POLITECNICO DI TORINO

MASTER's Degree
in
Aerospace Engineering

Analysis of a complex socio-technological system of aeronautical transport with the functional resonance analisys method (FRAM)

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Summary

This thesis aims to analyze an incidental event concerning the De-Icing procedure of an Airbus A320-216 aircraft, which occurred at Munich International Airport (MUC), as a complex socio-technological system using the Functional Resonance Analysis Method (FRAM). This study aims to understand which steps of the standardized De-Icing procedure (Work As Imagined) are different from the actions actually performed (Work As Done) as they conceal an intrinsic variability which, when combined, led to the generation of an *emergence*. To support this thesis, the procedural approaches of the airport involved in this incident will be compared with those of Milan Malpensa Airport (MXP, managed by SEA – Società Esercizi Aeroportuali), which has contributed by providing documentation regarding de-icing, along with an in-depth on-field study regarding the alignment of Work as Imagined with Work as Done, alongside an exploration of how continuous and meticulous attention to the work performed can mitigate the variability inherent in such a complex system as the airport environment.

SEA Milan Airports

"Non si può pensare che tutto ciò avvenga senza failures, senza rotture, senza risultati inaspettati e, soprattutto, la paura di un fallimento non può e non deve limitare il nostro bisogno di conoscenza e la spinta all'innovazione per superare i nostri limiti"

Tommaso Ghidini, Homo Caelestis

a nonna Rita, nonna Pina, nonno Elio e nonno Tomm

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Acronyms

- ATC…………………………………………………………………Air Traffic Control
- ATIS………………………………………Automatic Terminal Information Service
- BFU…………………...…German Federal Bureau of Aircraft Accident Investigation
- CVR…………………………………………………………...Cockpit Voice Recorder
- DA……………………………………………………………………..De-icing Area
- FRAM………………………………………Functional Resonance Analysis Method
- HFM…………………………………………………………..Human Factor Method
- PIC…………………………………………………………… Pilot In Command
- SM……………………………………………………………………Shell Method
- WAD………………………………………………………………… Work As Done
- WAI…………………………………………………………….Work As Imagined

Chapter 1

Functional Resonance Analysis Method (FRAM)

The commonly employed methods for incident analysis in the aeronautical field involves the examination of events leading to failure, whether of a technological, organizational, or human nature. The analysis, utilizing the SHELL and HFACS methodologies, is conducted retrospectively, commencing from the incident itself and methodically retracing the sequence of events with the objective of identifying the critical factor or constellation of factors that culminated in the accident.

However, this approach is not without inherent limitations, as it remains impossible to fully reconstruct the precise conditions that gave rise to the incident under investigation. At best, one can attempt to approximate these circumstances, yet such approximations may fail to guarantee the accuracy of the conclusions drawn. As a result, the recommendations and the measures subsequently developed to prevent the recurrence of similar incidents may also be insufficient in fully mitigating the risk.

The objective is to meticulously investigate the occurrences to identify the "trigger," the committed error, with the aim of rectifying it and preventing its recurrence in the future. Additionally, these methodologies inherently possess several limitations, segregating the social aspect from the technological one, assuming the human factor as a negative aspect and a source of errors. Above all, they consider the sequence of events as causal and linear over time, somewhat predictable (if certain parameters are known), and thus retroactively traceable.

In reality, the analyzed systems consist of a high number of closely interconnected variables. Therefore, merely separating "human error" or regulatory deficiencies in the organizational field from the failure of a technological apparatus appears to be an approximation that poorly models reality. Furthermore, incidental events linked to technical failures are rare due to the high safety standards in the aviation sector (approximately 1 case per 109 events). Therefore, studying their nature and causes and extending solutions within the industry proves to be complex. In this context, the FRAM method, which aims to study the ($10^9 - 1$) successful events, expands the scope of study, enabling the analysis of modeled procedures for functions of different natures that, interconnected, may give rise to system resonance events. Consequently, safety assessment should go beyond traditional measures based on the number of failures: both incidental events (accidents and mishaps) and successful outcomes (normal operations) stem from performance variability. Therefore, determining the safety level of a system involves measuring the presence of acceptable outcomes: the more there are, the safer the system is. For the purposes of risk assessment, FRAM analysis can help identify suitable leading indicators to monitor system safety. This perspective aligns with the principle of approximate adjustments, in that a system can be considered highly safe if it has the capacity to adapt its functioning to cope with both expected and unforeseen conditions. Conversely, a system failure results from the unintended interaction of multiple signals, arising from normal performance variability, which leads to disproportionately large effects from small or even negligible variations.

1.1 A method that goes beyond the causality of events

The primary strength of the FRAM method lies in the assumption that the complex socio-technical system under analysis, divided into temporally unordered steps called functions, is not fully known in every aspect: it is not possible to predict every parameter that influences a system, nor how or to what extent it will affect it. The method embraces the equivalence of successes and failures, affirming their common origin, which is the *variability* of performance. In this sense, the FRAM analysis aligns with the resilience engineering perspective on failures: a failure may be experienced due to the challenges arising from the system's adaptation to the real world, rather than viewing failures as normal system events.

For a given function, depicted by a block with connections as shown in the figure below (Fig. 1.1), variability is the characteristic that represents its ability to unpredictably alter its behavior, consequently changing its output. This introduces unforeseen connections between functions or halting the process.

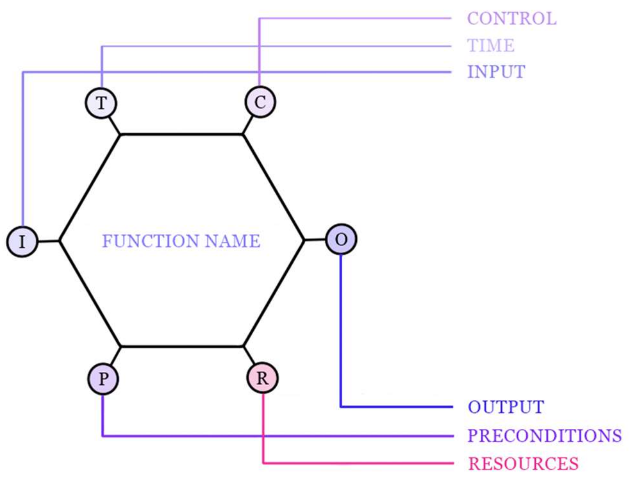


Fig. 1.1: *Elementary function block*

INPUT	What activates the function and/or is used or transformed to produce the output; it represents the connection to upstream functions.
PRECONDITIONS	System conditions that must be fulfilled before a function can be performed.
RESOURCE	This indicates what is necessary or utilized by the function during the activity phase.
CONTROL	What oversees or regulates the function, such as plans, procedures, guidelines, etc.
TIME	Temporal aspects influencing the performance of the function (e.g., de-icing liquid hold over time).
OUTPUT	It is the result of the function. It constitutes the connections to downstream functions.

Tab.1.1: *Definition of the types of connection points of the functions*

The variability depends on the type of function to which it is associated, whether Organizational (O), Technological (T), or Human (H). There are two categories:

- *Time Variability*

  This category indicates within what timeframes the function can be or is typically performed for each function type and what consequences this has on the overall variability of the system, as reported in the following table.

		Temporal range of *Variability* of response			
		TOO EARLY	**ON TIME**	**TOO LATE**	**NOT AT ALL**
Function type	**TECHNOLOGICAL (T)**	Unlikely	Normal, expected	Unlikely, but possible if software involved	Very unlikely, only in the case of breakdown
	HUMAN (H)	Possible, snap answer	Possible, should be typical	Possible, more likely than too early	Possible, to a lesser degree
	ORGANIZATIONAL (O)	Unlikely	Likely	Possible	Possible

Tab.1.2: *Temporal range of Variability of response*

		Upstream OUTPUT coupling variability				
		INPUT	**PRECONDITIONS**	**RESOURCE**	**CONTROL**	**TIME**
Variability over temporal range	**TOO EARLY**	V+	V+	V=	V+	V+
	ON TIME	V-	V-	V-	V-	V-
	TOO LATE	V+	V+	V+	V+	V+
	NOT AT ALL	V+	V+	V+	V+	V+

Tab.1.3: *Variability over temporal range*

- *Precision Variability*

  This category represents the accuracy with which a function is executed; it can be performed in the following ways:

  - Precise → typical for technological functions, less common for human and organizational functions, is executed exactly as expected;
  - Acceptable → the function is performed with sufficient precision not to influence variability. Common for human functions;
  - Imprecise → The function is performed incorrectly, resulting in an increase in variability.

		Precision range of *Variability* of response		
		PRECISE	**ACCEPTABLE**	**IMPRECISE**
Function type	**TECHNOLOGICAL (T)**	Normal, expected	Unlikely	Unlikely
	HUMAN (H)	Possible, but unlikely	Typical	Possible, likely
	ORGANIZATIONAL (O)	Unlikely	Possible	Likely

Tab.1.4: *Precision range of Variability of response*

		Upstream OUTPUT coupling variability				
		INPUT	**PRECONDITIONS**	**RESOURCE**	**CONTROL**	**TIME**
Variability over precision range	**PRECISE**	V-	V-	V-	V-	V-
	ACCEPTABLE	V=	V=	V=	V=	V=
	IMPRECISE	**V+**	**V+**	**V+**	**V+**	**V+**

Tab.1.5: *Variability over precision range*

In a system, functions that are subject to variability are considered those that are not *background functions*, meaning all those that possess both an upstream and a downstream function.

The modeling of a system will consist of the set of function blocks, appropriately connected according to the criterion of "how it should be done," with the attribution of internal variability. Functional resonance comes into play when a detectable signal emerges from the involuntary interaction of variabilities from multiple functions. The FRAM analysis aims to identify how to dampen (i.e. "reduce the amplitude of") this resonance, which is the result of undesired variability.
Care should be taken regarding the consequences of an increase in the variability of a function:

- **Increased Uncertainty**: An increase in variability leads to greater uncertainty in function outcomes, complicating the prediction of operation outcomes and increasing the risk of errors.

- **Error Propagation**: When a function exhibits higher variability, resulting errors can propagate to other interconnected functions. In complex environments such as airports or flights, an error in one phase can adversely affect subsequent phases, amplifying issues along the operational chain.

- **Reduced Reliability**: Increased variability can decrease the overall reliability of the system. Operations become less predictable, undermining the system's robustness as a whole.

- **Increased Workload**: To compensate for increased variability, personnel may be compelled to increase their workload. This can lead to additional stress, fatigue, and a heightened risk of errors.

- **Need for Increased Supervision and Control**: Increased variability necessitates greater supervision and control to ensure operations remain within safety limits. This may involve implementing additional monitoring and verification measures, complicating overall system management.

- **Performance Degradation**: Increased variability can result in operational performance degradation. This may manifest in longer response times, delays, and more frequent inefficiencies, impacting service quality and customer satisfaction.

- **Increased Risk of Incidents**: Lastly, increased variability in a function can elevate the risk of incidents or adverse events. Growing unpredictability makes it harder for personnel to anticipate and mitigate potential issues, thereby increasing the likelihood of hazardous situations.

On the other hand, an unforeseen event, such as human intervention, can reduce system variability, attenuating the effects of other variations compared to WAI. The importance of monitoring all aspects of the event, the functions in which it is modeled, and the connections that bind them, allows for evaluating which events, by increasing system variability, have led to the incident and which unforeseen and mitigating actions have attenuated its effects.

1.2 Comparison with current methods: SHELL and HFACS

The methodologies used thus far to reconstruct and determine the phases of an incident event, namely the SHELL (Software, Hardware, Environment, Liveware and Liveware) and HFACS (Human Factors Analysis and Classification System), are characterized by a deterministic viewpoint. This perspective inevitably directs investigations towards identifying a singular error or unsafe acts committed by an individual, responsible for initiating the sequence of events. While these methods have enabled the modeling of complex systems like aviation incidents, they have traditionally compartmentalized technological aspects from psychological, human, and social factors. Moreover, they tend to view the human factor primarily through a lens of negative impact within the system. In this paragraph, the focus is specifically on highlighting the most notable differences between SHELL, HFACS, and FRAM.

1.2.1 SHELL Model

The SHELL model is one of the oldest and most established tools for incident analysis, developed in the 1970s by Elwyn Edwards and later expanded by Frank Hawkins. The model's name is an acronym representing the interactions between four key elements of the aviation system:

- **Software (S)**: Procedures, manuals, checklists, and other operational instructions.
- **Hardware (H)**: Machinery, equipment, and technological systems.
- **Environment (E)**: The operational environment, including weather conditions, visibility, and airport infrastructure.

- **Liveware (L)**: Human operators such as pilots, engineers, etc.;
- **Liveware (L)**: Interaction between human operators.

The SHELL model focuses on analyzing the interfaces between these elements. For instance, it examines how the interaction between personnel (Liveware) and procedures (Software) can *contribute to errors*, or how environmental conditions (Environment) can affect human performance and equipment reliability (Hardware). The model is graphically represented as a diagram where each element is connected to the others, highlighting the interactive and interdependent nature of the system.

1.2.2 HFACS (Human Factors Analysis an Classification System)

The HFACS (Human Factors Analysis and Classification System) system is an analytical method developed in the 2000s and designed for analyzing military incidents and later adapted for civil aviation. This method draws inspiration from James Reason's "Swiss Cheese Model," which illustrates how a system's defenses can be penetrated by aligned failures or errors.
HFACS classifies human factors contributing to incidents into four hierarchical levels:

- **Unsafe Acts**: Errors and violations committed directly by operational personnel, such as pilots and air traffic controllers. These include decision errors, execution errors, and perceptual errors.

- **Preconditions for Unsafe Acts**: Factors related to the psychological and physical conditions of personnel, such as stress, fatigue, or health problems.

- **Unsafe Supervision**: Errors and omissions at the supervisory level, such as inadequate risk management or lack of proper training.
- **Organizational Influences**: Systemic and organizational factors, such as company policies, organizational culture, and deficiencies in support infrastructure.

The HFACS approach allows tracing the causes of incidents from operational failures back to organizational roots, providing a detailed and layered view of incident causes. This model is particularly useful for identifying the interconnections between individual, supervisory, and organizational factors, but still modeling the incident linearly, acknowledging that multiple aspects of the system interact with each other, thereby generating sequences of consequential errors.

In the page below the diagram of the analysis is shown with the nanocodes that identifies the errors.

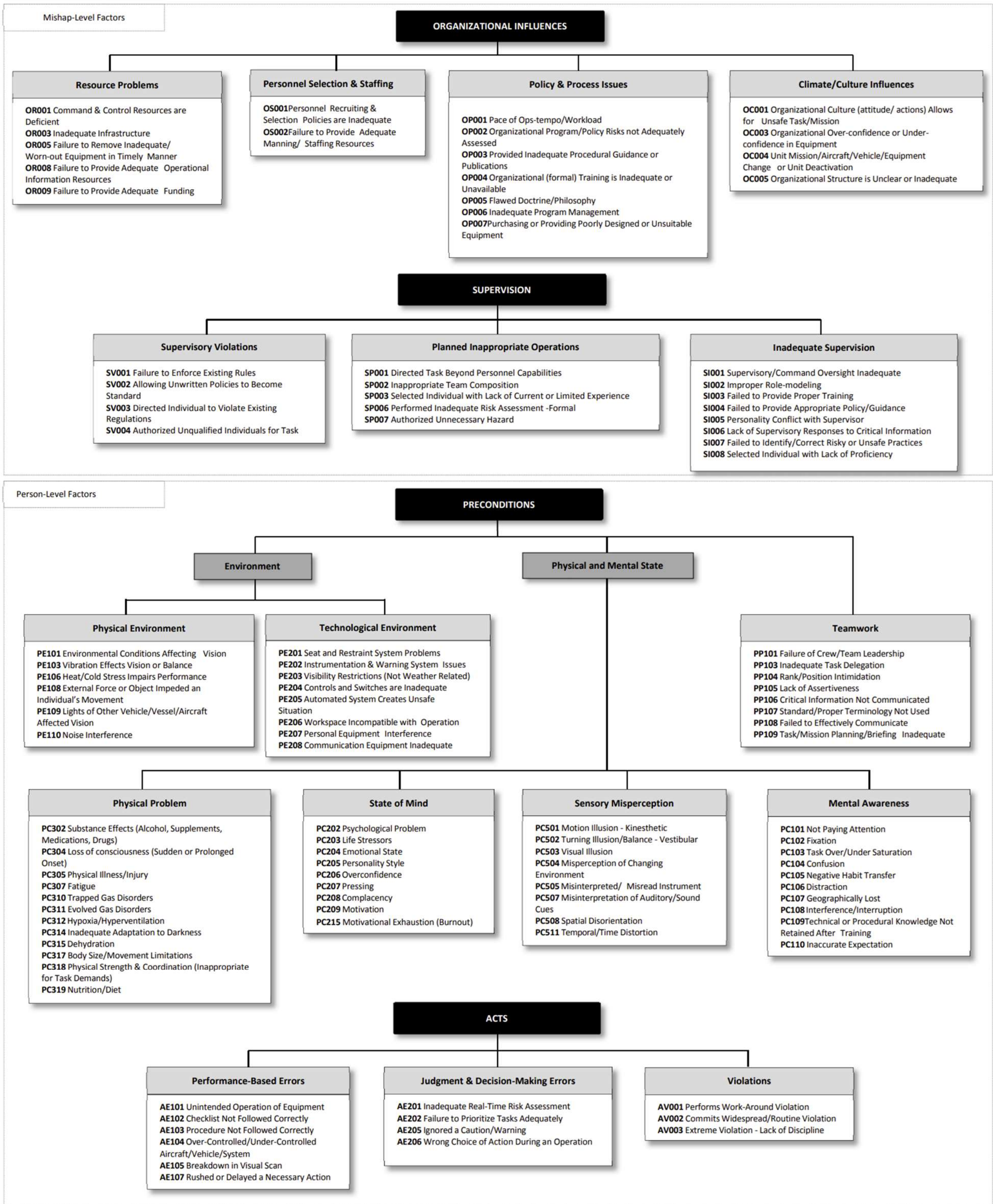


Fig. 1.2: *HFACS Structure*

In summary, while SHELL and HFACS focus on interactions and hierarchical causes of errors, respectively, FRAM offers an analysis based on understanding functional dynamics and variability within the system, considering that the actions leading to positive events are the same as those leading to negative events, and it is only the final outcome that defines the effect on the system. This provides a more modern and complex perspective on operational safety.

Such comparison with the two mainly utilized and just described methods will be revisited in the analysis of the Iberia 5570 flight incident presented in this thesis.

Chapter 2

A serious incident: the collision of an A320-216 aircraft with two de-icing vehicles

On January 20, 2016, Iberia flight 5570 departing from Munich Airport towards Madrid, with 110 passengers and 6 crew members on board, has been involved in a collision with two de-icing vehicles during the *de-icing* procedure.

2.1 The incident dynamics

After receiving instructions from Apron Control, the aircraft taxied from the parking position to the holding position S6. Subsequently, the flight crew contacted Munich Air Traffic Control (ATC) at **07:41** and received instructions to continue taxi via taxiway S to the de-icing area DA14.

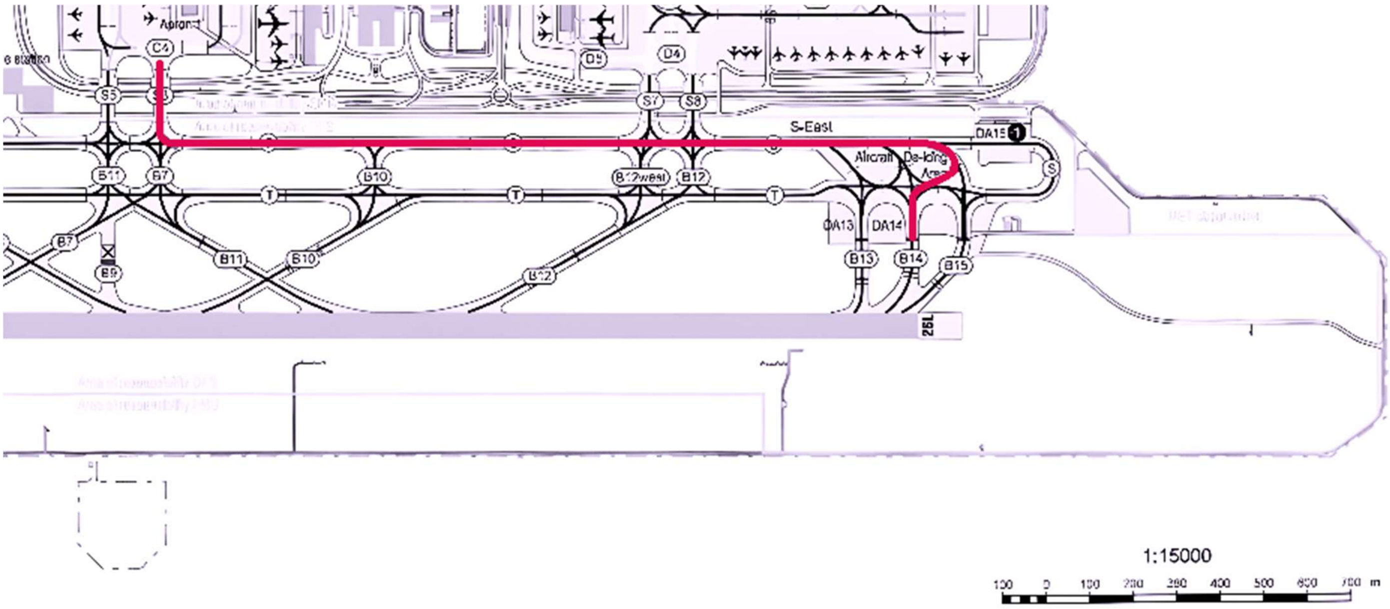


Fig. 2.1: *Munich Airport map with aircraft movement highlighted*

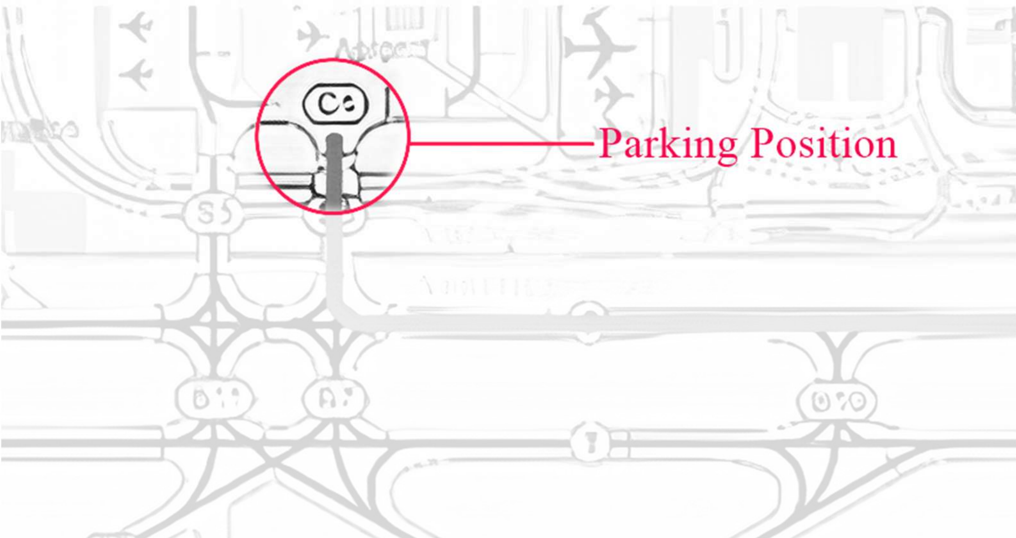


Fig. 2.2: *Iberia flight 5570 parking position*

According to Flight Data Recorder (FDR) data, the aircraft taxied on taxiway S at a speed of approximately 20 knots. From the Cockpit Voice Recorder (CVR) recordings, it appears that the co-pilot listened to the ATIS (Automatic Terminal Information Service) during taxiing and later informed the Pilot in Command (PIC) about its content, while the aircraft was taxiing straight, passing the intersection for taxiway B14 at approximately 20 knots at **07:45:32**.

About 60 meters east of the intersection, the aircraft's speed began to decrease, reaching approximately 6 knots at **07:45:50**.

After the ground controller became aware that the aircraft had overshoot the authorized taxiway, the following instruction was given to the flight crew at **07:45:52** am:

«*Maintain position* […]»– followed, after about 20 seconds, by –«[…] *you overshot de-icing area One Four, Bravo One Four. Can you make a sharp right turn to Bravo one four and the de-icing area?*».

After the crew's affirmative response, the aircraft reversed direction, taxiing back towards DA14.

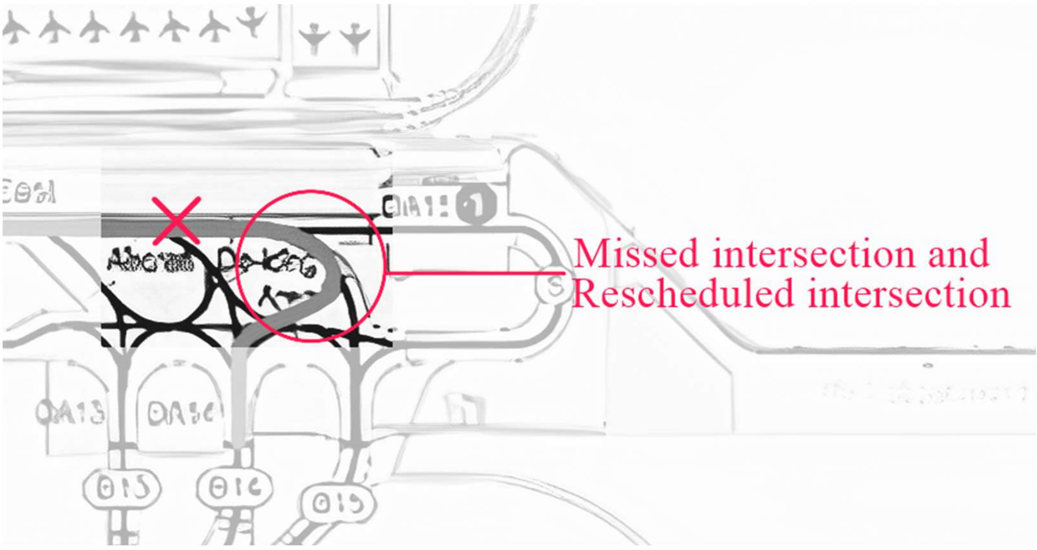


Fig. 2.3: *Missed intersection and rescheduled intersection*

At **07:47:39** am the ground controller requested the Flight crew to switch to the de-icing frequency, and the crew confirmed the frequency change. According to the CVR, the pilots established radio contact with the de-icer at **07:48:08** am;

the de-icing vehicle lead asserted:

«*Please stop at the de-icing holding area and confirm that the parking brake is set and the aircraft is ready for de-icing*»

and the crew confirmed the information:

«*We will do that. Confirmed.*»

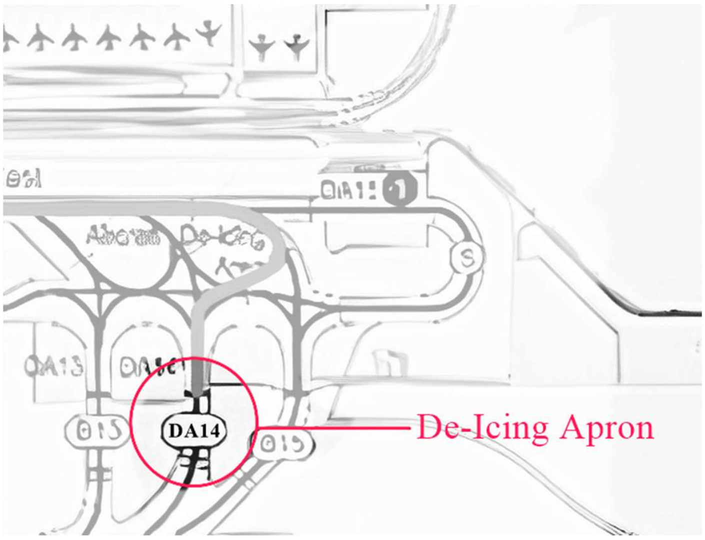


Fig. 2.4: *De-Icing Apron*

The de-icers were positioned respectively at the side lights of the taxiway, facing each other.

At **07:48:30** am the pilots began to complete the pre-deicing checklist:

- The **CAB PRESS** mode selector was selected and set to Auto;
- both **BLEED ENG1+2** were turned off;
- the **BLEED APU** was turned off.

At **07:48:49** am The captain asked the co-pilot to switch the DITCHING switch to ON, requesting confirmation:

«*Confirm DITCHING?*» - following which, after three seconds, the pilots began a conversation about whether the cargo fire suppression system had been activated at that moment instead of the DITCHING switch.

The communications continued as follows

07:49:09, De-icing vehicles team leader→ Flight crew

«[…] *are you ready for de-icing?*»

Flight crew → De-icing vehicles team leader

« *Ah, hold on* […]»

De-icing vehicles team leader→ Flight crew

« *Okay, de-icing commences and ah we, make a two-step and ah anti-icing with type one fluid a hundred percent, I call you back.*»

07:49:43, Flight crew → De-icing vehicles team leader
« *So control, […], we need to go back to the parking.*»

De-icing vehicles team leader→ Flight crew

« *Please […] please say it again*»

07:49:53, Flight crew → De-icing vehicles team leader

« *We need to go back to the stand please. We have one problem.*»

07:49:55, De-icing vehicles team leader→ Flight crew

« *You have technical problems, we will wait.*»

07:50:25, Flight crew → Ground controller (through ATC ground frequency)

« *Yeah we have a technical problem. We need to go back to the parking area.*»

The ground controller confirmed and, after coordinating with the tower, informed the flight crew approximately two minutes later:
« So we have to take you later then via the runway. So initially hold position here and monitor tower one two zero five. He will call you. »

The German Federal Bureau of Aircraft Accident Investigation (BFU) has a photo taken by an employee of the de-icing company from the adjacent DA13. The image, shown below, documents the positions of the aircraft and de-icing vehicles, as well as the weather conditions at the time **07:52** am.

Fig. 2.5: *Iberia flight 5570 on DA14 at 07:52 am ph. from the adjacent deicing area DA14*

The control tower contacted the flight crew, instructing how the aircraft should move: according to this clearance, the aircraft was supposed to taxi on the runway after the passage of two other landing aircraft, then immediately vacate it to enter taxiway B13. After receiving acknowledge from the flight crew, at **07:54:16** am, the controller continued, saying:

« *Ok, prepare for that and I will give you a call as I said behind the second landing traffic.* »

At **07:56:54** am the controller said:

« […] *as we talked about line up runway two six left, make a one eighty and vacate the runway via bravo one three*. »

The crew acknowledged this.

The FDR recording confirms that at **07:56:57** am, the parking brake was released and the thrust levers of both engines were pushed forward, resulting in an increase in N1 engine thrust at **07:57** am, causing the aircraft to start moving up to a speed of approximately 3 knots. At **07:57:10** am, the FDR recorded a longitudinal acceleration change from 0.2 g to -0.15 g.

Two seconds later, the wheel brakes were applied, and at **07:57:16** am, the parking brake was re-engaged.

At **07:57:51** am the de-icer shouted via the radio:

« […] *what have you ... what do you doing?* »

The Pilot In Command (PIC) replied:

« *Sorry, sorry, we were cleared to entering the runway and we leaving contact you. What has happened?* »

The deicer operator answered: « *What have you done. Now we are crashed.*

You ... please stop now. »

The pilot acknowledged this replying «*We have stopped* ».

At **07:58:23** am the pilot informed the controller that the airplane collided with both de-icing vehicles.

Fig. 2.6: *Iberia flight 5570 on DA14 after the collision; overhead view.*

Fig. 2.7 : *Iberia flight 5570 on DA14 after the collision; lateral view*

2.2 The events that led to the incident

Summarizing, therefore, how the events unfolded, during ATIS listening, the flight crew inadvertently overshoot a designated taxiway. While preparing for de-icing, they completed the checklist meticulously, but the co-pilot mistakenly activated the cargo compartment fire extinguishing switch instead of the ditching switch. Despite the PIC's hesitation regarding de-icing readiness, routine communication ensued. When the PIC decided to return to parking due to technical issues, the team leader misunderstood, expecting only a delay. Unaware of the miscommunication and due to the lack of situational awareness regarding the events occurring around the aircraft the PIC, after setting the radio to the appropriate frequency, communicated to the ground controller the intention to taxi back. After receiving instructions from Munich Tower, the aircraft began moving, resulting in a collision with de-icing vehicles.

From the transcripts of the communications during the events described so far, it seems to be clear that the lack of clarity in communications, exacerbated by the absence of standardized phraseology for pilots and de-icing personnel (and the resulting misunderstandings), was a key if not the primary factor in the incident, as reported in the investigation report prepared by the BFU. However, it is evident that both organizational and psychological conditions, particularly concerning the cockpit crew, significantly influenced the unfolding of events. Furthermore, the incident investigation conducted here relies on the traditional approach of focusing on identifying the underlying cause of failures in technological systems or procedures, which is rooted in the "*fault-finding*" tradition dating back to the Industrial Revolution. This approach assumes that a mechanical system will function properly unless there is a failure or malfunction.

However, this assumption may not hold true for socio-technical systems, where understanding the complexities of human behavior and organizational dynamics is crucial. Unlike mechanical systems, human behavior and organizational processes are not predictable, making it challenging to determine what should have occurred. Therefore, investigations, whether of past or future events, must begin by establishing what should have gone right rather than assuming a predetermined outcome.

Chapter 3

Analysis of the event through the Functional Resonance Analysis Method (FRAM)

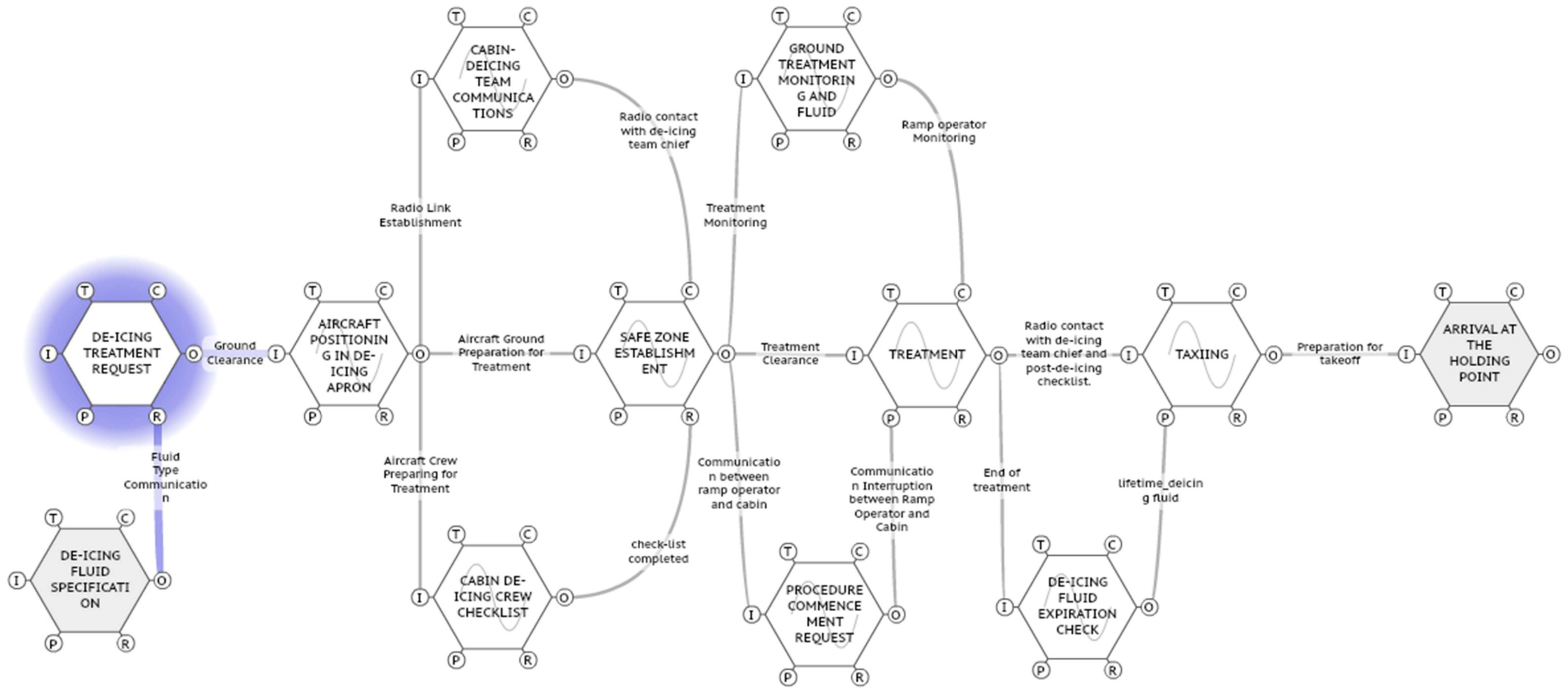
The analysis of this incident will commence with an examination of the intended procedure, identifying process steps, describing the *Work as Imagined* (WAI). Subsequently, it will proceed to assess the day-to-day execution of tasks, defined as *Work as Done* (WAD), followed by an exploration of system variability and the impact of increased variability on the onset of the emergence.

3.1 Work as Imagined

The *Work as Imagined* represents the procedure as outlined in the airport staff Standard Operating procedures, a model that highlights the focal elements to be executed to achieve the desired outcome. In the present case, the WAI scheme described through the graphical representation of the FRAM model is provided in the next page.

The representation below illustrates as the starting point the request for aircraft de-icing treatment, a step performed by the cockpit crew while the aircraft is still in the parking area, while the final step indicates arrival at the holding point. Through this model, it is possible to study which steps and/or connections could result in increased, decreased, or non-impactful variability of the system, comparing it with the WAD model, which includes errors, delays, and non-compliance. Moreover, in the development of the model, the time factor has been omitted, due to its lack of precise specification: considering a complex socio-technological system, incorporating time could introduce unnecessary complications because of the natural fluctuations in the process.

The process is set to start with the function *De-Icing treatment request* and end with the function *Arrival at the holding point* (in the next page - **Fig. 3.1**: WAI diagram) .



DE-ICING TREATMENT REQUEST
Ground Clearance
AIRCRAFT POSITIONIN G IN DE-ICING APRON
Radio Link Establishment
CABIN-DEICING TEAM COMMUNICA TIONS
Aircraft Ground Preparation for Treatment
Aircraft Crew Preparing for Treatment
CABIN DE-ICING CREW CHECKLIST
Radio contact with de-icing team chief
check-list completed
SAFE ZONE ESTABLISHM ENT
Treatment Monitoring
GROUND TREATMENT MONITORIN G AND FLUID
Ramp operator Monitoring
Treatment Clearance
Communicatio n between ramp operator and cabin
PROCEDURE COMMENCE MENT REQUEST
Communicatio n Interruption between Ramp Operator and Cabin
TREATMENT
End of treatment
DE-ICING FLUID EXPIRATION CHECK
lifetime_deicin g fluid
Radio contact with de-icing team chief and post-de-icing checklist.
TAXIING
Preparation for takeoff
ARRIVAL AT THE HOLDING POINT
Fluid Type Communicatio n
DE-ICING FLUID SPECIFICATI ON

The functions within the model, depending on their type, will be characterized by different intrinsic variability (as reported in Chapter 1). Therefore, they have been defined as follows:

FUNCTION NAME	FUNCTION TYPE
DE-ICING TREATMENT REQUEST	Human
DE-ICING FLUID SPECIFICATION	Human
AIRCRAFT POSITIONING IN DE-ICING APRON	Human
COCKPIT-DEICING TEAM COMMUNICATIONS	Human
CABIN DE-ICING CREW CHECKLIST	Organizational
SAFE ZONE ESTABLISHMENT	Organizational
PROCEDURE COMMENCEMENT REQUEST	Human
GROUND TREATMENT MONITORING AND FLUID DISTRIBUTION CONTROL ON AIRCRAFT	Human
TREATMENT	Human
DE-ICING FLUID EXPIRATION CHECK	Organizational
TAXIING	Human
ARRIVAL AT THE HOLDING POINT	Human

Tab. 3.1: *Correlation between the functions and their respective types*

As evident from Table 1.6, the majority of functions in this model are categorized as *Human*, thus primarily associated with human action.
The variability in human performance occurs frequently and exhibits significant magnitude.

High frequency indicates the ability for rapid fluctuations in performance, sometimes happening from one moment to the next.

Humans display prompt reactions to changes, especially in their interactions with others. Moreover, the large amplitude implies that differences in performance can be substantial, occasionally leading to dramatic shifts, either for better or for worse.

On the other hand, the frequency of *Organizational* performance variability tends to be low, while the amplitude is significant. The low frequency indicates that organizational performance evolves gradually, often accompanied by high inertia. However, the differences in performance, or the amplitude, can be substantial. This implies that the change in the case of *Operational* type functions occurs very slowly over time, such as legislative or procedural adjustments.

3.1.1 Model description

In the following paragraph all of the function of the FRAM method will be described.

1. Deicing treatment request;
2. Deicing fluid specification;
3. Aircraft positioning in deicing area;
4. Cabin deicing crew checklist;
5. Cockpit crew - deicing team communications;
6. Safe zone establishment;
7. Procedure commencement request;
8. Ground treatment monitoring and fluid distribution control on aircraft;
9. Treatment;
10. Deicing fluid expiration check;
11. Taxiing;
12. Arrival at the holding point.

For all functions, the following tables will also highlight the connections (and their descriptions) with those that are related.

Function Name	De-icing treatment request
Description	Aircraft treatment request and evaluation of the type of treatment required; the notification of the treatment shall include flight-number, aircraft-type and parts of aircraft (e.g. wing, underwing, gear etc.) to be deiced. Clear-ice conditions on wing and special checks (e.g. hands on or tactile check) shall be reported to the deicing coordinator with deicing notification also. This notification is automatically transferred to ATC to build up the pre-departure sequence. [2]
Input	
Output	Ground clearance
Precondition	
Resource	Fluid type communication
Control	
Time	

***Tab. 3.1.1**: Deicing treatment request*

Function Name	De-icing treatment request
Description	Cockpit crew specifies the composition of the de-icing fluid in terms of the percentage of glycole and water
Input	
Output	Fluid type communication
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.2**: De-icing fluid specification*

Function Name	Aircraft positioning in deicing apron
Description	The aircraft taxies from the parking area to the deicing spot
Input	Ground clearance
Output	Aircraft ground preparation for treatment Radio link establishment Aircraft crew preparing for treatment
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.3**: Aircraft positioning in deicing apron*

Function Name	Cabin de-icing crew checklist
Description	The cockpit crew goes through the de-icing checklist preparing the aircraft for the treatment
Input	Aircraft crew preparing for treatment
Output	Check-list completed
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.4**: Cabin de-icing crew checklist*

Function Name	Cockpit crew - deicing team communications
Description	The cockpit crew establish a radio contact with the de-icing team chief on a specific frequency
Input	Radio link establishment
Output	Radio contact with de-icing team chief
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.5**: Cockpit crew - deicing team communications*

Function Name	Safe zone establishment
Description	Establishment of a safe zone around the aircraft, enabling unobstructed movement for deicers performing the process and maintaining the correct distance between them and the aircraft to prevent conflicts. Additionally, communication must be provided to the treatment crew regarding the type of fluid that will need to be used. Hermetic sealing of all access points to the aircraft.
Input	Aircraft ground preparation for treatment
Output	Communication between ramp operator and cabin Treatment Clearance Treatment Monitoring
Precondition	
Resource	Check-list completed
Control	Radio contact with de-icing team chief
Time	

***Tab. 3.1.6**: Safe zone establishment*

Function Name	Procedure commencement request
Description	Communication between the de-icing team and the flight crew; such communication must be clear to avoid misunderstandings that may lead to errors. Additionally, the type, mixture ratio of the de-icing fluid, and the surfaces to be treated are specified.
Input	Communication between ramp operator and cabin
Output	Communication Interruption between Ramp Operator and Cockpit crew
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.7**: Procedure commencement request*

Function Name	Ground treatment monitoring and fluid distribution control on aircraft
Description	Monitoring vehicle positioning over time, monitoring safe distance between deicers, monitoring safe distance between deicers and aircraft, monitoring safe distance between deicers and other ground vehicles/obstacles. Monitoring proper fluid distribution to prevent unevenness and buildup across the entire aircraft.
Input	Treatment Monitoring
Output	Ramp operator Monitoring
Precondition	
Resource	
Control	
Time	

Tab. 3.1.8: *Ground treatment monitoring and fluid distribution control on aircraft*

Function Name	Treatment
Description	Vehicles approach; commencement of product distribution, followed by communication of treatment completion to the cockpit crew and removal of deicing vehicles from around the aircraft, along with communication of ground deicers to maintain a safe distance from the aircraft.
Input	Treatment Clearance
Output	Radio contact with de-icing team chief and post-de-icing checklist. End of treatment
Precondition	Communication Interruption between Ramp Operator and Cabin
Resource	
Control	Ramp operator Monitoring
Time	

Tab. 3.1.9: *Treatment*

Function Name	Taxiing
Description	After completing the de-icing procedures, the cockpit contacts ATC to resume taxiing and to a take-off position
Input	Radio contact with de-icing team chief and post-de-icing checklist.
Output	Preparation for takeoff
Precondition	Lifetime_deicing fluid
Resource	
Control	
Time	

***Tab. 3.1.10**: Taxiing*

Function Name	Arrival at the holding point
Description	At this point the aircraft waits for the clearance from the tower for the take off
Input	Preparation for take-off
Output	
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.11**: Arrival at the holding point*

Function Name	Deicing fluid expiration check
Description	Check for the waiting time to be less than the de-icing fluid expiation time; due to the characteristics of the de-icing fluid, the waiting time for the airplane to take/off must be less than the de-icing fluid expiation time, or the liquid will be ineffective and it will be necessary to repeat the treatment.
Input	Preparation for takeoff
Output	
Precondition	
Resource	
Control	
Time	

***Tab. 3.1.12**: Deicing fluid expiration check*

3.2 Work as Done

The work as executed has undergone variations compared to what was prescribed by the procedures, as can be seen from the FRAM diagram below. To understand how the incident occurred, it is necessary to study, function by function, the different behavior compared to what was anticipated, analyzing its effect on the system's variability.

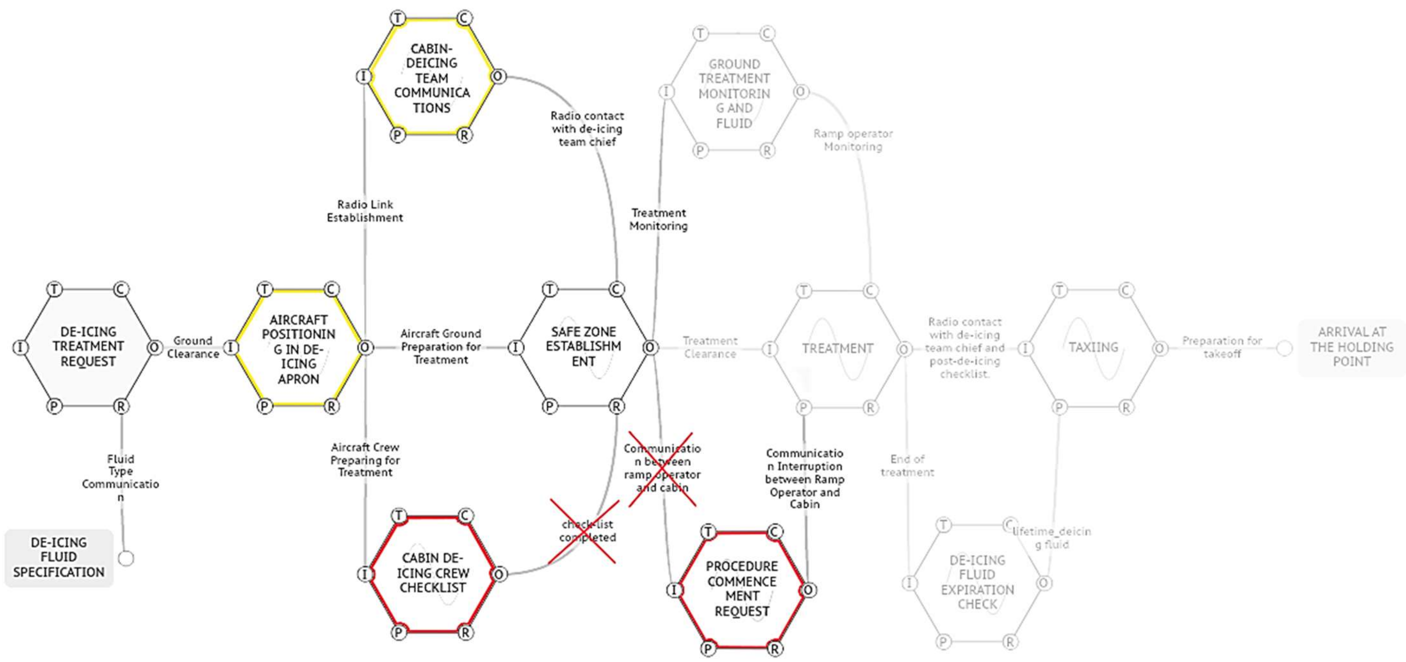


Fig. 3.2: *WAD scheme for the Iberia flight 5570*

3.2.1 Approaching the De-Icing apron

As evidenced in the archival photograph included in the report by the authorities [**Fig. 2.5**], the weather conditions were not favorable, due to limited visibility. During the taxiing phase from the parking area to the de-icing stand, the pilot mistakenly missed the correct track, resulting in a deviation from the aircraft's intended taxi route and a request from Ground Control to perform a sharp maneuver to reach the designated DA14 area. Due to this fact, the variability of the function associated with the positioning of the aircraft at the station increases, caused by the delayed completion of the function itself, as shown below.

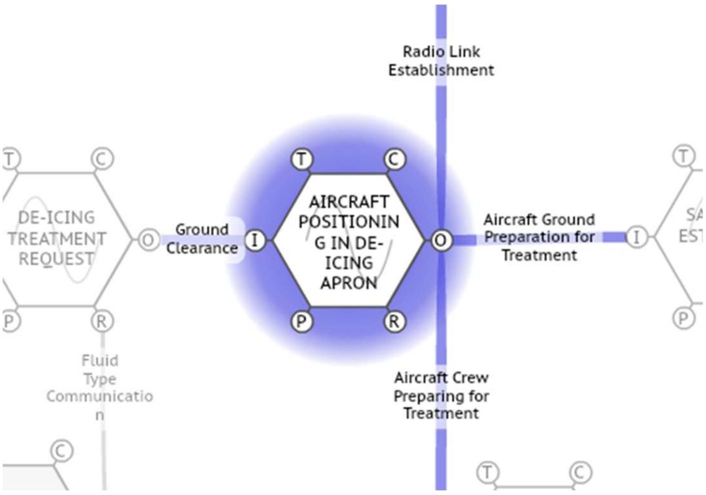


Fig. 3.3: "*Aircraft positioning in the de-icing apron*" function

		Upstream OUTPUT coupling variability
		INPUT
Variability over temporal range	**TOO LATE**	**V+**
Variability over precision range	**IMPRECISE**	**V+**

Tab. 3.2.1: *Variability over temporal and precision range*

3.2.2 Pre-deicing checklist

Following the incorrect approach to the designated path for positioning at the de-icing station and the subsequent maneuver assigned by ground control, the crew started the pre-deicing checklist; during this procedure, the fire extinguishers in the cargo hold were inadvertently activated.

Upon detecting this issue, the crew halted the checklist to report the incident. This event introduced variability into this function and prevented the complection of the checklist.

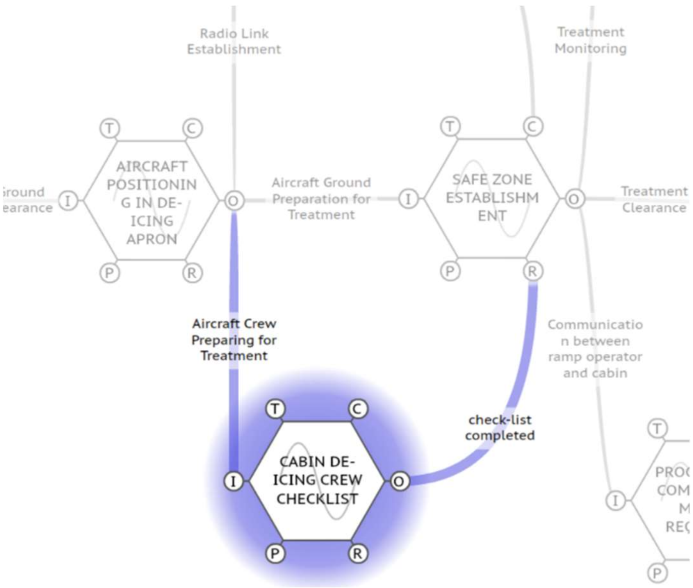


Fig. 3.4: "*Cabin de-icing crew checklist*" function

		Upstream OUTPUT coupling variability
		INPUT
Variability over temporal range	**TOO EARLY**	**V+**
Variability over precision range	**IMPRECISE**	**V+**

Tab. 3.2.2: *Variability over temporal and precision range*

3.2.3 Cabin/de-icing team communications

During communication with the de-icing team, the use of non-standard phraseology resulted in a misunderstanding between crews. Although the cockpit crew communicated the need to return to the parking area due to an issue in the cargo hold, the de-icing team did not understand the problem, initially stating that they would commence the procedure. After the pilot reiterated the onboard issue, the de-icing team only understood that they should wait before starting the work, but not that the aircraft needed to move from its current position.

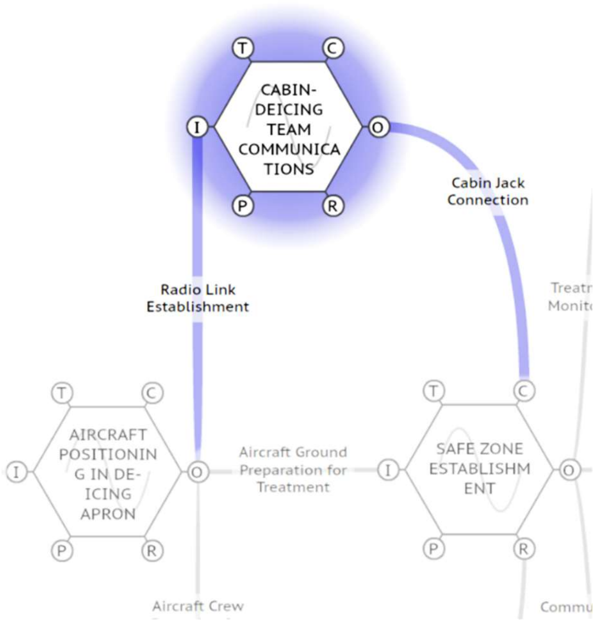


Fig. 3.5: *Cabin/de-icing team communications*

		Upstream OUTPUT coupling variability
		INPUT
Variability over temporal range	**ON TIME**	V=
Variability over precision range	**IMPRECISE**	V+

Tab. 3.2.3: *Variability over temporal and precision range*

3.2.4 Procedure commencement request

At this point the communication passed from the de-icing team to ground control which, after receiving the communication of the need to return from the aircraft, notified the pilots of the directions for returning to the parking lot. Once again the lack of regulated phraseology led to further misunderstandings, causing the aircraft to start moving before authorization was given. Additionally, it should be noted that communications between the cockpit crew, ground, and de-icers were not conducted on the same frequency, thereby 'fragmenting' the communication. Furthermore, from the PIC's perspective, the de-icing operation was assumed to be terminated.

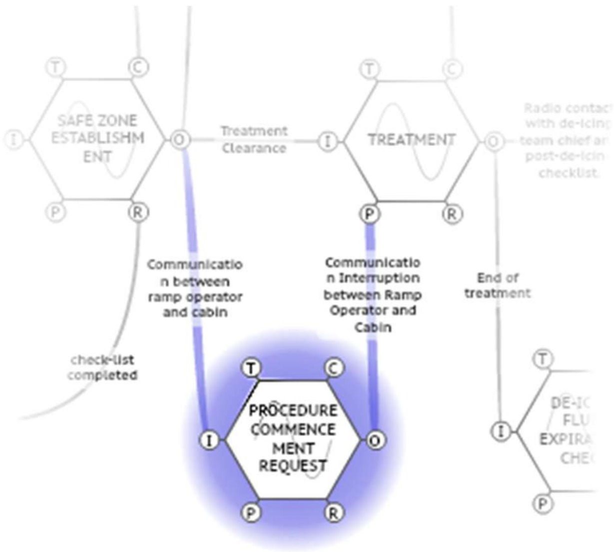


Fig. 3.6: *Procedure Commencement request*

		Upstream OUTPUT coupling variability
		INPUT
Variability over temporal range	**ON TIME**	V=
Variability over precision range	**IMPRECISE**	**V+**

Tab. 3.2.4: *Variability over temporal and precision range*

3.3 System variability analysis

In the following summary table, it is possible to see which functions have adhered to the Work As Imagined and which don't. It should be noted that, according to the FRAM logic, background functions – those functions characterized solely by an output and not by an input and an output – are not subject to variability, which is instead absorbed by the foreground functions.

FUNCTION NAME	OUTPUT	TIME	PRECISION
Deicing treatment request	Ground clearance	ON TIME	PRECISE
Aircraft positioning in deicing apron	Aircraft ground preparation for treatment Radio link establishment Aircraft crew preparing for treatment	TOO LATE	IMPRECISE
Pre-deicing checklist	Check-list completed	TOO EARLY	IMPRECISE
Cockpit crew - deicing team communications	Radio contact with de-icing team chief	ON TIME	IMPRECISE
Safe zone establishment	Communication between ramp operator and cabin Treatment Clearance Treatment Monitoring	ON TIME	ACCEPTABLE
Procedure commencement request	Communication interruption between ramp operator and cockpit crew	ON TIME	IMPRECISE
Ground treatment monitoring and fluid distribution control on aircraft	Ramp operator Monitoring	X	X
Treatment	Radio contact with de-icing team chief and post-de-icing checklist End of treatment	X	X
Deicing fluid expiration check			X
Taxiing	Preparation for takeoff	X	X
Arrival at the holding point			X

Tab. 3.3: *System's variability overview*

The tables reveal that none of the functions succeed in mitigating the variability of the system, which, as a result, progressively increases across the entirety of the model. All functions that were intended to follow the incidental event, as clearly outlined by WAI, were evidently not executed, thus impacting not the "subsystem" of the aircraft, but rather the broader airport system.
It is emphasized that this type of study can be comprehensive, as it allows for the expansion of the model under examination, enabling the integration of multiple different subsystems to create a more extensive model.

This is of critical importance for an environment as complex and densely interconnected in all its aspects as an airport, where any deviation from routine operations, no matter how minor, has the potential to affect the entire system (whether positively or negatively).

Chapter 4

A merged model: the performance of the FRAM method combined with the practicality of the HFACS method.

The FRAM analysis, theorized by E. Hollnagel, while allowing for effective modeling and study of complex socio-technological systems, does not provide insights for action on the system or its improvement, lacking in practicality. For this reason, professors P. Maggiore and M. Gajetti from the *Politecnico di Torino* propose a combination with the HFACS method, which has been explained previously. This method categorizes the causes of errors, which can be useful for our study as it suggests actions aimed at mitigating or preventing the specific errors in question. This additional step enables those conducting the study to provide clear and precise guidance to the airport authority, the ground handler, or the airline, so that they can implement the appropriate modifications to reduce the likelihood of the incidental event recurring, since this allows for alignment with established terminology in the aeronautical field.

4.1 Assignment of HFACS nanocodes to FRAM Functions

FUNCTION	ISSUE	HFACS NANOCODE
Aircraft positioning in the de-icing apron	The pilot mistakenly missed the correct track	PC106 - Distraction
Pre-deicing checklist	During the pre-deicing checklist, the fire extinguishers in the cargo hold were inadvertently activated, so the crew halted the checklist to report the incident.	PP111 - Task/mission-in-progress re-planning PC108 – Checklist interference PC207 – Pressing
Cabin/de-icing team communications	Although the cockpit crew communicated the need to return to the parking area due to an issue, the de-icing team did not understand the problem.	PP107 – Standard proper terminology PP112 - Miscommunication
Procedure commencement request	Ground control informed the aircraft of the instructions for returning to the parking area, not giving the authorization to move.	PP107 – Standard proper terminology

Tab. 4.1: *HFACS nanocodes association to FRAM functions*

- **PC106 – Distraction**

Distraction is a factor when the individual has an interruption of attention and/or inappropriate redirection of attention by an environmental cue or mental process that degrades performance.

In the case under analysis, insufficient attention was given to the taxiing towards the de-icing area, leading to the revision of the aircraft's operations and a build-up of delays, as well as the requirement for a complex operation by the aircraft to reach the designated runway.

- **PP111 - Task/mission-in-progress re-planning**

Task/mission-in-progress re-planning is a factor when crew or team members fail to adequately reassess changes in their dynamic environment during mission execution and change their mission plan accordingly to ensure adequate management of risk.

Due to the failed approach to the prescribed taxiway, the aircraft taxi route has been re-planned, causing delays in schedule and requiring the pilots to perform a complex maneuver, such as making a turn of nearly 90 degrees.

- **PC108 - Checklist interference**

Checklist Interference is a factor when an individual is performing a highly automated/learned task and is distracted by another cue/event that results in the interruption and subsequent failure to complete the original task or results in skipping steps in the original task.

During the execution of the pre-deicing checklist, an incorrect button was pressed, not aligned with the required functionality specified in the checklist. This error, likely influenced by the highly automated nature of the procedure and compounded by stress from prior events, triggered the discharge of the fire extinguishers in the cargo hold, leading to the immediate cessation of all subsequent procedures.

- **PC207 – Pressing**

Pressing is a factor when the individual knowingly commits to a course of action that presses them and/or their equipment beyond reasonable limits.

The accumulation of unforeseen events caused stress among the cockpit crew, leading to a decrease situational awareness and clarity in communications, also due to the lack of dedicated phraseology.

- **PP107 – Standard proper terminology**

Standard/proper terminology is a factor when clear and concise terms, phrases hand signals, etc per service standards and training were not used.

That kind of event has not a proper phraseology; that led to a miscomprehention between the cockpit crew and the de-icing team.

Upon revisiting the FRAM analysis of the WOD in light of the recent discussion, it is feasible to identify the functions whose variability has surpassed the thresholds established by the system's performance parameters. The identified HFACS nanocodes can then be applied to these functions accordingly.

Chapter 5

From direct observation of the procedure to pilot experiences: an analysis of the current de-icing processes for aircraft across different categories.

Thanks to the opportunity given to the author of this thesis by S.E.A. to observe firsthand the de-icing procedure as it is performed at Milan Malpensa Airport in 2024, this chapter will present the process, highlighting the aspects that, in the case of the Munich incident, would have mitigated the variability of the functions. Additionally, the contributions of Captain Floriani and the interview of crew from different airlines and type of aircraft will be included, each offering insights from the pilot's perspective for their respective aircraft category.

5.1 A learning experience observed at Malpensa Airport (MXP)

After passing through various levels of security checks and gathering the necessary materials to attend the procedure, the author of this thesis was guided to the de-icing area at Malpensa Airport, where it was possible to observe directly in person what had previously only been studied through documents and reports. The de-icing procedure commences with the thorough preparation of the aircraft and meticulous coordination among the various personnel involved.

Once the aircraft has been assigned a de-icing position, it will proceed towards the designated spot until it reaches the entrance of the area, where it will wait for the arrival of the "FOLLOW ME" vehicle. This vehicle guides the aircraft to the precise assigned position where the de-icing treatment will take place. The presence of the "FOLLOW ME" vehicle is of critical importance, as it helps minimize potential positioning errors of the aircraft, as well as prevent any premature movements in relation to the airport's schedule.

The de-icing team is coordinated by a ground handler specifically trained, the *ramp agent*, who plays a critical role in facilitating communication between the ground crew and the flight crew:

after the aircraft has been positioned and the "FOLLOW ME" vehicle has completed its task, the ramp agent approaches the aircraft and establishes a direct connection with the cockpit using a headset plugged into the aircraft. This connection allows for direct and secure communication with the pilots, ensuring that all necessary information is exchanged in real time.

Before the de-icing procedure begins, the ramp agent receives confirmation from the pilots regarding the type of de-icing fluid to be used and the specific surfaces to be treated.

This information is already available to the de-icer via an application on the tablet within the de-icing truck, which is updated based on the requests made by the flight crew to ground operations at the time of the de-icing request.

In the figure below, a photo of the interior of the de-icing truck cabin token at the de-icing spot of Malpensa Airport is shown.

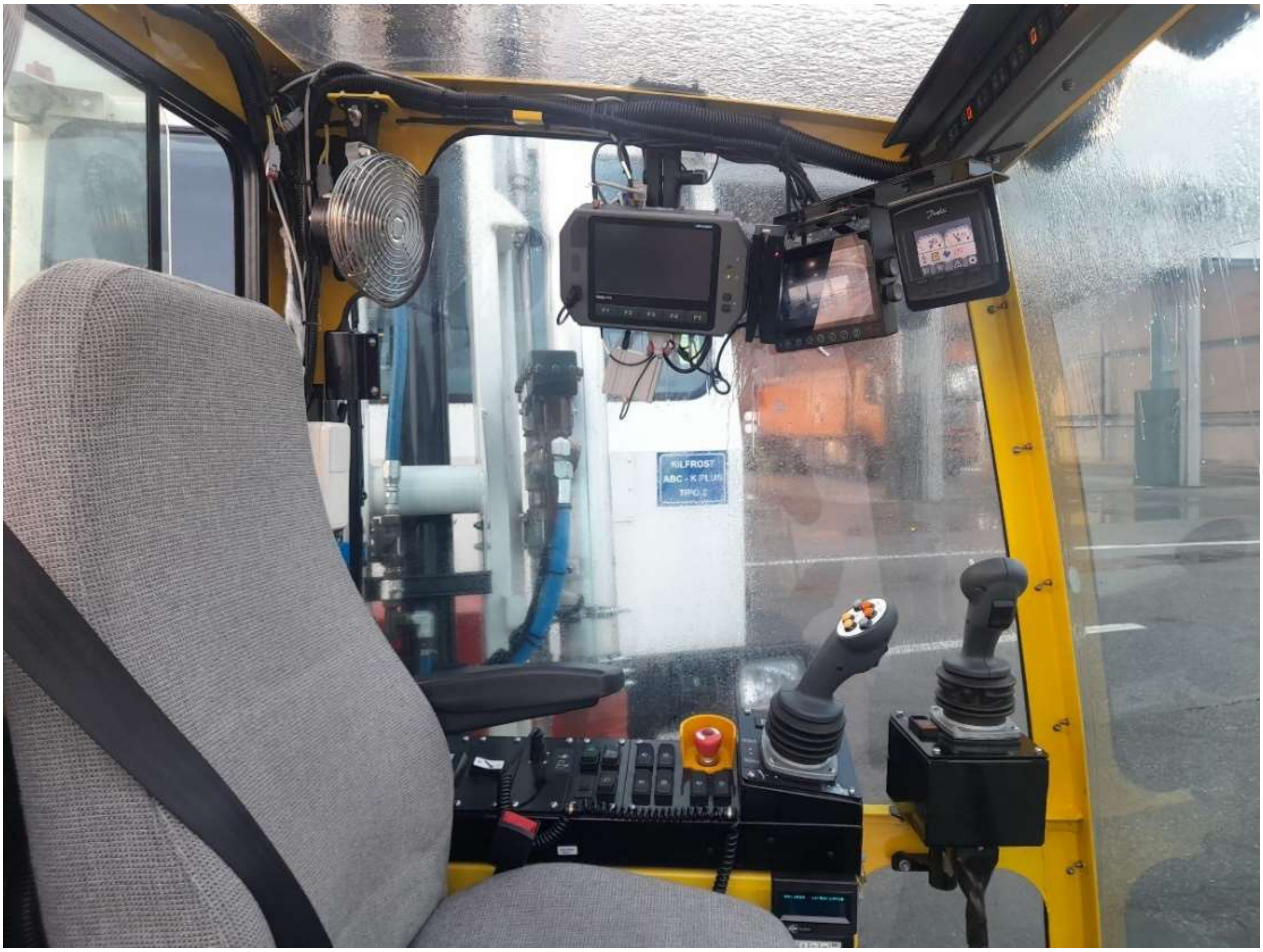


Fig. 5.1: *De-icing truck cabin*

Fig. 5.2: *Tablet through which informations are communicated to the de-icing operator.*

Regrettably, as it was not possible to observe the interior of the vehicle during the procedure, it was not possible to witness its active operation during the observation. Nevertheless, this allowed for the possibility of witnessing the procedure most commonly used at airports, specifically the radio communication between the cockpit and the ramp operator, followed by the exchange between the ramp and ground control. The latter communication was made available via a portable radio transceiver issued to airport staff, which can be tuned to various frequencies, including the one dedicated for de-icing communications.

Once all preliminary checks have been completed and the pilots have given their clearance, the ramp agent disconnects the headset, signaling that the de-icing procedure can commence.

Upon receiving clearance from the flight deck, the de-icer, stationed in the de-icing truck, initiates the operation.

Fig. 5.3: *An aircraft during the treatment process*

Fig. 5.4: *An aircraft undergoing treatment in the presence of the ramp operator in front of the A/C*

Fig. 5.5: *Detail of the previous photo - ice accumulation on the fuselage*

During the application, the de-icing operator carefully monitors the flow and distribution of the fluid, ensuring that all critical surfaces, such as the wings, fuselage, tail horizontal surface, and vertical stabilizer, are treated thoroughly. The tablet provides continuous feedback on the treatment status, allowing the operator to immediately correct any discrepancies.

Once the de-icing treatment is completed, the de-icer communicates with the ramp agent to inform them that the procedure has been finalized. The ramp agent then reconnects to the aircraft using the jack and headset to confirm to the pilots that the de-icing has been successfully accomplished as requested and that the aircraft is released for taxiing and takeoff.

At this point, the aircraft can safely proceed to the runway, with the assurance that all surfaces have been adequately treated to prevent ice formation.

Following the completion of the treatment, the aircraft is required by ATC to position itself in a holding area near the runway, in order to queue for takeoff. Should the wait time extend beyond the hold-over time, which is the "validity" period of the de-icing fluid, the aircraft will need to undergo the treatment again.

What emerges from the experience, in comparison to the sequence of events that occurred at Munich Airport, is that:

- The integration of the "FOLLOW ME" vehicle plays a pivotal role in reducing the variability associated with aircraft positioning on the apron. The vehicle ensures precise guidance for the aircraft, escorting it from the designated holding area to the de-icing position. This minimizes the potential for human error during aircraft maneuvering, particularly during complex ground operations. The relatively straightforward layout of the Munich Airport, which lacks intricate or challenging taxiways, further aids in reducing the likelihood of operational mistakes. The airport's design, combined with the assistance of the "FOLLOW ME" vehicle, mitigates the risk of errors that could arise during taxing, especially under adverse weather conditions or when pilots are unfamiliar with the airport layout. These factors significantly contribute to reducing the impact of human factors, specifically the potential issues identified by the HFACS (Human Factors Analysis and Classification System) nanocode PC106, which previously highlighted the potential for errors in this phase of aircraft handling. The reliable guidance provided by the vehicle helps ensure that aircraft arrive at the correct de-icing station efficiently, without unnecessary deviations or delays, thereby maintaining smooth operational flow.

- The use of direct communication via cable between the ground crew and the ramp operations introduces another layer of efficiency and safety. This method of communication offers a more immediate and reliable connection between the key personnel involved in ground operations. Specifically, it provides a direct line of communication to the ramp, who is in a unique position to have a clear and comprehensive understanding of the surrounding environment and the movements of the various elements involved in the operation. The enhanced situational awareness of the ramp, due to their proximity to the aircraft and other ground equipment, allows for better real-time decision-making. This direct communication channel also has the added benefit of shortening the overall communication chain, which in turn increases the speed of the decision-making process and reduces the possibility of miscommunication or delays that could occur in more traditional, less direct communication systems.

5.2 The procedure observed from the pilot's perspective

In furthering the investigation into the de-icing process, the perspectives of pilots from various types of aircraft and airlines provide critical insights into several operational aspects that directly affect performance. The objective of these interviews is to gather diverse viewpoints on how the de-icing procedure is managed across different operational contexts, while also exploring the challenges and complexities pilots encounter during this crucial phase of flight preparation. By engaging with pilots from a range of commercial airlines and general aviation aircraft, this chapter aims to offer a comprehensive understanding of the variability in de-icing practices, the communication protocols employed, and the impact of these factors on flight operations. Furthermore, the interviews seek to shed light on how pilots perceive the balance between standardized procedures and situational adaptability, and how this balance influences the overall safety and efficiency of de-icing activities. These firsthand accounts contribute valuable insights into the practical realities of de-icing, providing a deeper understanding of the intricacies involved and identifying potential areas for improvement within this essential aviation process.

5.2.1 Commercial aviation aircraft

With regard to commercial aviation aircraft, it has been noted that communications during the de-icing process are exclusively routed through ground control, without direct interaction between the cockpit and the de-icing operators via headset and an intercommunication system. This operational structure ensures that all relevant information concerning the procedure is transmitted well in advance, typically while the aircraft is still positioned in the parking stand. During this stage, details about the impending de-icing treatment are conveyed, allowing the cockpit to prepare accordingly. Once the aircraft transitions to the designated de-icing apron, communication becomes more focused and limited to confirming the completion of the procedural checklist and signaling the commencement or conclusion of the de-icing operation. This communication is conducted through a direct, wired connection between the cockpit and the ramp agent responsible for overseeing the procedure from the ground.

In relation to the de-icing checklist, pilots have indicated that it is relatively straightforward and unambiguous, thus minimizing the risk of any misinterpretations, even in the selection of specific controls within the cockpit. The simplicity of the checklist design ensures that the de-icing procedure can be carried out efficiently and accurately, avoiding operational delays or complications. Moreover, the phraseology used during these communications adheres to standardized aviation protocols, which are meticulously regulated to maintain consistency and clarity across various operational environments. This standardization serves to enhance the overall safety and effectiveness of the de-icing process, ensuring that all parties involved have a clear understanding of the procedures at hand.

However, it is important to note that the current communication protocols do not explicitly account for the possibility of an abort request for the de-icing procedure. This absence stems from the assumption that such a scenario is not typically required, given the structured nature of the operation. Nonetheless, in the event of an unforeseen issue or emergency, pilots may attempt to alert the ramp agent by non-verbal means.

This, however, poses a challenge due to the considerable physical distance between the aircraft and the agent, as well as the often adverse weather conditions that accompany de-icing operations, which can severely impair visibility. These constraints highlight potential areas for improvement, particularly regarding the need for more robust contingency measures and enhanced real-time communication channels, which would allow for greater operational flexibility and heightened safety in complex weather conditions.

5.2.2 General aviation aircraft

In the case of general aviation aircraft, Captain Floriani kindly provided valuable insights into the de-icing procedures specific to this area, offering a nuanced perspective that complements the broader understanding of commercial aviation processes. His experience shed light on the operational intricacies faced by general aviation pilots, particularly in smaller airports where certain protocols differ significantly from those observed at larger commercial hubs.

When a small aircraft remains parked outside overnight, frost can accumulate on critical surfaces, in particular the wings. It is imperative for the pilot to conduct a thorough tactile inspection before flight, as visual confirmation alone may be insufficient. If frost cannot be easily removed by a simple swipe of the finger, it signals the need for de-icing treatment. In general aviation, this decision is often discussed directly with the ground handler, facilitating a more personalized approach. This face-to-face communication enables the pilot and ground personnel to agree on the specific de-icing measures needed, ensuring that the process is tailored to the aircraft's condition and the prevailing weather.

Notably, such direct interaction is common in smaller airports, where the proximity between the aircraft and ground services allows for more immediate coordination. In larger airports, however, this level of communication may not be possible, necessitating the use of more formalized channels.
The composition of the de-icing fluid, as Floriani noted, is typically determined by the airport authorities rather than by the pilot or operator. While some airports, such as Malpensa, do not impose specific requirements on general aviation aircraft, others may mandate particular fluid compositions based on environmental factors or regulatory guidelines. This variability across airports requires pilots to be adaptable and informed about local de-icing regulations, ensuring compliance and operational safety.
One distinguishing feature most common in general aviation aircraft is the absence of wired communication between the cockpit and the ramp during de-icing procedures, a system commonly found in commercial aviation. Business jets, for instance, often lack this direct communication link, relying instead on visual signals or verbal exchanges between the pilot and ground crew. This approach requires greater situational awareness and precise coordination, as there is no formalized communication infrastructure to manage the de-icing process. The absence of wired communication, however, is balanced by the ability of the pilot to perform both visual and tactile inspections of the aircraft pre- and post-de-icing, allowing for direct confirmation that the treatment has been properly executed.
In terms of operational procedures, the de-icing checklist in general aviation is typically completed while the aircraft remains on the apron, prior to any movement. This ensures that all necessary precautions have been taken before the aircraft begins taxiing toward the runway. Communication during this phase may occur either verbally or through visual signals, depending on the available resources and the proximity of ground personnel.

Another notable operational difference is that, in general aviation, the engines often remain running during the de-icing procedure. This contrasts with some commercial aviation practices, where engines are shut down to minimize risks associated with fluid application.
In general aviation, however, the shorter duration of the de-icing process and the need for quick turnaround times often necessitate keeping the engines on, streamlining the procedure and reducing the time spent on the ground.
The actual de-icing process itself, while not entirely manual, still involves a more hands-on approach compared to large-scale commercial operations. Instead of using automated systems, the de-icing fluid is applied by an operator manually maneuvering a hand gun to spray the liquid. This method allows for greater precision in targeting the areas that require treatment, ensuring that the application meets the specific needs of the aircraft as determined by the pilot. Although this process requires more direct involvement from the ground crew, it provides a level of control that is essential in the smaller, more varied aircraft typically found in general aviation.
In general aviation, the possibility for the pilot to conduct visual and tactile inspections after the de-icing procedure further distinguishes these operations from those in commercial aviation. This step is particularly important in monitoring the holdover time, the period during which the de-icing fluids remain effective. By performing these inspections, the pilot can verify that the aircraft remains in compliance with safety standards, particularly in changing weather conditions that may impact the de-icing fluid's efficacy.
Ultimately, the de-icing procedures in general aviation are characterized by a blend of direct communication, operational flexibility, and hands-on methods.

For general aviation the reliance on pilot expertise, combined with the ability to perform real-time inspections, ensures that de-icing operations are both effective and adaptable to the specific demands of each flight. This approach highlights the importance of coordination between the cockpit and ground personnel, emphasizing the pilot's role in overseeing and ensuring the success of the de-icing process.

Chapter 6

Conclusions

Following the FRAM analysis of the accident at Munich Airport, and considering on-field observation alongside the accounts provided by experienced pilots, it becomes clear that the interconnection between technical malfunctions, human factors, and the standardization of procedures plays a critical role in complex aviation systems such as de-icing operations. Each of these components can act as either a mitigating or aggravating factor for the variability inherent in such systems, impacting the safety and efficiency of flight operations.

De-icing is a crucial procedure for ensuring flight safety, particularly in adverse weather conditions. It prevents the accumulation of ice and snow on critical aircraft surfaces, which could otherwise lead to a loss of aerodynamic performance. However, as evidenced by the FRAM analysis, the de-icing process is embedded within a system that involves the interaction of advanced technologies, personnel management, and standardized operational procedures. This system is subject to unforeseen variations, which are often exacerbated by external conditions such as severe weather or operational delays. The Munich accident provides a stark example of how these factors can interact and lead to tragic outcomes when not properly managed.

One of the key aspects highlighted in the analysis concerns the de-icing checklist.

While pilots interviewed for the study indicated that the checklist for de-icing is typically straightforward, immediate, and unlikely to be misunderstood—even during communication with the cockpit—the FRAM analysis revealed that stress induced by operational delays and adverse weather conditions can lead to errors in its execution.

This observation underscores the potential for human factors, especially stress, to compromise the accuracy of even well-defined and standardized procedures. Errors in aircraft movement or timing, coupled with pressure to meet operational slots, can negatively affect the flight crew's ability to maintain focus and adhere to the checklist, thereby jeopardizing the overall safety of the operation.

Moreover, another crucial finding from field analysis and pilot testimonies is the absence of standardized phraseology that would allow for the abortion of the de-icing procedure in the event of complications after the process has commenced. According to the pilots, this scenario is not typically accounted for in current operational regulations. Nevertheless, from both a safety and economic perspective, the lack of such phraseology can lead to significant inefficiencies. If an aircraft encounters a technical issue that requires it to return to the parking area after the de-icing process has begun, the entire operation is rendered futile. The de-icing fluid applied may lose its effectiveness due to elapsed holdover time—the period during which the treatment remains protective—thus requiring a repeat of the procedure. This not only leads to additional time and resource costs but also increases the likelihood of further operational delays, compounding the inefficiency.

This situation highlights the importance of establishing clear and precise phraseology for managing such eventualities. Without a regulated procedure allowing for the safe and orderly termination of the de-icing process, the system's variability is amplified, increasing the probability of human error and operational inefficiency.

The development of specific protocols that provide for the possibility of aborting the procedure in the event of complications would mitigate these risks and help reduce variability. This is particularly important given the complex and dynamic nature of de-icing operations, where multiple actors and systems must work in harmony under time-sensitive and often stressful conditions.

In addition to these operational concerns, it is essential to consider the psychological implications for the flight crew.

Being confronted with an unregulated and unfamiliar situation can impair the cockpit's ability to respond appropriately and in a timely manner. Without a specific procedural guide to follow, the risk increases that the crew, under pressure, may fail to perceive the reality of the situation accurately. This can result in the crew either replicating mistakes made in previous incidents or reacting in a way that exacerbates the situation. A case in point is the tragic accident in 2016, where the lack of standardized procedures to handle complications arising during the de-icing process contributed to a disastrous outcome.

Given these considerations, the necessity of standardizing communications and establishing specific procedures for managing unforeseen events during the de-icing process becomes evident. The regulation of clear and universally accepted phraseology, enabling pilots to terminate the treatment safely if needed, would not only improve operational efficiency but also significantly enhance risk management. Furthermore, these regulations should be complemented by more effective communication tools that facilitate continuous interaction between the cockpit and ground personnel throughout the de-icing procedure. This would reduce the risk of miscommunication and foster greater situational awareness among all parties involved, improving coordination and safety.

The FRAM analysis of the Iberia 5570 flight incident and the accompanying testimonies demonstrate how the absence of precise regulations, combined with external pressures, can amplify the variability within an already complex system. The standardization of procedures, along with careful consideration of the psychological dynamics affecting the crew, are key elements in mitigating this variability and enhancing the overall safety of de-icing operations. By codifying these aspects through clear, regulated protocols, future incidents may be prevented, ensuring more secure and efficient management of this essential process.

In conclusion, the Munich incident serves as a stark reminder of the interdependencies between technical, human, and procedural factors in the de-icing process. The introduction of standardized phraseology and operational flexibility, coupled with enhanced communication protocols, is critical in reducing system variability and safeguarding against the risks posed by unforeseen complications. Furthermore, addressing the psychological pressures faced by the flight crew in stressful situations, through clearer guidelines and support mechanisms, can prevent the recurrence of similar incidents and improve the overall safety and reliability of de-icing procedures across the aviation industry.

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