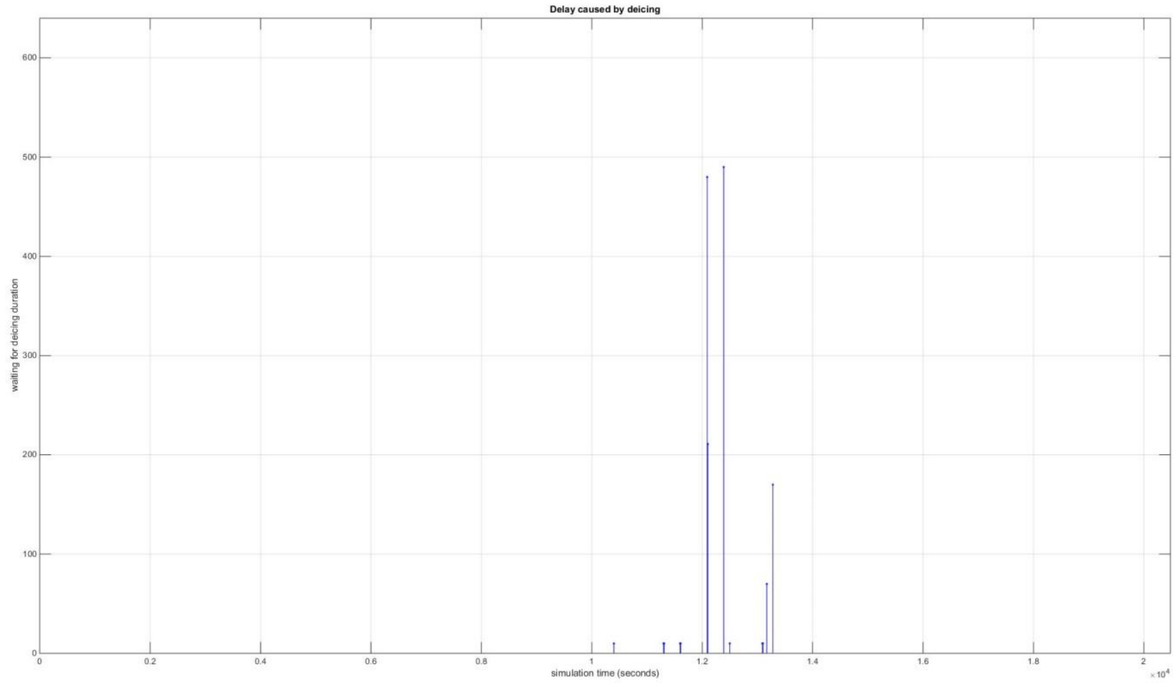



**Figure 76. Delay caused by deicing. Oslo (ENGM), 05.03.2011, 4 pads active**

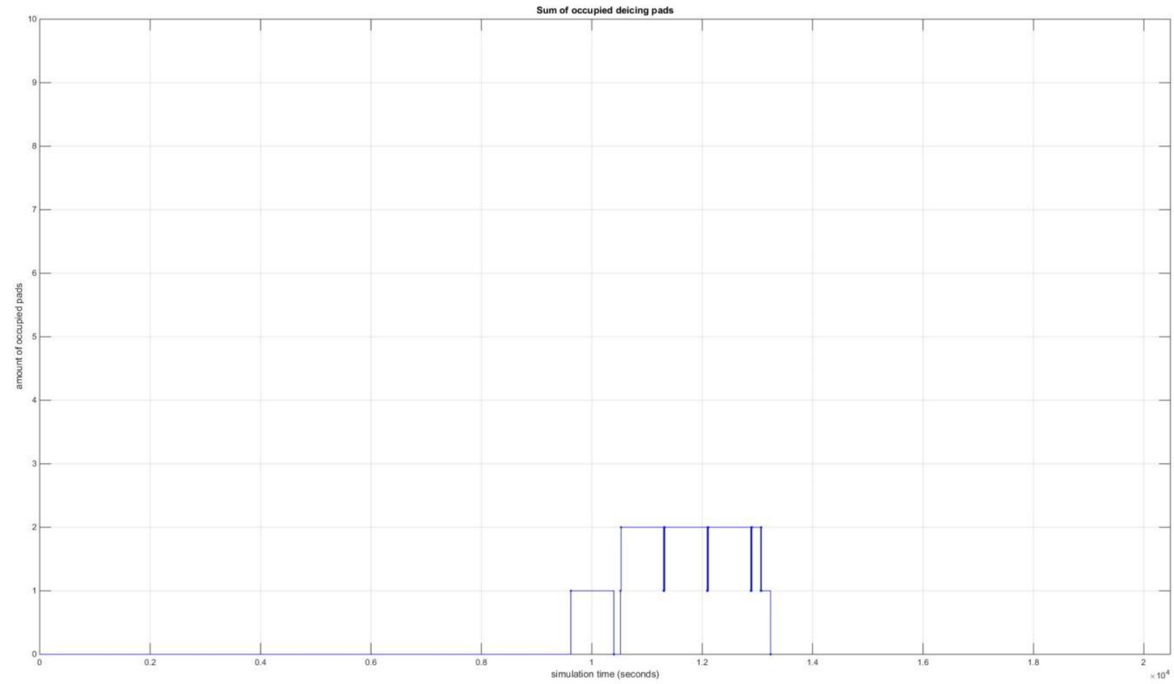



**Figure 77. Number of simultaneously used deicing pads. Oslo (ENGM), 05.03.2011, 2 pads active**

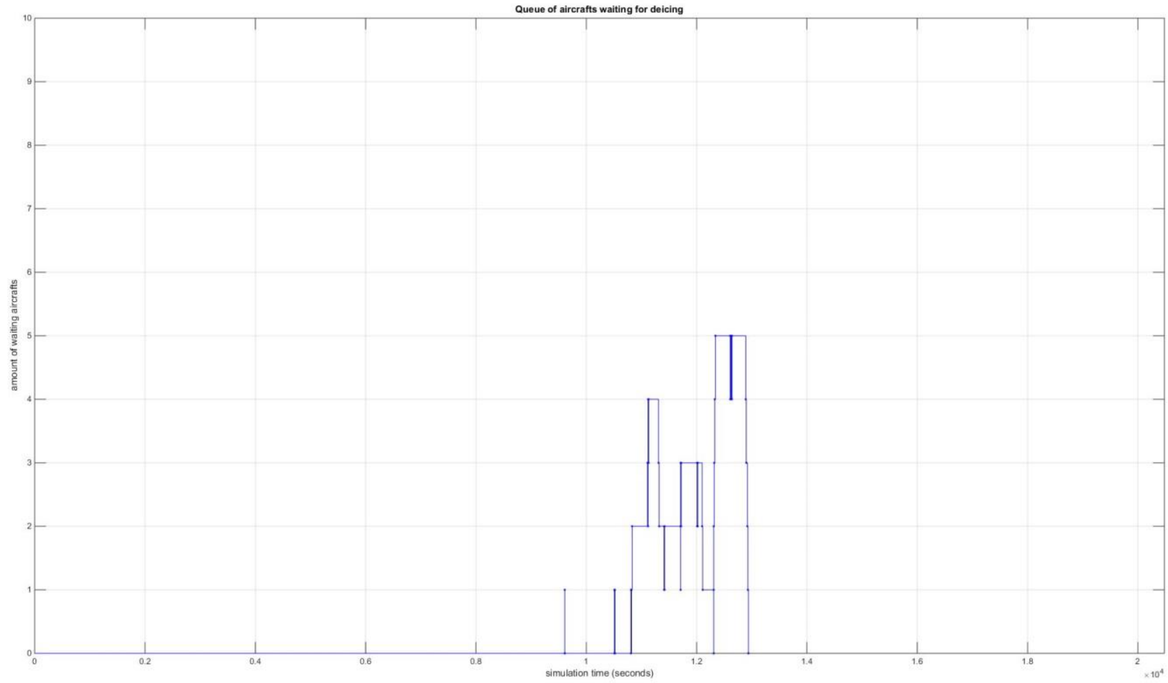



**Figure 78. Queue of aircrafts waiting for deicing. Oslo (ENGM), 05.03.2011, 2 pads active**

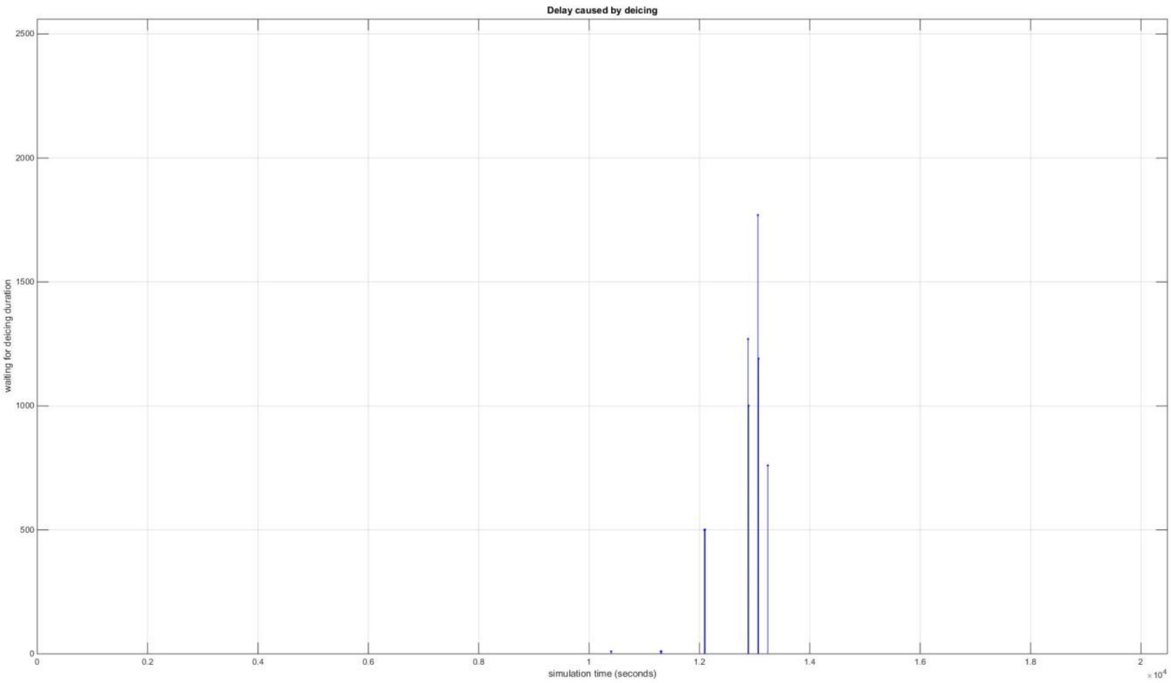



**Figure 79. Delay caused by deicing. Oslo (ENGM), 05.03.2011, 2 pads active**

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## 4.6 Annex 5: Abbreviations and Acronyms

This table lists all abbreviations and acronyms used in the description of the current ATM system which is presented in Annex 2. This is relevant especially in the A-CDM context. Short descriptions of the particular terms respective times are given.

| **Abkürzung / Akronym** | **Beschreibung** | **Definition** |
|---|---|---|
| AAL | Above Aerodrome Level | |
| ACC | Area Control Center | A unit established to provide air traffic control service to controlled flights in control areas under its jurisdiction. [ICAO 2007] |
| A-CDM | Airport Collaborative Decision Making | Process which allows decisions about events to be taken by those best positioned to make them on the basis of most comprehensive, up-to date and accurate information. This in turn will enable decisions about a particular flight to be made according to the latest information available at the time, thereby enabling the flight to be dynamically |

| | | |
|---|---|---|
| | | optimised to reflect near or real-time events. [EUROCONTROL 2013] |
| ACGT | Actual Commence of Ground Handling Time | The time when ground handling on an aircraft starts, can be equal to AIBT (to be determined locally). [EUROCONTROL 2012] |
| ADIT | Actual De-icing Time | Metric AEZT – ACZT [EUROCONTROL 2012] |
| AEZT | Actual End of De-icing Time | The time when de-icing operations on an aircraft end. [EUROCONTROL 2012] |
| AIBT | Actual In-Block Time | The time that an aircraft arrives in-blocks. (Equivalent to Airline/Handler ATA –Actual Time of Arrival, ACARS = IN). [EUROCONTROL 2012] |
| ALDT | Actual Landing Time | The time that an aircraft lands on a runway. (Equivalent to ATC ATA –Actual Time of Arrival = landing, ACARS=ON). [EUROCONTROL 2012] |
| AO | Aircraft Operator | A person, organisation or enterprise engaged in or offering to engage in an aircraft operation. [ICAO 2007] |
| AOBT | Actual Off Block Time | Time the aircraft pushes back / vacates the parking position (Equivalent to Airline / Handlers ATD – Actual Time of Departure & ACARS=OUT). [EUROCONTROL 2012] |
| APU | Auxiliary Power Unit | Gas turbine in the tail of an aircraft to provide power and bleed air. The bleed air is used for engine starting and the air conditioning. |
| APR | Aircraft Operator Position Report | |
| ARDT | Actual Ready Time<br><br>(for Movement) | When the aircraft is ready for start up/push back or taxi immediately after clearance delivery, meeting the requirements set by the TOBT definition. [EUROCONTROL 2012] |
| ARR | Arrival | Inbound flight [EUROCONTROL 2012] |
| ARZT | Actual Ready for De-icing Time | The time when the aircraft is ready to be de-iced. [EUROCONTROL 2012] |
| ASAT | Actual Start Up Approval Time | Time that an aircraft receives its start up approval. [EUROCONTROL 2012] |

| | | |
|---|---|---|
| ASBT | Actual Start Boarding Time | Time passengers are entering the bridge or bus to the aircraft. [EUROCONTROL 2012] |
| ASRT | Actual Start Up Request Time | Time the pilot requests start up clearance. [EUROCONTROL 2012] |
| ATC | Air Traffic Control | Service provided by ground-based controllers who direct aircraft on the ground and in the air. This to separate, organise and expedite the flow of air traffic. [EUROCONTROL 2012] |
| ATFCM | Air Traffic Flow and Capacity Management | ATFM extended to the optimisation of traffic patterns and capacity management. Through managing the balance of capacity and demand the aim of ATFCM is to enable flight punctuality and efficiency according to the available resources with the emphasis on optimising the network capacity through Collaborative Decision Making process (CFMU Handbook ATFCM_Operating_Procedures_for_FMP_1.0). [EUROCONTROL 2012] |
| ATOT | Actual Take Off Time | The time that an aircraft takes off from the runway (Equivalent to ATC ATD–Actual Time of Departure, ACARS = OFF). [EUROCONTROL 2012] |
| CASA | Computer Assisted Slot Allocation | |
| CAT II | Cloud base and visibility category | 100ft ≤ DH < 200ft; 300m ≤ RVR < 550m |
| CAT IIIa | Cloud base and visibility category | DH < 100ft; 200m ≤ RVR < 300m |
| CAT IIIb | Cloud base and visibility category | DH < 50ft; 75m ≤ RVR < 200m |
| CAT IIIc | Cloud base and visibility category | no DH, no RVR |
| CDM | Collaborative Decision Making | Process which allows decisions about events to be taken by those best positioned to make them on the basis of most comprehensive, up-todate and accurate information. This in turn will enable decisions about a particular flight to be made according to the latest |

| | | |
|---|---|---|
| | | information available at the time, thereby enabling the flight to be dynamically optimised to reflect near or real-time events. [EUROCONTROL 2013] |
| C-DPI | Cancel – Departure Planning Information message | |
| CFMU | Central Flow Management Unit | Central Flow Management Unit (CFMU), Brussels – A Central Management Unit operated by EUROCONTROL. [EUROCONTROL 2012] |
| CPR | Correlated Position Report | |
| CTO | Calculated Time Over | |
| CTOT | Calculated Take Off Time | A time calculated and issued by the appropriate Central Management unit, as a result of tactical slot allocation, at which a flight is expected to become airborne. [EUROCONTROL 2012] |
| DEP | Departure | Outbound flight[EUROCONTROL 2012] |
| DH | Decision Height | |
| DLA | Delay | Standard message sent to Network Operations to delay flight plan OBT. [EUROCONTROL 2012] |
| DME | Distance Measuring Equipment | |
| ECZT | Estimated Commence of De-icing Time | The estimated time when de-icing operations on an aircraft are expected to start. [EUROCONTROL 2012] |
| EDIT | Estimated De-icing Time | Metric EEZT – ECZT [EUROCONTROL 2012] |
| E-DPI | Early – Departure Planning Information message | First DPI message that is sent from the CDM Airport to the Network Operations (ETFMS) notifying the ETOT [EUROCONTROL 2012] |
| EEZT | Estimated End of De-icing Time | The estimated time when de-icing operations on an aircraft are expected to end. [EUROCONTROL 2012] |
| ELDT | Estimated Landing Time | The estimated time that an aircraft will |

| | | |
|---|---|---|
| | | touchdown on the runway. (Equivalent to ATC ETA–Estimated Time of Arrival = landing) [EUROCONTROL 2012] |
| EOBT | Estimated Off Block Time | The estimated time at which the aircraft will commence movement associated with departure. [ICAO 2007] |
| ERZT | Estimated Ready for De-Icing Time | The estimated time when the aircraft is expected to be ready for de-icing operations. [EUROCONTROL 2012] |
| ETA | Estimated Time of Arrival | For IFR flights, the time at which it is estimated that the aircraft will arrive over that designated point, defined by reference to navigation aids, from which it is intended that an instrument approach procedure will be commenced, or, if no navigation aid is associated with the aerodrome, the time at which the aircraft will arrive over the aerodrome. For VFR flights, the time at which it is estimated that the aircraft will arrive over the aerodrome. [ICAO 2007] |
| ETFMS | Enhanced Tactical Flow Management System | |
| ETO | Estimated Time Over | |
| ETOT | Estimated Take Off Time | The estimated take off time taking into account the EOBT plus EXOT. [EUROCONTROL 2012] |
| FAF | Final Approach Fix | |
| FMP | Flow Management Position | Provides a vital flow of information from their operational ATC Unit to the Network Operations about the current situation within their ACC and the operational situation at the airport. [EUROCONTROL 2012] |
| FUM | Flight Update Messages | |
| GBAS | Ground Based Augmentation System | |
| GLS | GBAS Landing System | |
| GPU | Ground Power Unit | Power generator on the ground to deliver |

| | | |
|---|---|---|
| | | power to the aircraft. |
| HOT | Holdover Time | The time that it is safe to take-off without needing to be de-iced again. |
| IAF | Initial Approach Fix | A fix that marks the beginning of the initial segment and the end of the arrival segment, if applicable. In RNAV applications this fix is normally defined by a fly-by waypoint. [ICAO 2006] |
| IFR | Instrument Flight Rules | The symbol used to designate the instrument flight rules. [ICAO 2007] |
| ILS | Instrument Landing System | |
| LOUT | Lowest operational use temperature | Lowest temperature at which specific de-icing fluids may be used |
| MET | Meteorological Office | |
| NM | Nautical Mile | 1852 meter |
| NM | Network Manager | Function provided by the Eurocontrol Network Manager Directorate (NMD) as described in the Network Manager Implementing Rule of the European Commission. [EUROCONTROL 2013] |
| OAT | Outside Air Temperature | |
| OPS | Operations Office | |
| Pax | Passengers | |
| REA | Ready Message | For flights having already received their slot and being in a situation to depart before their CTOT (doors closed and ready to depart), the AO may ask local ATC to send a Ready (REA) message. In the REA local ATC may also include a MINLINEUP time, to indicate the minimum time needed for that flight to get from its position to take-off. [EUROCONTROL 2014] |
| RMP | Reduced mobility passengers | Passengers who are limited in their mobility. E.g. wheelchairs |
| RNAV | Area Navigation | |

| | | |
|---|---|---|
| RVR | Runway Visual Range | |
| SAL | Slot Allocation List | |
| SAM | Slot Allocation Message | The SAM is used to inform AOs & ATS of the Calculated Take-Off Time (CTOT) computed by CASA for an individual flight, to which AOs/ATC must adhere. [EUROCONTROL 2014] |
| SID | Standard Instrument Departure | Published flight procedures followed by aircraft on an IFR flight plan immediately after take-off from an airport. [EUROCONTROL 2012] |
| SIT | Slot Issue Time | |
| SLC | Slot Requirement Cancelation Message | In case of cancellation of a regulation, a SLC may be sent. This can happen any time up to the CTOT. The main reason is to inform the Tower and the pilot that the flight is no longer regulated. [EUROCONTROL 2012] |
| SRM | Slot Revision Message | The SRM notifies a significant change of slot It is issued not earlier than 2 hours before the last received EOBT. This EOBT may be provided by DLA or CHG. [EUROCONTROL 2014] |
| STAR | Standard instrument arrival | A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced. [ICAO 2007] |
| T-DPI | Target - Departure Planning Information message | This DPI message is sent from the CDM Airport to the Network Operations (ETFMS) notifying the Target Take Off Time (TTOT) [EUROCONTROL 2012] |
| T-DPI-s | Target - Departure Planning Information message – Sequenced | |
| T-DPI-t | Target - Departure Planning Information message - Target | |
| TMA | Terminal Manoeuvring Area | A control area normally established at the confluence of ATS routes in the vicinity of one |

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| | | or more major aerodromes. [ICAO 2007] |
| TMAi | TMA with the index i | For modelling purposes, the TMAs are numbered and the variable i is used as a variable. |
| TOBT | Target Off-Block Time | The time that an Aircraft Operator or Ground Handler estimates that an aircraft will be ready, all doors closed, boarding bridge removed, push back vehicle available and ready to start up / push back immediately upon reception of clearance from the TWR. [EUROCONTROL 2012] |
| TSAT | Target Start Up Approval Time | The time provided by ATC taking into account TOBT, CTOT and/or the traffic situation that an aircraft can expect start up / push back approval Note: The actual start up approval (ASAT) can be given in advance of TSAT. [EUROCONTROL 2012] |
| TTOT | Target Take Off Time | The Target Take Off Time taking into account the TOBT/TSAT plus the EXOT. Each TTOT on one runway is separated from other TTOT or TLDT to represent vortex and/or SID separation between aircraft. [EUROCONTROL 2012] |
| TWR | Tower | Air traffic control tower |
| UM | Unaccompanied Minors | Children traveling unaccompanied by an adult |
| VMC | Visual Metrological Conditions | |