Developing a human-centric de-icing system to increase airport capacity and operational safety

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SUMMARY

This research paper presents an innovative automated de-icing system designed to enhance operational efficiency, safety, and environmental sustainability at airports during cold weather conditions. Traditional manual de-icing methods, which are labour intensive and pose significant safety risks and environmental concerns, are inefficient and costly. The proposed system incorporates human-centric design principles and advanced automation technologies, including predictive modelling and real-time data analytics, to facilitate safer and more efficient de-icing operations with reduced physical labour and improved aircraft turnaround times. Drawing upon interviews with Bucharest International Airport subject matter experts, the research identified key operational, safety, and environmental challenges in current de-icing processes in order to provide relevant human-centric design requirements. Subsequent system development focused on minimizing human error and physical strain, streamlining equipment preparation, and reducing environmental impact through sustainable practices. The research underscores the need for further empirical testing to validate the system's effectiveness in real-world settings, offering a significant step forward in achieving safer, more efficient, and environmentally responsible airport de-icing operations.

KEYWORDS

Airport Capacity, De-icing System, Human-Centric Design, Operational Safety, Risk Management

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Introducon

De-icing plays a pivotal role in aviation maintenance, serving as a crucial process to eliminate snow, ice, or frost from an aircraft's surfaces (ICAO, 2018). Clean surfaces are imperative for safe and efficient flight operations - the impact of frozen contaminants on an airplane's aerodynamic properties can lead to decreased lift and increased drag (Li & Paoli, 2022). Airports worldwide frequently face sub-zero temperatures, requiring them to operate safely amid harsh winter weather conditions. Current manual de-icing procedures, as portrayed in Figure 1, are inherently labour intensive and rely heavily on specialized equipment and skilled personnel (EASA, 2017). These manual procedures often result in significant delays and operational inefficiencies, leading to increased costs for airlines and airports alike (Norin et al., 2012). Moreover, the reliance on manual labour introduces a higher risk of human error and potentially compromises operator safety during the de-icing process. The de-icing operations are also susceptible to extreme weather-related disruptions, which exacerbate manual labour and operational challenges (Landau et al., 2017). Additionally, the use of de-icing fluids, while necessary for safety, poses environmental concerns due to their chemical composition and disposal requirements (Krivanek et al., 2019). These factors underscore the urgency for advancements in de-icing technology that not only streamline operations but also address environmental sustainability concerns (Johnson, 2012).

Figure 1 – Aircraft De-icing Procedure

A new de-icing system is in development which prioritizes the safety of airport staff whilst simultaneously optimizing operational effectiveness and safety, reducing environmental impact, compared to current systems which mainly focus on operational efficiency (ICAO, 2018). The design and development of the novel de-icing process is informed by combining human-centric ergonomic principles to deliver a system comprising of user-friendly interfaces that shall facilitate interaction with state-of-the-art automation; Automation that combines predictive modelling and real-time data analytics to facilitate the alignment of resource allocation with aircraft schedules (Dolgov et al., 2021). Overall, the new system will enable ground crews to perform safe and efficient de-icing procedures that emphasises intuitive interaction and involves a reduced level of physical labour. In turn, the new system will optimise the time management aspects of aircraft while grounded, reducing aircraft turnaround times, and ultimately benefiting both the aviation industry and the surrounding environment.

Working towards the goal of developing this new de-icing system - this research represents a case study approach to investigating the challenges encountered during current de-icing processes at Bucharest International Airport. Structured interviews were conducted with subject matter experts (SMEs) to gather information in relation to two research objectives:

1. Understand specific operational challenges and safety considerations of the de-icing process from SMEs to elicit human-centric system requirements for the new de-icing system.
2. Incorporate requirements into development of new system prototypes.
3. Acquire SME feedback on prototypes for future design and development iteration.

Methodology

Participants

Nine SMEs from the Safety Department of Bucharest International Airport volunteered as participants for this research. These individuals possess extensive experience and knowledge regarding safety protocols and operational procedures related to de-icing activities at the airport, they have a variety of experience between 4 to 15 years in the domain.

Data collection and analysis

Data collection occurred through structured interviews held in the department's meeting room, spanning seven months.

In the initial month, conversations with SMEs focused on current operational efficiency to find ways to improve airport de-icing efficiency. These discussions primarily centred on the impact of winter on airport operations, highlighting how snowfall leads to significant delays which necessitates a substantial ground crew of de-icers to ensure minimal time loss.

The following two months were dedicated to exploring safety issues. Additionally, environmental protection was a concern discussed, particularly regarding the disposal of de-icing chemicals. These substances pose a risk to both the environment and airport infrastructure, since de-icing occurs on the apron without designated chemical drainage systems that permits chemicals to flow through rain drainage systems.

Discussions during the final 2 months related to a cost-benefit analysis of various de-icing methods, including chemical, thermal, electrical, mechanical, and anti-icing techniques. It also involved an assessment of the strengths and weaknesses of de-icing equipment, such as trucks, platforms, pads, fluid pumps, and brushes. In addition, discussions during this time aimed at eliciting design requirements, including automated process, real-time interface features and to improve the de-icing system's efficiency and safety. Prototypes were developed in AutoCAD and MATLAB which incorporated beneficial features identified through SME interviews. SME feedback was received whilst they examined prototypes interfaces designed to facilitate the seamless interaction between operators and the de-icing system automation. The prototype interfaces allowed operators to experience input instructions and receive real-time feedback on the de-icing process, incorporating intuitive visual representations for monitoring progress. In addition, prototype design discussions were complemented by a potential procedure for the new de-icing system. (Figure 2).

The transcribed interviews underwent a thorough qualitative analysis, involving coding and categorisation of responses to identify recurring themes and patterns.

Figure 2 – The procedure of the de-icing process in current research

Results

Operational Efficiency

Critical efficiency challenges identified by SMEs included the time-consuming preparation of deicing equipment, the pre-checks to ensure operational readiness, and the precise formulation of chemical mixtures for effective de-icing.

These operational inefficiencies provided valuable requirements for new system's design. Specifically, a de-icing platform that allowed aircraft to de-ice closer to its designated take-off location was proposed to expedite logistics (Figure 3). In terms of chemical mixture challenges, the design incorporated underground tanks that would be stocked with mixtures tailored to varying weather conditions. The SME's initial analysis of the system found that the automated system's capacity was perceived to likely enhance the flow of the de-icing process.

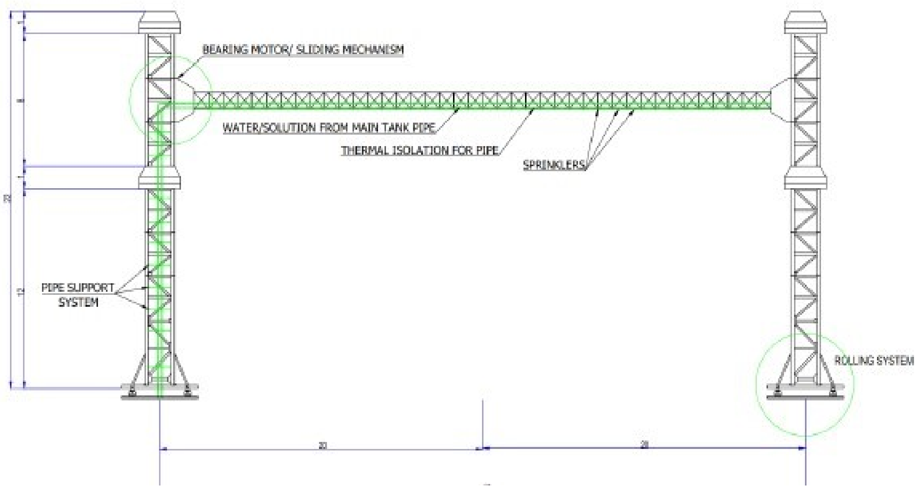

Figure 3 – Proposed Automated De-icing System Prototype Design. The design features a metal crossbar structure for airflow and cost efficiency. The platform moves on electrified rails to position over aircraft, adjusting in height via a motorized sliding rod mechanism up to 7.8m with 1m safety buffers. Equipped with advanced sensors, the system disperses de-icing fluid from a thermally insulated main tank through high-pressure nozzles for precise application.

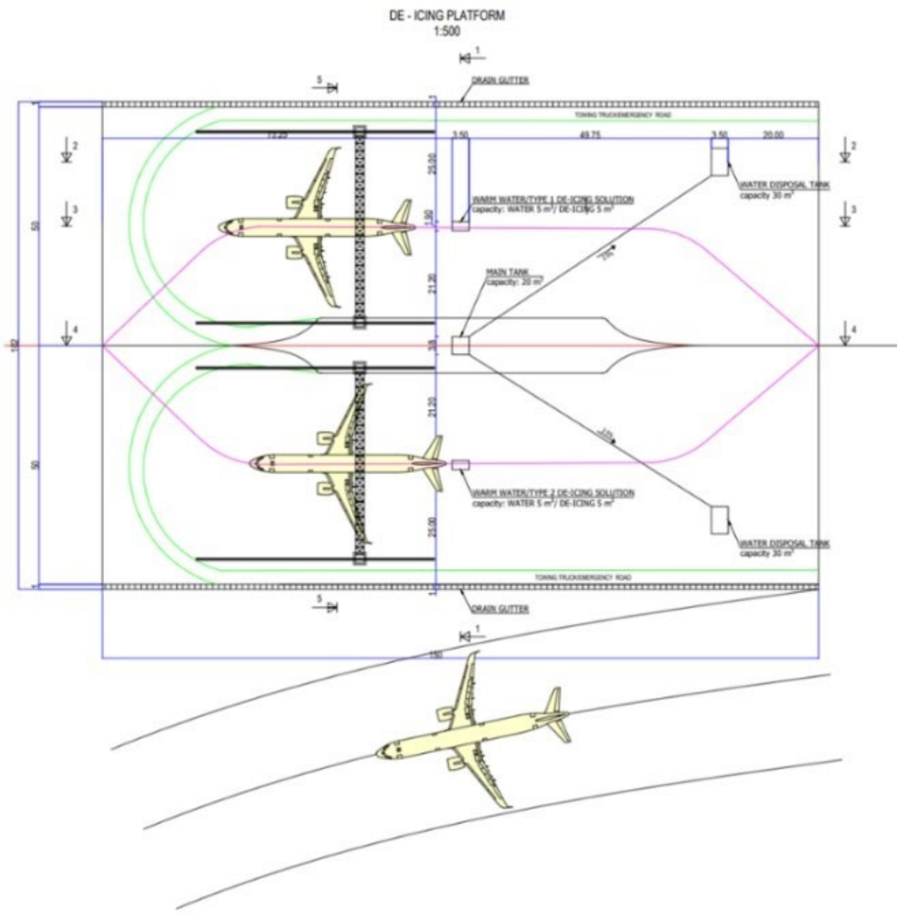

Figure 4 – Designated platform design for the airport. The AIHCB-compatible platform accommodates dual aircraft de-icing for Category C planes, with an alternate route for larger aircraft. Located 220m from runway 08R, it features a drain system leading to 30m³ disposal tanks for efficient fluid management, minimizing maintenance. Safety buffers of 6m prevent collisions. Equipped with perimeter lighting and a backup generator, operations remain visible and uninterrupted, even at night. Pink lines guide aircraft to the system, while red and green lines manage queueing and emergency towing truck paths. In case of system failure, manual de-icing trucks can be refilled from the tanks.

Safety Enhancements

Safety concerns for de-icing crews raised by SMEs included the possibility of the de-icing movable cabin colliding with aircraft fuselages, operators encountering technical issues like hydraulic failures (which could risk operators falling), and the high level of physical labour involved in the de-icing process.

To try and address these challenges the development of the new de-icing system placed a significant emphasis on providing a fully automated de-icing process. In this way, the entire de-icing operation can be remotely controlled via touchscreen displays inside the control room, significantly reducing the risk of human error or incidents. Similarly, the process of automating the process serves to minimise the level of physical labour involved in the de-icing process, thereby reducing the risk of accidents and physical strain for ground crews.

Environmental and Economic Impact

The environmental and economic implications of existing de-icing methods were consistently highlighted by interview participants as they had no specified disposal place of the chemicals, damaging both airports infrastructure and safety. The SMEs believed that by recollecting and recycling the used mixtures (through a extraction process), we can lower the costs of type 1 and 2 de-icing chemicals purchases, thereby offering significant environmental and economic benefits.

SME comments prompted a design which integration of eco-friendly and cost-reducing features. While the system is yet to transition from development to full-scale application, its design—focused on fluid recycling and minimizing chemical use—promises to address these critical concerns effectively.

System Prototype Feedback

Over the last two months, AutoCAD prototypes - that were developed based on SME input - were showcased to the SMEs.

Initial discussions surrounding the prototype focussed on identifying a suitable area within the airport to position the platform (Figure 3). Issues such as height restrictions, avoiding interference with traffic flow, accommodating different aircraft sizes, regulatory compliance (distance to runway), and optimizing performance and design required consideration. Eventually, the taxiway to runway was chosen as the most viable location (Figure 4). For example, the proximity of its location to the runway met critical regulatory requirements concerning de-icing and its impact on engine start-up procedures.

The ergonomic design and user-friendly HMI prototype were identified as significant improvements over conventional methods, heralding the potential to markedly lessen cognitive and physical strains for operators. Furthermore, it was acknowledged that the development would enhance the airport's operational efficiency and reduce environmental impact. However, the major concerns raised pertained to the construction and upkeep of the platform. It was noted that both the initial costs and ongoing maintenance expenses would be substantial. Despite these challenges, the majority of SMEs endorsed the design for its potential benefits, while two participants critiqued it for the high construction costs, predicting it would take years to become profitable and noting that maintenance would be expensive.

Discussion

The exploration and development of a human-centric automated de-icing system presented in this research directly respond to the multifaceted challenges outlined in the existing literature on airport de-icing operations (Landau et al., 2017). The integration of qualitative insights from structured interviews with airport personnel has significantly contributed to the design of a novel system aimed at addressing operational inefficiencies, safety concerns, and environmental impacts associated with traditional de-icing methods (Norin et al., 2012). This approach aligns with previous studies that have emphasized the need for operational improvements and risk management in deicing practices, as well as the importance of considering environmental sustainability (Johnson, 2012).

The findings from this study, particularly the feedback from subject matter experts, have illuminated the operational inefficiencies and safety risks inherent in current de-icing processes, corroborating the literature's emphasis on the critical nature of maintaining clean aircraft surfaces for safe flight operations (Li & Paoli, 2022). The development of an automated de-icing system, informed by these insights, signifies a progressive step towards mitigating the delays and hazards associated with manual de-icing operations (Dolgov et al., 2021). This system's emphasis on reducing de-icing times, streamlining equipment preparation, and minimizing the physical labour required promises to enhance the safety and efficiency of de-icing operations, directly addressing the concerns raised.

Furthermore, the environmental considerations of de-icing operations, a recurring theme in both this research and the literature, have guided the system's design towards minimizing chemical use and promoting recycling. This focus not only addresses environmental sustainability concerns but also reflects a growing recognition of the need for de-icing solutions in the aviation industry. However, as this research progresses towards potential operational deployment, it echoes the literature's call for empirical validation of new de-icing technologies. The distinction between anticipated benefits and their realization in operational settings underlines the critical need for comprehensive field testing. This step is essential to substantiate the system's efficacy in enhancing efficiency, safety, and sustainability in airport de-icing operations, ensuring it aligns with the aviation industry's rigorous standards.

Conclusion

In conclusion, this research represents a potential advancement in the field of airport de-icing operations, offering an approach to addressing the challenges of operational efficiency, safety, and environmental sustainability in cold weather conditions. By leveraging SME insights the proposed de-icing system that could transform the way airports manage snow and ice removal from aircraft surfaces. The system's design, focused on automation and user-friendly interfaces, will likely reduce de-icing times, minimize the risk of human error, and enhance operational safety, all while considering the environmental impact of de-icing chemicals. Future collaborative work with airport personnel is imperative to validating the system's effectiveness in real-world scenarios. This research not only contributes to the academic discourse on airport operations but also provides a practical framework for enhancing the safety and efficiency of de-icing procedures.

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