European Union Aviation Safety Agency

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RESEARCH PROJECT [EASA.2022.HVP.22]

[STAGE 4.1: CONCLUSIONS AND RECOMMENDATIONS]

Final Report:

Detection of lithium batteries using security screening equipment

An Agency of the European Union

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APPROVED BY:	AUTHOR	REVIEWER	MANAGING DEPARTMENT
	Sophie Hibbin	Dean Smith	Rapiscan

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SUMMARY

Problem area

Lithium batteries are now ubiquitous in portable electronics devices. Their diverse form-factors and favourable energy storage characteristics make them a prime choice of batteries in many applications. Yet the high density of stored energy along with the combustion characteristics of lithium batteries can also constitute a safety hazard that may result in a thermal runaway fire. This hazard is particularly acute in the aviation field onboard the aircraft and, in particular, in the baggage and cargo hold, where fire hazards pose particularly severe safety risks.

For these reasons, the carriage of lithium batteries in hold baggage[1] and cargo is addressed through ICAO rules and guidance, and enacted through individual Member States' safety regulations. Enforcement of this regulation to mitigate the safety risk could be aided by a means to detect the presence of lithium batteries. An opportunity lies with the use of existing imaging and detection equipment already deployed as part of aviation security infrastructure. With adaptations to its detection characteristics as well as operational procedures, certain aviation security detection equipment can be made to also mitigate the specific safety risk posed by lithium batteries deemed non-compliant with the provisions for transport by air.

Description of work

In December 2022, EASA appointed a consortium to deliver a research study for the specific case of detecting lithium batteries in hold baggage. The consortium is led by Rapiscan Systems and supported by consortium partner UK CAA International. This project will consist of four technical tasks.

- Task 1: Review of state-of-the-art solutions, development of test plan and protocol and consultation with Stakeholders
- Task 2: Performance of tests, collection of data
- Task 3: Analysis of tests performed, consultation with Stakeholders
- Task 4: Conclusions and recommendations

In addition to the technical tasks, this project includes a fifth, non-technical, workstream:

- Task 5: Communication, dissemination, knowledge-sharing and stakeholder management

As per the tender specification, the objective of this fifth workstream is to identify the target audience and their different needs and support EASA in the planning and organisation of the stakeholder events as well as in the preparation of briefings and presentations. The project includes several consultations with the main Stakeholders concerned with the detection of lithium batteries at aerodromes. Two workshops were organised to present the results of Tasks 1, 2, and 3 and to facilitate this information gathering.

[1] Hold baggage is the baggage that is placed on the hold, otherwise known as check-in/checked baggage. It does not refer to carry-on baggage or cabin baggage.

Toward the end of the project, the dissemination of the study results is to be structured in a way that allows the contractor and EASA to identify the most appropriate communication formats to transfer the knowledge gained according to the identified dissemination goals. The dissemination goals range from ***raising awareness of the research project*** to the final goal of ***establishing a long-term impact of the project results on its target group***. Such goals, as well as the audience to be reached will be identified jointly by the contractor and EASA and documented in the communication and dissemination plan. The plan shall also consider appropriate knowledge-sharing actions for the target group.

This report represents the deliverable for Task 4.1 – "Final Report on the Project: Conclusions and Recommendations."

This report is the result of a collaborative effort between EASA, CAA International, and Rapiscan. As such, certain areas of the study draw on the respective and appropriate organisation's expertise. For example, CAA International have led on the regulatory input, and Rapiscan have provided impartial technical input. The content herein is drafted based on objective evidence and exploratory research, with the overall direction set by EASA. All contributing organisations have worked to ensure the research remains unbiased.

To this end, whilst each contributing organisation has provided its own expertise and insights, it is affirmed that no individual or organisation has influenced the content of this report in a manner that compromises its integrity or objectivity. The responsibility for the content rests with the authoring organisation, and any interpretations or recommendations are made in good faith, reflecting the consortium's professional judgement and the requirements of the commissioned study.

Results and Application

The purpose of this overall study was to provide objective data and recommendations concerning the use of certain existing security screening equipment to detect lithium batteries in hold baggage. By analysing this data, the impact of detecting lithium batteries on hold baggage operations and screener performance has been assessed. The results will be used to facilitate and underpin future discussions amongst stakeholders, including regulators. It is intended that the results of this study will be helpful to support future decision making and discussion by European aviation regulators to mitigate safety risks posed by lithium batteries.

This part of Task 4 shall draw the overall conclusions and recommendations regarding the overall work performed, based on all previous tasks. These overall conclusions shall serve as the basis for identifying the main recommendations that shall address those open issues identified but not covered by the work performed within the contract and the development of a technical standard and regulatory requirements for the harmonised deployment of the capability to detect lithium batteries. Requirements for additional work shall be appropriately identified and documented.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
CAA	Civil Aviation Authority
DG	Dangerous Goods
EASA	European Union Aviation Safety Agency
EDS	Explosives Detection System
EU	European Union
FAA	Federal Aviation Administration
HBS	Hold Baggage Screening
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IED	Improvised Explosive Device
Level 1 / L1	X-ray scanner, as part of the HBS process
Level 2 / L2	Human screener, reviewing escalations from level 1 as part of the HBS process
Level 3 / L3	Human screener, reviewing escalations from level 2 as part of the HBS process
Level 4 / L4	Human screener, reviewing escalations from level 3, typically where passengers are reconciled with the aerodrome operator/air operator representative and their bag
LiBAT	Lithium battery
OOG	Out-of-gauge, otherwise referred to as oversized baggage
TIP	Threat Image Projection
Wh	Watt hours

1. Introduction

1.1 Executive Summary

Lithium batteries might pose a risk to civil aviation, particularly when carried in passenger hold baggage. This EASA project investigated the use of existing security screening equipment and process to mitigate this risk, through various deliverables, including: stakeholder consultation, development and testing of a lithium battery detection algorithm, a live operational trial, analysis and feedback. This report presents the conclusions and recommendations of this work series.

Lithium batteries are commonly used in day-to-day life, and millions travel safely and securely onboard aircraft. However, lithium batteries can also be dangerous, and as such are subject to international and national restrictions for their carriage by air. Contrary to such requirements, they are commonly packed in hold baggage by passengers who are unaware of the rules or who do not comprehend the risk. Combined with limitations in the hold baggage screening regime, there is a real potential that a non-compliant lithium battery causes an incident from the hold of an aircraft after being loaded as hold baggage.

Regulations that restrict the carriage of lithium batteries apply to air operators (airlines) via applicable safety rules. Regulations that define the hold baggage screening process apply to aerodrome operators (airports) via applicable security rules. Enhancing the screening process and aligning the regulatory frameworks are two challenges addressed by this study.

This project found that using a lithium battery detection algorithm, deployed to existing EDS equipment and processes in operation at airports, is a feasible solution to address the risk posed by unauthorised carriage of lithium batteries in hold baggage. This was achieved through a detailed examination of stakeholder feedback, and evaluating the operational impact, resolution process, algorithm performance, and screener performance during a live operational trial of the detection algorithm. Stakeholders all perceive the lithium battery risk to be important, and there are significant levels of concern – there is much alignment on the fact that action needs to be taken to address the risk of their non-compliant transportation (including support for future regulation), and this action must include a collaborative approach across safety and security and between aerodromes and air operators.

The live operational trial of the algorithm demonstrated its capability of detecting relevant lithium batteries, and showed that screeners could adapt well to its use. The algorithm is likely to enhance the process of screening for security threats (as lithium batteries can be a component of an IED), but any future trial or algorithm implementation must take into account a comprehensive human factors picture of the screening process. There are also impacts identified on the hold baggage screening system and resolution process.

This study makes four overall recommendations:

1. Conduct additional research to steer future developments in an informed manner. Consider the expansion of the research scope to other dangerous goods screening capabilities.

2. Provide screeners with the required awareness on the existing rules concerning dangerous goods, and lithium batteries in particular.

3. Explore options for the future regulatory framework based on additional data.

4. Consider the use of hold baggage screening equipment to detect non-compliant lithium batteries.
Recommendations are referenced with a number (e.g. R1.0) throughout the text.

This study has shown that a lithium battery detection algorithm deployed to hold baggage screening equipment is a viable option for detection of relevant lithium batteries. This could be on a voluntary basis, or could be defined by future regulatory approaches. There should also be steps taken to improve passenger awareness at online and in-person check in.

The use of EDS equipment with the novel detection algorithm represents a quickly deployable solution to current lithium battery risks[2],which are only growing in likelihood. The risk posed by lithium batteries as a whole to civil aviation is one that is taken very seriously by regulators and industry alike. This work therefore represents an important step for informing future decision making in regulatory change and process change. The intent of this study was to gauge cross-industry sentiment on the issue, raise awareness and demonstrate that lithium batteries could be detected using existing EDS machines. Additionally, the study was intended to help regulators make appropriate and informed regulatory changes before a serious hold baggage incident occurs.

1.2 Overview of Tasks[3]

Task 1	Task 2	Task 3	Task 4
• **Report on state of the art solutions for the detection of lithium batteries in hold baggage** • Test plan, scenarios, and protocols for the trials • **Report on Stakeholder consultation held (including workshop 1)**	• Report on tests performed and collected datasets • **Presentation material on the tests performed**	• **Report on main results obtained** • Report on Stakeholder consultation held (including workshop 2)	• **Conclusions and recommendations**

[2] Risk in this context is defined as "the likelihood of an event occurring and the severity of the effect, specifically smoke or fire onboard an aircraft from a lithium battery and the associated potential impacts".
[3] Tasks in **bold** are available on the EASA website at the following link: Detection of Lithium Batteries Using Security Screening Equipment | EASA (europa.eu)

2. Discussion

2.1 Statement of Problem – Risk Context

The term "lithium battery" refers in fact to a family of batteries with different chemistries; for the purposes of their regulation in civil aviation, they are separated into lithium-metal batteries and lithium-ion batteries (International Air Transport Association, 2024 - Lithium Battery Guidance Document). Lithium batteries are generally used to power personal electronic devices (PEDs), power tools, e-scooters, watches, electronic fobs, and toothbrushes, for example – all very common, day to day items, frequently carried and/or used by airline passengers. However, lithium batteries can be dangerous. Whilst considered safe during normal use, they can result in a fire when over-charged, short-circuited, submerged in water, damaged, or if poorly manufactured (Forbes, 2023). And if the battery ignites, the resulting fire can be severe, especially if that fire is in the hold of an aircraft.

Domestic and international incidents relating to lithium batteries have often involved incorrectly packed, marked and labelled batteries, as well as mis-declared or undeclared items. In some cases, it has also been discovered that the batteries have not met international standards for manufacturing and testing (UK Civil Aviation Authority, 2024 - Transport of lithium batteries). There have been several reported aviation incidents involving passenger devices, with phones or other lithium powered items overheating and/or catching fire, thus needing to be dealt with by the crew in-flight. These incidents were in the cabin, but in the confined and inaccessible space of a hold, such a fire could be catastrophic, and comprise the safety of the flight.

This is well illustrated by tragedies such as United Parcel Service (UPS) flight 6, which crashed in Dubai on September 3rd 2010, because of the combustion of lithium batteries. The cause was a "catastrophic main deck cargo fire, which auto-ignited and remained in a sustained state of combustion, resulting in damage to the fire protections and critical systems, leading eventually to the loss of the aircraft and crew." (FAA, 2022 - Boeing 747-44AF | Federal Aviation Administration (faa.gov)).

With such a risk posed, lithium batteries are subject to specific conditions and restrictions when travelling by air. Internationally, ICAO Annex 18 – "Safe Transport of Dangerous Goods by Air" – sets down broad principles for carriage of lithium batteries, with one of the Standards therein requiring that dangerous goods be carried in accordance with ICAO Doc. 9284, Technical Instructions for the Safe Transport of Dangerous Goods (Technical Instructions). The IATA Dangerous Goods Regulations (IATA DGR) further add to this, being fully aligned with the Technical Instructions, and also being recognised by ICAO.

Lithium batteries are carried regularly and routinely by air all over the world. To ensure they do not put aircraft and occupants at risk, each State, under the provisions of the Chicago Convention, is required to introduce the aforementioned international Standards into national legislation. This system ensures governmental control over the carriage of dangerous goods by air and gives world-wide harmonisation of safety standards (ICAO (a), N.d).

The restrictions for lithium batteries in hold baggage are presented below (International Air Transport Association, 2019):

Wh rating or lithium metal content	Configuration	Carry-on baggage	Checked baggage	Operator approval
≤ 100 Wh / 2g	In equipment (PED or PMED)	Yes (max 15 PED/PMED[1])	Yes	No[1]
	Spare battery(ies)	Yes (max 20 spare batteries[2])	No	No[2]
>100 to ≤160Wh	In equipment (PED or PMED)	Yes	Yes	Yes
	Spare battery(ies)	Yes (max 2 spare batteries)	No	Yes
>160Wh	Must be prepared and carried as cargo in accordance with the IATA Dangerous Goods Regulations			
> 2g ≤ 8g	In equipment (PMED only)	Yes	Yes	Yes
	Spare batteries for PMED	Yes (max 2 spare batteries)	No	Yes

[4]

No spare or loose lithium batteries are permitted to be carried in hold baggage, and those within devices are only permitted up to 100, or 160 Wh with a previous approval from the operator. The Watt-hour rating, expressed in Watt-hours (Wh) and defined as "a measure of electrical energy equivalent to a power consumption of one watt for one hour", is calculated by multiplying the rated capacity in ampere-hours by the nominal voltage (International Air Transport Association, 2024). For perspective, a 100 Wh battery is the equivalent to the size of a modern smartphone, albeit double the thickness.

Despite these regulatory measures and stringent guidelines for transporting lithium batteries, incidents continue to occur, with evidence found during this research that non-compliant lithium batteries persistently travel in hold baggage. Both limitations in applied detection methodologies and limitations in passenger awareness can be posited as causes of the non-compliance. There are therefore two key factors in favour of implementing a robust and comprehensive screening solution, applicable to all hold baggage. Firstly, passengers are fallible, and will continue to pack restricted lithium batteries in their hold baggage. Secondly, there are improvements to be made in the existing screening process for dangerous goods.

Currently available technology could provide a solution; various manufacturers of security screening equipment have produced dangerous goods (including lithium battery) detection algorithms for deployment on Explosive Detection Systems (EDS) – a common screening equipment at many EU aerodromes. EDS machines already rely on algorithms to detect explosives under relevant security regulations. There is the potential for EDS suppliers to quickly and easily deploy a lithium battery detection algorithm to their fleet, enabling screening of all hold baggage for lithium batteries to begin (where EDS is in use). Other technological options are in development, such as canine or other biological sensors, but the maturity of the lithium detection algorithm approach and its ease of integration with existing screening methodology makes it a viable option. Hence, it is a lithium battery detection algorithm that has been explored in this research.

From one-to-one interviews and two webinars, it is clear that key stakeholders are aligned on the risk posed by prohibited lithium batteries in hold baggage. All key groups (air operators, airport operators, regulators, industry bodies) perceive the risk to be significant, and concur that further action is needed to mitigate it. Furthermore, many are advocating for additional actions, including further regulation. However, finding a solution is complicated; any viable path forward will have to span stakeholder groups and regulatory regimes, and cross lines of current responsibility.

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[4] Image taken from: passenger-lithium-battery.pdf

A comprehensive mitigation strategy to the risk posed by lithium batteries to civil aviation requires more than an approach within screening of hold baggage. Additionally, the risk needs to be mitigated “at source”, with strategies to reduce the number of unsafely manufactured batteries in the system, along with robust reporting systems and analysis of the output for lithium battery incidents. There also needs to be further work on containment and suppression in-flight, such as fire-resistant containers and appropriate inflight fire extinguishers. That said, the detection (and therefore prevention from entering the hold of aircraft) of lithium batteries is a key step in such a comprehensive mitigation plan.

With the risk context and the statement of the problem thus defined, two key strands of research are examined in the following sections: the consultation with stakeholders and the live operational trial. Where recommendations are generated by the analysis, these are referenced and tabulated in section 3.2.

2.2 Stakeholder Consultation

This study included two phases of stakeholder consultation, both involving a webinar and associated qualitative research, conducted via interviews and surveys, including aerodrome operators, air operators, regulators, industry associations, and cargo agents.

The insights from aviation industry stakeholders illuminated the complex challenges of ensuring the safe transport of lithium batteries and DG. Collaboration was found to be perceived as pivotal in addressing these issues, with a focus on the lack of standardised regulations, passenger awareness, and operational challenges. Across the board, stakeholders emphasised the need for clearly defined lines of responsibilities and operational models for implementing a solution.

The initial stakeholder research highlighted the fact that an absence of EU-wide rules for the *detection* of lithium batteries in hold baggage has led to a considerable variation in practices across different countries. In the EU, the responsibility for *preventing* lithium batteries from travelling in contravention of the rules primarily rests with air operators. A few EU states share these responsibilities between air operators and aerodrome operators, though this is less common.

Air operators make concerted efforts to alert passengers to the restrictions on lithium battery carriage, as required by ICAO standard, both during online check-in and face-to-face interactions at the airport. However, they acknowledge that passengers may not always be diligent or fully grasp the regulations, for example devices don’t always clearly display Watt Hours of the batteries, potentially leading to unauthorised carriage even by a well-informed and well-intentioned passenger. Aerodromes are currently making "best endeavours" to detect and prevent non-compliant lithium batteries from travelling, but this largely occurs as a by-product of explosive detection screening. The consensus is that existing systems and processes do not catch all lithium batteries requiring removal.

The stakeholder consultation showed, therefore, that the system for preventing the unauthorised carriage of lithium batteries is not fully robust. A shared desire for a collaborative solution was identified, with all parties viewing lithium batteries as a safety concern rather than a security matter, but the complexity of responsible and accountable parties within the hold baggage system necessitates a solution involving both safety and security resource. Ultimately, cohesive regulations, education, and collaboration across safety and security and between aerodromes and air operators were pinpointed as essential for a safer approach to handling lithium batteries (and other DG), with a shared commitment to aviation safety. There is a crucial role that regulatory bodies, such as the European Commission, can play in conceiving these collaborative links between safety and security (R5.2).

As defined in the risk context: air operators, aerodromes, and other stakeholders acknowledge the risk posed by lithium batteries. The second webinar showed clear alignment in the issue being highly important, with significant levels of concern. However, stakeholders also asserted that without appropriate legislation, the pace of change will remain slow, and process will remain inconsistent. One identified example of this is in the processes undertaken once unauthorised lithium batteries are found in hold baggage. Some States consider it a joint action and involve the air operator in resolving the issue, in other cases the aerodrome operator independently handles it. Most countries do not impose fines for unauthorised lithium batteries, although there are a few that do. Fines imposed on passengers could be an effective way to change their behaviours, but would also have to be implemented in conjunction with significant additional engagement activity, such as increased communications and awareness campaigns, to improve the level of understanding of the risks posed by lithium battery in the travelling public (R5.1).

This research also illuminated two items of prevalence data: Firstly, one aerodrome operator opened 1,000 items of hold baggage to gauge the frequency of unauthorised lithium batteries therein. They found that 1.1% of these bags contained unauthorised lithium batteries. With billions of hold bags processed annually, this percentage could translate into a significant number – potentially millions of bags containing unauthorised lithium batteries. Indeed, the second item of data (reported at the second webinar) involved an air operator having removed over 7,500 non-compliant lithium batteries from hold baggage over a period of approximately 6 months. All stakeholders anticipated a substantial increase in the quantity of lithium batteries carried in both hold and carry-on baggage, which further amplifies the importance of effective detection.

Another key issue identified through the consultation was concern around financial implications with the implementation of a new screening process. Aerodrome operators expressed the need for additional resource, including screeners, potential infrastructure changes, new IT equipment, adjustments to baggage handling systems, and additional personnel to resolve issues with passengers. Without doubt, there will need to be careful considerations of economic and resource impacts when implementing this new screening procedure, as would be the case with any larger regulatory change that affects the processes in place at airports. In recent times, manufacturers have reported an increased demand for detection algorithms that go beyond the standard need for addressing the terrorist threat via the mechanism of an IED. The security threat picture is also constantly evolving, with new attack methodologies emerging which need to be addressed through technological development and dynamic regulation. Input from stakeholders in this study has shown that there must be a balance between the resource cost of a solution and level of mitigation it affords to a defined severity of risk. There is therefore a role that manufacturers and regulators can play in supporting and encouraging the deployment of such algorithms (R5.2).

In summary, there was very strong alignment on the viewpoint that lithium batteries do pose a safety risk and that there is further action needed from industry and regulators. There were high levels of concern about this risk, identified via the survey, and a high level of importance was ascribed to the issue. Not all respondents were likely to take further mitigation action without an additional regulatory mandate, which raises further questions on the most appropriate future direction from a stakeholder perspective. A regulatory change to introduce mandatory lithium battery algorithm would be an effective way to ensure a concerned stakeholder population can act in an informed way, but there may still be scope for EASA and other relevant authorities to influence behaviours toward action without regulation. Furthermore, stakeholders had wide-ranging questions on the project which were sometimes beyond its scope – these concerns should be taken forward as potential areas of focus for future research and decision making.

2.3 Operational Trial

The trial was carried out according to the Test Plan at an airport with more than 2 million passengers per year, taking place from Wednesday 17th to Friday 19th July 2024. The lithium battery detection algorithm was deployed to one of the airport's two hold baggage x-ray machines (an RTT110 EDS machine) between 09:00 and 17:00 each day, being switched off at approximately 15:00 at the end of the trial period on the 19th.

Observations were conducted in two locations, the level two screening room (L2) and the level three screening room (L3), as per the Test Plan. The standard operating procedure for screening and reconciling hold baggage was observed, with the RTT110 configured to run dual algorithms (EDS & lithium battery detection). Observations were held within the parameters of the standard processes and practices of the aerodrome without affecting regulatory security requirements.

Quantitative and qualitative data were collected in parallel, with data produced in situ throughout the period. Quantitative data was drawn from the EDS system, relating to: number of images, screener decision time, type of alarm, and number of rejects or accepts at each level. Qualitative data was drawn from the security screeners and supervisors, and passengers (where available), and 20 screeners participated in the trial. Methods used included observations, semi-structured interviews, and verbal questionnaires, as well as image-based quantitative data.

All baggage was not opened to determine whether the lithium battery algorithm alarms were real or not. Only baggage which was rejected by the level 2 and 3 operators was opened at level 4 and the lithium battery alarm verified. Therefore, the published lithium battery false alarm rate is somewhat open to interpretation. A false alarm was determined on a 'clear' decision from the level 2 or 3 screener. A further study would benefit from all lithium battery alarmed bags being opened to absolutely establish whether it is a false or real alarm.

Summary of Key Findings

A **lithium battery detection algorithm** was developed, deployed, and tested on existing security screening equipment. The algorithm proved **capable of detecting in-scope lithium batteries** in offline testing and the live operational environment.

Test criteria required detection of **power banks** and **spare batteries** and any battery contained in a Personal Electronic Device (PED) with **capacity exceeding 50 Watt-hour**.

The **false alarm rate** during the trial was relatively high, and if the algorithm were to be deployed again, would require refinement. A lower false alarm rate was observed during offline testing. This false alarm rate is based on subjective criteria, as not all bags were opened to establish alarm legitimacy.

Screeners adapted well to the new algorithm, and **perceived no negative effect** on their security screening process.

Lithium battery alarms took the longest to resolve by screeners, asserted to be caused by the novelty of the new alarm – it is to be expected that **screeners take time to adapt** to a new process.

Decision times were increased during the trial, when compared to the standard operating environment (i.e. no lithium battery detection algorithm running). This shows that **the operational context of the trial was having an effect** on the data.

The **reject rate was elevated** during the trial, and without planning this will have implications for screener **workload** and have **operational impacts**.

Observed searches of oversized baggage showed that the bag search can be efficient, whilst highlighting the **importance of knowledge of the restrictions** in both **screeners and passengers**.

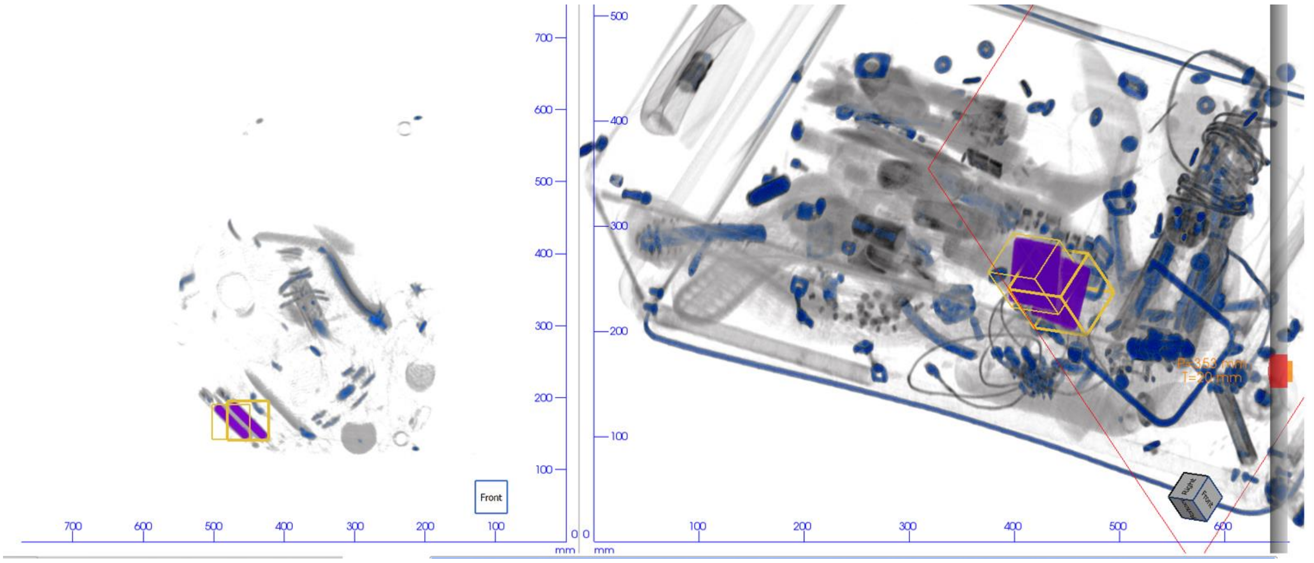
Any challenges with implementing such an algorithm would appear to centre on: **operational processes such as screener training, process for increased rejects and decision time, and communications with passengers.**

2.3.1 Algorithm Performance

A key aim of the trial was evaluating the performance of the deployed lithium battery detection algorithm. To this end, the algorithm's speed, clarity, and accuracy in identifying non-compliant lithium batteries was assessed, through analyses of detection rates, false alarm rates, and screener perception (examined in further detail in 2.3.4).

Ahead of the trial, offline data collection had shown a 15% alarm rate, with 4.5% being verified as false alarms, representing a lithium battery prevalence of 1 out of every 10 bags. The algorithm performed efficiently at this stage, although it often detected lithium batteries with smaller power than the set threshold of 50 Wh.

During the operational trial, the deployment of the algorithm had no negative effect on the user interface, and observations showed that the alarms generated were clear and there were no delays to the functionality. An example of the image as seen during the trial is shown below:



There were two key findings in respect of the algorithm's accuracy. Firstly, one observed instance of a heavily cluttered bag potentially causing non-detection (false negative) and secondly, a higher than expected false alarm rate (false positives). This false positive rate was above the 4.5% false alarm rate seen in offline testing, attributed to the data set used to develop the algorithm. Bag images used were more business baggage orientated, whereas during the trial, considerably more leisure baggage was observed. It must be noted that this rate includes all batteries identified from the algorithm, even those in a configuration allowed to travel in hold baggage, as well as items which clearly were not batteries. The 'true false positive' rate – where the lithium battery detection algorithm detects non-battery items – will be lower. And indeed, screeners during the trial were adept at identifying false alarms and cleared them efficiently and quickly, which means the operational impact of false alarms is mitigated by the screener's performance. Nevertheless, a high false alarm rate has significant implications for screener work rate, which must be considered.

Key data from the trial are shown on the following page.

Prohibited lithium battery prevalence:

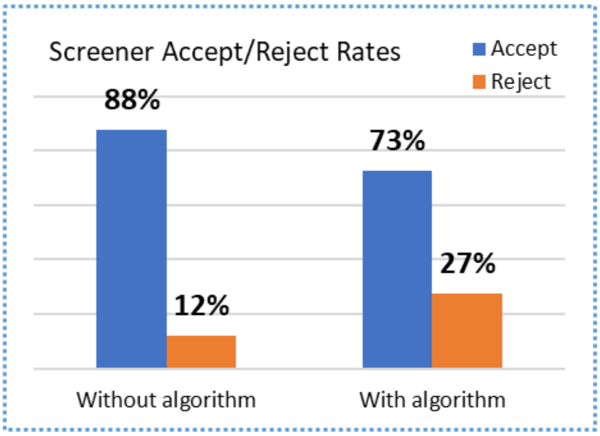
1.34%

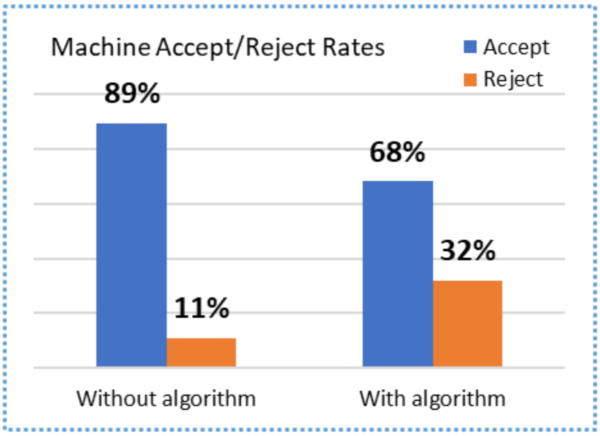
Lithium alarm rate:
21%

748 bags screened

154 with a lithium alarm

Estimated **10** observed non-compliant lithium batteries

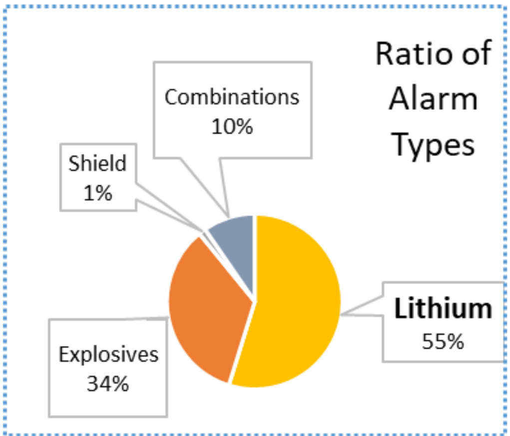




Machine reject rate: **32%**

Human reject rate: **27%**

*50% of bags seen by a human reviewer were rejected (including time outs)



19% false alarm rate

(144 out of 748 bags)

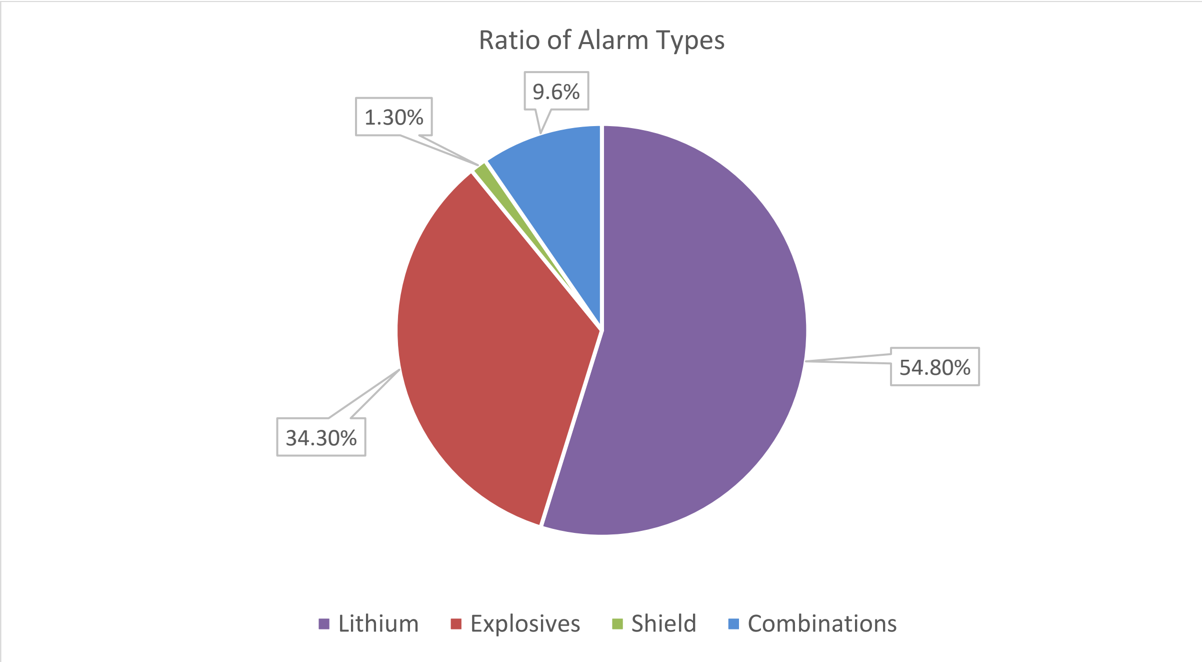
94% of lithium alarms were cleared

- Compliant batteries
- Non-battery items

*bags were not opened to confirm if real or false alarm. Solely based on operator "accepts"

2.3.2 Operational Impact

Deployment of the algorithm had no observable impact on the functionality of the EDS equipment in terms of threat detection, but there was a measurable operational impact, evidenced by the elevated reject rates at all stages of the screening process. Additionally, most alarms during the trial were lithium battery alarms, with an overall lithium alarm rate of 21%.



These increases show that the screeners had to review more images during the trial than during standard operating procedures and conducted more passenger reconciliation activity and more bag searches – both of which need consideration in terms of operational impact. The prevalence rate for lithium batteries is also higher than the prevalence rate of prohibited articles in hold baggage. Further data collection would be needed to determine whether this prevalence level is robust (R2.0). This data could also feed into a broader assessment of the risk posed by lithium batteries (R2.0). This research can strongly assert that the deployment of a lithium battery detection algorithm would increase the operational workload of the screeners and the baggage handling systems.

As the addition of another alarm category is likely to increase the number of images rejected at each level, and therefore the number of bags rejected, the impact on the baggage handling system will also need to be carefully considered. For example, the physical parameters of the level 3 reject lanes must have contingency to deal with multiple rejects – it is far more likely that multiple (real) lithium battery alarms are encountered than multiple (real) EDS alarms (R2.3).

2.3.3 Resolution Process

The resolution process is defined here as the final step in the detection process, when the bag is reconciled with the passenger and the lithium battery is either removed from the hold baggage or identified as a compliant item. Due the low throughput of bags and the low prevalence of non-compliant lithium batteries, this process was only observed once during the trial, but findings were supplemented from observations that took place at the out-of-gauge (OOG) screening area.

Where identification of prohibited lithium batteries was observed, the screeners were confident of the regulations and the passengers were able to remove the batteries from their hold baggage and carry them on to their flight in their cabin baggage. This process appeared efficient and did not add undue strain or complexity for the passenger or the screener. Indeed, on one occasion, the passenger was grateful for the process as they perceived an increase in their own safety.

Whilst no conclusive data was obtained on the L3 to L4 process, the end-to-end resolution process was observed once. A power bank and some loose AA batteries were detected by the lithium battery detection algorithm, and were rejected at L2 and L3. The passenger was successfully reconciled with their baggage, and the search identified a power bank and loose batteries (some of which turned out to be zinc, rather than lithium, which highlights a potential limitation of an algorithm), in addition to two lithium batteries within a personal electronic device (compliant for travel in the hold). The passenger packed the prohibited batteries into their cabin baggage. There was some input from the researchers to the process in the form of referencing the regulations, but overall the process was observed to be efficient, and the screener was highly competent at conducting the search and dealing with the passenger.

From the observed removals of prohibited batteries from hold baggage, there can be a number of assertions made. Firstly, passenger behaviour is key to an efficient resolution. Although passengers behaved compliantly, there were instances where they exhibited confusion at the requirements. Furthermore, it can be asserted that *preventing* lithium batteries from entering the baggage handling system is more critical from an efficiency and safety perspective than detecting them once the baggage is checked-in. Making passengers aware of the lithium battery restrictions therefore, remains a critical process (R5.1). It is beneficial where this information is clearly and consistently presented to passengers at check-in as per the defined responsibilities of the operator under ICAO requirements; observed signage was potentially ambiguous. One screener even reported that they did not believe passengers take much notice of signage on restrictions, and this was also found to be a perception in the stakeholder consultation as part of Task 1.3.

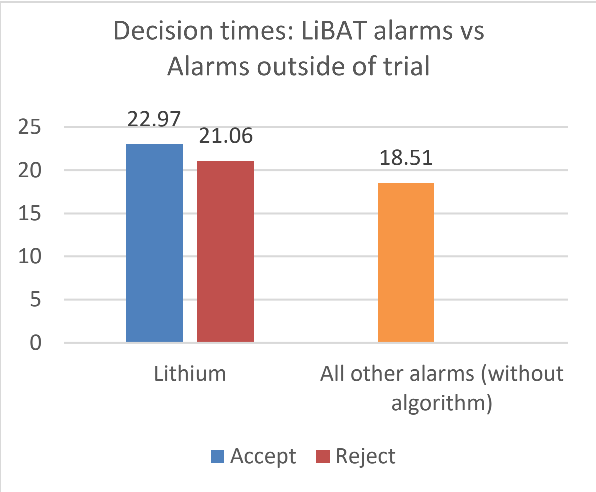
Secondly, variable levels of knowledge of the lithium battery measures were noted – the regulations themselves are quite complex, with different categories (power ratings) of lithium batteries being allowed or not allowed in various configurations and quantities, between cabin and hold baggage. In order to aid the search process, it would be valuable to have reference material available to the screeners to assist their resolution process. This would need to be embedded into a clearly defined operational process for lithium battery screening (R2.0).

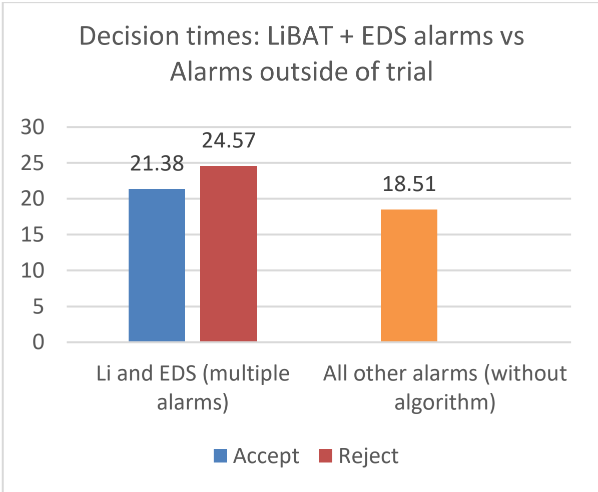
2.3.4 Screener Performance

The live trial also investigated the performance of the operator review component, or screener performance. Human performance incorporates a wide variety of themes; this research focused on the accuracy and speed of on-screen threat resolution, alongside self-perception of performance and other intrinsic performance values, such as motivation, in order to analyse the problem with sufficient breadth and depth (International Civil Aviation Organisation, 2021 - Human Performance Manual). See Task 3.1 for a detailed examination of this research.

All screeners appeared adept at identifying alarms within an image, including the new battery alarm, with expected variation in assimilation times. Operationally, as screeners behave and adapt differently, there must be contingency (in on-job-training and implementation procedures, for example) (R2.0).

The evidence collected shows very little perceived negative impact on the screeners' performance, although their decision times were increased, as shown in the following charts. Specifically, lithium battery alarms took longer to resolve when compared with alarms outside of the trial period, and when compared with other alarms during the trial. This is as expected, as screeners take time to learn and adjust to a new functionality.

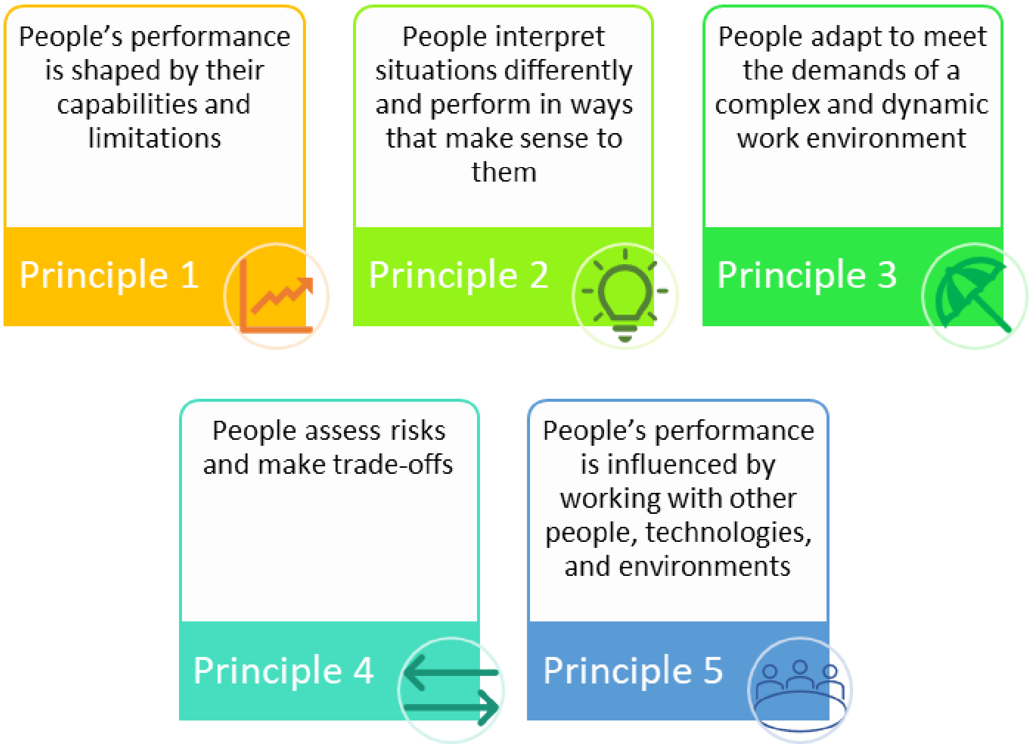




Critically, it was observed that all decision times were increased during the trial period, so EDS alarms were taking longer to resolve than usual. Therefore, it can be concluded that the context of the trial was affecting the screeners, and indeed it was observed that interactions between researchers and screeners were lengthening the screening process (though never to the detriment of the security operation). It is a fair assertion, therefore, that after adapting to the new algorithm, and in a standard operating environment (or better controlled research environment) the increase in decision times would be seen to lessen, or regress to the mean. There is very strong evidence for this presented in the qualitative findings, with screeners reporting positive feedback on the algorithm and its ease of use. The screeners were observed to become more familiar with the novel algorithm relatively rapidly, even over the short duration of the observation periods.

All screeners observed remarked that the new algorithm did not inhibit their ability to screen, with some also recognising that it was a change they would have to get used to.

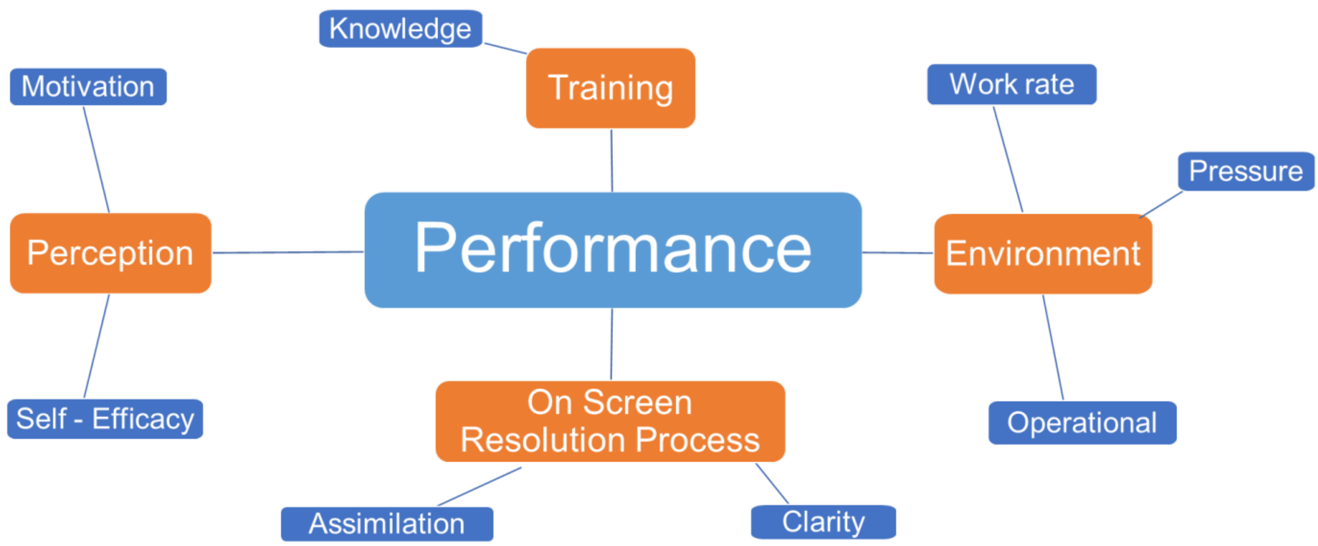
Any change to process, and the associated learning and adaptation of the screeners, must be seen in the context of human factors principles (R5.0). ICAO defines five principles for human behaviour (see figure below), the understanding of which helps to define and explain why people behave in certain ways within systems, and therefore helps in the design of process change – allowing the avoidance of added vulnerability and the addition of efficiency.



In the trial, the screeners performance was observed to be influenced by or interact with the following four factors:

1. Training
2. Environment
3. On-screen resolution process
4. Perceptions

The main observed concepts are highlighted in the diagram below.



Humans performing technical tasks have a finite ability to cope with multiple changes (Adler & Benbunan-Fich, 2012 - https://doi.org/10.1016/j.ijhcs.2011.10.003) and therefore the algorithm must be introduced with consideration to the operational context i.e. not loading security critical operatives with too much change (R5.0). To note, during the trial screeners did not highlight any issues with identifying the lithium batteries that were presented to them by the lithium battery detection algorithm.

Nevertheless, the threefold increase in rejections to L2, and the more than doubling of rejections to L3 clearly shows that the screeners work rate increased during the time the algorithm was running. Increased work rate increases cognitive load and risk of mistakes occurring (Galy et al., 2012 - https://doi.org/10.1016/j.ijpsycho.2011.09.023; International Civil Aviation Organisation, N.d. - Human Performance Principles). Although increased motivation could be posited as a mitigation to this more pressured environment (at least one screener reported that the algorithm made the screening process more variable and therefore added a different motivation) there must be considerations for managing this effect (R5.0). However, it must also be noted that at no point were the screeners in contravention of the regulations requiring breaks after set periods of reviewing continuous images – the image flow never became continuous. Further to this, lowering the false alarm rate will mitigate increases in screener work rate.

Perception is a critical element of performance, with higher self-efficacy (defined as a belief in one's competency to execute courses of action to manage prospective situations, put simply "self-belief") linked to higher performance in the literature (e.g. Chen & Chen, 2014 - https://doi.org/10.1016/j.ssci.2013.09.013). The perceived performance of the algorithm by the screeners, and their own ability to screen using it, was positive overall. Screeners were asked if their process for identifying security threats (e.g. EDS alarms) was impacted by the new lithium battery alarm – they reported that they would examine the EDS alarms first, followed by the lithium battery alarm. This is indicative that the lithium battery alarm is not interfering with or distracting from the existing security threat identification process and is merely slotting into the screener's image review as an additional step (although one that does take more time per image).

Interestingly, screeners also reported that the **additional alarm was a beneficial tool, allowing them to identify potential components of an improvised explosive device (IED).**

There was occasional observed uncertainty over the regulations defining the limits for lithium batteries in hold baggage, and what should or should not be rejected. This points to a requirement for further training to increase competency in knowledge of the regulations, and for the operational process for battery rejection to be well defined (R2.0).

Overall, the addition of a safety screening process (for lithium batteries) **was reported by users to aid the security screening process** (for prohibited articles under the relevant regulations) during this trial, with no significant negative impacts on screener performance. This data gathered is representative of individual viewpoints, and therefore cannot be held as definitive, although it absolutely provides significant insight into the human element of the screening process.

2.3.5 Capabilities vs Limitations of the Algorithm

Capabilities	Limitations
Can detect relevant lithium batteries in the operational environment	False alarm rate of the algorithm used during the trial (algorithm needs further "tuning" on a wider set of baggage, to better represent different passenger types, which would result in improved performance)
Straight-forward to deploy to existing security equipment	Work rate and alarm rate is increased – additional training, resourcing, and passenger communications required
Screeners can easily adapt to using the algorithm	Additional data is required for a comprehensive evaluation
Potential to enhance the security screening process, through enhanced identification of security threat components	
Can improve passenger perceptions of their own safety and security when travelling	

3. Conclusions and Recommendations

3.1 Conclusions

The main conclusions of the project can be summarised as follows:

- Addressing the lithium battery risk is important for global aviation safety goals.
- Consultation with aviation industry stakeholders and regulatory bodies has highlighted the need for cohesive regulations, comprehensive education, and collaborative efforts across industry.
- A screening solution via use of a lithium battery detection algorithm has been trialled.
- The lithium battery detection algorithm shows capability of detecting relevant lithium batteries.
- Screeners can successfully perform the task of lithium battery detection using the algorithm.
- The lithium battery detection algorithm has an impact on airport operations.
- The algorithm may enhance security threat detection.
- This technology can become available for the detection of non-compliant carriage of lithium batteries at aerodromes.
- Further research is needed on the capability of the algorithm, operational impacts, and the legislative framework.

Addressing the lithium battery risk is important to achieve and maintain global aviation safety goals. Both regulators and industry agree on the potential risks posed by lithium batteries and on the importance of their mitigation. However, the current methodologies applied to prevent restricted lithium batteries from being transported by air in passenger hold baggage are only partially successful. Although ICAO and IATA have published restrictions and guidelines, and EASA and other authorities have developed safety promotion material, incidents continue to occur on a regular basis.

Consultation with aviation industry stakeholders and regulatory bodies highlights the need for consistent regulations, comprehensive education, and collaborative efforts to mitigate the safety risks associated with lithium batteries and Dangerous Goods. The urgency of addressing these issues is underscored by concerns voiced by stakeholders. A lithium battery detection solution, deployed to existing security screening equipment, appears to be a viable solution allowing detection of non-compliant lithium batteries.

A multi-stage trial has been conducted on such a solution, and the performance, capabilities, operational impacts, and limitations of the lithium battery detection algorithm have been successfully assessed during

this research. The algorithm performs to a standard sufficient to detect prohibited lithium batteries in the live, operational environment, utilising existing security screening equipment and processes. The algorithm has demonstrated capability of detecting single, low-power, lithium batteries and hence capability of identifying non-compliant batteries, as defined by ICAO DG Technical Instructions.

The algorithm, as deployed, does have an impact on airport operations and screener performance. Current levels of knowledge of the relevant dangerous goods regulations amongst passengers and staff executing the screening function are variable. This would indicate that any deployed solution will need to take into account further training and procedural approaches to the full resolution process. Also, decision times for screeners were observed to increase for all threats, with lithium batteries taking the longest to resolve, though this can be balanced by the strong feedback received that the algorithm was an enhancement to the screening process; at least part of the increase was due to the context of the trial; and that it is predicted this decision time would come down with time as the operatives adjust.

As the trial has shown that there is no significant negative impact on a screener's ability to detect security threat items and perhaps even an enhancement on security threat detection, airport operators (or responsible parties) could consider the adoption of such an algorithm. Making the algorithm mandatory immediately without further data on detection capability and impact assessment is not suggested. However, if the risk picture is deemed to require it, **regulatory change might be necessary to instigate the level of harmonious and informed adoption and transformation to screening processes required to effectively mitigate the risk posed by lithium batteries.**

Further research is needed to assess the limitations of the algorithm, specifically an examination of false negatives. However, any challenges with implementing such an algorithm would appear to centre around operational processes: adequate screener training, mitigations for the increased number of bag rejections, improved communications with passengers, and ensuring competency in the relevant regulations, rather than with the algorithm itself.

The broad questions asked by this project can be answered successfully by the trial data: **The lithium battery detection algorithm *can* identify lithium batteries in the live, operational environment, and screeners *can* successfully perform the task of Lithium battery detection using the algorithm.** The gathered data provide an initiation point for further discussions on the potential need to address the risk posed by the non-compliant transportation of lithium batteries through legislative means. To this end, a series of recommendations have been made and an exploration of the regulatory context undertaken, relevant to deployment of such an algorithm – there is a gap identified between the frameworks of safety and security and therefore no immediate and simple regulatory solution can be presented.

As mentioned, stakeholder groups are aligned in the perception of the risk, and in their perceptions of the challenges in finding a solution. More data is needed to indicate an immediate need for regulatory change (including detail on impacts, and an appraisal of the overall threat and risk context), however, the algorithm represents a valid step on path to identifying lithium batteries and thus mitigating the risk.

The scope of this project was not to examine the risk picture for lithium batteries, although useful prevalence data was gathered through the trial. Any regulatory change would need research centred on the parameters of the risk (the risk picture). **As this research has shown that a lithium battery detection algorithm could prove capable of detecting non-compliant batteries and thus prevent them from travelling in hold baggage, hence mitigate the risk, this security screening solution should therefore be seen as a viable option in any potential future regulatory framework** (i.e. if there is regulation that demands lithium battery screening, the algorithm and existing security process are capable of delivering the aim of the legislation).

3.2 Recommendations

The research has highlighted various recommendations for actions towards a solution for mitigating the risk posed by lithium batteries via security screening processes. These recommendations can be divided into four main categories:

1. Technical – pertaining to technological solutions.
2. Operational – pertaining to the operational impact at aerodromes and on air operators and passengers.
3. Regulatory – pertaining to the legislative and regulatory framework for carriage of and screening for lithium batteries, including guidance material.
4. Future Work – pertaining to a recommendation for additional research.

All recommendations are directly linked to findings, analysis, or limitations resulting from either the stakeholder consultation or the live operational trial, hence, where relevant, have been referenced throughout the discussion and evaluation sections. The table below collates these recommendations with a brief description of the aims and benefits each action will entail.

The recommendations are further divided into three additional categories. Firstly, there are four **overall recommendations** drawn from the entirety of the research, followed by **supporting recommendations**. These recommendations are aimed at regulators, air operators, airport operators, and other relevant stakeholders, however, it is advised that all recommendations are considered holistically by all stakeholders. Many recommendations could be underpinned by regulatory change, however some can be seen to add benefit without any necessary change to regulation. Given that the regulatory picture is complex (see section 3.2.3) it is well worth considering approaches that can bring mitigation without reliance on legislative change.

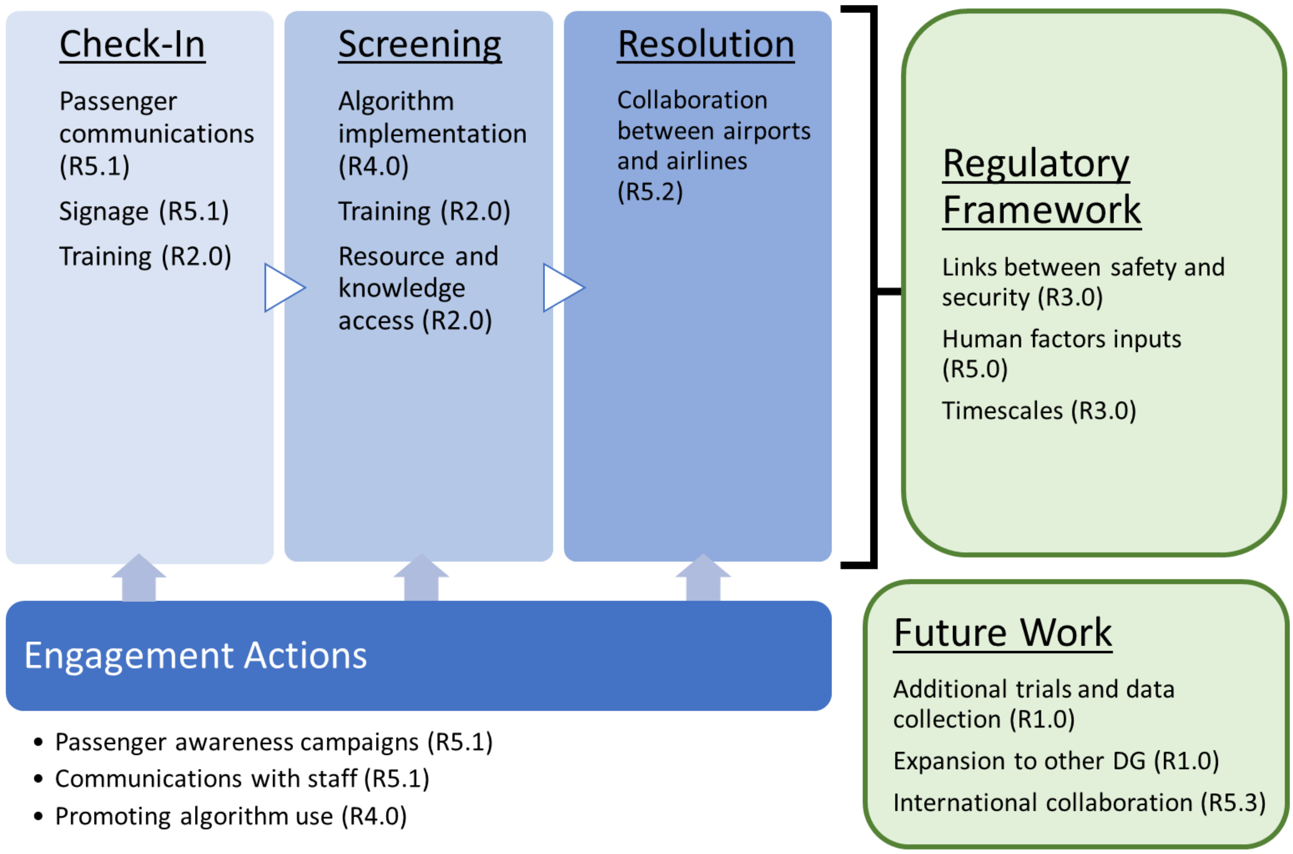
Additionally, many of the recommendations are aimed at aerodrome operators[5] and air operators (airlines) together, whilst in reality there is a single entity accountable for executing the security function for hold baggage, and associated training (although this can be subcontracted). There must be a consideration given to encouraging collaboration such that the accountable party for transport of dangerous goods can appropriately support the actions of the screening entity.

[5] Aerodrome operators within this report refers to any entity that executes the security screening function at an airport, which may be a private or a state entity.

Overall Recommendations:

1. Conduct additional research to steer future developments in an informed manner. Consider the expansion of the research scope to other dangerous goods screening capabilities.
2. Provide screeners with the required awareness on the existing rules concerning dangerous goods, and lithium batteries in particular.
3. Explore options for the future regulatory framework based on additional data.
4. Consider the use of hold baggage screening equipment to detect non-compliant lithium batteries.

3.2.1 Recommendation Themes and Table



This diagram shows the hold baggage system with the main themes of the recommendations, organised into a new framework. There are specific and implementable recommendations for the system process, as they apply to check-in, screening, and resolution. All of these themes are underpinned by potential regulatory change and engagement activities, and of particular note is the "screening" theme. To be effective, a new regulatory framework is needed, which will enable industry to implement the requirement – until this point algorithm implementation will be voluntary and limited. However, this must be seen in the context of the wider risk landscape. Future work forms the last key section, with themes of recommendation which will address limitations in this research and give additional data for informed decision making. The full table of recommendations follows overleaf.

	Ref.	Aimed at	Recommendation	Description	Category
Main Recommendations	1.0	European Commission, EASA	**Conduct additional research to steer future developments in an informed manner. Consider the expansion of the research scope to other dangerous goods screening capabilities.**	Additional research and trials are needed in order to equip regulators and industry with necessary data to steer future developments in a fully informed manner. The areas of further research and trials should focus on the following aspects: a) Data collection to determine lithium battery prevalence rate. Additional trials at relevant airports should be conducted to investigate the prevalence of non-compliant lithium batteries, to aid regulators, States, and operators in determining an accurate scale of the risk. b) Trials to develop a robust evidence base. Deployment of the algorithm at different sized airports should be trailed with different passenger profiles. c) Trials to confirm detection capability – potentially offline. d) Further trials to confirm the efficiency and issues with the resolution process. Consideration should be given to enlarge the scope of future research to cover the application of screening equipment and processes to mitigate the risks of transporting non-compliant lithium batteries in cabin baggage and cargo. Furthermore, an examination should be undertaken to determine the possibility of expanding or utilising EU funded research for the detection of other dangerous goods through security screening and processes.	Future work, technical, operational

	2.0	Aerodrome operators, air operators	**Provide screeners with the required awareness on the existing rules concerning dangerous goods, and lithium batteries in particular.**	Create or promote easy access reference material, based on existing passenger guidance and the DGR, that screeners can efficiently use to assist their screening and resolution process in line with the requirements of Part 8 of the Technical Instructions.	Technical, operational
	3.0	European Commission, Regulators	**Explore options for the future regulatory framework based on additional data.**	Based on additional data to be gathered as part of further research, the European Commission and regulators should explore options for the future regulatory framework to enable the use of screening equipment to mitigate the risk posed by the inadvertent transport of lithium batteries. There is no immediate regulatory solution, given the intersection of the frameworks of security and safety, hence a detailed examination of possible options should be conducted.	Regulatory, future work
	4.0	Air operators, airport operators, regulators	**Consider the use of hold baggage screening equipment to detect non-compliant lithium batteries.**	Air operators, in cooperation with airports, should consider the deployment of a lithium battery detection algorithm to existing hold baggage screening equipment to detect non-compliant lithium batteries. The benefits of using detection algorithms to enhance screeners' ability to detect security threats should be considered by the involved parties to achieve safety and security objectives. In the absence of regulatory requirements, the benefits of voluntary action should be explored by operators. Regulators should encourage air operators and airport operators to deploy the algorithm to support the implementation of their respective obligations.	Technical, operational

Supporting Recommendations	5.0	All	**Implement a future change centred on human factors**	Using ICAO's HF principles, any change created should be centred around human factors and security culture – including but not limited to: appropriate on-job-training, phased implementation procedures, awareness of effects of increased workload.	Operational, regulatory
	5.1	All	**Launch communications and awareness campaigns**	Design and deploy communications and awareness campaigns for passengers, to further highlight the severity of the consequences of transporting non-compliant lithium battery and suitable mitigations for the risks posed. The above can be implemented quickly and effectively, without the need for a regulatory change, and can be initiated by regulators, operators, and any relevant stakeholders. This would include improving passenger communications, improving signage, focusing on check in staff – this can be achieved through awareness campaigns and/or supported by regulatory change (e.g. changes to the regulations defining what signage must look like).	Operational
	5.2	ICAO, Regulators, European Commission	**Set up new collaborative channels between responsible stakeholders**	To support the aim of a collaborative solution, and to bridge the gaps between aerodromes deploying a security solution with air operators accountable for a safety measure, ICAO and regulators should take steps to encourage joint working between the two sectors.	Operational
	5.3	EASA	**Collaborate with countries who are implementing or using lithium battery detection methodologies**	Gathering data from existing research and deployed solutions (such as Hong Kong and Norway).	All

Recommendations by Stakeholder		
European Commission, National Appropriate Authorities (Regulators), and ICAO	1.0	**Conduct additional research to steer future developments in an informed manner. Consider the expansion of the research scope to other dangerous goods screening capabilities.**
	3.0	**Explore options for the future regulatory framework based on additional data.**
	4.0	**Consider the use of hold baggage screening equipment to detect non-compliant lithium batteries.**
	5.2	Set up new collaborative channels between responsible stakeholders.
	5.3	Collaborate with countries who are implementing or using lithium battery detection methodologies.
EASA	1.0	**Conduct additional research to steer future developments in an informed manner. Consider the expansion of the research scope to other dangerous goods screening capabilities.**
	5.3	Collaborate with countries who are implementing or using lithium battery detection methodologies.
Aerodrome operators, air operators	2.0	**Provide screeners with the required awareness on the existing rules concerning dangerous goods, and lithium batteries in particular.**
	4.0	**Consider the use of hold baggage screening equipment to detect non-compliant lithium batteries.**
All	5.0	Implement change centred on human factors
	5.1	Launch communications and awareness campaigns.

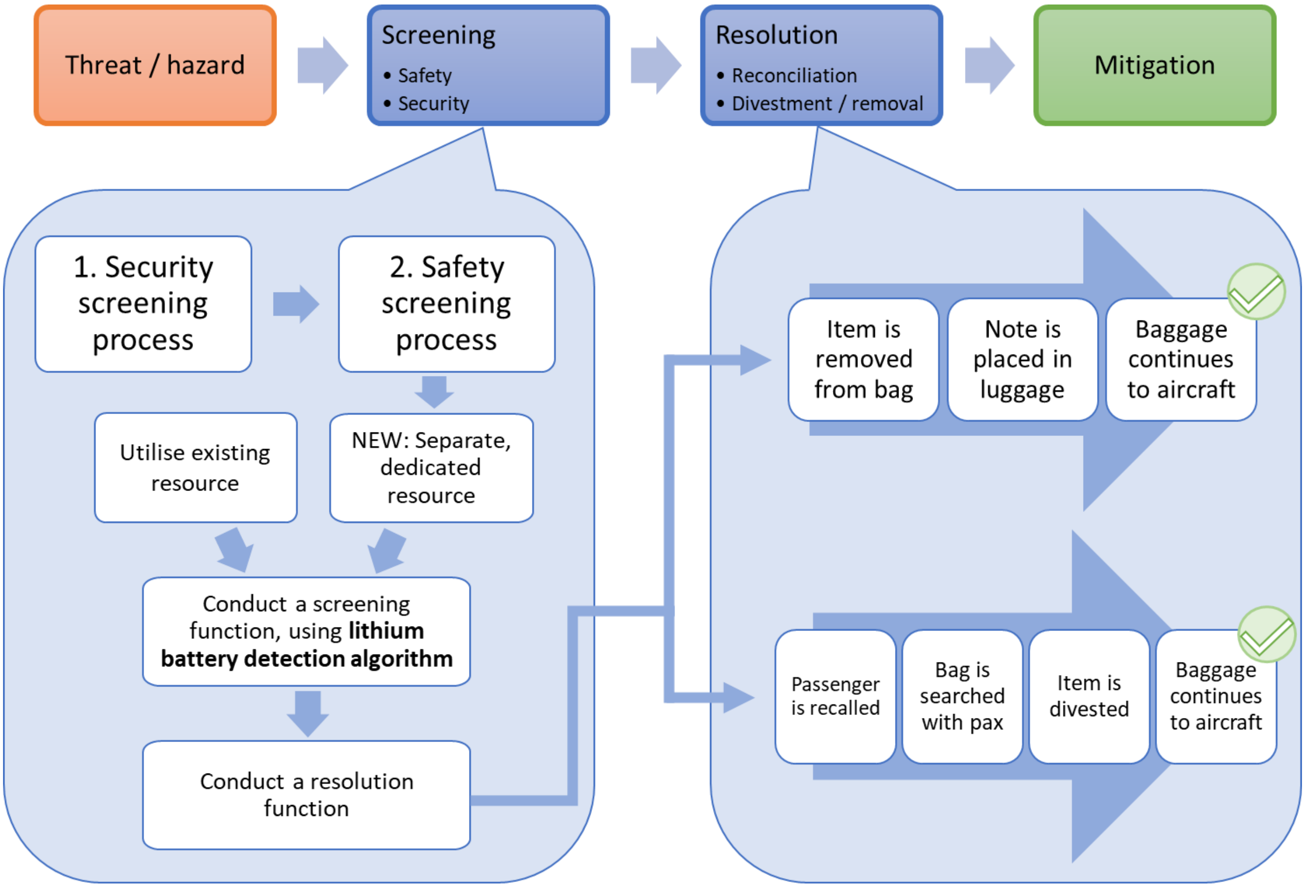
3.2.2 Security Process Solutions

This section details an overview of potential operational options, comparing a full security process with a combined safety and security process. The trialled procedure involved a full integration of the lithium battery identification process into the security screening regime, however it is pertinent to examine other options, one of which would be enacting a separate safety screening process alongside the existing security screening process. Such a safety process could be informed by approaches already in place in the EU, for example, removing a non-compliant lithium battery and leaving a sticker or note in place to inform the passenger.

The figures below map out a high-level process solution using the trialled lithium battery detection algorithm. There are two key elements to the process:

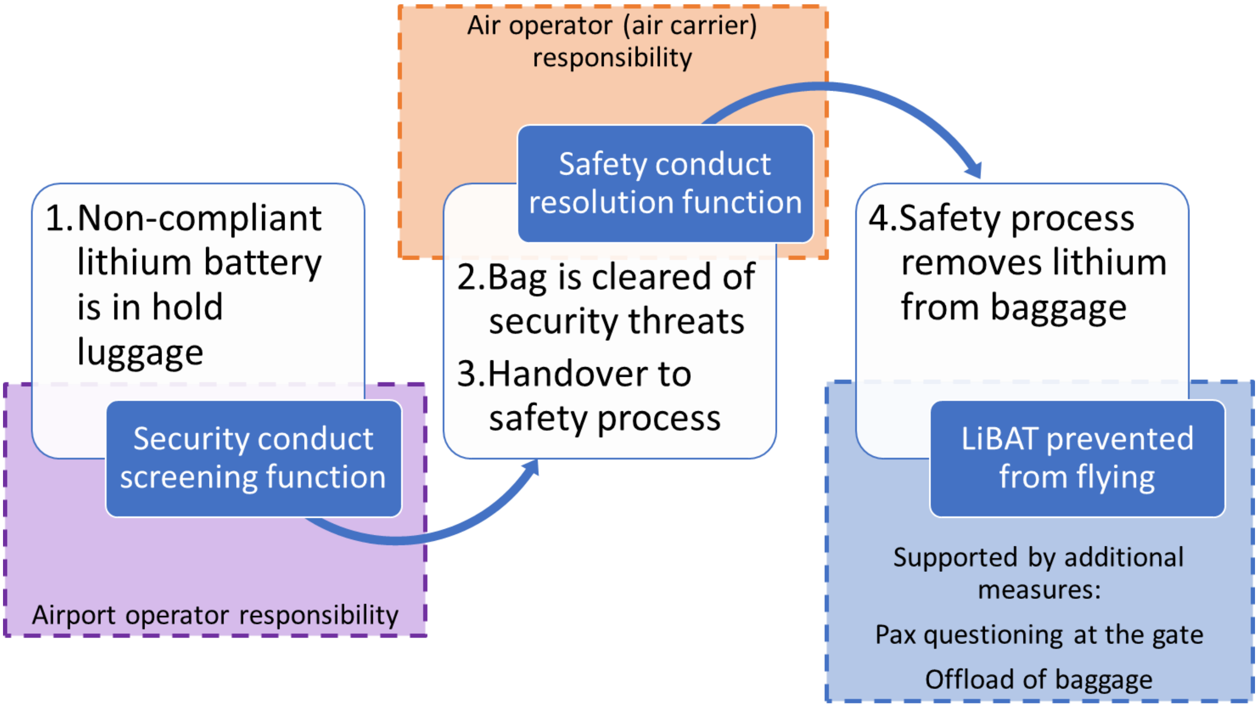
1. Screening (left bubble) – identifying lithium batteries using the detection algorithm.

2. Resolution (right bubble) – removing the identified lithium battery from hold baggage and therefore mitigating the risk.



One possible path through the above process is shown below (entity responsibilities are generalised).

1. An item of hold baggage containing a non-compliant lithium battery is screened by the security process at an aerodrome (under relevant security regulations).
2. The bag is cleared of any security threats, but a lithium battery is identified (either by the EDS machine or by the security screener).
3. The bag is handed over to a separate safety process (under the responsibility of the air operator and under relevant safety regulations).
4. The safety screening process removes the lithium battery from the baggage, either in the presence of the passenger who can divest the item to cabin baggage, or without the passenger present.



There exist **two options for achieving the screening function**:

1. Integrating the screening for lithium batteries into the security process (as per the live operational trial conducted as part of this research), or
2. The creation of a new (and separate) resource for "safety screening".

It is also possible that there could be a partial integration of these duties.

There also exist **three options for achieving the resolution** function, which could be undertaken by existing security resource or by safety staff:

1. Follow the security resolution process of recalling the passenger to their luggage in order to conduct a search. This allows the battery to be divested to cabin baggage (which is compliant under the relevant ICAO restrictions.
2. Establish a dedicated safety resolution process with recalling the passengers to their luggage at a location and time operationally convenient to the operator.

3. Remove the lithium battery item without the passenger present (effectively confiscating it). This is easier operationally as there is no lengthy passenger recall process, but there remain questions on what additional issues are created in removing items without passengers' presence, and thereby consent – although specifying this process in the air operators' conditions of carriage is a simple solution. In this option the battery does not fly, and therefore the risk is removed entirely.

It is also possible that there could also be a blend of removal and divestment.

The security screening process will need to take place first as there cannot be a scenario where a safety process is being resolved with an extant security threat within the bag. Security threats would take priority over unintentional safety hazards. Additional mitigation could be provided by air operator (safety) staff in the form of questioning passengers at the gate, although operationally this is a more disruptive mitigation method.

Advantages and disadvantages of the pathways discussed above are presented in the following tables.

Full integration of lithium battery screening into security process	
Advantages	**Disadvantages**
The research has shown capability with this integrated approach	It is difficult to create harmonious regulation to cover both safety and security
The additional screening process is easily assimilated into the security process	New relationships and communications links need to be created between safety (air operators) and security (airports)
New functions can be undertaken by existing staff using existing equipment	It is difficult to reconcile the bag with the passenger to remove the item (either for discarding or to cabin baggage)
New collaborative working practices may enhance overall safety and security standards	Considerations of the training load of security screeners from a human factors perspective
Security screeners already remove numerous dangerous goods	

Separate safety screening process	
Advantages	**Disadvantages**
No need to assimilate to security procedures – the lithium battery screening is kept separate	Would require large amount of additional resource (as currently there is no safety screening process – this would need to be designed from the ground up, including new staff, training, and regulations)
Lines of responsibility are kept distinct	The deployment of the algorithm and hold baggage system design could be more complex
Easier to develop a regulatory framework	No easy solution for dealing with combined threats
	Further separates safety and security – a loss of an opportunity for collaboration

Resolution Process – Passenger Reconciliation with Baggage	
Advantages	**Disadvantages**
Full consent of passenger gained for removing or removing the item	It can take a long time to recall the passenger
The bag search takes place with the passenger present, allowing the security (or safety) operative to undertake a behavioural evaluation and question the passenger	If the passenger is not recalled successfully, the bag cannot fly unless the lithium battery is removed

Resolution Process – Item Confiscation without the passenger	
Advantages	**Disadvantages**
The item can be removed quickly, and there is no lengthy recall process	No consent gained from the passenger for the removal of the item
The prohibited battery does not fly (not even in cabin baggage)	No behavioural evaluation can take place as part of the bag search process

3.2.3 Discussion of Possible Regulatory Framework Solutions

The effectiveness of any security or safety process is often dependent upon the regulatory framework in which it resides. In the case of the lithium battery detection algorithm, the solution crosses through two regulatory systems – aviation security and aviation safety. At the ICAO level and within the EU, security and safety come under different legislative and regulatory frameworks. Stakeholder research has highlighted the issues with defining a unified solution across both spheres, without a single regulatory policy or direction and without singular lines of responsibility and accountability. If the risk picture is accepted to require a regulatory solution, a question beyond the scope of this research, then such issues will need resolving.

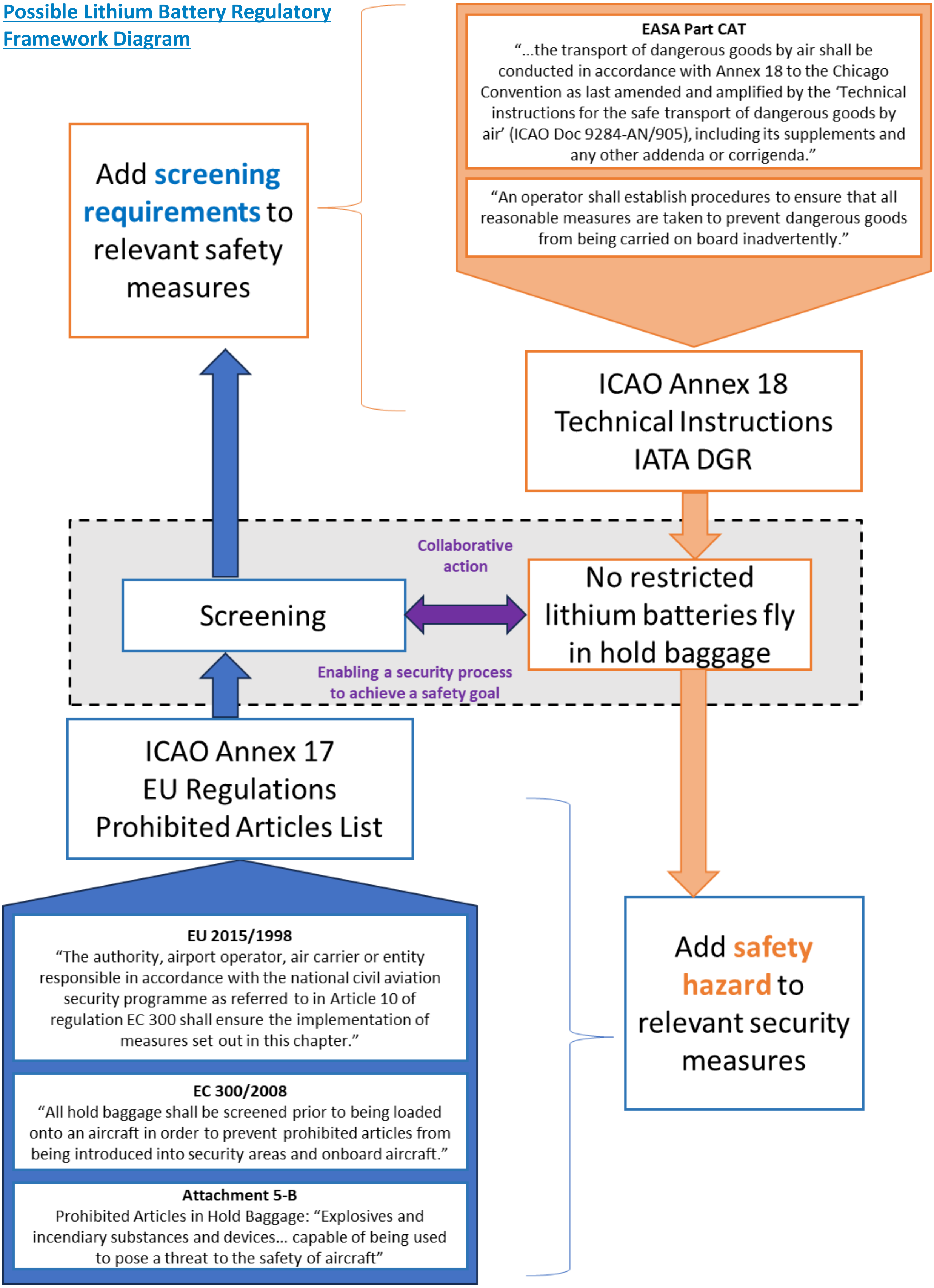
Dangerous goods posing a safety risk (in this case, lithium batteries) are restricted for carriage in hold baggage via ICAO Annex 18 and the associated Technical Instructions, which Member States are required to enforce through domestic legislation. Hence, the regulatory framework under which the transport of dangerous goods by air is conducted will vary from state to state. Relevant security threats are restricted for carriage in hold baggage via ICAO Annex 17 and the associated Security Manual, of which Member States are also required to enforce through domestic legislation (in the EU, this involves EC 300, EC 2015/1998, and other implementing regulation). Screening for security threats will also therefore be enacted under varying regulatory and legislative frameworks. There is therefore *not* an immediate regulatory solution.

States are required under ICAO Annex 17 to ensure that (a) all passengers and their bags, and (b) all cargo are screened before travelling on board an aircraft. Screening is required to ensure the absence of items that represent a threat to the security of the aircraft, primarily meaning improvised explosive devices; generally, preventative security legislation can only act to mitigate "acts of violence" or "acts of unlawful interference that jeopardise the security of civil aviation." Unintentional safety hazards do not fall in scope of this definition.

EU regulations specify a list of prohibited articles for hold baggage – items that may not travel in the hold of an aircraft as they present a security risk. One solution could be to create a new prohibited article category for lithium batteries (which would require a detailed risk and impact assessment). Yet, given that lithium batteries are safety hazards as opposed to security threats, for the regulatory reasons highlighted previous, this will not be an acceptable solution. All Member States are free to make their own More Stringent Measures under Annex 17, however these would need to be executable under relevant domestic legislation – an article on the prohibited list for security would have to be a security threat for the relevant screening parties to have the legal power to remove it. It is possible, given the evolving threat picture for lithium batteries, that there could be an extension of their definition as *capable of being used* (intentionality) to harm the safety of an aircraft, however security measures must be bounded in their power and applicability.

The solution, therefore, lies in linking the two areas of responsibility; where aerodrome operators are responsible for screening processes, and air carriers are responsible for carriage of lithium batteries, there will need to be a delegation of responsibilities across the two regulatory regimes. There would need to be a detailed examination of the legal lines of responsibility to ensure any implemented regulatory change is effective and enforceable (i.e. can be applied to all stakeholders) and it will need to be based on risk assessment. A diagram of potential framework changes can be found in the exploratory figure below, which aims to highlight issues, rather than suggest a solution. It explores a regulatory solution in adding screening requirements and responsibilities to relevant safety regulations and processes, and/or adding a safety hazard definition to relevant security regulations. Both the European Commission and EASA are supportive of cooperative measures on security matters related to civil aviation, where interdependencies with safety exist (Article 88 of the Basic Regulation EU 2018/1139).

Possible Lithium Battery Regulatory Framework Diagram



Lithium Battery Screening – Regulatory Framework Diagram – Explanatory Note

The overall aim of the lithium battery screening algorithm is to prevent non-compliant lithium batteries from travelling by air in the hold baggage of passengers (and therefore in the hold of aircraft). There are many mitigations that can feed into this system, however, the algorithm itself focuses on mitigation through screening – identifying undeclared lithium batteries in hold baggage via EDS machines and human screeners. Such screening is mandated by Annex 17 and EU regulations (in the EU), **hence the addition of the safety hazard (as defined by ICAO Annex 18 etc) to the relevant security measures could present a solution.**

Issues with this approach could be defining lines of responsibility (EU 2015/1998 widely specifies who is responsible for implementing security screening measures, in the UK for example this is the airport operator, but the overall responsibility for ensuring no DG flies on the aircraft is with the air carrier, in the EU via EASA Part CAT) and ensuring that the primary legislation gives the correct powers to deal with unintentional safety hazards (Attachment 5-B in the EU security regulations, for example, uses the language of "capable of being used to pose a threat to the safety of aircraft"). Existing powers allow air operators to interrogate hold baggage and require carrier-specific screening (e.g. via remote image review).

ICAO Annex 18 and EASA Part CAT define that air operators are responsible for preventing unauthorised DG from flying – **this regulation could also be made to reference specific screening requirements**. In practice, there are no defined responsibilities for security screening in these safety measures, and EASA Air Ops rules cannot be made to include security provisions. Therefore, air operators and those responsible for security screening would have to create new lines of collaboration to screen for relevant lithium batteries via a security process. This could be achieved by various legal means (for example, a Memorandum of Understanding), but again would require careful examination of the relevant lines of responsibility. In various ICAO Member States, aerodrome operators are already trusted to prevent security prohibited articles (explosives) or dangerous goods from flying on behalf of the air carriers.

EASA Air Ops regulations (as applicable) make reference to acceptable means of compliance for procedures under which any kind of portable electronic device (PED) may be used onboard, encompassing lithium batteries. This includes requiring the operator to identify the safety hazards and manage the associated risks of permitting the carriage and use of portable electronic devices. The risk assessment is required to consider the hazards from battery fires, and incidents are well known to industry, so operators are well placed to establish their own policies on whether power banks, for example, may be used and to brief passengers accordingly. This provides an adequate framework for mitigating risks of compliant lithium batteries *in flight in the cabin*, and shows that carriers must have understanding of the risk, which can be transposed to hold baggage.

CAT.GEN.MPA.200 Transport of Dangerous Goods states: "An operator shall establish procedures to ensure that all reasonable measures are taken to prevent dangerous goods from being carried on board inadvertently." The question remains, whilst it is the operator's responsibility to prevent DG (lithium batteries) from being carried on board an aircraft, and they well-understand the risk, how can they access the security process and legislative regime that enables this function to be executed? Any process of making mandatory an algorithm within the screening process would need to be seen hand-in-hand with the legislative landscape.

Further research is likely needed to formulate a decision on whether additional regulation is the correct next step. Stakeholder research within this project has shown that there is wide ranging support for a regulatory approach (such as a mandatory lithium battery algorithm), as it would allow operators to take informed mitigation steps and provide the incentive for change. However, it may also be appropriate to target operators and passengers with guidance to increase awareness of the problem (e.g. EASA Safety Information Bulletins, and communications campaigns). This research was not expansive enough to indicate an immediate need for a regulatory change, nor to offer a risk-based timescale for solution implementation, but does highlight that regulatory change would be advantageous, and that whilst the lithium battery detection algorithm can mitigate the risk effectively, its implementation across Member States would perhaps be more effective with the support of a regulatory change based on robust further research.

Moreover, as indicated by the above examination of the framework, a regulatory solution is not possible without further co-operation between safety and security. This research has shown that it is possible to detect safety hazards (lithium batteries) through security screening and therefore security and safety authorities should cooperate in finding solutions to reduce the number of unauthorised lithium batteries in passenger hold baggage, which would result in a safety increase.

3.1 Evaluation and Limitations

This research was subject to a number of limitations, which will be discussed in this section. It is important to note that where possible, these limitations have been considered and minimised, with data gathered from the research still deemed as sufficiently representative for an exploration of the problem. There is a detailed evaluation of the research limitations as they apply to the data collection during the trial and stakeholder consultation activities, and also an evaluation of the overall study.

Stakeholder Consultation Limitations

A wide number of targeted stakeholders were used for data collection in the first phase, with interviews allowing a breadth and depth of qualitative data collection, combined with surveys allowing a large volume of data to be collected. During the second webinar, there was no targeted data collection; engagement and surveys were conducted with a self-selected sample of webinar attendees. A better picture could have been built if the survey had been sent wider, for example to a set distribution of stakeholders spanning the required industry areas, however, the qualitative data that was collected was significant enough to offer an insightful analysis. Additional stakeholder research could still add value to this problem area, specifically using workshops or interviews to evaluate the suggested security process solutions and regulatory framework solutions.

Trial Limitations

The most significant limitation to this research comes from the sampling strategy. Due to constraints on resources and – critically – the availability of suitable aerodromes to conduct the trial, only one location and three consecutive days have been used for data collection. In an ideal scenario, the sampling strategy would demand that multiple airports were used, of varying sizes with varying passenger profiles, and that the trial is repeated both to verify the gathered results and to lessen the impact of any seasonal variation in passenger demographics (R1.0). This would add greater weight to both the quantitative and qualitative data, although both are still valid as part of the research undertaken.

Necessarily, the low throughput of bags meant that the operational impact of the trial was minimised, and allowed collection of rich qualitative data from extensive time spent with screeners. However, the low volumes also meant that sample sizes for various datasets were relatively low and may not, therefore, be representative. Furthermore, no statistical analysis has been conducted on the quantitative data, due to the small sample size. Therefore it cannot be said, at any confidence interval, that the reported differences decision time – for example – are a real change or due to chance/sampling error. For the majority of the prohibited lithium batteries identified by the algorithm during the trial, there was no verification of the item through a bag search, which limits the confidence of conclusion on detection and whether lithium battery alarms were real or false. This is the nature of conducting a live trial, without interfering with the operation – there has to be an on-screen resolution process. When viewed in parallel with the offline testing, confidence can be asserted in the detection ability. To give further insight to the detection accuracy, the images from the trial could be reviewed and additional testing could take place, potentially offline in a controlled environment where the accuracy of the detection capability can be further investigated with lithium battery test pieces/bags (R1.0).

It would also have been valuable to set up a control lane (or at a larger aerodrome, a control terminal), whereby one screening system is running the lithium battery algorithm, and another is running standard operating procedures, with one set of screeners acting as controls and another set screening with the algorithm. This would have allowed isolation of causative factors in decision time increases, for example.

Although a large amount of valuable data has been produced, there was very limited observation of the passenger reconciliation process, owing primarily to the limited number of lithium batteries present within hold bags. One of the key issues that arose from the stakeholder research was conflicting lines of responsibility for lithium batteries – security applying the process and safety owning the risk. This issue manifests operationally when bags are required to be reconciled and lithium batteries removed: how does the airport communicate with the airline, is there recourse to remove the battery without the passenger, how can an air operator assure itself of an item removal process applied by a different entity - all are extant issues that could have been better addressed from an operational standpoint had there been multiple reconciliations. It would also have provided better information on potential pinch points or opportunities for efficiencies to be generated in the reconciliation process (R1.0). Examining the OOG process did allow for some insights, and reduced this limitation.

There is also no reported data on L3 resolution times; L3 quantitative data was not taken forward as it is largely obsolete for this study, as the screeners were not solely focussed on screening the bag. It is therefore impossible to differentiate with the data obtained whether an increase in screening time is due to the algorithm or due to the screener attending to another task in the observation point (i.e. screening an out of gauge bag).

The screening environments were observed to be very pressured at times, and the data on resolution times and reject rates was no doubt affected by the operational context, however to what degree it is not possible to say. Additionally, it can be concluded that the context of the trial was affecting the screeners, and indeed it was observed that interactions between researchers and screeners were lengthening the screening process (though never to the detriment of the security operation). It must also be considered whether or not screeners were offering fully representative answers, given that they were being interviewed by a regulator who is also responsible for compliance activities at the aerodrome.

There is also no data available on false negatives at this time. From the trial, it was clearly observed that some items such as, laptops and similar PEDs in hold bags were not always alarming under the Lithium battery detection algorithm. Although it cannot be ascertained for certain whether any or all of these devices contained lithium batteries (and indeed a lithium battery within a personal electronic device is permitted in hold baggage) it does show that not all lithium batteries were identified by the algorithm. The conclusion on the algorithm's accuracy would be made more robust with a detailed image level analysis on false negatives (R1.0). Further, if the algorithm were to be universally deployed further tuning (as to be expected) on detection and false alarms would be necessary.

The execution of the trial itself was also subject to limitations. Owing to the setup of the screening process, there was no ability for a researcher to follow a bag from L2 to L3 in real time – the researchers were restricted to one level when positioned in each observation point. Although this has limited effect on the validity of the data, following a bag journey might have brought different insight. Furthermore, the timings of the data collection were not robustly planned to maximise the number of bags seen over the course of a day.

Finally, the deployed methods of qualitative data collection were not totally standardised. Whilst this approach allowed fully flexible and exploratory questions to be asked within the dynamic screening environment, future research would be strengthened by standardised questionnaires or interviews being implemented outside of the active screening locality. This could be further bolstered by gathering in-depth data on screener competency and experience (for example, specific certifications, TIP scores, time since last training, 6x6 currency, etc). This would give the ability to deepen the analysis on human performance.

Overall Evaluation

The study has been successful in achieving the aims of evaluating the feasibility of the detection of lithium batteries transported in hold baggage using the security screening equipment and processes in operation at airports. Technical, operational, and regulatory recommendations have been proposed, with the aim of supporting safety-related requirements without negatively affecting security performance. Limitations for implementation have been identified.

One of the key elements of the project was investigating the use of security screening equipment with a dedicated lithium battery detection algorithm; a trial at a European aerodrome of such hold baggage screening equipment has successfully demonstrated a technical and operational solution alongside assessment of the performance, limitations, and impacts. Further analysis of operational process solutions and regulatory framework solutions within this deliverable also contribute to achieving this key element. A detailed examination of screener performance has been completed, informed by human factors principles, to allow analysis and recommendations with respect to competency and training for screening personnel to perform additional safety duties.

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European Union Aviation Safety Agency

Konrad-Adenauer-Ufer 3
50668 Cologne
Germany

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Mail EASA.research@easa.europa.eu
Web www.easa.europa.eu