# DANGEROUS GOODS PANEL (DGP)
# MEETING OF THE WORKING GROUP OF THE WHOLE

**Rio de Janeiro, Brazil, 20 to 24 October 2014**

**Agenda Item 5: Review of provisions for the safe transport of lithium batteries**
**5.1: Improved hazard communication for energy storage devices**
**5.2: Simplification and clarification of provisions**
**5.3: Development of guidance material to assist States with oversight and awareness programmes related to the safe transport of dangerous goods, with an emphasis on lithium batteries**
**5.4: Consideration of recommendations from the International Multidisciplinary Lithium Battery Transport Coordination Meeting**

## THE DETECTION OF LITHIUM CELLS AND BATTERIES THROUGH X-RAY SCREENING

(Presented by R McLachlan)

**SUMMARY**

The United Kingdom Civil Aviation Authority, in conjunction with a supplier of x-ray equipment has carried out research into the feasibility of detecting lithium cells and batteries through x-ray screening.

**Action by the DGP-WG:** Action by the DGP-WG is in paragraph 2.

## 1. INTRODUCTION

1.1 Despite the detailed requirements for how lithium cells and batteries must be prepared and shipped and the efforts of States and international organisations to provide outreach to shippers, there continue to be large numbers of cells and batteries that are sent in non-compliance with the requirements of the Technical Instructions.

1.2 Previous analysis of incidents and fires involving lithium cells and batteries showed that the majority involved consignments that were 'undeclared'; i.e. neither declared as dangerous goods, nor marked in accordance with Section II of the applicable packing instructions. Such consignments are also often deliberately mis-described on accompanying cargo documents such as the air waybill in an attempt to prevent identification of the true contents by the aircraft operator or their handling agent.

1.3 Whilst the recently agreed prohibition of lithium metal cells and batteries on passenger aircraft will prevent correctly prepared and declared consignments from travelling on passenger aircraft, it is very unlikely to prevent those consignments that are undeclared from continuing to be carried. Indeed, it is suggested that unscrupulous shippers that previously complied with the requirements may choose to send future consignments undeclared so that they can continue to be carried by passenger aircraft.

1.4 At the same time, advances in x-ray screening technology have resulted in the ability for x-ray screening to be automated. Whilst this has resulted in improved security screening with less human interaction, an unintended consequence is that undeclared dangerous goods, including undeclared lithium batteries, are less likely to be detected.

1.5 As a result of all of the above concerns, the United Kingdom Civil Aviation Authority (CAA) recently contracted an x-ray screening equipment manufacturer to examine the feasibility of using x-ray equipment to automatically detect lithium cells and batteries. This project has now been completed and attached to this working paper is an extract from the final report containing details and results of the tests that may be of interest to the working group.

1.6 The method used was to adapt the software algorithms used on existing current technology x-ray machines in order to detect lithium. It is believed that other manufacturers of x-ray equipment use similar methods of detection, so the method used in the trials may also be able to be used by those manufacturers.

1.7 In summary, the report indicates that whilst the rates of detection and false alarms depend partly on the size and number of lithium cells/batteries in a cargo being screened together with the amount/density of other products in the same cargo, effective detection of lithium cells and batteries is feasible, particularly bearing in mind that further development work would be likely to improve both rates. In particular, bulk consignments of lithium batteries, which is the greatest area of concern so far as fires on board aircraft are concerned, are able to be detected with a high degree of confidence. Although the detection rates for smaller numbers of cells/batteries are lower, this is still a significant improvement on a zero detection rate for existing automated x-ray screening equipment.

1.8 As a result of the research project's findings, the United Kingdom CAA is looking to develop an operational performance standard which manufacturers of x-ray equipment in general could potentially meet. The CAA is therefore proposing to initiate standard-setting by an appropriate international industry body.

## 2. ACTION BY THE DGP-WG

2.1 The DGP-WG is invited to review and discuss the extract from the report provided in the appendix to this working paper and consider how the outcomes could be developed further.

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# APPENDIX

## EXTRACT FROM FINAL REPORT ON A FEASIBILITY STUDY FOR AUTOMATICALLY DETECTING BATTERIES IN AIR CARGO

# Feasibility Study for Automatically Detecting Batteries in Air Cargo

Extract From Final Report

In partial fulfillment of

United Kingdom Civil Aviation Authority

Contract Number 2009

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# Revision History

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|---|---|
| Version 1.0 - initial release | 19 September 2014 |

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# Table of Contents

# Executive Summary


Lithium (Li) batteries can ignite if damaged or improperly packaged, designed or assembled, their shipment within air cargo. Thus, a means of identifying the presence of these types of batteries in air cargo is desired. However, no acceptable means of doing so currently exists. To address this safety gap, the United Kingdom Civil Aviation Authority (UK CAA) contracted with Rapiscan Systems to determine the feasibility of using the Rapiscan 632DV cargo-scanning system and to-be-developed image-processing tools for the automatic screening air cargo for Li batteries.

Rapiscan developed a prototype algorithm that leveraged its knowledge and expertise in advanced image processing of x-ray images. The algorithm processes effective atomic-number ($Z_{eff}$) images and "organic" images derived from the dual-energy, dual-view x-ray data provided by the 632DV.

A variety of Li-battery test objects were provided by the UK CAA for investigation. Even when cargos with highly-metallic clutter are included in the evaluation, automatic detection is possible with high probability and low false alarm rate for bulk multiple batteries packed for commercial shipment. This battery type and configuration has been identified as of greatest concern, for the ignition of one battery can lead to a chain reaction of ignitions.

For the image-data set collected, the optimal prototype algorithm developed in this study demonstrated a detection rate exceeding 70% for bulk C- and D-size Li-metal batteries, and a false alarm rate below 10%. Single-quantity Li battery types were detected in the 40% - 60% range.

Additional work is required to bring the prototype algorithm to commercial-ization, including (a) additional data collection of various types of bulk batteries; (b) investigation of a larger sample of alkaline and other non-Li batteries to determine if they can be distinguished from Li batteries; (c) collection of stream-of-commerce data with manifest information to validate false-alarm performance; and (d) additional algorithm improvements.

**CHAPTER 1**

# Introduction

The shipment of lithium (Li) batteries in air cargo is regulated; for they can ignite if damaged, or improperly packaged, designed, or assembled.

In December 2013, the United Kingdom Civil Aviation Authority (UK CAA) contracted with Rapiscan Systems to determine the feasibility of using the Rapiscan 632DV inspection system, and advanced image-processing tools (algorithms), to automatically detect lithium batteries contained within air cargo. The 632DV system was selected since it is currently in use at the air-cargo handling facilities at the Hong Kong International Airport, a major transportation hub for air cargo containing lithium batteries. The goal of this feasibility effort is to develop a prototype algorithm capable of identifying lithium batteries in air cargo with high probability and low false alarm rate.

CHAPTER 2
# Technical Approach

## 2.1 Background

### 2.1.1 Rapiscan 632DV Inspection System

The 632DV inspection system is designed for inspection of pallet and break-bulk air cargo. With a tunnel size of 1.5 m x 1.6 m, the 632DV utilizes transmission x-ray technology, and is comprised of two x-ray sources that deliver images from two views—horizontal and vertical (see Figure 1 below).


Figure 1. The Rapiscan 632DV cargo inspection system

Each view is supported by an array of dual-energy detectors that separate the x-rays received into two energy bins—the low-energy bin and the high-energy bin. This dual-energy data is the foundation for generating the atomic number (Z) information, thereby providing material discrimination essential for effective detection algorithms.

### 2.1.2 Effective Atomic Number Image and Histogram

Details not included in this extract.

### 2.1.3 Organic Image

Details not included in this extract.

## 2.2 Algorithm Approach

Details not included in this extract.

CHAPTER 3

# Data Collection

## 3.1 Overview

The main goal of the data collection effort was to gather 632DV images sufficient in number and diversity to support this feasibility study. Three types of data collection activities were performed:

- **Target characterization data collection.** This data collection effort involved acquisition of x-ray images of bare Li batteries to determine which set of features can be used to detect the batteries in cargo.
- **Probability-of-detection data collection.** During this data collection, x-ray images of Li batteries attached to real air cargo were acquired. These images provide a training set of data for developing the prototype detection algorithm, and a test set of data for establishing the probability of detection (PD).
- **Stream-of-commerce data collection.** This data collection involved acquisition of x-ray images of standard stream-of-commerce cargos that pass through the 632DV inspection system. These images represent a data set for training the prototype algorithm to recognize potential false-alarm regions, and a test set for establishing a probability of false alarm (PFA).

## 3.2 Details

### 3.2.1 Data-collection Locations

To ensure that the algorithm was developed and tested on a variety of air cargo data--rather than on a specific type of cargo, which can skew detection and false-alarm results--x-ray data were collected at the following locations:

(a) a Servisair cargo handling facility at Gatwick airport (LGW) in late January 2014. For this target-classification and PD data-collection effort, the majority of cargo types observed at Gatwick were suitcases, mail, and organics (e.g., produce and fish).

(b) a World Freight Services facility at Heathrow airport (LHR) in April/May 2014. For this PD data-collection effort, most of the observed shipments were machine parts, electronics, and industrial cargos.

(c) a cargo-handling facility at Hong Kong International Airport (HKG) in June 2014. For this stream-of-commerce data-collection effort, the majority of cargos consisted of electronic items.

Additionally, near the end of this study, a limited data-collection effort was performed at Rapiscan Laboratories to acquire x-ray images of laptop-computer batteries, both bare and attached to cargo.

### 3.2.1 Target Materials

The project sponsor, the UK CAA, provided Rapiscan with a selection of lithium-ion and lithium-metal batteries for test and evaluation as potential algorithmic identification. These consisted of:

a) Rechargeable consumer electronic batteries (AA, C, D, etc.)

b) Laptop computer batteries

c) Cell phone batteries

d) Power tool batteries

Rapiscan also purchased a number of alkaline batteries that would normally be allowed without restrictions in air cargo shipments. A summary of all battery types used in this study is provided in Table 1.

**Table 1. Summary of battery types used in the project**

| Lithium-ion | Lithium-metal | Other |
|---|---|---|
| Electric bike | LSH14 (C size) | Alkaline |
| 50 cycles | LSH20 (D size) | |
| Laptop Computer | LS14250 (1/2 AA) | |
| Cell phone | LS33600 (D size) | |
| Power tool | "Button" | |

### 3.2.2 Data Collection Plan

For the target-characterization and PD data collection, the process was divided into two stages. In the first stage, bare batteries were run through the 632DV. Since it was not feasible to position the batteries within the stream-of-commerce cargos, in the second stage the batteries were attached to the exterior of palletized cargo. For both stages, the following parameters were varied to obtain a large variety of images:

a) Type of battery

b) Quantity of batteries

c) Battery position within the field of view (both vertical and horizontal)

d) Battery orientation

When scanning bare batteries, batteries were placed directly on the cargo-support rollers; to position targets above the belt, a low-density foam was used. For each type and quantity of battery, scans were performed at each of the tunnel positions shown in Figure 5. Scans of batteries attached to stream-of-commerce cargos were performed in a similar manner, except that the quantities of batteries and number of scan positions were limited due to physical constraints imposed by the cargo.

| | | |
|---|---|---|
| 9 | 8 | 7 |
| 6 | 5 | 4 |
| 3 | 2 | 1 |

Figure 2. Grid representing palletized cargo passing through the 632DV system. Pallet motion is perpendicular to the plane of the figure. Each numbered section represents a location where batteries are placed (when possible).

For each set of data collected, a developer test and evaluation (DT&E) subset was released to the algorithm team for developing the prototype algorithm. The remaining subset, the independent test and evaluation (IT&E) set, was released to the testing team for evaluating the performance of the prototype algorithm.

## 3.3 Data Collected

### 3.3.1 Bare Lithium Batteries

Bare batteries were scanned as described in section 3.2.2. The scan results from one such configuration are illustrated in Figure 6. This figure shows a photograph of a box of cell-phone batteries and the corresponding x-ray images.

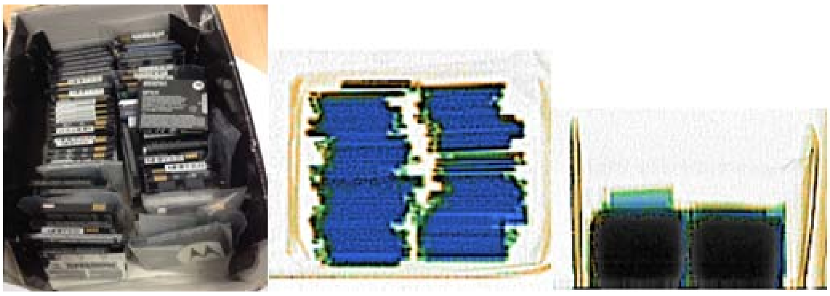


Figure 3. 632DV scans of cell phone batteries. Left: photograph. Middle: X-ray image (vertical view). Right: X-ray image (horizontal view)

The number of bare-batteries images collected, and identified for DT&E or IT&E, is summarized in Table 2.

**Table 2. Number of x-ray images of bare batteries collected during the project, and those assigned for developer test and evaluation (DT&E) or independent test and evaluation (IT&E).**

| Data Sets | Gatwick | Heathrow | Rapiscan Laboratories |
|---|---|---|---|
| DT&E | 335 | 20 | 35 |
| IT&E | 161 | 10 | 17 |
| **Total** | **496** | **30** | **52** |

### 3.3.2 Lithium Batteries Attached to Cargo

Batteries attached to the exterior of stream-of-commerce cargo were scanned using the 632DV. Each cargo had a unique shape and size, so the locations of the batteries were often restricted. The same cargo was often scanned multiple times with different battery types and configurations. A few x-ray images of batteries attached to cargos are shown in Section 3.4.2. Over 800 images were collected in this configuration (see Table 3).

**Table 3. Number of x-ray images produced for batteries attached to cargos, divided by DT&E and IT&E sets.**

| Data Sets | Gatwick | Heathrow | Rapiscan Laboratories |
|---|---|---|---|
| DT&E | 243 | 430 | 22 |
| IT&E | 119 | 130 | 11 |
| **Total** | **362** | **560** | **33** |

### 3.3.3 Stream of Commerce Cargo

Approximately 4,500 x-ray images of stream-of-commerce cargos that passed though the three air-cargo inspection facilities were retrieved from the respective 632DV computer disk drives (see Table 4). A few examples of these images are shown in Section 3.4.3.

**Table 4. Number of x-ray images of stream-of-commerce cargos collected, and divided by DT&E and IT&E sets.**

| Data Sets | Gatwick | Heathrow | Hong Kong |
|---|---|---|---|
| DT&E | 500 | 750 | 1700 |
| IT&E | 250 | 370 | 850 |
| **Total** | **750** | **1120** | **2600** |

## 3.4 Initial Assessment of Data

### 3.4.1 Bare Lithium Batteries

Photographic and x-ray images of bare batteries are shown in Figure 7, with vertical and horizontal views of low-energy images shown for four exemplar sets of batteries. The battery types are noted in the figure caption. The data collected covered a variety of battery types (Table 1) for a number of target positions (Figure 5) and orientations. These data support the study and identification of battery characteristics, and enable the development of a feature set that can be used to develop an automated detection algorithm.


Figure 4. X-ray images of bare batteries. (A) LSH20 Lithium-metal batteries. (B) LSH14 Lithium-metal batteries. (C) 50-cycle electric bike battery. (D) BL1830 power tool lithium-ion battery (left) and 6-cell laptop-computer lithium-ion battery (right).

### 3.4.2 Lithium Batteries Attached to Cargo

X-ray images of batteries attached to cargo are shown in Figure 8. For lightly- to moderately-cluttered cargos (the first and second rows), respectively, the batteries are clearly visible in blue. Specifically, in the color scheme displayed, organic materials are orange, and inorganic materials are green to blue, depending on the atomic number. The lithium batteries appear as blue since their measured $Z_{eff}$ ≈15. The third row of Figure 8 exemplifies the challenges to be expected when batteries are placed in cluttered cargo. As can be seen here, the superposition of cargo structures and the batteries can obscure detectable features, thereby making it difficult for an algorithm to identify the presence of the batteries.

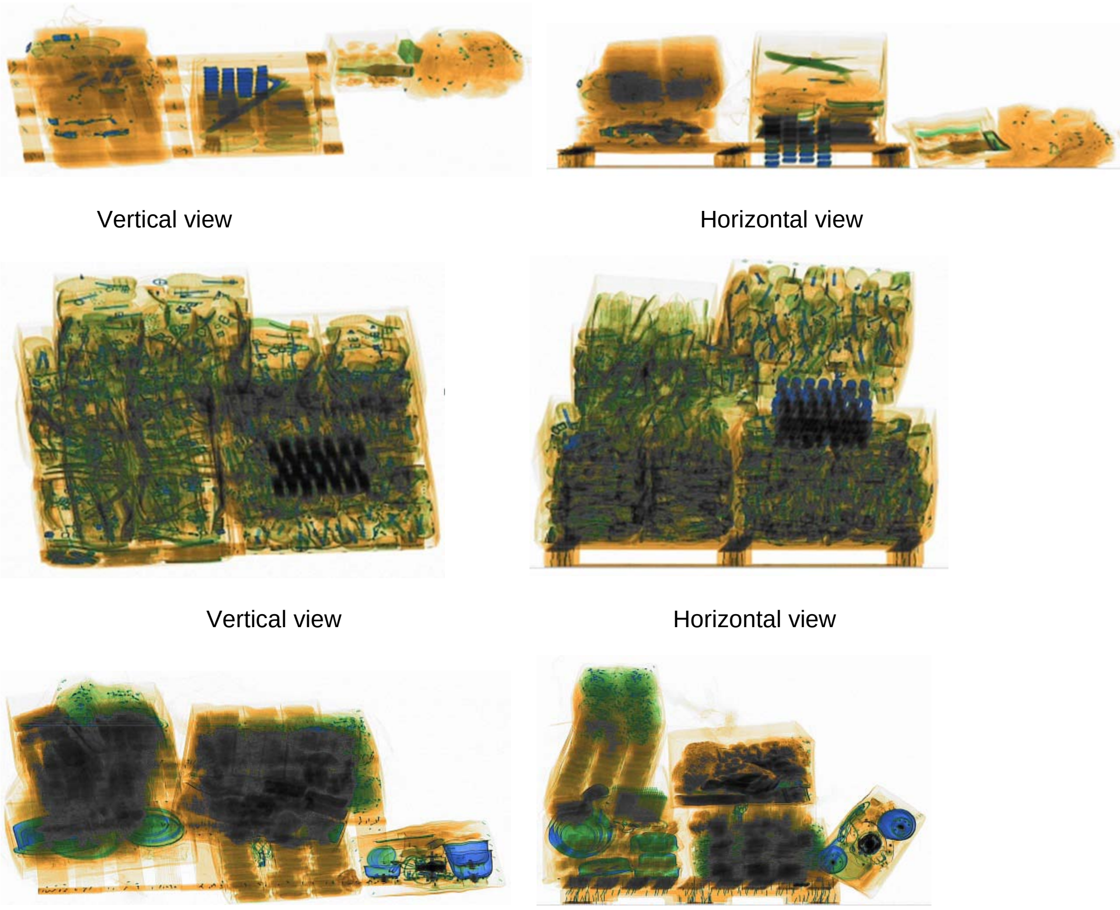
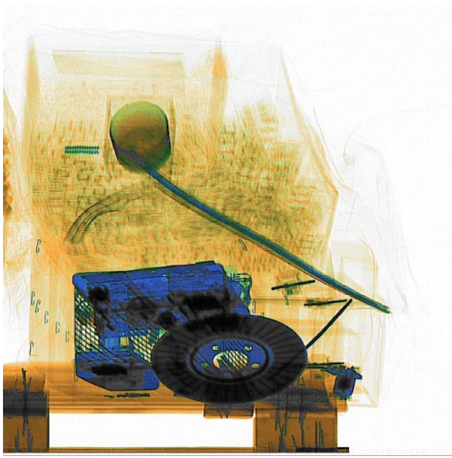



Figure 5. X-ray images of batteries attached to cargo. First row: low clutter. Second row: moderate clutter. Third row: high clutter.

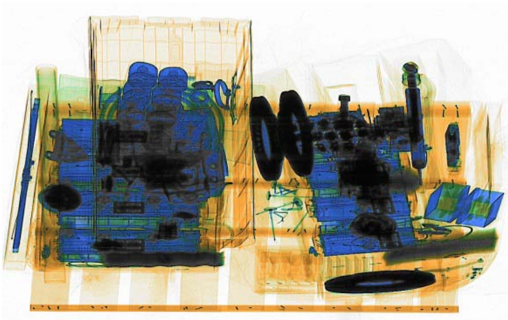
### 3.4.3 Bare Cargo

X-ray images of clean stream-of-commerce cargos are shown Figure 9. The images show different types of cargos with various degrees of clutter. The primary purpose of collecting such images is to assess the false-alarm performance of the algorithm. As such, it is important to obtain scans of a wide variety of cargos representative of the types of cargos to be "seen" by the algorithm. The data taken from the three cargo-inspection facilities do indeed span a broad mix of cargos--including luggage, mail, produce, machine parts, electronics, and industrial cargos.

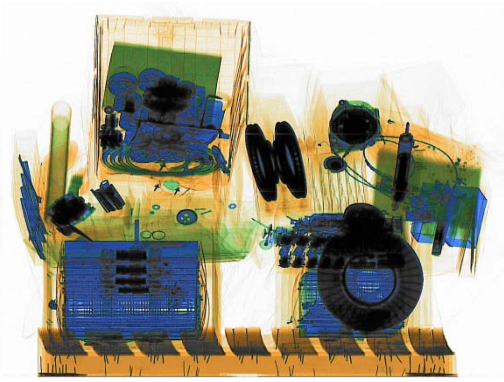
Top view



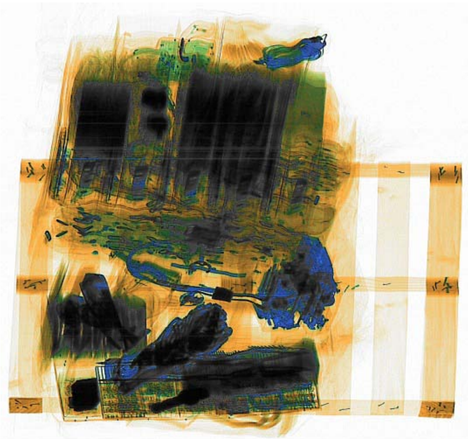
Side view



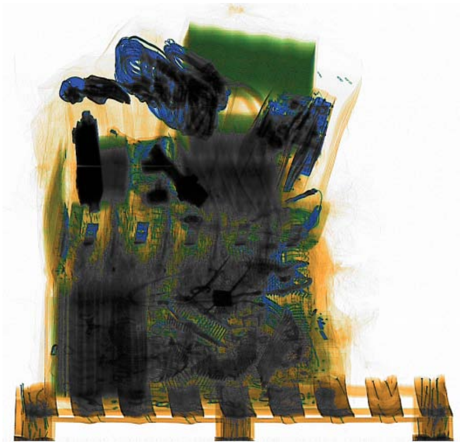
Top view



Side view



Top View



Side View

Figure 6. X-ray images of cargos. First row: low clutter. Second row: moderate clutter. Third row: high clutter.

CHAPTER 4

# Algorithm Development

## 4.1 Overview

Details not included in this extract.

## 4.2 Segmentation

Details not included in this extract.

### 4.2.1 Bare Lithium Batteries

Details not included in this extract.

### 4.2.2 Lithium Batteries Attached to Cargo

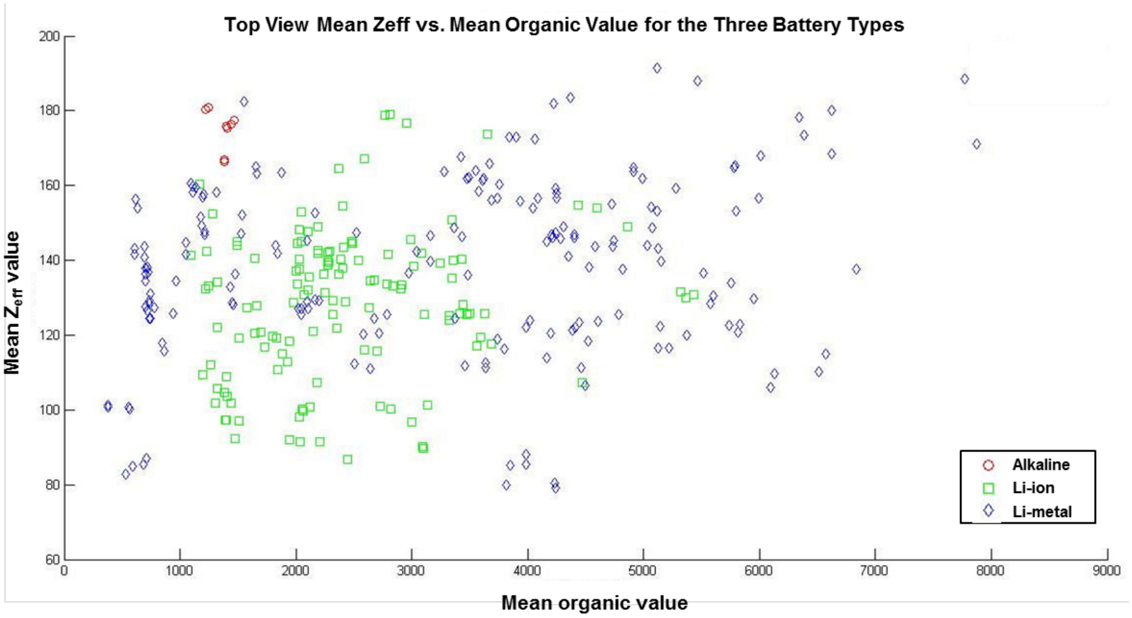
Details not included in this extract.

### 4.2.3 Bare Cargo

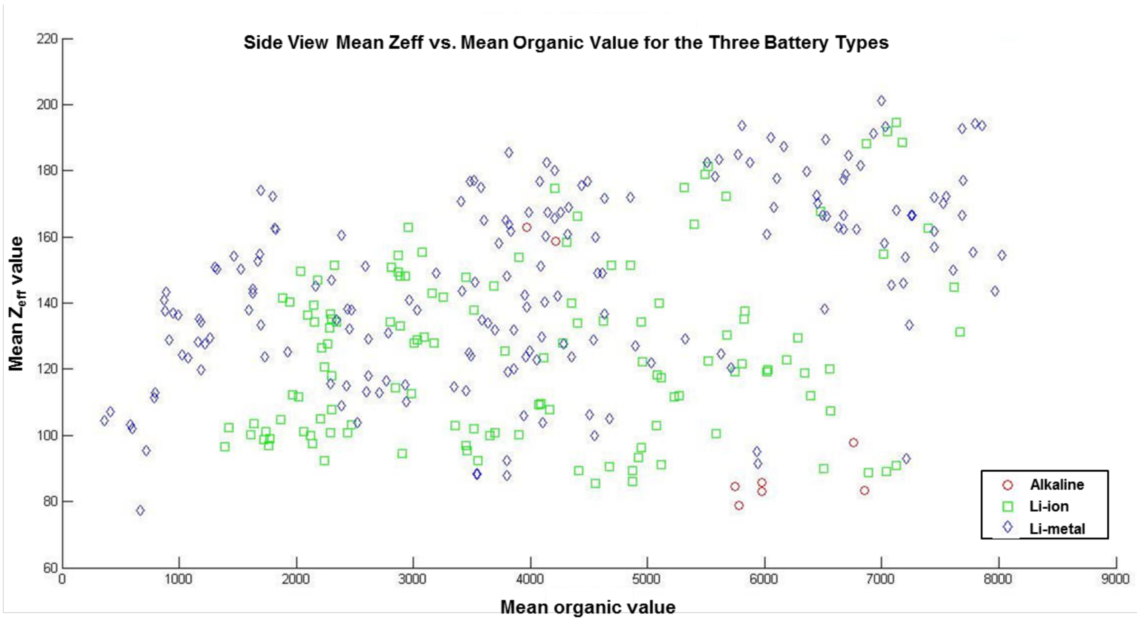
Details not included in this extract.

### 4.2.4 Comparing Battery Types

The 335 scans of bare batteries from the Gatwick DT&E data set were sorted according to battery type: Li-ion, Li-metal, and alkaline. Using the Zeff images, the mean Zeff over the battery region only was computed for both views. Similarly, the mean organic value over the battery region only was computed for both views of the organic images. The mean Zeff was plotted against mean organic value for top- and side-view images (Figure 25).




(A)




(B)

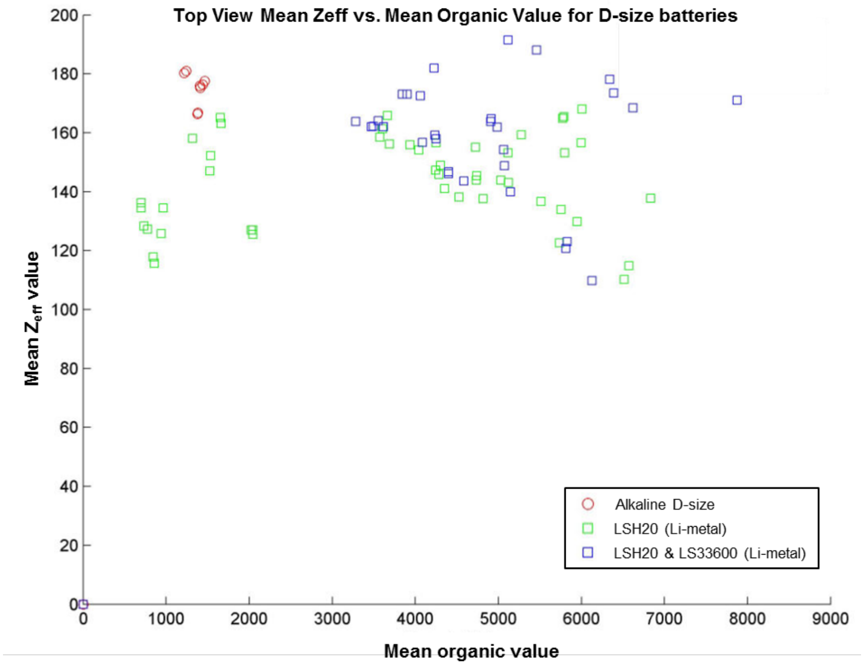
Figure 7. Comparison of Li-metal, Li-ion, and alkaline batteries based on mean Zeff (x10) and mean organic value. (A) Top view. (B) Side view.

Regarding Figure 25, the following observations can be made:

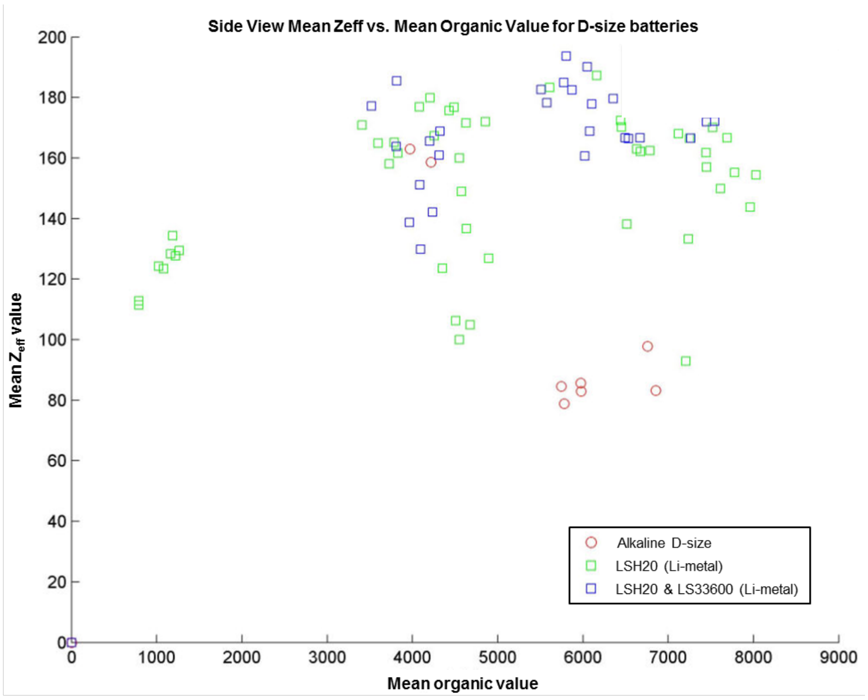
- Intermingling of the blue points (Li-metal batteries) and green points (Li-ion batteries) suggests that it is not possible to distinguish between Li-metal and Li-ion batteries based on Zeff and organic values. On the other hand, it does appear that, at least in the top-view images, these physical quantities may be used to distinguish alkaline batteries (red points) from the Li battery types. While this appears encouraging, it must be noted that the number of samples of alkaline batteries is very small (one box of six D-size batteries). A larger sample would be needed before making any conclusions.

- The range of mean Zeff is approximately 8 - 18, rather than being a much narrower range roughly centered at Zeff =15. This appears to be caused by the orientation of the target object. In particular, when the x-ray beam experiences higher attenuation as it traverses the longer axis of an object, the estimated Zeff is less, as can be seen in the fairly dim side-view Zeff image in Figure 14.

The mean Zeff and organic values for batteries of the same shape and size were also examined. The results obtained for D-size alkaline and Li-metal batteries are shown in Figure 26. In the top-view images, the range of mean Zeff is seen as narrower than before. However, in the side-view images, the range is as large as previously observed. Again, this is caused by different orientations of the batteries. For example, Figure 27 compares two side-view Zeff images of D-size alkaline batteries. In both images the direction of the x-ray beam is perpendicular to the plane of the page. The beam experiences a higher attenuation on the left image since the object has a larger dimension in this direction; subsequently, the observed Zeff is lower. In this case Zeff ≈ 9 compared with Zeff ≈ 16 for the image on the right.

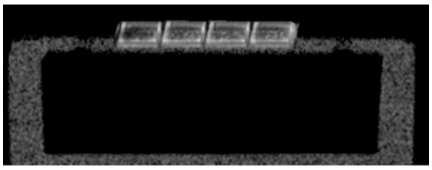



(A)




(B)

Figure 8. Comparison of D-size Li-metal and alkaline batteries based on mean Zeff (x10) and mean organic value. (A) Top view. (B) Side view.



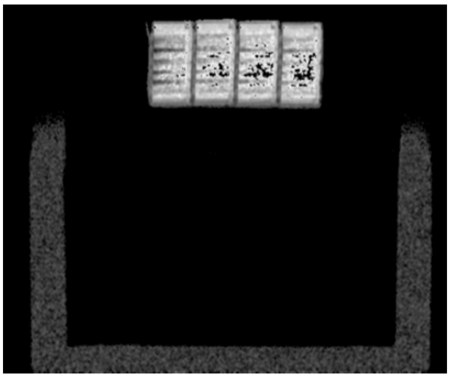


Figure 9. Comparison of two side-view Zeff images of D-size alkaline batteries. In the left image, the batteries appear long and thin and the Zeff image is dimmer (i.e. lower Zeff values) than on the right. The image on the left has a mean Zeff of ~9 while the image on the right has a mean Zeff of ~16, which is closer to the values obtained for the top-view images shown in Figure 25.

## 4.2.5 General Observations

Based on the results discussed in Sections 4.2.1 - 4.2.4 the following observations are made:

1. Applying both thresholding of the Zeff image *and* region-growing segmentation of the organic image has a fairly high probability of

segmenting the batteries in at least one of the four segmented images produced.

2. Cargos with a combination of metal clutter and very large amounts of organic material will be challenging for Li battery detection, since the segmented regions may also include large regions in which discriminating Li batteries from other materials is difficult. Under these circumstances the procedures developed in the classification stage of the algorithm will have to be used to help identify the target objects.

3. Small packages of batteries, especially in cluttered cargo, will be difficult or impossible to detect. As observed in Figure 19, a small package of batteries will have a weak to non-existent peak in the Zeff image histogram. Similarly, segmentation of the organic image may fail to reveal the presence of the batteries. As shown in Section 4.3, this suggests the need to establish a minimum package size, and the operating conditions that must exist, for the batteries to be detected.

4. An algorithm that deploys Zeff and organic images to detect Li batteries will not be able to distinguish between Li-metal and Li-ion batteries. Also, due to the small sample of alkaline battery data collected, it is not possible at this time to determine if such an algorithm could be tuned to distinguish between Li and alkaline batteries.

## 4.3 Object Identification and Classification

Following the segmentation step, all segmented regions are examined in the object identification phase to determine if they should be analyzed further in the classification stage. During object identification, regional characteristics such as area, organic thickness, Zeff number, and other properties such as distance to neighboring regions, are used to extract all possible regions of interest from the segmented image. Regions that meet predefined criteria, such as for minimum area or for a repetitive pattern of similar regions, are retained for further analysis in the classification step, while the other regions are discarded.

In the classification step, several classifiers were devised that apply various features to determine which segmented regions could be classified as Li batteries. Determination of optimal parameters for the classifiers was accomplished empirically and also by receiver operating characteristic (ROC) analysis. The latter analysis is a standard technique whereby a graphical plot of PD vs. PFA (the ROC curve) is used to illustrate the performance of a binary classifier system as its discrimination threshold is varied. Based on examination of x-ray images of batteries attached to cargo, it was determined that small-sized batteries would be very difficult or impossible to detect in clutter (see Figure 19). The ROC analysis was performed to select an optimal region size (in the segmented image) for determining whether or not a region of the segmented Zeff image is a Li battery. For this analysis, batteries were grouped into the following five categories based on size and arrangements:

- **LSH:** this group consists of C- and D-size Li-metal batteries (LSH20, LS3660, LS14250, LSH14) that were arranged in "egg carton" packaging (see Figure 7 and Table 5).
- **Single Large Batteries (SLB):** these are the single, large Li-ion batteries (50 cycles and electric bike). See Figure 7 and Table 5.
- **Assorted Box:** this group consists of an assortment of 12 power-tool and laptop-computer batteries randomly arranged in a box.
- **Button:** this group was an array of "button" Li-metal batteries.
- **Box of Cell Phone Batteries:** these are the box of cell phone batteries shown in Figure 6.

The remaining battery configurations, such as individual laptop-computer batteries and individual power-tool batteries, were too small to be detected in clutter. Thus they were not included in the ROC analysis.

The Zeff images of the DT&E data collected from Gatwick and Heathrow airports were segmented, and classifiers were applied. A threshold parameter was established--the minimum area (in pixels) for which a region satisfying all other constraints imposed by the classifiers would be identified as a Li battery--and PD and PFA were computed as a function of this parameter value. A plot of PD vs. PFA was then made to generate the ROC curves for the five groups of batteries (Figure 28).

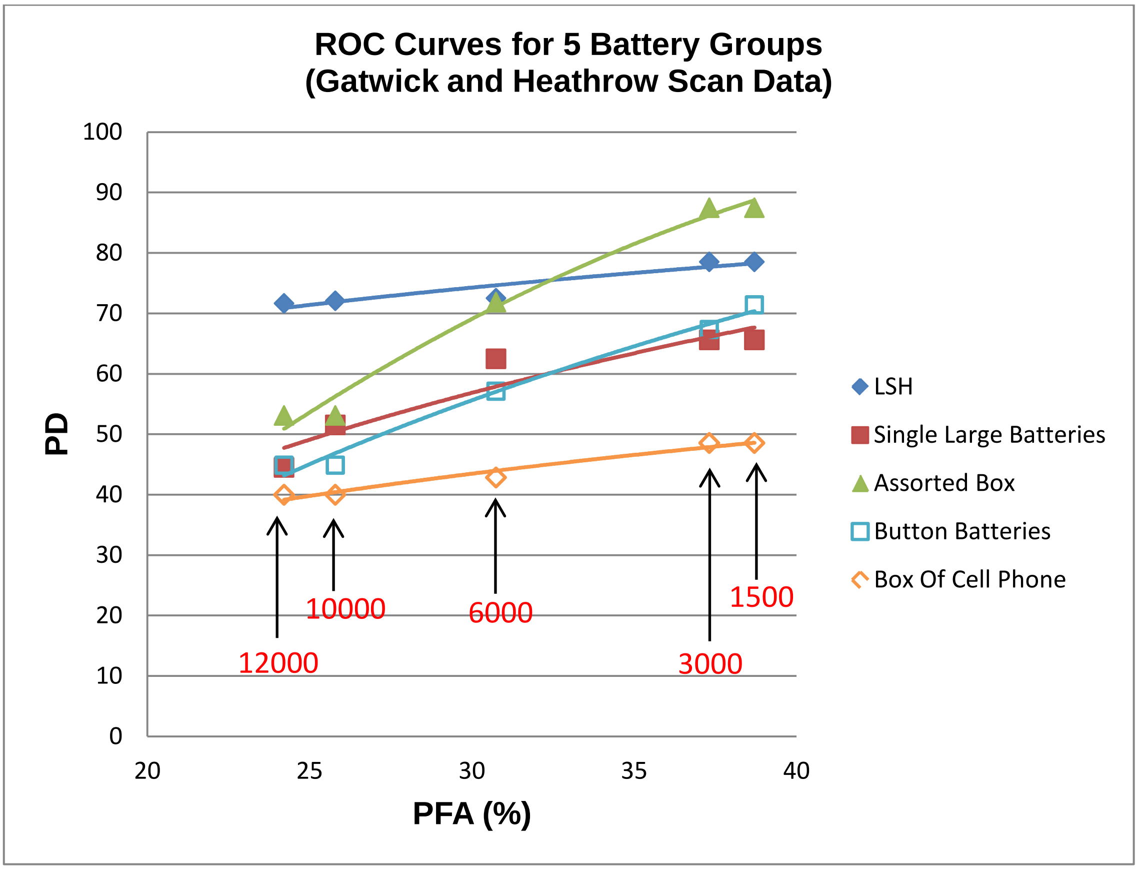



Figure 10. ROC analysis for the five battery groups. The threshold, the minimum area for identifying a region as a Li battery, is varied. The numbers in red indicate the magnitudes (in pixels) of the areas.

In Figure 28, the numbers in red indicate the minimum area thresholds used. As can be seen, for all five groups of batteries, the general trend is as follows:

- The highest minimum area (12,000 pixels) achieves the lowest false alarm but also achieves the lowest detection results since batteries with area less than this "large number of pixels" will not be detected.
- Conversely, selecting the lowest minimum area (1500 pixels) delivers the highest detection results but would also attain the highest false alarm since more benign regions are misidentified as batteries.

It can be seen that the PD for the LSH category was fairly insensitive to the area change. This was primarily due to a "composite region" classifier designed to detect batteries arranged in "egg carton" packaging (Figure 7A, B). This classifier "looks" for segmented regions that consist of multiple sub-regions satisfying several specific characteristics. Note, also, that the PD for the assorted box of batteries exhibits a wide range (from 53% to 88%) between the two area threshold extremes. This was due to the different sizes of batteries that were placed in the box. With a threshold of 12,000 pixels, the smaller batteries in the box were rejected and therefore the PD fell to 53%. With a threshold of 1500 pixels the smaller batteries were detected and the PD rose to 88%.

As can be seen in Figure 28, at 12,000 pixels the false alarm rate is about 24%. In an effort to further reduce the FA rate to 10% while improving detection, the 12,000-pixel threshold was selected, while other classifier parameters were fine-tuned and additional classifiers were introduced. The best and final results are shown in Table 8.

Table 5. Detection and false alarm results for DT&E data from Gatwick, Heathrow, and Hong Kong airports

| **Detection Performance by Li Battery Type (DT&E Data)** | | | | | **FA Performance** |
|---|---|---|---|---|---|
| LSH | SLB | Assorted Box | Button | Box of Cell Phone | 8% |
| 78% | 56% | 59% | 40% | 49% | |

**CHAPTER 5**

# Results and Discussion

## 5.1 Independent Test Results

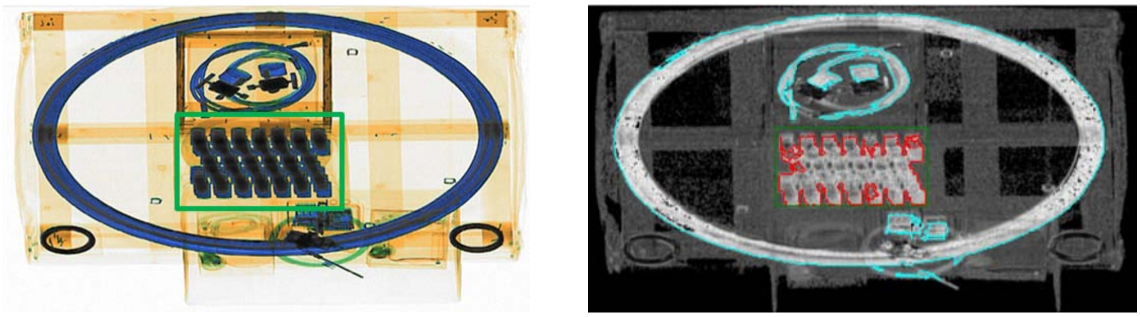
The prototype algorithm that delivered the results shown in Table 8 was applied to the sequestered IT&E data (see Table 3 and Table 4). The performance results for the five categories of battery configurations identified in Section 4.3 are shown Table 9. In general, the algorithm performance is very similar to that of the DT&E set (Table 8), an expected result since both data sets are taken from the same population.

The best detection performance, a PD of 74%, is observed for the LSH category, which consists of Li-metal batteries in bulk packaging. The combination of relatively strong signal in the Zeff image and the ordered battery arrangement were big factors in this high-PD achievement. At some x-ray views, the composite region classifier was able to detect the batteries based on the sub-region pattern characteristic of the array. At other x-ray views, the batteries appear as a single, large region easily detectable through a generic bulk, single-region classifier.

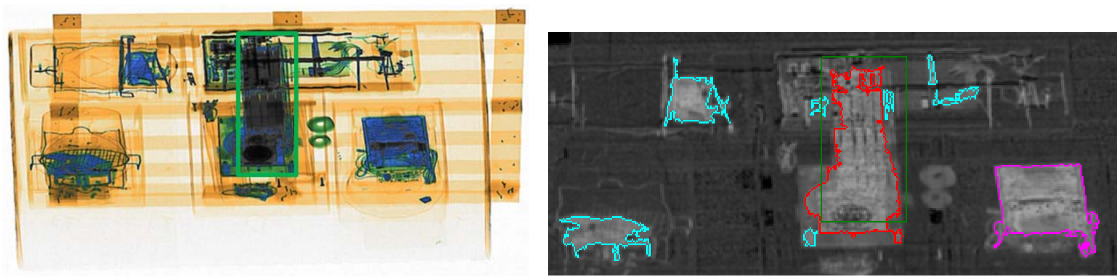
Table 6. Detection and false-alarm results for IT&E data from Gatwick, Heathrow, and Hong Kong airports

| **Detection Performance by Li Battery Type (IT&E Data)** | | | | | **PFA** |
|---|---|---|---|---|---|
| LSH | SLB | Assorted Box | Button | Box of Cell Phone | 9% |
| 74% | 60% | 47% | 46% | 43% | |

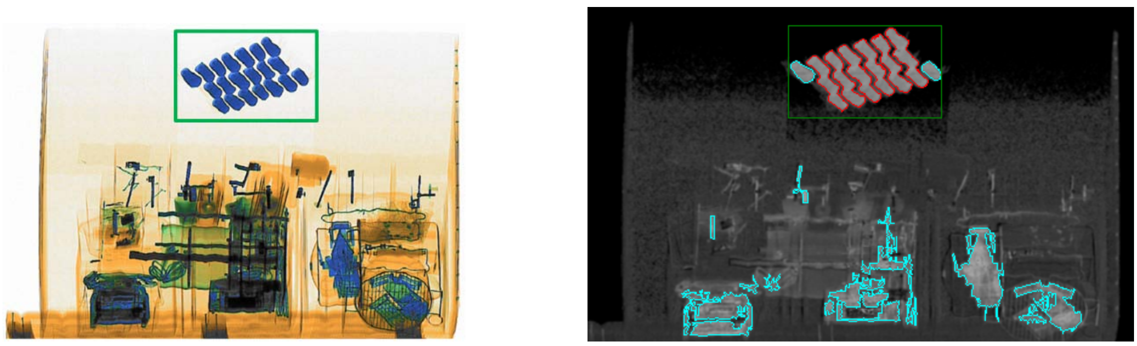
Examples of images of detected batteries are shown in Figure 29. The images on the left are the colorized radiographs, where the batteries are indicated within the hand-drawn green box. The corresponding images at the right show the algorithm results. The regions enclosed by the red lines are the detected batteries. The hand-drawn green boxes are the “ground truths” that indicate the locations of the batteries. Regions enclosed by the purple lines have been misidentified as batteries (i.e., false alarms), while regions enclosed by the blue lines are identified as benign and are discarded by the algorithm.



LSH20 D size Li-metal batteries attached to cargo



50 cycles Li-ion battery attached to cargo



LSH20 D size Li-metal batteries attached to cargo

Figure 11. Some sample results for the prototype algorithm. Images on the left are x-ray images of batteries attached to cargo. Images on the right are the algorithm results. Red outline: detected battery. Green box: hand-drawn ground truth. Purple outline: false alarms. Blue outline: benign regions rejected by the algorithm.

## 5.2 Laptop-Computer Battery Study

As noted in Section 4.3, the data for individual laptop-computer batteries were excluded from the algorithm development since their small size made them nearly impossible to detect in clutter. In practice, detection of bulk shipments of laptop-computer batteries is of more importance than the detection of individual batteries. Given the encouraging detection results for the LSH category, an investigation into the automated detection of multiple laptop-computer batteries was undertaken. A limited 632DV data-collection effort took place at Rapiscan Laboratories, where x-ray images of arrayed laptop-computer batteries, in both bare and attached-to-cargo configurations, were acquired. Figure 30 shows one arrangement of the batteries, a 5 x 2 array, and the detection result. The detected batteries are outlined in purple, the thin region at the right of the detected batteries is a false alarm, and the blue outlines are regions that have been rejected by the algorithm. It is very encouraging that the batteries were detected even though these types of batteries were excluded from the training data set. Further algorithm development and performance evaluation in detecting these types of batteries should be part of any future investigation.

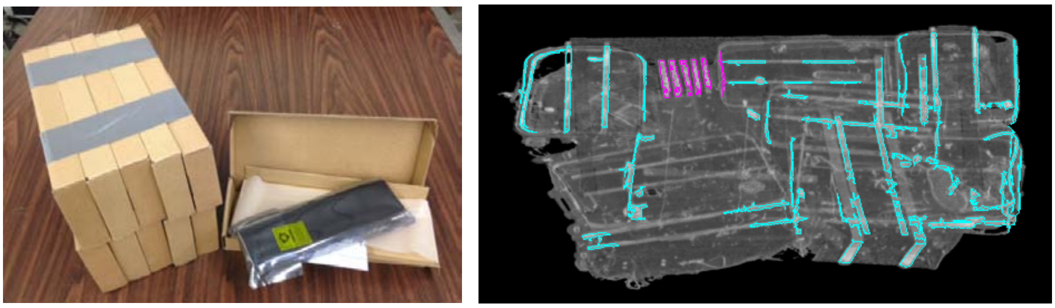


Figure 12. Detection of laptop-computer batteries arranged in 2 rows of 5 batteries. The photograph at the left shows the bulk packaging of the batteries. The image at the right shows the algorithm result. The group of batteries are outlined in purple; the thin purple line at the right of the group is a false alarm. The blue outlines are regions that have been discarded by the algorithm.

## 5.3 Discussion and Recommendations

### 5.3.1 Discussion

In this prototype Li battery detection algorithm, as with many detection algorithms, there is a trade-off between maximizing detection performance and minimizing the false alarm rate. Evidence of this was seen in the ROC curve of Figure 28. As seen in Section 4.3, the price to pay for a workable false alarm rate (based on the processing of available data) is setting a minimum-size threshold of 12,000 pixels. From this position, additional fine-tuning and development of new classifiers were performed to reach the 10% FAR goal. Since bulk shipments of undeclared batteries are of greater concern than the shipment of individual batteries, the 12,000-pixel threshold is not considered a major setback for the feasibility study.

It should be noted that the false-alarm results reported in Table 8 and Table 9 are based on counting multiple false alarms in an image as a single alarm. To determine, on average, the number of false alarms per image an operator would clear, results from the 2,950 DT&E stream-of-commerce images collected from Gatwick, Heathrow, and Hong Kong airports were analyzed. Figure 31 shows the distribution of false alarms per image for the 236 stream-of-commerce images that alarmed. Approximately 68% of false-alarming images had only a single false alarm, and less than 5% had 4 or more alarms. It should be noted that all of the false-alarm incidents with 4 or more alarms came from the Hong Kong data.

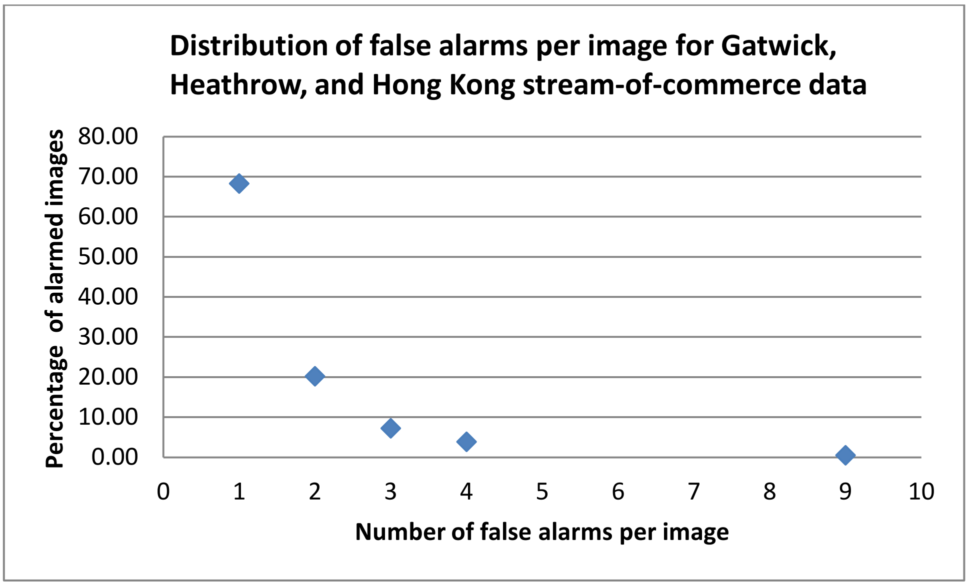



Figure 13. Distribution of false alarms over the entire DT&E stream-of-commerce data set

A large percentage of the Hong Kong cargos contained metals, electronics, and other high-Z merchandise that presented major challenges for the algorithm. It is very encouraging that for these scenarios, fewer than 8% of the cargos alarmed. It is conceivable that some of these recorded false alarms may actually be "true" alarms. For example, in Figure 32 some of the structures within the hand-drawn red box do look like Li batteries in bulk packaging, and the figure on the right shows that the algorithm did alarm on some of these regions. Without the "ground truth" for this data, i.e., without knowing whether or not Li batteries are present within the imaged cargo, accurate assessment of false-alarm performance is not possible.

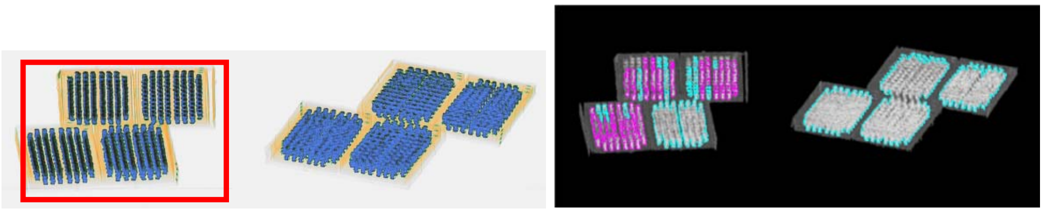


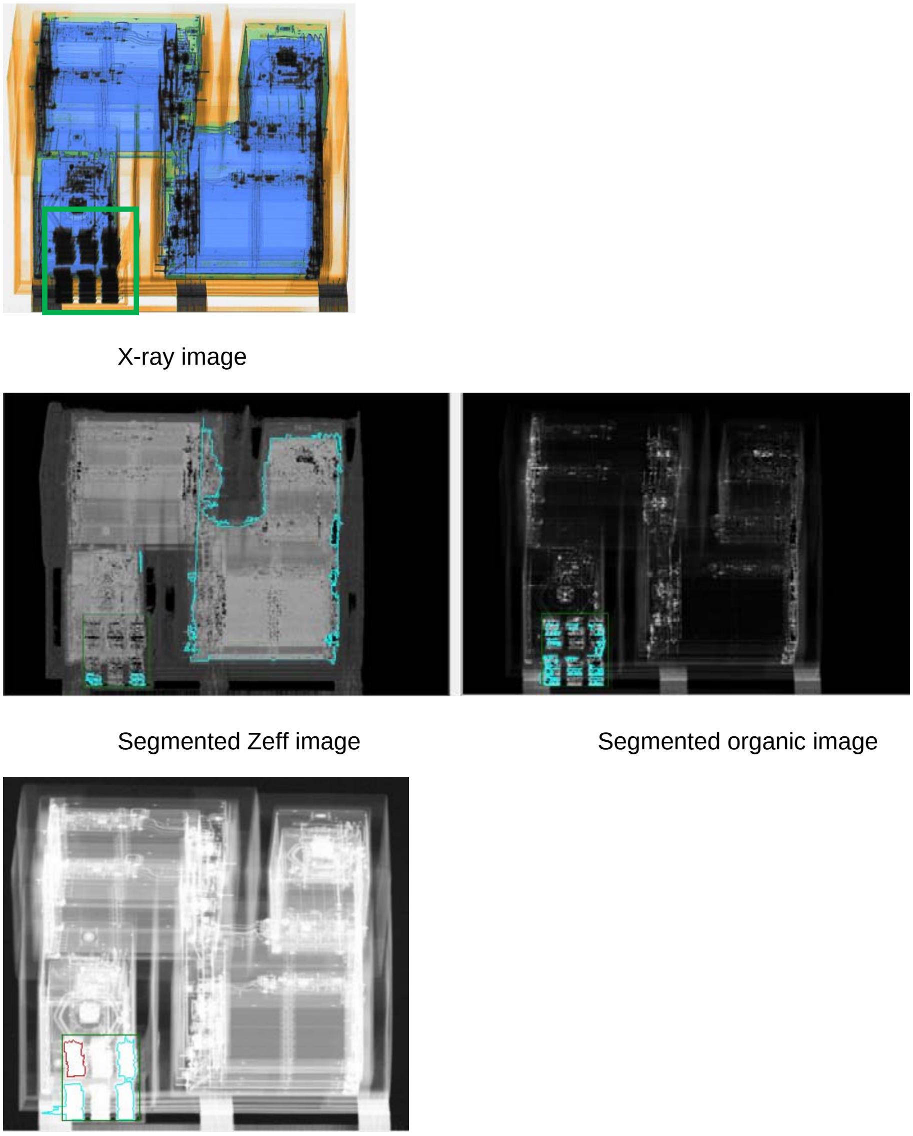
Figure 14. Sample x-ray image (at left) from the Hong Kong data and algorithm detection result (at right). Some structures (within the hand-drawn red box at left) could be Li batteries. Some of these structures yield alarms (regions on the right outlined in purple).

It very encouraging to note that the 74% PD for the LSH category was achieved even though approximately 31% of cargos on which these batteries were placed contained metal clutter such as machine parts, metallic disks, metal tubing, and other high-Z materials. In general, for the groups of batteries studied, it was found that several factors contributed to lowering the detection performance. Some of these causes and potential mitigation strategies are outlined below:

- *Distance of target (batteries) from x-ray source*. For LSH batteries attached to non-metal cargos, many of the missed detections occurred when the batteries were positioned farthest from the x-ray source. This reduced the magnification of the image and also resulted in a lower Zeff signature. For these cases, the Zeff threshold of 14.5 was too high and the targets were not segmented. An adaptive-thresholding technique may resolve this issue.

  *Failure of segmentation in both Zeff and organic images*. For some cargo configurations, particularly those including high metal clutter, Li batteries cannot be properly segmented because the signature is too weak. As shown in Figure 33, batteries in the hand-drawn green box are not cleanly segmented in either the Zeff image (middle left) or the organic image (middle right). This is primarily due to approximations in the LUTs used to generate the Zeff and organic images. Further optimization of the LUT is needed to address this condition.

  An alternative approach, which was briefly explored under this project, is to utilize the high-energy (HE) x-ray image. It was found that, in some situations, batteries can be extracted from the HE image. This can be seen in Figure 33, where the batteries (red outline in the lower image) have been detected from the segmented HE image. Another slightly different approach is to utilize the ratio and difference of high-energy attenuation and low-energy attenuation values. This approach avoids use of LUTs.




Segmented high-energy image

Figure 15. Example showing that batteries can be extracted from the high-energy image even though segmentation fails in the Zeff and organic images. Top row: x-ray image with batteries shown within hand-drawn green box. Middle row: failed segmentation of Zeff and organic images. Bottom row: batteries (red outline) extracted and detected from segmented high-energy image.

### 5.3.2 Recommendations

The automatic detection of Li batteries contained within air cargo is a very challenging task, and this feasibility study has shown that it is possible to do so for battery types and configurations that are of greatest interest to stakeholders. Additional investigation, as outlined below, is required before the approach developed herein can be deployed commercially:

1. *Additional data collection*. Additional data should be acquired for multiple quantities of batteries packaged similar to those transported in commercial shipments. Such configurations should be the focus of any additional work, since bulk shipments of undeclared batteries are of primary stakeholder interest, and this study has shown that the detection of individual batteries increases the false alarm rate.

2. *Additional studies of non-Li batteries*. In this study, it was found that the 6-count D-size alkaline batteries were identified as Li batteries in 90% of the cargo. However, only 20 images containing these alkaline batteries were collected, and the batteries were attached to low-Z cargo. Thus, a larger sample of data with alkaline and other "benign" batteries is required to determine if the algorithm could be trained to distinguish between Li batteries and other types of batteries that can be shipped without restriction.

3. *Collection of manifested stream-of-commerce data*. Assessment of false-alarm performance remains somewhat suspect without knowledge of the contents of the cargo. Thus, it is important to obtain manifest information (ground truth) for acquired stream-of-commerce data.

4. *Algorithm improvements*. Additional algorithm development should focus on strategies for detecting bulk shipment of batteries in commercial packaging. For example, a "composite region" classifier similar to one developed for the Zeff image can be developed for the organic image. Studies should be performed to determine how the quantities, size, and packing of the batteries affect detection performance.

## 5.4 Developing a Li Battery Detection Standards Test

### 5.4.1 Introduction

One aim of this feasibility study is to propose a performance standards test for inspection systems that provide for the automatic detection of Li batteries contained within air cargo. Such a standards test would be similar to standards tests for the detection of explosives that are employed by aviation-security authorities around the world. A standards test could be used to qualify air-cargo inspection systems as being capable of automatically detecting lithium batteries in cargo per regulator-approved performance criteria.

### 5.4.2 Strategy

Any standards test should call for a cargo-inspection system to demonstrate the ability to:

- detect one or more Li battery configurations that are considered high security risk by regulators.
- detect Li batteries present within typical cargo clutter.
- differentiate Li batteries from certain common benign objects, thus suggesting that the system will have a manageable false alarm rate.

### 5.4.3 Proposed Test Materials and Procedure

**Test Materials:**

- Test kit: a rugged equipment case containing 3 layers of D-size Li-metal batteries, with 20 batteries arranged in a 4 x 5 matrix in each layer. Batteries should be electrically isolated from each other and packaged in a manner per approved guidelines for air transport.
- One or more layers of polyethylene of TBD-thickness placed appropriately within the case to simulate the presence of cargo clutter.
- One or more non-alarming objects, placed appropriately within the case---non-Li batteries possibly, electronics, etc.—that should not be identified by the algorithm

**Test Procedure:**

Position the test kit in the appropriate orientation upon the input conveyor for the air-cargo inspection system under test. The inspection system should have at least two x-ray views. Scan the test kit.

Repeat the steps above until 10 scans are collected. (Different orientations of the test kit may be specified for some of the scans.)

**Detection Performance Standard:**

The air-cargo inspection system shall detect the Li batteries at least TBD times. The air-cargo inspection system shall alarm on the non-Li objects within the test kit no more than TBD times.

**CHAPTER 6**
# Conclusions

The automatic detection of Li batteries in air cargo is a technical challenge, especially in highly-cluttered metallic cargos. In this feasibility study, Rapiscan has shown that even when cargos with metallic clutter are included in the evaluation, automatic detection is possible with high probability and low false-alarm rate for bulk quantities of batteries packed for commercial shipment. For the image-data set collected, the optimal prototype Li battery detection demonstrated a detection rate exceeding 70% for bulk C- and D-size Li-metal batteries, and a false-alarm rate below 10%. Other Li battery types were detected in the 40% - 60% range.

Additional work is required prior to the commercial deployment of an algorithm. This work includes (a) additional data collection of various types of bulk batteries in commercial packaging; (b) investigation of a larger sample of alkaline and other non-Li batteries to determine if the algorithm can be trained to distinguish them from Li batteries; (c) collection of stream-of-commerce data with manifest information to validate false-alarm performance; and (d) additional algorithm improvements focused on strategies for detecting multi-battery shipments.