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Survey of Technologies for the Airport Border of the Future

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IMPORTANT INFORMATIVE STATEMENTS

This project for the Border and Transportation Security Community of Practice was supported by the Canadian Safety and Security Program (CSSP) which is led by Defence Research and Development Canada's Centre for Security Science, in partnership with Public Safety Canada. Lead partners in the project is Health Canada. CSSP is a federally-funded program to strengthen Canada's ability to anticipate, prevent/mitigate, prepare for, respond to, and recover from natural disasters, serious accidents, crime and terrorism through the convergence of science and technology with policy, operations and intelligence

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Survey of Technologies for the Airport Border of the Future

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Table of Contents

1	Executive Summary	4
2	Background	5
2.1	Centre for Security Science	5
2.2	Key Issues	5
2.3	Key Questions	6
3	Border Modernization Around the Globe	7
3.1	Australia	7
3.2	United Kingdom	8
3.3	European Union	8
3.4	United States.....	9
3.5	Canada	10
4	Efficiency, Security and Costs	11
5	Database Integration and Information Sharing	12
6	Technology.....	14
6.1	Identity Verification Technologies	14
6.1.1	Literature and Patent Analysis	14
6.1.2	Technology Readiness Levels	23
6.2	Baggage and Passenger Screening.....	24
6.2.1	Literature and Patent Analysis	26
6.2.2	Technology Readiness Levels	29
6.2.3	Future Trends.....	30
7	Conclusions	31
8	References	32
9	Appendices.....	36
9.1	Search and Analysis Methodology.....	36
9.2	Technology Readiness Levels Methodology	39
9.3	Glossary of Biometric Technologies.....	41
9.4	Bibliography in Support of Key Question 2b.....	44
9.5	Technology Readiness Levels – Assessment Data.....	58

Table of Figures

Figure 1. Identity Verification, Literature and Patents, Temporal Distribution.....	16
Figure 2. Identity Verification, Patents, Co-occurrence of Biometric Technologies and Companies.....	18
Figure 3. Identity Verification, Literature and Patents, Biometric Subject Groups	19
Figure 4. Identity Verification, Literature, Subject Group Momentum 2008-2013	21
Figure 5. Identity Verification, Patents, Subject Group Momentum 2004-2012.....	22
Figure 6. Identity Verification, Literature, Biometric and Application Groups Co-occurrence Matrix.....	23
Figure 7. Baggage and Passenger Screening, Literature and Patents, Temporal Distribution	26
Figure 8. Baggage and Passenger Screening, Literature, Subject Groups	27
Figure 9. Baggage and Passenger Screening, Literature, Subject Group Momentum, 2008-2013	28

List of Tables

Table 1. Summary of Findings	4
Table 2. Subject Groups	15
Table 3. Identity Verification, Top Publishing Organizations and Patent Assignees	17
Table 4. Technology Readiness Levels – Biometric Technologies.....	24
Table 5. Baggage and Passenger Screening, Top Publishing Organizations and Patent Assignees	27
Table 6. Baggage and Passenger Screening, Passenger Tracking Patents	29
Table 7. Technology Readiness Levels – Baggage and Passenger Screening Technologies.....	29
Table 8. Search Strategy.....	37
Table 9. Modified Technology Readiness Levels.....	40
Table 10. Technology Readiness Levels – Biometric Technologies – Assessment Data	58
Table 11. Technology Readiness Levels – Baggage/Passenger Screening – Assessment Data.....	69

1 EXECUTIVE SUMMARY

Defence Research and Development Canada's Centre for Security Science (DRDC-CSS) commissioned a literature and patents review by the National Research Council's Knowledge Management section (NRC-KM) to investigate emerging technologies to support the airport border of the future. The focus of the review is on technologies that enhance and improve the traveller authentication process as well as the screening of passengers and their luggage at the point of entry. The project was divided into three phases according to the three key questions (see Table 1). Phases I and II consisted of a review and summary of the available literature. Phase III involved a survey of technologies currently deployed in airports and those that may emerge in the next 5-10 years, and was divided into two main areas: identity verification (i.e. biometrics) and baggage/passenger screening. Literature and patent databases were searched for each question, and bibliographic records imported to text mining software for analysis.

Table 1. Summary of Findings

Key Question	Findings
I. Scene-setting: current status of technology implementation and airport modernization initiatives around the world (Australia, United States, Europe); trends in border usage; evolution of international agreements such as registered traveller programs	<ul style="list-style-type: none"> • Drivers: numbers of passengers increasing; border budgets shrinking • Significant recent activity (last 1-2 years) surrounding national border security initiatives • Increasing use of automated technologies and biometrics to enable passenger self-processing (e.g. eGates) • Registered traveller programs are being expanded and integrated • Collaboration and information sharing within nations and nation-to-nation for the purposes of passenger screening is accelerating
II. The impact of identity verification technologies (i.e. biometrics) on efficiency, security and cost-reduction	<ul style="list-style-type: none"> • Biometrics are significantly impacting identity management vis-a-vis border security (more reliable, more efficient, cheaper) • Traditional (manual) methods of processing becoming increasingly unsustainable due to rapidly rising passenger volumes • System implementation and standardization are nascent but growing quickly
III. Current and future technologies for passenger and baggage screening	<p>Identity Verification:</p> <ul style="list-style-type: none"> • <i>Fingerprinting, Face recognition and Iris recognition</i> are the dominant technologies and have the highest Technology Readiness Level • Research into <i>vein matching</i> is showing momentum • Academic institutions in the US and China are the top players in the literature. Top patent assignees are Hitachi, Fujitsu and NEC <p>Baggage/Passenger screening:</p> <ul style="list-style-type: none"> • X-Ray and CT scanning dominate the literature • Modest annual patenting activity since 2004 (less than 20/year) • Imaging technologies continue to be improved and refined • Promising future technologies include <i>Raman spectroscopy, LIDAR and Terahertz screening</i>

2 BACKGROUND

According to the International Civil Aviation Organization (ICAO), by 2030 global air passenger traffic is expected to more than double, from 2.7 billion in 2011 to 6 billion annually, with the corresponding number of flights increasing from 30 million to 60 million.¹ Traditional border processing systems and procedures will not be able to cope with such an increase in volume, yet travellers will still expect to be processed quickly and with minimum inconvenience. Governments are in the difficult position of balancing the economic benefit of cross-border travel with the need to ensure traveller safety, all at a time when spending reductions are the norm.

Defence Research and Development Canada's Centre for Security Science (DRDC-CSS) commissioned a study of technologies that will impact the evolution of customs and immigration at Canadian airports from the perspective of efficiency, security and the impact of technologies maturing in the next 5 to 10 years.

2.1 Centre for Security Science

DRDC-CSS operates the Canadian Safety and Security Program (CSSP), an outcomes-based program of S&T projects with the mission to strengthen Canada's ability to anticipate, prevent, prepare for, respond to and recover from acts of terrorism, crime, natural disasters and serious accidents through the convergence of science and technology with policy, operations and intelligence.^a One of the desired immediate outcomes of the CSSP is that Canada's border-related economic vitality and sovereign integrity is enabled.

CSS also leads a community of practice and associated portfolio of projects in the area of border and transportation security (BTS). The community of practice includes the Canadian Border Services Agency (CBSA), RCMP, and several other federal departments. To help guide the portfolio and identify where best to support the BTS community, CSS commissioned this study to gather information about the context for future border modernization.

The requested work includes research, review and analysis of contemporary international border modernization trends and maturing technologies. The study is conceptual in nature; that is, the purpose is to examine general categories of technologies and overall trends rather than specific products.

The following areas were deemed out-of-scope:

- Commercial air travel; i.e. cargo shipping.
- Departures from Canada and associated processes, e.g. ticketing, boarding passes.
- Analysis of international trade and supply chains.

2.2 Key Issues

To help guide the community of practice and identify where the BTS portfolio at CSS can best support the community, this study examined information about the context for future border modernization. The project's objective consisted of detecting and categorizing R&D activities from the available literature and patents to provide evidence-based interpretation points for future reviews of the state-of-the-art.

^a For more information on DRDC-CSS see <http://www.drdc-rddc.gc.ca/en/science-tech/security-science.page>

2.3 Key Questions

In order to address the key questions below, various commercial databases and Internet sources were searched to obtain relevant literature and, in the case of Key Question 3, patents. The complete list of sources and the search strategy used are described in detail in the Methodology section (9.1) of this report.

1. Provide a brief scene-setting:
 - a. What is the current status of security technologies in use at airport borders, particularly in North America, Europe and Australia?
 - b. Likely trends in airport border usage in Canada (i.e. predictions of numbers of air travellers in the next 5-10 years).
 - c. The evolution of international agreements for borders such as the Trusted Traveller Program in the US; are there similar agreements in Europe?
 - d. Review of recent (past 5 years) international initiatives on modernization of borders in airports.
2. Opportunities for modernization of airports that increase efficiency and security and reduce costs:
 - a. What has been the impact of increasingly reliable determination of identity (i.e. biometric technologies) on efficiency, costs and safety?
 - b. What studies have been released in the past 5 years on the use of operational research and/or modeling and simulation to improve/optimize flows and processing across the border continuum, from pre-border, at-border, post-border and enforcement?
(Bibliography provided as a separate attachment. See Section 9.3).
 - c. What has been the impact of the integration of databases (such as from different authorities like police or government border security agencies) on efficiency, safety and costs?
3. Establish the technological context for screening travellers and their baggage:
 - a. What are the emerging technologies likely to be deployed in airports before 2020?
 - b. What are the technology readiness levels of these technologies?

The study was divided into three phases according to the three key questions. Phases I and II consisted of a review and summary of the available literature and Phase III involved a survey of technologies currently deployed in airports and those that may emerge in the next 5-10 years. Phase III was divided into two main areas: identity verification and baggage/passenger screening. For this phase, records were uploaded to text-mining software for analysis.

3 BORDER MODERNIZATION AROUND THE GLOBE

In recent years there has been significant activity in a number of countries with respect to border modernization. Border control agencies around the world are increasingly turning to automated technologies to enable self-processing in order to strengthen security and cope with swelling passenger numbers. At the same time, initiatives such as registered traveller programs are growing in popularity and are increasingly being linked to similar programs in other countries, making it easier for participating members to cross international borders. Greater collaboration and information sharing among nations is accelerating and serving to push the screening process beyond the border.

The following is a brief summary of recent border modernization initiatives in Australia, the United Kingdom, the European Union, the United States and Canada.

3.1 Australia

In 2012, 32 million international travellers were processed at Australia's eight international airports. By 2017 the number is expected to reach forty million, and by 2023, 50 million.² In July 2013, the Australia Customs and Border Protection Service announced the *Blueprint for Reform 2013-2018*, with the goal of modernizing its border systems to meet the expected rise in passenger volume. Among the highlights are:

- Establishment of the National Border Targeting Centre to target high-risk passengers through better coordination and sharing of intelligence between partner agencies and targeting centres in the United States, Canada, the United Kingdom and New Zealand.
- Installation of next-generation eGate technology to process travellers faster.
- Future goal of a seamless, low-touch process from pre-departure to arrival and clearance.³

In addition, in February 2013 the Prime Minister announced the *Traveller Processing of the Future* project, a two year initiative to evaluate the latest technology offerings to support the "extending the border" concept (i.e. assessing passengers before they land in the country), and investigate future technologies such as "face on the move" and "face in the crowd".³

All eight international airports in Australia currently employ an automated border control (ABC) kiosk system called SmartGate,^b which uses the data in the traveller's ePassport combined with face recognition technology to perform the customs and immigration checks traditionally conducted by a border official. With additional investigation into next generation eGates and mobile eGates to allow more travellers to self-process, including in remote locations, it is estimated that by 2020, 90 percent of international travellers will be able to use SmartGate (from a current rate of 20 percent).³

As part of the Trans Tasman agreement, Australians and New Zealanders can cross each other's border using SmartGate (both nations employ the identical system). Travellers from the United Kingdom can also use SmartGate as of November 2013, and it is currently being trialled with ePassport-holding members of the United State's Global Entry program. A trial with Chinese ePassport holders will begin in 2015.⁴

^b More information on SmartGate: <http://www.customs.gov.au/smartgate/default.asp>

Australia and New Zealand have been issuing ePassports since 2005 (the applicant must be over 16 years of age). The biometric chip and the electronic equipment used to read and write the chip meet the standards set by the ICAO.⁵

3.2 United Kingdom

The UK Border Force processed 220 million passengers through its airports in 2012, and that number is expected to jump to 315 million by 2030.⁶ In an effort to ease the growing congestion, the UK's Minister for Immigration announced a new registered traveller scheme in September 2013 that will provide expedited clearance at border controls for regular travellers to the UK from certain countries. The program is open to individuals from Australia, Canada, Japan, New Zealand and the US who have travelled to the UK four or more times within a preceding 52-week period. The pilot program runs to March 2014.⁷

Concurrently, the UK and Ireland announced a plan in July 2013 to enable business travellers and tourists from fast-growing Asian economies to travel on common visas between the two islands (currently visitors must apply for visas to both countries).⁸ This is an expansion of the already existing Common Travel Area, a zone with minimal border controls comprising Ireland, Great Britain, the Isle of Man and the Channel Islands.

The UK has deployed eGates at its international airports which, similar to the Australian system, utilize facial recognition technology for identity authentication. The gates can be used by UK citizens with an ePassport or by ePassport holders from a country in the European Economic Area. E-Passports have been issued in the UK since 2006 and there are now roughly 25 million in circulation.⁹

3.3 European Union

In February, 2013 the EU Commissioner for Home Affairs announced the *Smart Border* initiative, intended to speed-up and reinforce border check procedures for foreigners and help the EU cope with an increasing number of travellers (expected to reach 720 million by 2030).¹⁰ The package is comprised of two parts:

1. Registered Traveller Program (RTP): the RTP will allow frequent travellers from non-EU countries to enter the EU using simplified border checks, subject to pre-screening and vetting. It is estimated that 5 million legitimate non EU-travellers per year will enroll in the new program. The RTP will make use of automated border control systems (eGates) at airports.
2. Entry/Exit System - an Entry/Exit System will record the time and place of entry and exit of non-EU country nationals travelling to the EU. An alert will be sent to national authorities when there is no exit record by the expiry time.

Within the EU is a border-free zone called the Schengen Area which guarantees free movement to the more than 400 million citizens of the 26 member nations.¹¹ It functions as a single country for international travel purposes, with a common visa policy. Ireland and the UK are the only EU countries that are not part of the Schengen Area, while four non-EU countries (Iceland, Liechtenstein, Norway, and Switzerland) are Area members. The backbone of the Area is the Schengen Information System (SIS), which is the largest shared information system for public security in Europe.¹²

The EU does not issue passports; rather they are issued by individual EU countries. However, EU passports do have a common design and layout; they are burgundy in colour with the words "European Union" printed on the cover, accompanied by the name of the issuing EU State. Schengen countries were obliged by law to implement machine readable facial images in their passports by August 28, 2006 and fingerprints by June 29, 2009.

A number of registered traveller programs are established in individual EU nations. Germany's Automated and Biometrics-Supported Border Controls (ABG) program has been linked to the US's Global Entry program since 2010. The US has also joined with the Netherlands in a program called Flux, and Canada may join via CANPASS.¹³

In the past year alone several European countries began trials of automated border clearance systems. By the end of 2014 Germany will have installed 90 new eGates in its busiest airports.¹⁴ Ireland started a trial in May, 2013.¹⁵ Norway deployed new eGates at Oslo airport in September, 2013¹⁶, and Portugal installed 24 at Lisbon International on November 7, 2013.¹⁷

3.4 United States

Just over 815 million passengers passed through US airports in 2012. The Federal Aviation Administration (FAA) forecasts that US passenger growth will average 2.2 percent per year over the next 20 years.¹⁸ Technology will play a key role as the US tries to deal with the influx of visitors and immigrants. Registered traveller programs such as the joint US/Canada program NEXUS^c and its international program Global Entry^d will continue to grow and become increasingly integrated with other programs around the world.

Similarly, collaboration and information sharing among both national and international security agencies will expand. For example, the availability of Advance Passenger Information (API) and Passenger Name Record (PNR) data^e from airlines (as required by law) allows US Customs and Border Protection (CBP) to screen passengers against watch lists before they even arrive on American soil.

The problem of overstays creates additional border security issues for the US. There are records of at least one million foreign nationals who entered the country legally for whom the Department of Homeland Security (DHS) has no record of departure, or evidence that they obtained permission to stay. At a Congress hearing on Sept 29, 2013, DHS said a biometric exit plan will be in place to address the issue by 2015, but that it needs \$3 billion to implement the system at airports alone. CBP is working with the science and technology branch of DHS, which will open a facility in early 2014 to test biometric technology for the system. By mid-2015 the agency plans to test a pilot biometric exit system at a mid-size airport yet to be named.^{19,20}

^c For more information on NEXUS see the Canada Border Services Agency website: <http://www.cbsa-asfc.gc.ca/prog/nexus/menu-eng.html>.

^d See <http://www.globalentry.gov/>.

^e More information on API/PNR data here: http://www.cbsa-asfc.gc.ca/security-securite/api_ipv-eng.html.

3.5 Canada

Like other nations around the world, Canada is experiencing growth in air travel. According to Statistics Canada, the total number of passengers (domestic and foreign) arriving at Canadian airports increased 4.8 percent in 2012, to almost 119 million.²¹ Twenty-six million travellers were processed from international destinations in 2012-13, representing a 12% increase since 2008-09.²² The agency responsible for processing passengers at Canada's 13 international airports is the Canada Border Services Agency (CBSA), part of the Public Safety Portfolio. The role of the CBSA is to ensure Canada's security and prosperity by managing the access of people and goods to and from Canada. The Agency is responsible for administering the Immigration and Refugee Protection Act as well as the Customs Act, in addition to 90 other Acts administered on behalf of other departments and agencies.²³ With respect to airport security, the Canadian Air Transport Security Authority (CATSA)^f is the Crown corporation responsible for screening air travellers and their baggage before boarding.²⁴

As in other parts of the world, border modernization (BM) initiatives are currently underway in Canada. On February 4, 2011, the Prime Minister of Canada and the President of the United States announced *Beyond the Border: A Shared Vision for Perimeter Security and Economic Competitiveness*, with the goal of strengthening security while maintaining the free-flow of people and goods across the border.²⁵ In the next three years, the CBSA and its partners will implement a series of BM initiatives that will allow Canada to deal with threats earlier in the travel continuum and improve program integrity. For example, by 2015, visa-exempt foreign nationals, with the exception of U.S. citizens, will be required to apply for an Electronic Travel Authorization (eTA) through Citizenship and Immigration Canada.^g This online process will improve CIC's capacity to identify inadmissible visa-exempt foreign nationals before they board a plane to Canada.

Canada and the US have already been working closely to expedite travel for low-risk, pre-approved travellers across the border. The aforementioned NEXUS traveller program is a joint venture managed by both the CBSA and the US CBP. CANPASS^h is a CBSA program open to both citizens and permanent residents of Canada and the US. The membership fee is \$50 (valid for one year; versus NEXUS, which is the same cost but valid for five years) and the registration process requires an iris scan for the purposes of identity verification. Dedicated kiosks are available at Canada's international airports utilizing iris recognition technology to facilitate expedited processing for CANPASS and NEXUS members.

In partnership with the Airport Authorities, the CBSA has also installed automated border clearance (ABC) kiosks at three of Canada's international Airports (Vancouver, Toronto and Montreal). The kiosks (which are not biometric-based) are free to use and no registration is required; all that is needed is a valid Canadian passport. The passport and declaration card are inserted into the machine and scanned. A receipt is produced which then must be manually checked by a border official.

Canada began issuing ePassports to its citizens as of July 1, 2013, joining more than 100 other countries and adding to the over 400 million ePassports now in circulation worldwide.²⁶ Like those of other nations, Canada's ePassport conforms to all ICAO and International Standard Organization (ISO) regulations for machine-readable identity documents, including ICAO 9303, ISO/IEC 14443 and ISO/IEC 7816.²⁷ By the end of 2018, all valid Canadian passports in circulation will be ePassports.

^f For more information on CATSA visit <http://www.catsa.gc.ca>.

^g For more information on Citizenship and Immigration Canada see <http://www.cic.gc.ca>.

^h For more information on CANPASS visit <http://www.cbsa-asfc.gc.ca/prog/canpass/menu-eng.html>.

4 EFFICIENCY, SECURITY AND COSTS

As outlined above, there has been a significant amount of very recent activity around the globe with respect to border modernization. In Europe, the majority of eGate projects are still in the pilot phase. Regulation and standardization are also still emerging; standards exist for biometric documents (e.g. ePassports)⁵ but not yet for capture devices. The rate at which nations are adopting technology is also varied, with countries such as Canada and Russia having only recently begun issuing ePassports to its citizens, whereas others have been doing so for several years. Within the private sector, the biometric border management market is still nascent but growing quickly. Consulting firms Frost & Sullivan and Acuity Market Intelligence both predict a 20% compound annual growth rate in the market until 2020.^{28,29}

At the same time as border modernization is accelerating, border management resources world-wide are being reduced alongside other public services. The UK Border Agency is looking to find savings of £350 million between 2011 and 2015.³⁰ The Australian Customs and Border Protection budget has dropped by more than \$560 million over the past four years, forcing the agency to cut about 740 staff positions.³¹ In Canada, the Canada Border Services Agency's *Deficit Reduction Action Plan* will result in a savings of \$143.4 million by the end of 2015.³²

With increasing passengers and shrinking resources it is imperative that available funds be allocated to areas where they will have maximum impact. The focus must be on high-risk passengers because undifferentiated processing is not efficient – the vast majority of travellers pose no threat. Biometric identity verification systems play a large role in border security because the technology facilitates more secure, faster, and automated processing of low-risk passengers. The result is a triple benefit of increased safety, more processing capacity and fewer required (human) resources.

Efficiency

The 2013 International Air Travel Association (IATA) Global Passenger Survey found that 79 percent of travellers would be comfortable using biometrics for airport processes (check in, security, screening, boarding and immigration).³³ This is good news since traditional (manual) forms of processing are not sustainable. In Australia, for example, the number of people using the country's international airports is projected to grow 5.4 percent annually over the next seven years.³⁴ Traditional methods will not be able to cope with that many travellers. As noted earlier, the SmartGate system used by Australia and New Zealand allows border officials in both countries to streamline passenger clearance and securely process more travellers while maintaining the existing standards of border protection. Processing takes an average of 16 minutes from aircraft arrival to clearing Customs for passengers using SmartGate, compared to 20 minutes for non-SmartGate passengers, so queues and wait times are shorter.³⁵ With the continuous expansion and linking of international traveller programs, 90 percent of international travellers will be able to use SmartGate by 2020 (up from a current rate of 20 percent). Other examples include:

- New Zealand is already processing almost 25 percent of passengers using SmartGate.³⁶
- Schiphol airport in Amsterdam, one of the world's busiest airports, has 36 eGates that process passengers through the border in just eight seconds (from placing a passport on the scanner until the exit doors open). The fastest processing time recorded was under four seconds. Sixty-five percent of passengers do not have to queue to enter an eGate and 97 percent wait less than four minutes to enter an eGate during peak times.³⁷

- Dublin airport is currently processing up to 1,000 passengers per day through its eGates in about 7.5 seconds each.³⁸

As technology advances "contactless" processing will be even faster (and cheaper) since it will not be necessary to verify a passenger against a physical document.³⁹

Cost and security benefits

Shrinking budgets and growing passenger volumes are forcing border security agencies to increasingly find ways to keep costs down while maintaining security standards and low wait times. Biometric technology allows border authorities to lower costs by reducing the number of employees, or shifting them from simple tasks such as checking identity to handling more analytical work such as traveller risk assessment.⁴⁰ Advances in technology like networked imaging scanners allow for remote screening of baggage in a centralized location, often reducing the number of staff needed and limiting idle time between images. Remote screening is also usually performed in a quiet location, helping the screener to keep his or her focus on the image.⁴¹

Additionally, automated systems allow more throughput and faster, more reliable processing, which is convenient for the customer and economically beneficial for the airport and border authority. A 2004 study of self-service airport check-in versus check-in using human agents⁴² found that the self-service cost is \$0.16 on average, compared to \$3.68 for human-mediated check-in.ⁱ The IATA suggests that automating the travel document compliance process with its Timatic AutoCheck system can save airlines up to US \$0.50 per passenger, comprised of:

- Reduction in manual screening processes - \$0.21
- Reduction of passenger fines and managing these passengers - \$0.10
- Increased cost savings due to increased penetration of self-service check-in - \$0.24⁴³

As well as being more reliable, more secure and less costly than human processing, biometric systems can also help reduce fraud. The presence of a biometric element inside a document such as an ePassport ensures that only one person can use it.⁴⁴ The difficulty of forging ePassports compared to traditional passports also decreases the possibility of illegal immigration and identity theft. Similarly, visa and registered traveller programs that require pre-enrollment and provision of biometric data ensure that the person who applied for the visa or program membership is the same one at the border.

5 DATABASE INTEGRATION AND INFORMATION SHARING

At the same time as visa and registered traveller programs expand, nations are increasingly partnering with one another to integrate their systems in order to enable faster border processing for their citizens. Travellers from the US and Canada who are members of the NEXUS program, for example, can enjoy expedited cross-border travel between the two countries. US citizens enrolled in the US Global Entry program may use the Smartgate system without registration when entering Australia, and they can also apply for the Dutch Privium program, the Korean SES program, or the Mexican Viajero Confiable program for accelerated entry into those countries.⁴⁵ As mentioned earlier, the Netherlands have created a program called Flux, which is intended to grow into a global alliance of trusted traveller programs to ease bottlenecks and expedite passenger processing around the world.

ⁱ The study concerned airport check-in as opposed to border processing, but the costs are likely comparable.

In addition to the expansion and integration of registered traveler programs, sharing of security information within and among nations is also growing. In the US, one of the primary reasons for the creation of the Office of Biometric Identity Management, or OBIM (replacing the United States Visitor and Immigrant Status Indicator Technology program, or US-VISIT) was to integrate and centralize the government's various biometric databases:

Before OBIM, the U.S. immigration and border management system had disparate information systems that lacked coordination. Today, OBIM provides a single source for biometrics based information on criminals, immigration violators and known or suspected terrorists. No longer can someone give one name to U.S. Customs and Border Protection and a different name to U.S. Citizenship and Immigration Services without getting caught. Thanks to biometrics, we know who a person is and the facts of his or her immigration history.⁴⁶

Canada and the US are increasingly sharing information to secure the border. On December 13, 2012 the two countries signed a treaty to enable immigration and visa information sharing on third-country nationals. Biographic information sharing was slated to be implemented in late 2013, and biometric information sharing will be implemented by the fall of 2014.⁴⁷ The *Beyond the Border Action Plan*²⁵ committed Canada and the U.S. to establishing a coordinated Entry/Exit information system, permitting the sharing of information so that the record of a land entry into one country can be utilized to establish an exit record from the other.

One of the largest examples of database integration is the Schengen Information System (SIS). As noted previously, it is crucial to the success of the EU's Schengen Area and is used by border guards, police, customs, visa and judicial authorities from all member states. SIS consists of three components: a central system, each EU states' national system and a communication infrastructure between the central and national systems. Information is entered into SIS by national authorities and forwarded via the central database to all Schengen states.¹² A similar scheme called the Visa Information System (VIS) allows Schengen countries to exchange visa data. Like SIS, VIS consists of a centralized technology infrastructure that links the main system to the national systems. VIS connects consulates in non-EU countries as well as all the external border crossing points of Schengen nations. It processes data and decisions pertaining to applications for short-stay visas to visit, or transit through, the Schengen Area. The system can perform biometric matching (primarily fingerprints) for identification and verification purposes.⁴⁸

Integration and information sharing also facilitates the goal of "extending the border", or assessing passengers prior to departure or during flight. By analyzing the Advance Passenger Information (API) and Passenger Name Record (PNR) data provided by airlines, authorities can risk-assess travellers before they arrive at the border. The API contains basic information about the passenger (e.g. passport data), while the PNR contains information about a passenger's travel reservation (number of bags, where they are going, return date, form of payment). The PNRGOV initiative from the IATA aims to standardize the collection and transmission of passenger data.⁴⁹ Standardization will likely lead to faster implementation, easier integration, lower costs and more reliable data.

6 TECHNOLOGY

The third phase of this study involved an investigation into technologies currently deployed in airports and those that may emerge in the next 5-10 years. This phase was divided into two main areas: identity verification and baggage/passenger screening. Literature and patent databases were searched for each, and the resulting bibliographic records imported to text-mining software for analysis. The full strategy and database list can be found in the Methodology section of this report (9.1).

6.1 Identity Verification Technologies

As seen in the previous phases of this study, there are many recent initiatives and trials of identity verification technologies underway in various parts of the world. Clearly, biometrics are central to the development and integration of products and systems such as eGates, ePassports, registered traveller programs and visa applications, and will likely continue to be well into the future. However, although the focus of this study is on technologies related to border security, confining the literature search to that application alone severely limits the quantity of retrieved documents and precludes discovery of technologies that may yet emerge and be relevant to the domain in the future. Consequently, the search strategy was broadly designed to retrieve the breadth of current research and patenting in the field of biometrics, no matter the specific application or industry. Additionally, the literature dataset only comprises publications from the past five years (2008-2013) in order to capture the latest trends. In total, 4238 records were retrieved for the literature dataset and 7,162 patent families^j for the patent dataset.

6.1.1 Literature and Patent Analysis

In the literature set, the identifiers (usually author-supplied), keywords, descriptors, and subject headings were merged to facilitate subject analysis. The terms were cleaned to harmonize variant spellings, acronyms and similar meanings and then classified into a total of 53 subject groups representing 93% of the entire set. The same process was applied to the patents.

^j A patent family is defined as a group of substantively equivalent depositions made by the same applicant within a prescribed period of time. Each patent family essentially describes one invention and includes a priority patent (the first deposition) as well as any other applications made in other countries.

The complete list of groups is provided in Table 2. Biometric technologies comprise 17 of the groups, with others related to application areas (*Border control, E-passports, ID Cards, Airport security*) and statistical or processing methods (*Algorithms, Fuzzy logic, Support Vector Machines, etc.*).

Table 2. Subject Groups

2-D	3-D	Airport security
Algorithms	Artificial intelligence	Authentication
Border control	Computer vision	Cryptography/Encryption
Data security	Discriminant analysis	DNA matching
Ear recognition	Eigenvalues and functions	Emotion recognition
E-passports	Face recognition	Feature extraction
Fingerprinting	Footstep recognition	Fuzzy logic
Gabor filters	Gait recognition	Gender recognition
Gesture recognition	Hand geometry	Handwriting recognition
ID cards	Image classification	Image enhancement
Image fusion	Image matching	Image processing
Image segmentation	Iris recognition	Machine learning
Multi-modal biometrics	Neural networks	Odour recognition
Palm print recognition	Pattern recognition	Periocular recognition
Principal component analysis	Privacy	Recognition accuracy
Retinal recognition	RFID	Signal processing
Support vector machines	Tongue print	Vein matching
Voice recognition	Wavelets	

Figure 1 shows the temporal distribution of all records in both the literature and patent^k datasets for identity verification technologies. In the literature, the years 2010 to 2012 see a significant surge in publication activity, followed by a decline in 2013. Conversely, patenting has been on the decline since 2008 but began to show signs of leveling in 2012. This juxtaposition of high publication/low patenting may be explained by the typical R&D cycle, where technologies are initially debated and tested in the literature until they have demonstrated real or anticipated commercial attractiveness, at which point they are ripe for patenting. Consequently, there may be an increase in patent activity over the next few years as technologies mature and publishing activity slows.

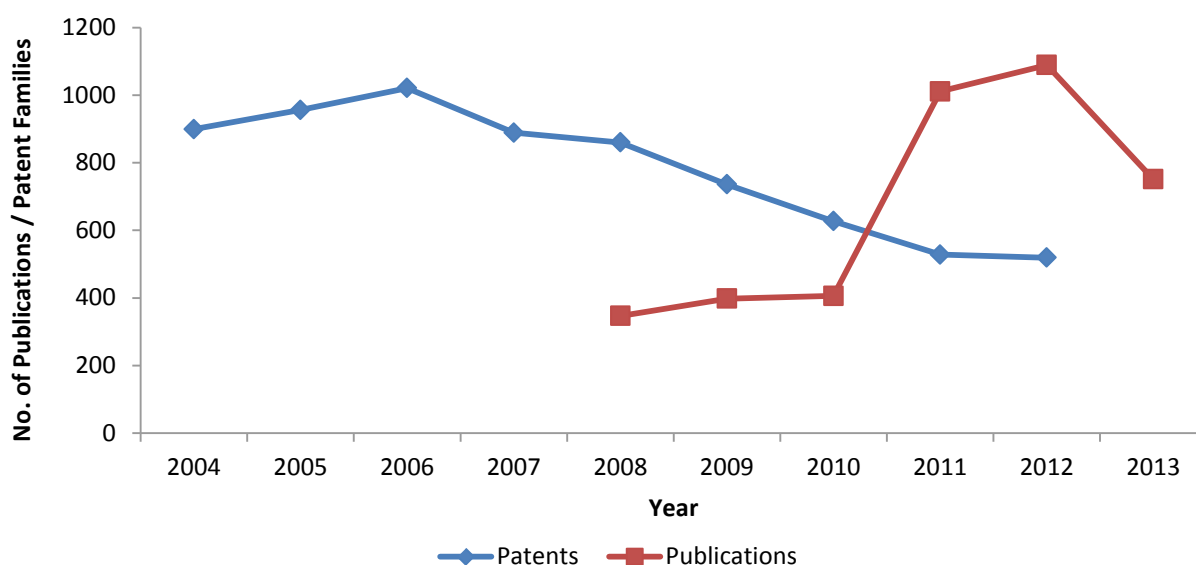


Figure 1. Identity Verification, Literature and Patents, Temporal Distribution

^k Due to the normal 18-month patent blackout period (the time between the deposition of a patent and its publication), 2013 is incomplete and therefore has been omitted.

Table 3 lists the top publishing and patenting organizations in the two datasets. On the publishing side, the organizations are mostly academic institutions, as might be expected, with the exception of the Chinese Academy of Sciences. In Canada, most of the publishing originates from the University of Calgary's Biometric Technologies Lab.^l The majority of the patenting activity concerns three large Japanese multinationals (Hitachi, Fujitsu and NEC), followed by France-based Morpho, the manufacturer of the SmartGate border control system currently deployed in Australia, New Zealand and elsewhere.

Table 3. Identity Verification, Top Publishing Organizations and Patent Assignees

Top Publishing Organizations (# pubs)	Top Patent Assignees (# patent families)
<ul style="list-style-type: none"> Michigan State University, East Lansing, MI, USA (51) West Virginia University, Morgantown, WV, USA (45) Chinese Academy of Sciences, Beijing, China (42) Harbin Institute of Technology, China (39) Hong Kong Polytechnic University, Hong Kong (38) Yonsei University, Seoul, South Korea (32) Carnegie Mellon University, Pittsburgh, PA, USA (28) Tsinghua University, Beijing, China (27) University of Salerno, Italy (27) University of Notre Dame, South Bend, IN, USA (26) University of Salzburg, Austria (25) Shandong University, Jinan, China (21) University of Calgary, AB, Canada (21) University of Milan, Italy (20) University of Twente, Enschede, Netherlands (20) 	<ul style="list-style-type: none"> Hitachi (187) Fujitsu (153) NEC (75) Morpho (41) Honeywell (36) Daon Holdings (22) Lumidigm (16) Accenture (13) Giesecke and Devrient (12) Raytheon (11) Nuance (10) Ultra-Scan Corp (9) NitGen (9) Thales Group (6) 3M (6)

Figure 2 is a co-occurrence matrix from the patent dataset, illustrating the biometric technologies in which the known border control companies are most interested.^m The large Japanese companies again figure prominently, with *Fingerprinting* the most-patented biometric technology followed by *Face recognition* and *Iris recognition*.

^l More information about the Lab is available at <http://www.ucalgary.ca/btlab/>.

^m For the purposes of this matrix a group was created in the patent dataset consisting of companies known to be active in the border control/security domain, as derived from various market reports and the literature.

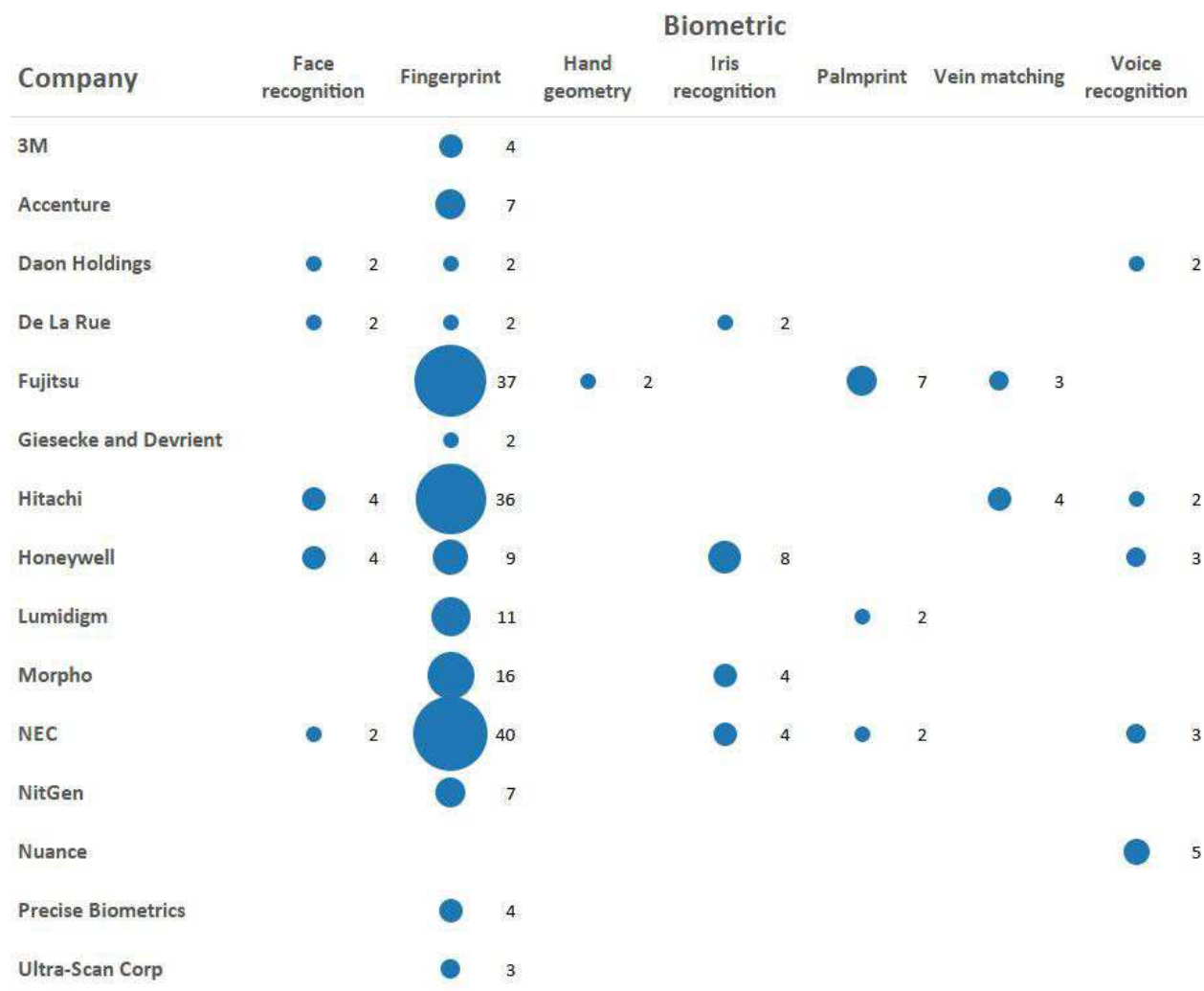


Figure 2. Identity Verification, Patents, Co-occurrence of Biometric Technologies and Companies

As indicated earlier, biometric technologiesⁿ comprise 17 of the 53 subject groups in the literature set, and for comparison the same groups were created in the patents. Figure 3 illustrates the distribution of literature and patent records within each group. *Face Recognition* and *Fingerprinting* are dominant in both datasets, particularly in the patents where there are more than nine times more patent families for *Fingerprinting* than the next largest group. This may not be especially surprising given that fingerprint technology has existed for decades and is currently deployed in various applications and industries, including border security, law enforcement and banking. Residing at the other end of the scale are the relatively newer biometric technologies such as *Footstep recognition* (which has 99.8% accuracy and direct application to airport security⁵⁰) and *Tongue print* (the advantage of the tongue is that it is very difficult to forge, making it attractive to the financial industry⁵¹).

ⁿ Definitions of each biometric technology are provided in section 9.2.

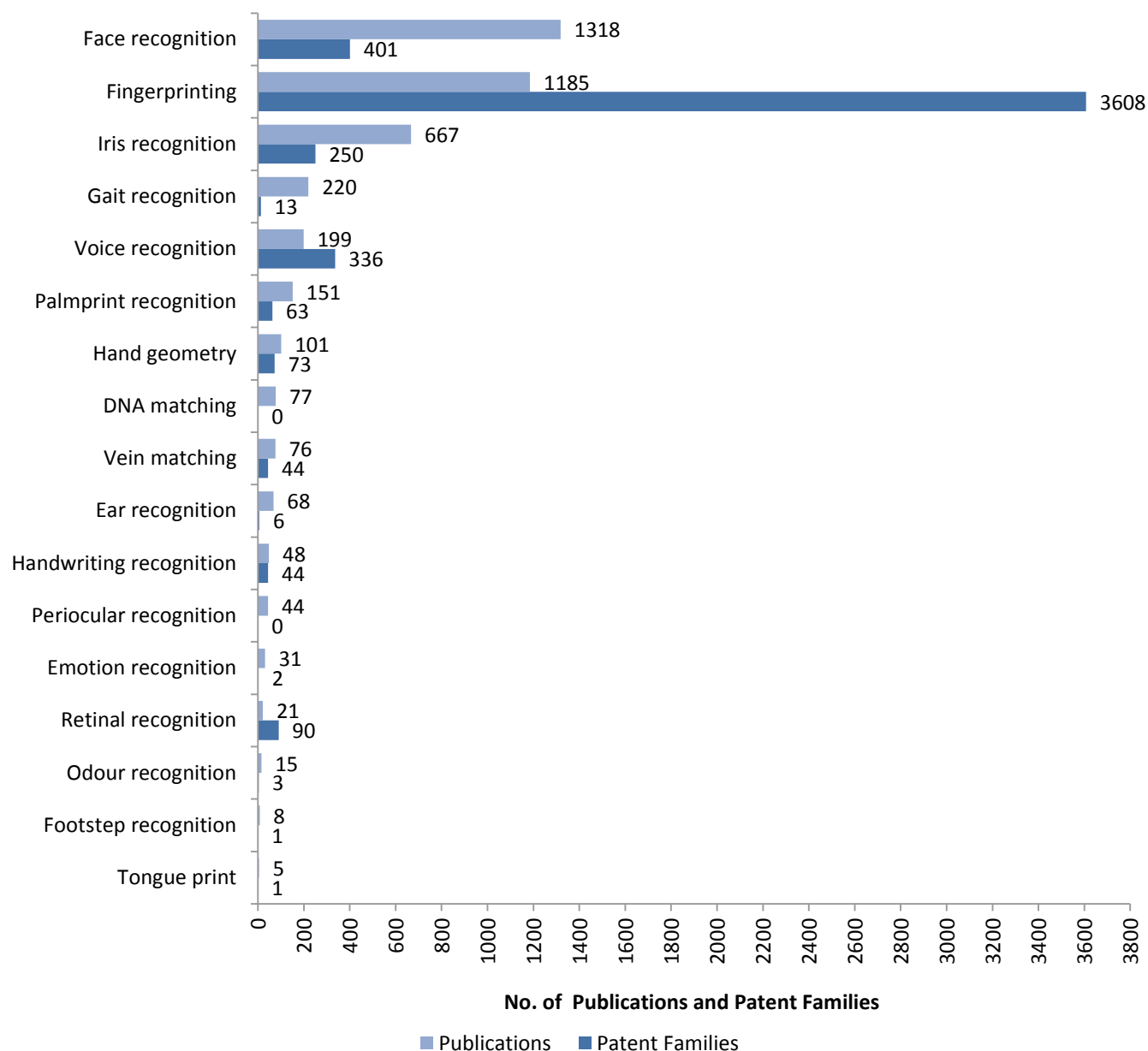


Figure 3. Identity Verification, Literature and Patents, Biometric Subject Groups

Although a simple count of publications and patents within each group provides some insight into the quantity of research and patenting activity on a given topic, it does not sufficiently convey the momentum of a topic relative to others in the same set of data. In other words, the quantity of records in a group does not necessarily suggest which topics are "hot", which are fading and which are emerging.

For topics in the literature, the determination of momentum is based on the relative velocity of each subject group in the dataset. Research momentum is interpreted in terms of rising numbers of publications as well as increasing rates of growth and is expressed in a matrix.^o In Figure 4, the 17 biometric subject groups in the literature are plotted on the vertical axis according to a normalized publication number. The horizontal axis measures the relative rate of publishing velocity. A third dimension is added by linking the size of each bubble to the total number of publications for that group (representing the 2008-2013 time period). The intersection of the axes on the momentum graph marks the central point in standard deviation^p for the two measures. Values on the right hand of the intersection demonstrate greater than average research interest (in order not to congest the diagram, not all nodes are labelled).

In the top left quadrant (i.e. "Enduring" topics) we find *Fingerprinting*, as might be expected, since this topic is relatively mature. The bottom-left quadrant comprises a number of topics (e.g. *Hand geometry*, *Periocular recognition*, *Tongue print*, *Ear recognition*) that can be described as either having fading research interest or are brand new. The "Hot" topics (high number of publications, high acceleration) are *Face recognition* and *Iris recognition*.

Since truly emerging topics rarely have large numbers of publications associated with them, topics which plot into the lower right quadrant (small numbers but high rates of growth) may be viewed as those with the greatest degree of novelty and emergence. In this quadrant we see the presence of groups such as *Footprint recognition*, *Palmprint recognition* and *Gait Recognition*. *Vein matching* (sometimes called vascular technology) exhibits the greatest velocity in this quadrant. Perhaps best known as the technique used to identify the killer of Wall Street Journal reporter Daniel Pearle,⁵² it is a biometric technology that recognizes the pattern of blood vessels under the skin and, although introduced a decade ago, has only recently attracted increased research interest. Blood vessel patterns are unique to each individual (even twins⁵³), are virtually impossible to counterfeit, and allow for contactless applications that are more hygienic and less intrusive than, for instance, fingerprints. The low cost of the systems due to its single-chip design has contributed to the growing implementation of the technology in a number of environments, such as hospitals, law enforcement, military facilities, ATM identification and other applications that require very high levels of security.⁵⁴

^o The methodology for this indicator is described in further detail in Section 9.1.

^p The term "standard deviation" is used here as it is defined in: Gravetter, F.J. and Wallnau, L.B. *Statistics for the behavioral sciences*, 9th ed. Belmont, CA: Wadsworth Cengage Learning, 2013.

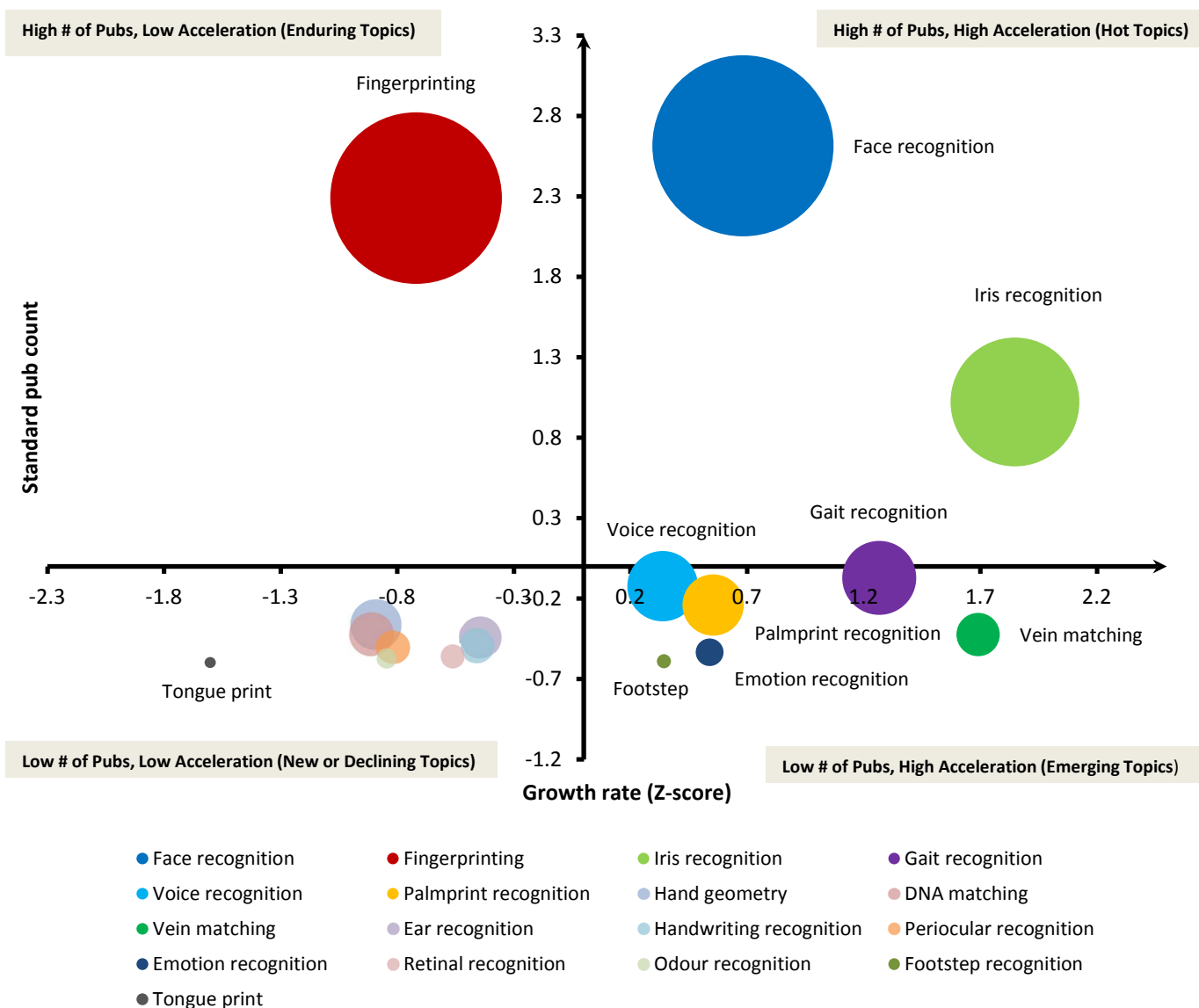


Figure 4. Identity Verification, Literature, Subject Group Momentum 2008-2013

To characterize momentum in the patents, a normalized growth rate of patenting interest (z-score) was plotted for the subject groups.^q Figure 5 shows the relative momentum of each group since 2004.^r As in the literature, *Face recognition* and *Fingerprinting* figure prominently in the patents. *Vein matching* also shows strong growth.

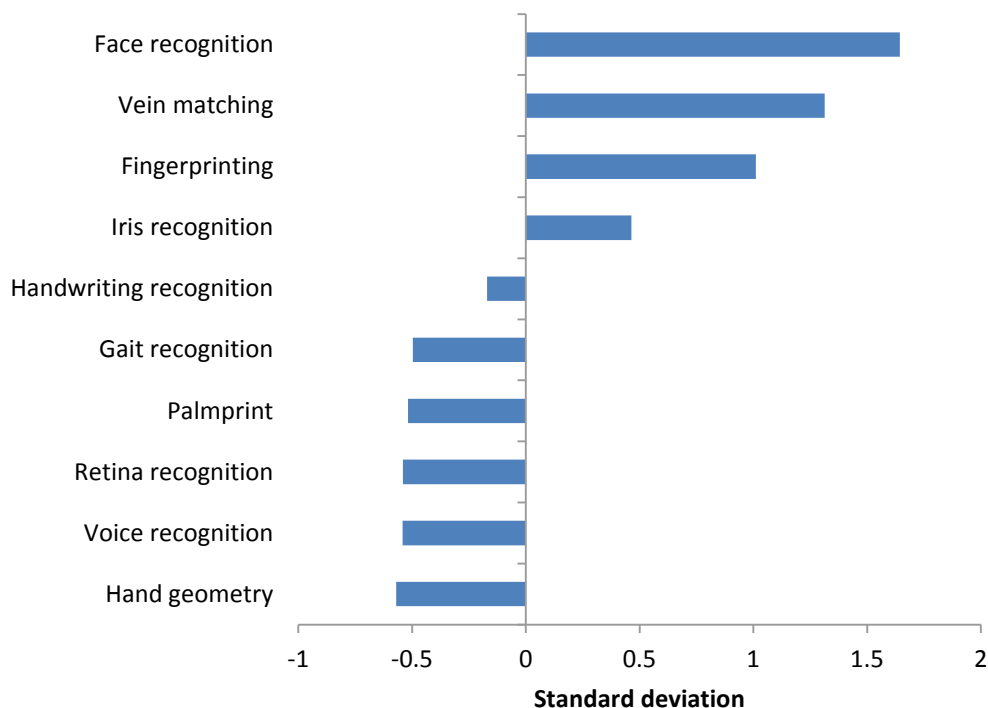


Figure 5. Identity Verification, Patents, Subject Group Momentum 2004-2012

In addition to the 17 biometric technologies in the 53 subject groups, there are also five "application" groups in the literature set: *Airport security*, *Border control*, *E-passports* and *ID cards*. In order to understand which biometric technologies are being used in which applications, a co-occurrence matrix was developed crossing both groups (Figure 6). *Face recognition*, *Fingerprinting* and *Iris recognition* dominate all four application areas, with the other groups having two or less publications in common.

^q The methodology for this indicator is described in Section 9.1.2.

^r 2013 omitted because it is incomplete. Some groups found in the literature do not appear in the patent groups because there were no patents associated with those groups in the patent dataset.

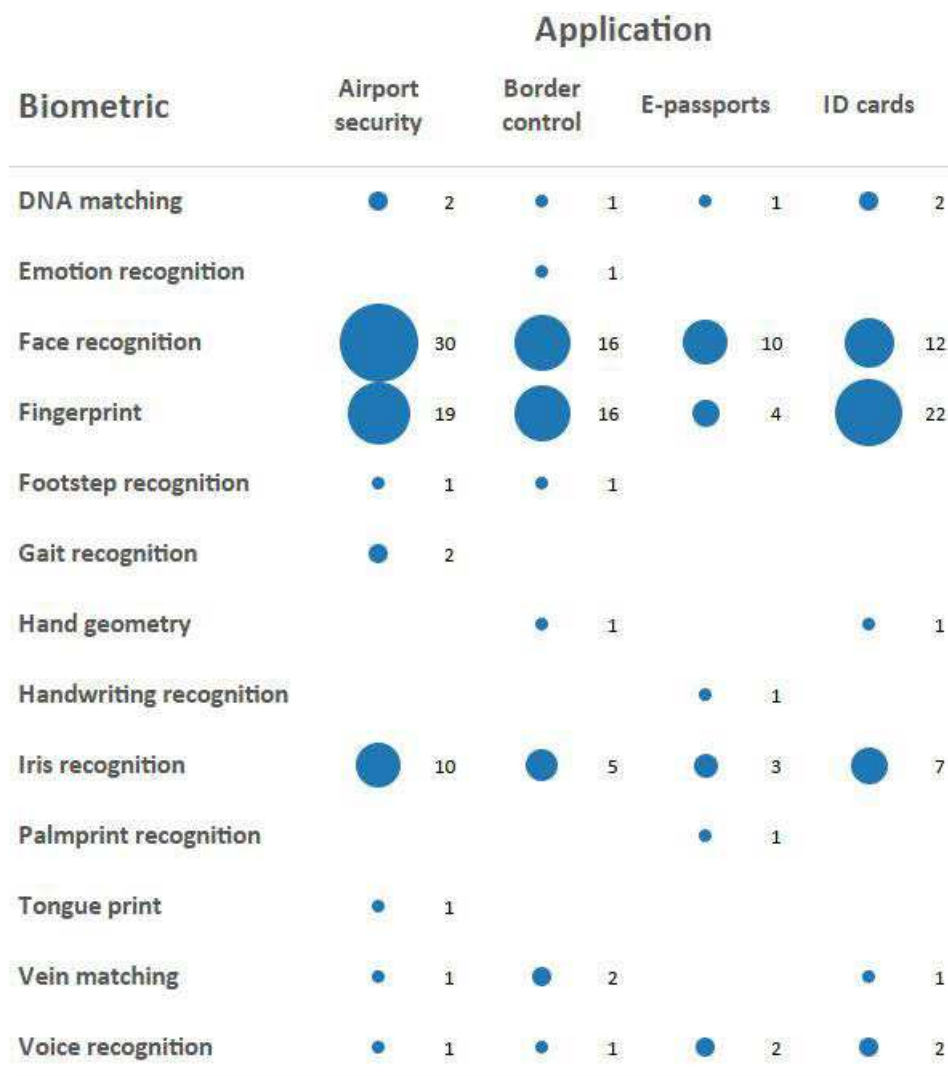


Figure 6. Identity Verification, Literature, Biometric and Application Groups Co-occurrence Matrix

6.1.2 Technology Readiness Levels

Technology Readiness Levels (TRLs) are used by the U.S. Department of Defense to assess the maturity of critical hardware and software technologies to be used in military systems. The scale is defined in DoD's *Technology Readiness Assessment (TRA) Deskbook*⁵⁵, and consists of nine levels, from basic principles to actual systems proven through successful mission operations. For the purposes of this study, the nine levels have been condensed into four (Experimental, Practical, Prototype, Product) to provide a general indicator of what level a technology may have reached, given publishing and patenting trends.

Table 4 summarizes our assessment of the Technology Readiness Levels for biometric technologies, where enough data existed to make a judgement (technologies with insufficient data are not included). When interpreting these ratings it is important to note that the readiness level is assessed in relation to the papers and patents that were gathered for this study, and so they are measured in that context only. The methodology is described in section 9.2 and complete data are provided in section 9.5.

The majority of the technologies are at the Product stage. *Fingerprinting*, *Face recognition* and *Iris recognition* are technologies that have already been applied to border applications such as registered traveller programs, visa application procedures and eGate systems. Although *Vein matching* is also at the Product stage, as yet there are no commercial systems that have been deployed in a border context. Of the remaining technologies, *Gait recognition* - currently at the Experimental stage - is the most likely to be eventually employed in an airport setting (for example, as a security tool to detect individuals remotely and without their knowledge).

Table 4. Technology Readiness Levels – Biometric Technologies

Technology	Experimental (1-3)	Practical (4-5)	Prototype (6-7)	Product (8-9)
Face recognition				•
Fingerprinting				•
Gait recognition	•			
Handwriting recognition		•		
Iris recognition				•
Odour recognition	•			
Palmprint recognition		•		
Retinal recognition				•
Vein matching				•
Voice recognition				•

6.2 Baggage and Passenger Screening

In addition to identity verification, another key component of airport and border security is the technology used to screen passengers and their baggage. These systems include visible systems with which most air travellers are familiar (scanners and physical inspections) and those that happen "in the background", such as closed-circuit television observation and API/PNR screening. There are a number of systems on the market, including metal detectors, full body scanners and explosive trace detection (dogs trained to detect explosives and drugs are not considered here).

Metal detectors

Conventional metal detectors (either step-through or the handheld "wand" type) have been used for decades and provide a relatively fast and inexpensive method of threat detection, particularly for weapons such as guns or knives. Their disadvantages include the fact that they cannot discriminate by type of metal, resulting in numerous false alarms, especially if the passenger has metal prostheses or implants.⁵⁶ They also cannot detect threats made of alternate materials such as ceramics.

Full-body scanners

Full-body scanners are designed to detect weapons and other contraband hidden against the skin of air passengers and can identify both metallic and non-metallic threats. There are two types of machines: x-ray backscatter and millimeter-wave. There is some debate about the safety of x-ray backscatter machines given that they are ionizing and therefore potentially cancer-causing. The science suggests that the risk is negligible, with the scans delivering an amount of radiation equivalent to three to nine minutes of the radiation received through normal daily living.⁵⁷ Millimeter-wave machines use non-ionizing radiation (similar to cell phones or Internet wi-fi) and therefore raise fewer safety concerns. The European Union does not yet use full-body scanners, although they have recently been approved for use in screening persons other than passengers (e.g. airport staff).⁴¹ In Canada, fifty-two millimeter-wave scanners are currently deployed at Canadian airports.⁵⁸

Due to privacy concerns, the Transportation Security Administration (TSA) in the US removed all 250 x-ray backscatter machines from 165 airports as of June 1, 2013, and replaced them with millimeter-wave systems.⁵⁹ The manufacturer of the backscatter machines was unable to develop a software solution to protect passenger's privacy. The new millimeter-wave machines display potential threats on a generic human pictogram that highlights potential areas requiring additional manual searching. The TSA says more than 99 percent of passengers choose to be screened by this technology over alternative screening procedures, and that travellers with joint replacements or other medical devices that would regularly alarm a metal detector often prefer this technology because it is quicker and less invasive than a pat-down.⁶⁰

Explosive Trace Detection (ETD)

ETD is used at security checkpoints to screen passengers and baggage for traces of explosives. A passenger's hands or a piece of baggage are swabbed or swiped with a handheld wand by a security official. The sample is placed into an ETD machine and analyzed for the presence of explosive residue. Ion mobility spectrometry is the most widely used technique for trace detection, however other processes are also available such as those using chemiluminescence or thermo-reduc.⁶¹

Explosion Detection System (EDS)

EDS works like a computed tomography (CT) scanner to provide images of potential threats in checked baggage. As per the 2011 *Beyond the Border Action Plan* with the US, Canada is installing TSA-certified EDS machines at preclearance airports and will seek to complete the deployment by March 31, 2015.²⁵ Concurrently, the US will lift the re-screening requirement on an airport-by-airport basis for US connecting checked baggage as each Canadian preclearance airport completes implementation. The goal is to alleviate the problem of Canadian passengers not receiving their luggage on US connecting flights because it has been removed for re-screening.

Liquid Explosive Detection (LED)

Following a foiled plot in 2006 to detonate a liquid bomb aboard an airplane, there have been restrictions on the amount and type of liquids, aerosols and gels passengers can bring onto commercial aircraft. Recently, research into technology that can detect the contents of a bottle using a laser or sonic scanner may eventually result in the removal of restrictions altogether. A trial of the technology began in Canada, the US and Australia in January 2014.^{62,63}

6.2.1 Literature and Patent Analysis

A literature and patent search for baggage and passenger screening technologies was conducted in the same databases used for identity verification (full methodology in section 9.1.2). In total, 926 records were retrieved for the literature dataset, and 106 for the patents.

Figure 7 illustrates the temporal distribution of both sets (2013 omitted for the patents). Similar to the identity verification dataset, a spike in publication activity is evident from 2010 to 2012, followed by a decline in 2013. There is little variation in the number of patents produced, with less than 20 patents published each year since 2004.

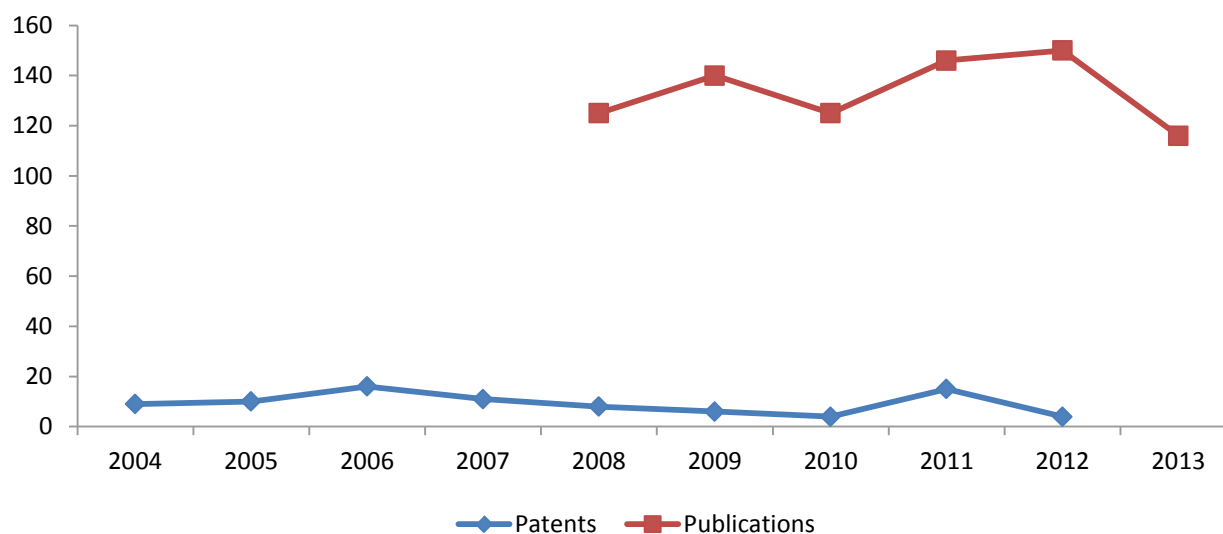


Figure 7. Baggage and Passenger Screening, Literature and Patents, Temporal Distribution

The top publishing organizations (Table 5) are mainly US-based universities. In the patents, companies dominate the top assignees. L3 Communications, a large multi-national security and defence contractor which supplies millimeter-wave full-body scanners to US airports, is the top patent assignee with five. Optosecurity, a Canadian threat-detection firm based in Quebec, has four patents along with United Technologies (US) and Suzhou Galaxy Electronic Technologies (China). Morpho Detection and Disney Enterprises (Disney has long used biometrics to combat ticket fraud at its theme parks⁶⁴) round out the list with three patents each.

Table 5. Baggage and Passenger Screening, Top Publishing Organizations and Patent Assignees

Top Publishing Organizations (# pubs)	Top Patent Assignees (# patent families)
<ul style="list-style-type: none"> • Old Dominion University, Norfolk, Virginia, USA (14) • University of Illinois at Urbana-Champaign, IL, USA (14) • Cranfield University, Cranfield, UK (13) • University of Zurich, Switzerland (10) • Carnegie Mellon University, Pittsburgh, USA (9) • Tufts University, Medford, MA, USA (9) • Pacific Northwest National Laboratory, Richland, USA (9) • Tsinghua University, Beijing, China (9) • University of Applied Sciences and Arts Northwestern Switzerland (8) • Center for Adaptive Security Research and Applications, Zurich, Switzerland (6) • Central Illinois Technology and Education Research Institute, Springfield, IL, USA (6) • Loughborough University, UK (6) • University College London, UK (6) 	<ul style="list-style-type: none"> • L3 Communications (5) • Optosecurity (4) • United Technologies (4) • Suzhou Galaxy Electronic Technologies (4) • Morpho Detection (3) • Disney Enterprises (3)

The same process for cleaning and grouping keywords in the identity verification datasets was performed in the baggage and passenger screening literature set (with only 106 records, the patent set was not large enough for this kind of analysis). In all, 6 subject groups were created: *X-ray*, *CT scanning*, *Neutron detection*, *Millimeter wave*, *Gamma radiography* and *Terahertz scanning*. Figure 8 shows the number of records within each group.

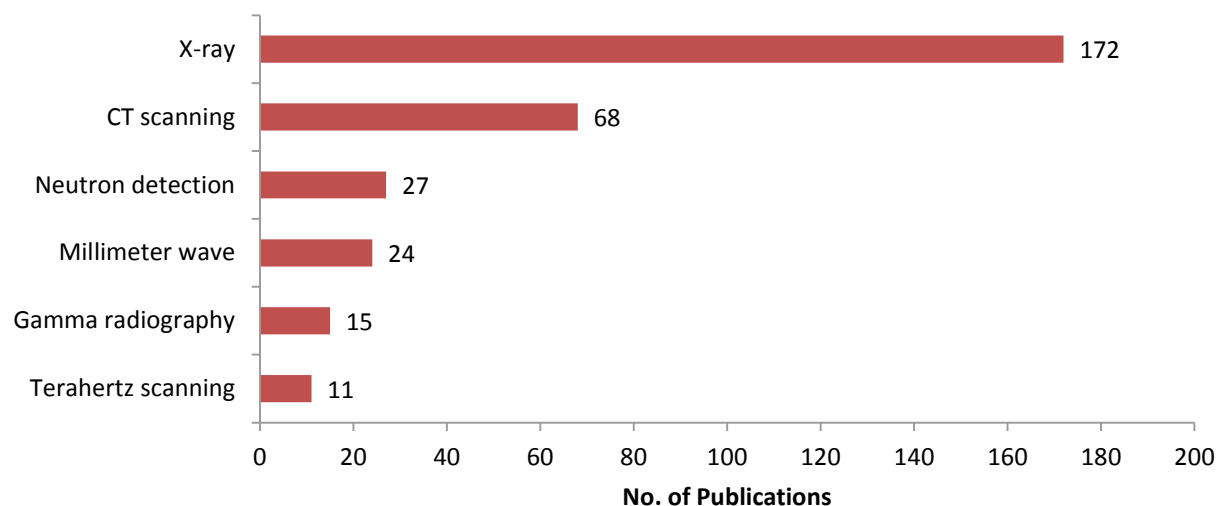


Figure 8. Baggage and Passenger Screening, Literature, Subject Groups

Plotting the literature groups on the momentum indicator graph (Figure 9) illustrates that *X-ray* and *CT scanning* are the dominant, "enduring" topics in the set, with *Gamma radiography* showing the most momentum. *Terahertz scanning* appears in the "New or Declining" quadrant (bottom left of the graph) and most likely is "new" in this case, since although the technology itself has existed for some time, it's applicability to border and airport security has only recently begun to be studied.

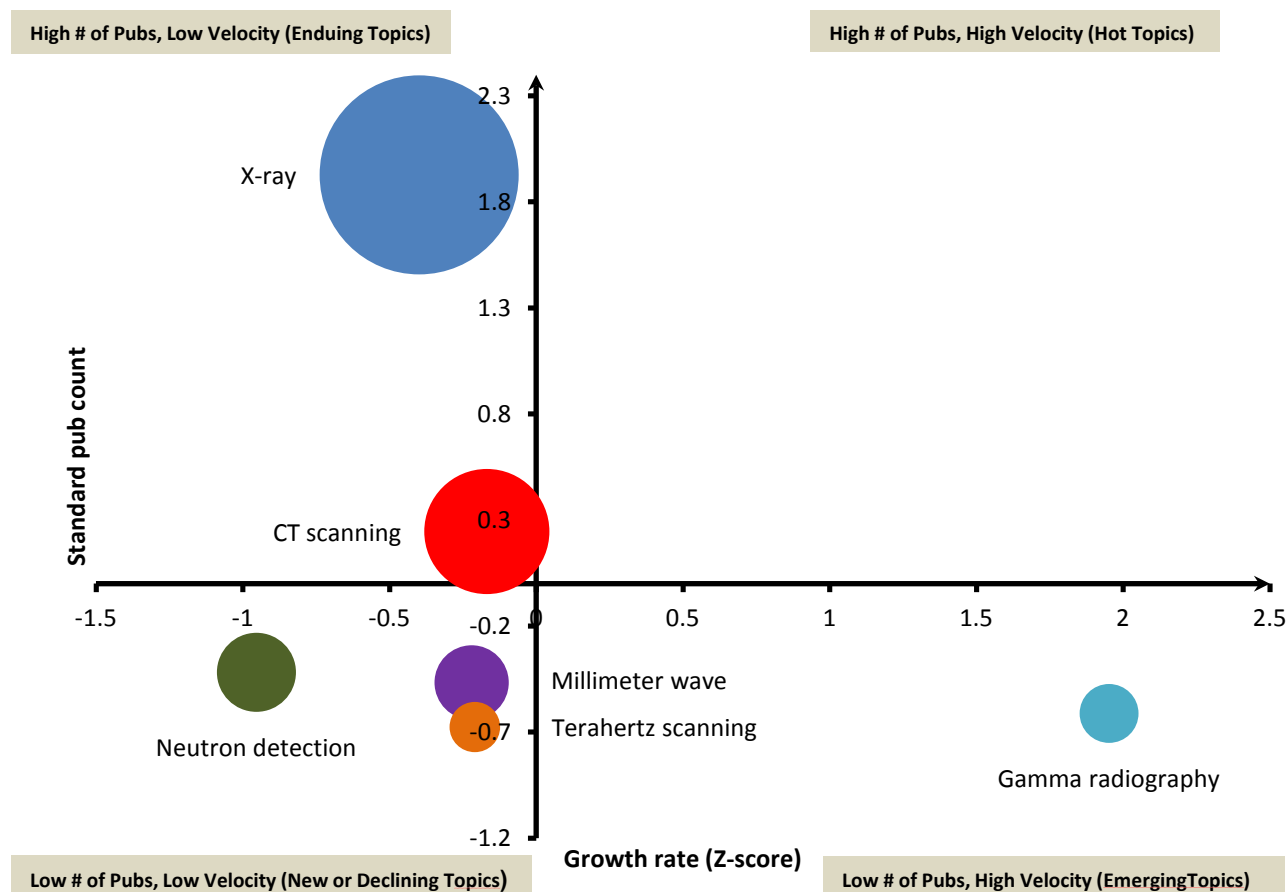


Figure 9. Baggage and Passenger Screening, Literature, Subject Group Momentum, 2008-2013

With so few records, a rigorous statistical analysis could not be performed on the patent set, but a survey of all 106 records revealed a significant amount of activity in the area of passenger tracking (13 patent families). China, with seven, and the US, with six, are the dominant patenting countries in this area (Table 6).

Table 6. Baggage and Passenger Screening, Passenger Tracking Patents

Title	Date	Priority number
System and device for positioning passengers in airport	2011	CN20110177845
Airport passenger recognition and positioning method and system based on target tracking technique	2011	CN20110261060
Airport passenger identification and location system based on target tracking technology	2011	CN2011U331223
Position system and position device for airport passengers	2011	CN2011U223475
Information system for self-help declaring and supervising of entry/exit passengers	2011	CN20110006824
Traveller self-help transit control system	2008	CN20080067705
Passenger flow volume detection method and system based on computer vision	2007	CN20070041616
Verification and screening system	2006	US20060385936
Integrated verification and screening system	2006	US20060385231
Airport Security System	2005	US20050906757
System and method for locating aircraft passengers	2004	US2004P592608
Passenger and item tracking with system alerts	2004	US20040837645
Improved airport system for safety and security	2004	US20040825261

6.2.2 Technology Readiness Levels

Table 7 summarizes our assessment of the Technology Readiness Levels for baggage and passenger screening. Given that products have been on the market for some time for almost all of these technologies, the TRL levels assessed here mainly serve to validate their maturity. The only technology assessed at the Experimental stage is *Terahertz scanning*, which shows promise as a potential future method for scanning passengers and their baggage simultaneously.

Similar to the biometric TRLs, the readiness level for baggage and passenger screening technologies is assessed in relation to the papers and patents that were gathered for this study. The methodology is described in section 9.2 and complete data are provided in section 9.5.

Table 7. Technology Readiness Levels – Baggage and Passenger Screening Technologies

Technology	Experimental (1-3)	Practical (4-5)	Prototype (6-7)	Product (8-9)
X-Ray				•
CT scanning				•
Neutron detection				•
Millimeter wave				•
Gamma radiography				•
Terahertz scanning	•			

6.2.3 Future Trends

The future trend in passenger and baggage screening will likely continue to be increased automation and better, faster, less intrusive and less expensive machines and systems.⁴¹ The increase in passenger traffic in the coming decade will simply demand it. Border authorities will be continually challenged to balance the competing goals of rigorous screening and high passenger throughput. Adding more checkpoints and personnel may have short-term benefit, but is not a long-term solution since the amount of available physical space within an airport is finite and the growing number of passengers will soon outpace the ability of manual processes to handle them. The Smart Security initiative of the Airports Council International (ACI) and the International Air Transport Association (IATA) predicts that by 2020 air travellers will experience an "uninterrupted journey from curb to aircraft door" unless advanced technology detects a potential threat.⁶⁵

According to a recent market report by Frost and Sullivan (April 2013)⁶⁶, some of the technologies likely to play a large (or larger) role in baggage and passenger screening in the next decade are the following.

- **Ion Mobility Spectroscopy** and related technologies have the dominant presence in the market and continue to undergo advancement to enhance their sensitivity and reliability.
- **Raman Spectroscopy and LIDAR** ("Light Radar" - measures the properties of scattered light to find range and/or other information about distant targets) also show promise in the timeframe of 5-7 years for accurate stand-off detection.
- **Terahertz screening** provides the ability to screen chemicals and explosives remotely. However, this technology is prone to environmental interferences. Advantages are: no radiation threat for personnel; ability to scan people and luggage at same time; higher throughput.
- **E-noses** ("electronic noses" designed to identify the specific compounds of an odour) have potential to be more widely adopted once they overcome their limitation to detect accurately in a complex environment.
- **Nanotechnology** appears promising as smaller, cheaper and more sensitive detectors can be produced.

7 CONCLUSIONS

The past few years have seen the implementation of initiatives such as trusted traveller programs and the emergence of international agreements to modernize border control and improve the safe, efficient and secure movement of air passengers. In addition, collaboration and information sharing among nations is accelerating and pushing the risk assessment of travellers beyond national borders. At the same time, advances in identity authentication and screening technologies have enhanced the ability of border control agencies to mitigate risk, reduce costs and minimize the negative impact of security procedures on the travelling public.

As passenger volumes increase and government budgets decrease, traditional methods of border clearance are unsustainable. Biometric technologies are being installed at airport borders because they are more reliable, more efficient and less expensive. In 2008, as little as 18 percent of airports world-wide used biometric technology for passenger identification and screening. Today it is much higher at 28 percent,⁶⁷ despite the fact that system implementation and standardization are still relatively nascent. Fingerprint, face and iris recognition are the dominant technologies for identity verification but others such as vein matching and gait recognition are emerging. For baggage and passenger screening, imaging technologies continue to be improved and refined while promising future technologies include Raman spectroscopy, LIDAR and Terahertz scanning.

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9 APPENDICES

9.1 Search and Analysis Methodology

A literature search was conducted in the research databases listed below. In addition, numerous Internet searches were performed to capture grey literature and government documents.

- Scopus
- Engineering Index (Compendex)
- Inspec
- Aerospace Database
- National Technical Information Service (NTIS)
- Transport Research International Documentation (TRID)

A similar search for patents was performed in the FamPat worldwide patents database from Questel-Orbit. Due to the nature of patenting language and the corresponding difficulty in locating precise records with acceptable recall (i.e. limited noise), several search strategies were undertaken.

For Key Question #3, four separate searches (literature and patents) were performed in the two main focus areas:

- **Identity Verification** - 4238 bibliographic records were selected for the literature analysis, covering publication years 2008-2013, and 7162 patent families were selected for the patent analysis, 2004-2013 (note that the patent term is 20 years from filing date, hence the longer date range).
- **Passenger and Baggage Screening** - 926 bibliographic records, 106 patents (same date ranges as above).

Table 8 lists the concepts included in the search strategy for Key Question #3.

Table 8. Search Strategy

Physical space/domain	Identity Verification	Baggage/Passenger screening	Processes
airport* or "air* travel*" or "air* passenger*" or customs or (border w/2 (control* or management or security or clear* or process*))	biometr* or multibiometr* or "multi-biometr*" or "identity w/3 (management or verification or authenticat* or "risk assess*)" OR G06F 21/32 OR fingerprint* or "finger-print*" or "finger print*" or "finger-vein" or "finger vein" or palmprint or "palm print*" or "vein match*" or "vein pattern*" or "vascular pattern*" or "tongue image" or "tongue print" or "retinal scan*" or "iris at a distance" or ((iris or face or facial or speaker or tongue or gait or voice or footstep or foot-step or "foot step") w/3 (analysis or recognition or identification or detection or track*) or "ear recognition" or "ear detection" or "dna matching" or (dna w/5 biometr*) or "retina* recognition" or "finger geometr*" or "hand geometr*" or "odour recognition" or "signature recognition" or "saliva recognition" or (saliva w/5 biometr*) or ((odour or scent) w/5 biometr*)) OR epassport* or e-passport* or "electronic passport*" or "digital passport*" or "rfid passport*" OR egate* or e-gate* or "automat* border control" or "automat* border clear*" or kiosk* or "self-service technolog*"	(baggage* or luggage* or suitcase*) w/3 (scan* or screen* or inspect* or monitor* or "risk assess*" or threat or illicit or contraband or illegal or prohibit* or image* or imaging or detect*) (passenger* or traveller* or traveller*) w/3 (scan* or screen* or inspect* or monitor* or "risk assess*" or threat* or illicit or surveil* or track* or image or imaging) OR vapour or vapor or xray* or x-ray* or neutron* or narcotic* or contraband or food* or terahertz or ct or "computerized tomography" or "computerised tomography" or "machine vision" or "computer vision" or mm-wave or "millimeter wave" or "millimeter wave" or cctv or "closed circuit television" or "smart video" or "intelligent video" or (video w/3 (track* or surveil*))	"pattern analysis" or "machine learning" or "computer learning" or "data analytic*" OR (passenger* or traveler* or traveller*) w/3 (flow or throughput or through-put or congest* or queu* or cue* or signage or wayfind*) OR Neuromarket* or "herd behavio*" or "group behavio*" or "psychological priming" or "psychological cueing" or crowd w/2 (density or model* or control or management)

All references were imported into VantagePoint software for analysis. VantagePoint enables the creation of various groupings, statistical analyses, matrices, graphs, and cross-correlations to analyze the data and profile the activities of the major players.

Different analytical tools were used to generate graphs based on statistical operations performed in VantagePoint. Tableau software was used to generate bubble graphs.

Intellixir is an online platform which allows for the visualization and analysis of patent information. All the patent data used for the current project as well as the generated graphs can be viewed on Intellixir at <https://zenit.cisti-icist.nrc-cnrc.gc.ca/intellixir/Default.aspx?Serveur=lev>. A user name and password are required to access the system.

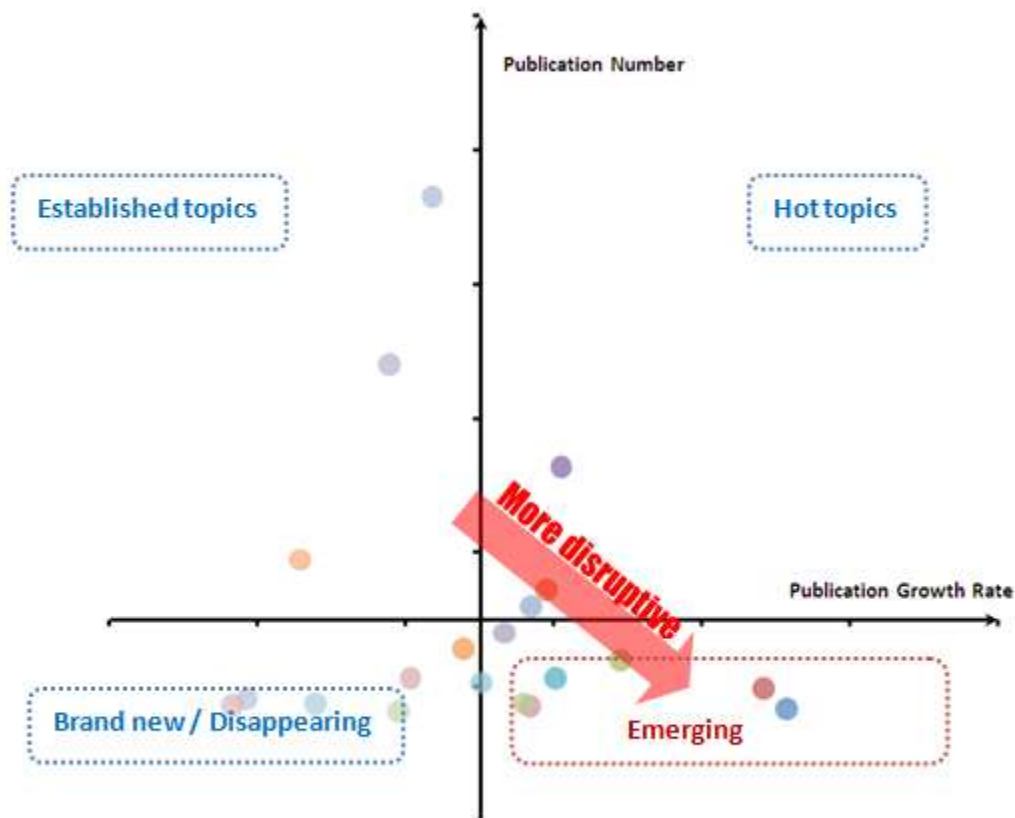
Normalized Growth Rates of Research or Patenting Interest

To ascertain the normalized growth rates and compare values according to their standard deviation for each of the subject groups, publication and patenting rates and the angle (slope) of their increase or decline over time were plotted using linear regression. Average slope degrees and standard deviation were then calculated and standardized to produce Z-scores.

Standardized scores can be used to reduce “noise” and identify topical areas with the greatest growth rates (velocity) in the dataset, as well as the subjects showing sub-standard rates.

The Momentum indicator is designed to identify rapidly rising subjects with relatively few publications. The challenge of identifying such subjects lies with the publication volume as a confounding factor, for their rapid growth and evolution is dwarfed by the high volume of established subjects. Specifically, the notion of “emerging” consists not only of a sharply rising trend line but also of a small footprint in the domain of interest. A *relatively* small footprint is the reason emerging subjects are often overlooked until their disruptive impacts become obvious. In the Momentum indicator, the two parameters correspond to (1) growth rate which is the slope of a subject’s trend line (right-left axis), and (2) volume which is the cumulated total number of publications (vertical axis).

Once growth rate and volume are separated, a two-dimensional coordinate can be used to plot a group of subjects. To do so, the two parameters have to be normalized with z-scores. The normalization process converts two sets of values in different units into the same measure by means of standard deviation, which also standardizes the variations for each of the two parameters. The four-quadrant visualization provides a structured view of the relative position of these subjects within the group.



The techniques involved in producing this indicator can be applied to both literature and patent data. However, emergence is a concept more relevant to scientific breakthroughs than to patents, because the latter is closer to the application stage when the technology of concern has matured. One should expect that the literature covers a broader range of topics, is more diverse, and explores pre-commercial problems by attempting different strategies. This sort of exploration usually precedes what eventually shows up in patents, whereas patents represent a relatively small subset of what is seen in the literature, i.e., a subset of what can be exploited commercially. Therefore, we may assume that emerging subjects are much more likely to appear in the literature. Once reaching the patenting stage, they have generally passed the exploration phase and have already demonstrated real or anticipated commercial attractiveness. Therefore, for this analysis, we have opted to apply the Momentum indicator only to topics in the publications datasets.

9.2 Technology Readiness Levels Methodology

Table 9 shows the methodology for reducing the Technology Readiness Levels from nine to four. Modified TRLs are determined through a relative comparison of the criteria in columns 3-6 as applied to the collection of research papers and patents for a given technology.

Tables 10 and 11 in section 9.5 contain the complete data for the biometric and baggage/passenger screening TRL assessments outlined in Tables 4 and 7, respectively, in the body of this report.

Table 9. Modified Technology Readiness Levels

Modified TRL Level	Includes TRL Levels	Types of Organizations Expected	# of publications/ # of patents	Publication treatment codes	Keywords in identifiers
1- Experimental	1-3	Universities, public labs	High number of publications, low number of patents	Theoretical Mathematical Experimental	Basic research Experiment Experimental Speculative Theoretical Analytic study Analytical study Basic properties Computer simulation Mathematical models Numerical simulation Controlled study
2-Practical	4-5	US Army Research Laboratory Government Labs Private Labs	High number of publications, more patents than experimental	Practical Applications	Applications Applied research Practical Low fidelity Integration Bread board Ad hoc Integrated components Laboratory integration High fidelity Simulation Virtual prototype
3- Prototype Stage	6-7	US Army ARDEQ Companies, esp. their research labs	High number of publications, high number of patents	Applications New Developments	Prototype Prototypical Representative model Testing Simulated operational environment Demonstration Demonstrated readiness Reduced-scale test Scale-model experiment Test bed
4- Product stage	8-9	Companies (predominantly)	Lower number of publications, high number of patents		Co. Company Corporation Product Product design Developmental test Developmental evaluation Weapon system Mission Operational test Operational environment Operational evaluation Patent

9.3 Glossary of Biometric Technologies

DNA matching (profiling)

DNA profiling (also called DNA testing, DNA typing, or genetic fingerprinting) is a technique that can be used to identify individuals through their respective DNA profiles. DNA profiles are encrypted sets of numbers that reflect a person's DNA makeup, which can also be used as the person's identifier. DNA profiling should not be confused with full genome sequencing.

Source: http://en.wikipedia.org/wiki/DNA_profiling

Ear recognition

The human ear is a new feature in biometrics that has several merits over the more common face, fingerprint and iris. It can be easily captured from a distance without a fully cooperative subject. Also, the ear has a relatively stable structure that does not change much with the age and facial expressions.

Source: http://link.springer.com/chapter/10.1007%2F978-3-642-39094-4_42

Emotion recognition

A handful of companies are developing algorithms that can read the human emotions behind nuanced and fleeting facial expressions to maximize advertising and market research campaigns. With the ability to capture, in video freeze-frame, fleeting expressions that are too quick for a human to definitively identify, the algorithms may already be smart enough to provide more information on what people are thinking than has ever before been available.

Source: <http://singularityhub.com/2014/01/19/with-emotion-recognition-algorithms-computers-know-what-youre-thinking/>

Face recognition

Facial recognition (or face recognition) is a type of biometric software application that can identify a specific individual in a digital image by analyzing and comparing patterns. Facial recognition systems are commonly used for security purposes but are increasingly being used in a variety of other applications (e.g. gaming).

Source: <http://whatis.techtarget.com/definition/facial-recognition>

Fingerprinting

Fingerprint identification, known as dactyloscopy, is the process of comparing two instances of friction ridge skin impressions to determine whether these impressions could have come from the same individual. Fingerprint identification, also referred to as individualization, involves an expert, or an expert computer system operating under threshold scoring rules.

Source: <http://en.wikipedia.org/wiki/Fingerprint>

Footstep recognition

Footstep recognition is a relatively new biometric and is based on the study of footstep signals captured from persons walking over an instrumented sensing area. Related to gait recognition.

Source: <http://www.springerreference.com/docs/html/chapterdbid/70827.html>

Gait recognition

Gait recognition aims to identify individuals purely through the analysis of the way they walk. While research is still underway, it has attracted interest as a method of identification because it is non-invasive and does not require the subject's cooperation.

Source: http://globalseci.com/?page_id=44

Hand geometry

Hand geometry involves computing the widths and lengths of the fingers at various locations

Source: http://researcher.watson.ibm.com/researcher/view_project_subpage.php?id=1927

Handwriting recognition

Handwriting recognition principally entails optical character recognition. However, a complete handwriting recognition system also handles formatting, performs correct segmentation into characters and finds the most plausible words.

Source: http://en.wikipedia.org/wiki/Handwriting_recognition

Iris recognition

Iris recognition involves analyzing the features in the coloured tissue surrounding the pupil, which has more than 200 points that can be used for comparison.

Source: <http://www.hrsid.com/company/technology/iris-recognition>

Odour recognition

The identification of an individual via their unique odour signature.

Source: <http://upi.com/1396718>

Palmprint recognition

Palmprint biometrics rely on unique features of the palm for personal recognition. Extracted features from 3D palmprint data include depth and curvature of palm lines and wrinkles on the palm surface.

Source: <http://www.springerreference.com/docs/html/chapterdbid/70995.html?redirected=71637>

Periocular recognition

Periocular biometrics uses information from the facial region in the immediate vicinity of the eye. It is an extended form of iris recognition.

Source: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6199790>

Retinal recognition

Retina recognition is a biometric technique that uses the unique patterns on a person's retina. It has been developed commercially since the mid-1970s.

Source: <http://www.springerreference.com/docs/html/chapterdbid/70899.html>

Tongue print

A biometric technology for automatically identifying or verifying a person using information from their tongue. As the tongue can be protruded from the body for inspection, the shape and texture information can be acquired from its images as "tongue-print"

Source: <http://www.springerreference.com/docs/html/chapterdbid/70984.html>

Vein matching

Vein matching, also called vascular technology, is a technique of biometric identification through the analysis of the patterns of blood vessels visible from the surface of the skin.

Source: http://en.wikipedia.org/wiki/Vein_matching

Voice recognition

The term voice recognition refers to finding the identity of "who" is speaking, rather than what they are saying. Recognizing the speaker can simplify the task of translating speech in systems that have been trained on a specific person's voice or it can be used to authenticate or verify the identity of a speaker as part of a security process.

Source: http://en.wikipedia.org/wiki/Speech_recognition

9.4 Bibliography in Support of Key Question 2b

The following is a compilation of references discovered in support of Key Question 2b: *What studies have been released in the past 5 years on the use of operational research and/or modeling and simulation to improve/optimize flows and processing across the border continuum, from pre-border, at-border, post-border and enforcement?*

Sohn, S. C., K. W. Kim, et al. (2013). **"User Requirement Analysis and IT Framework Design for Smart Airports."** *Wireless Personal Communications*: 1-11.

It takes a great deal of time for an airline passenger to go through the immigration process, security checks, and other airport-associated procedures. Furthermore, nowadays, large airports are competing to be hub airports, are striving to increase customer satisfaction, and wish to provide passengers with excellent travel experiences. When we reviewed airport processes in order to increase airport productivity and improve passenger convenience, we categorized passenger-related processes into three parts: passenger processing, guide services, and mobile services. In order to support a series of improvements in the process, a new paradigm, "Smart Airport Service Framework" is proposed to ensure faster service and greater convenience for passengers and improve work processes and resource utilization. As a part of this paradigm, and to meet the needs of passengers as regards mobile service, we reviewed a customer requirement analysis for smart phone applications using quality function deployment methodology. From this information, we drew the most necessary functions, such as the guide to airport amenities, and developed them, consequently enhancing passenger access to the airport IT systems, saving time, and increasing airport authority profits. © 2013 Springer Science+Business Media New York.

Mackey, M. (2013). **"SITA eases passenger flow."** *Asian Aviation Magazine* 11(2): 28-28.

The article discusses the role of air transport technology firm SITA for marketing of products related to the development of airports in the Asia-Pacific Region. It mentions that Ilya Gutlin, SITA's president, says technological development reduces passenger traffic and baggage flow. It further highlights that by management of airline traffic and passenger flow, SITA has helped the government.

Kirschenbaum, A. (2013). **"The cost of airport security: The passenger dilemma."** *Journal of Air Transport Management* 30: 39-45.

The cost of providing security in airports, especially in facilitating passenger throughput, has risen despite efforts to upgrade training and technology. The classic measure of passenger throughput assumes passengers are passive cogs in a carefully designed security matrix to optimize output. This perspective does not take into account passenger behavior, especially passenger negotiations during the screening process. To both clarify this social contextual process and estimate its differential costs on security screening, a case study emergent from the BEMOSA research project was arranged in an airport where both an ethnographic and 'time-motion' study were conducted. The results clearly showed the extent of negotiations that take place and the type of passenger most associated with delays in the "ideal" throughput scenario. Calculating direct costs of manpower associated with security screening of passengers and the different throughput times led to the conclusion that even though the "good passengers", those who pass through the security process in the minimum time, are the bulk of passenger throughput, "problematic" passengers who negotiate make up the bulk of the costs. These

findings highlight the dilemma faced by security managers but also provide a window of opportunity to seek appropriate solutions. © 2013 Elsevier Ltd.

Human Recognition Systems (2013) **Why you should be measuring the flow of passengers through your airport.** *Aviation White Paper*, 12p

<http://www.hrsid.com/markets/aviation/aviation-white-paper>

After entering the airport, most customers have to wait. This represents the greatest risk of negatively impacting the customer experience. In fact happy passengers spend an average 45 per cent more than unhappy passengers in airport retail areas. By measuring the flow of passengers you can optimise your staff by using alerts if set thresholds are exceeded thereby quickly identify potential bottlenecks. This allows the allocation of staff to problem areas to remove queues and creates operational efficiencies. Staff optimisation is about ensuring that the right amount of staff is in the right place, at the right time in order to achieve the correct staff to customer ratio and prevent bottlenecks from forming. These efficiencies can be extended further by easily and quickly accessing historical statistically reliable performance data to enable better forward planning decisions creating an improved customer service. This allows you to eliminate bottlenecks through knowledge and forecasting based on predictability.

Huang, Z., X. Wu, et al. (2013) **An Open-Access Modeled Passenger Flow Matrix for the Global Air Network in 2010.** *PLoS ONE* 8,

<http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0064317>

The expanding global air network provides rapid and wide-reaching connections accelerating both domestic and international travel. To understand human movement patterns on the network and their socioeconomic, environmental and epidemiological implications, information on passenger flow is required. However, comprehensive data on global passenger flow remain difficult and expensive to obtain, prompting researchers to rely on scheduled flight seat capacity data or simple models of flow. This study describes the construction of an open-access modeled passenger flow matrix for all airports with a host city-population of more than 100,000 and within two transfers of air travel from various publicly available air travel datasets. Data on network characteristics, city population, and local area GDP amongst others are utilized as covariates in a spatial interaction framework to predict the air transportation flows between airports. Training datasets based on information from various transportation organizations in the United States, Canada and the European Union were assembled. A log-linear model controlling the random effects on origin, destination and the airport hierarchy was then built to predict passenger flows on the network, and compared to the results produced using previously published models. Validation analyses showed that the model presented here produced improved predictive power and accuracy compared to previously published models, yielding the highest successful prediction rate at the global scale. Based on this model, passenger flows between 1,491 airports on 644,406 unique routes were estimated in the prediction dataset. The airport node characteristics and estimated passenger flows are freely available as part of the Vector-Borne Disease Airline Importation Risk (VBD-Air) project at: www.vbd-air.com/data. © 2013 Huang et al.

Compart, A. (2013). "**Long Time Coming.**" *Aviation Week and Space Technology* 175(17): 19.

The Customs and Border Protection (CBP) problem is substantial and has financial consequences for commercial airlines. Of course, lengthy lines are not new, but airline executives insist they became particularly bad in the US last summer. That led to the formation of a CBP coalition last November, launched by Airlines for America, the International Air Transport Association and Airports Council International-North America. The coalition is advocating the greater use of automated kiosks, separate lines for connecting travelers, the hiring of part-time employees and a reallocation of staffing and money to help speed up passenger processing. One of the coalition members wants a cost-based user fee study, after which resources would be allocated in proportion to the amounts contributed.

Palmer, A. J. and C. Hurrey (2012). **Ten reasons why IRIS needed 20:20 foresight: Some lessons for introducing biometric border control systems.** *2012 European Intelligence and Security Informatics Conference, EISIC 2012*. Odense: 311-316.

This paper describes ten lessons that programs should consider when introducing innovations to automatically identify and verify the eligibilities of travelers as part of border control and customs processes. These lessons are drawn from focus group discussions comprising former members of IRIS program. We argue that these and similar lessons should be incorporated into a systematic methodology to stimulate collaboration between designers and stakeholders in order to improve complex decision-making regarding the value of introducing innovations for controlling borders. © 2012 IEEE.

Noronen-Juhola, H. (2012). "**Smart Solutions at Helsinki Airport.**" *Journal of Airport Management* 6(2): pp 125-132.

The competitive advantage of Helsinki Airport is its location: the shortest route from Asia to North America and Europe is via Helsinki. Therefore it is under constant, innovative development, profiling itself as one of the leading transfer airports in the world. This means effective, reliable and high-quality service in all time frames for both passengers and airlines. The airport has worked for a long time to achieve a user-friendly layout of its terminal, including its interior design. As Finland has been a leading country of many technological innovations, the airport has tested and piloted new technological systems in order to improve the smoothness of traveling, as well as to ensure that flights can operate with minimum delay. The airport is implementing several solutions, especially critical for transferring passengers. Some examples are optimization of the flow of transfer passengers, automated border crossing, winter maintenance of runways, smart apron solutions and effective baggage handling. However, strong leadership is still the key to successful innovations.

Ma, W. and P. Yarlagadda (2012). **A micro-simulation of airport passengers with advanced traits**. 28th Congress of the International Council of the Aeronautical Sciences 2012, ICAS 2012. Brisbane, Australia. 6: 4382-4387.

An approach for modeling passenger flows in airport terminals by a set of devised advanced traits of passengers is proposed. Advanced traits take into account a passenger's cognitive preferences which would be the underlying motivations of route-choice decisions. Basic traits are the status of passengers such as travel class. Although the activities of passengers are normally regarded as stochastic and sometimes unpredictable, we advise that real scenarios of passenger flows are basically feasible to be compared with virtual simulations in terms of tactical route-choice decision-making by individual persons. Inside airport terminals, passengers are goal-directed and not only use standard processing check points but also behave discretionary activities during the course. In this paper, we integrated discretionary activities in the study to fulfill full range of passenger flows. In the model passengers are built as intelligent agents who possess a bunch of initial basic traits and then can be categorized into ten distinguish groups in terms of route-choice preferences by inferring the results of advanced traits. An experiment is executed to demonstrate the capability to facilitate predicting passenger flows.

Ma, W., C. Fookes, et al. (2012). **Modelling passengers flow at airport terminals: Individual agent decision model for stochastic passenger behaviour**. 2nd International Conference on Simulation and Modeling Methodologies, Technologies and Applications, SIMULTECH 2012. Rome: 109-113.

Airport system is complex. Passenger dynamics within it appear to be complicate as well. Passenger behaviours outside standard processes are regarded more significant in terms of public hazard and service rate issues. In this paper, we devised an individual agent decision model to simulate stochastic passenger behaviour in airport departure terminal. Bayesian networks are implemented into the decision making model to infer the probabilities that passengers choose to use any in-airport facilities. We aim to understand dynamics of the discretionary activities of passengers.

Lopez, R. (2012). **"Signs of change for wayfinding : airport wayfinding can be improved to facilitate safer and more efficient movement of passengers through complex airports, according to research in the US."** IHS Jane's airport review 24: p. 29-31.

Laik, N., M. Choy, et al. (2012). **Uncovering interesting business insights through the use of data analytics in Airport operation: An empirical study**. 2012 Annual SRII Global Conference, SRII 2012. San Jose, CA: 803-810.

Airport terminals around the world are faced with the limited capacity issue as the number of passengers flowing through the terminals is ever increasing especially for the Asia airports. Many airports in the world have benefited from the increase in their passenger volume by increasing their profitability through the use of shopping malls and duty free shopping. However, any further attempt to increase revenue depends on the capacity of the terminals to accommodate the passengers as well as aircrafts. In this paper, we will focus on the analysis of operational data of an airport and how data analytics can yield interesting insights about the behavior of the airlines as well as the terminals' strategy to manage the airlines. We will also demonstrate how these insights led to a list of proposed solutions which are sufficient to significantly improve the overall performance of the airport and customer satisfaction. © 2012 IEEE.

Kovács, G., I. Harmati, et al. (2012). "**Methods for airport terminal passenger flow simulation.**" International Journal of Mathematics and Computers in Simulation 6(6): 529-541.

Increased air traffic has also caused major rise of passenger flow at airport terminals. In order to provide efficient and comfortable service at airports, passenger flow has to be improved, which has to be based on analysis of simulation results. This paper presents an evaluation of two methods for simulating passenger flow of an airport terminal. The terminal is decomposed to several zones, referred to as cells, each having its own behavior. Passenger flow between these cells is defined as a directed graph. The paper presents the difference equation based store-and-forward model and a Petri net based model for the simulation of passenger flow. Principles of passenger flow modeling by the two methods are presented, and detailed description of typical cell models are given for both approaches. The methods are evaluated on the simulation of a smallscale example. Based on the results, comparison on the two methods is given and a conclusion is drawn.

Harding, J. (2012). "**How to Tell If Your Airport Has a Wayfinding Problem.**" Journal of Airport Management 6(3): pp 231-242.

Any airport without a wayfinding master plan and asset management program as part of its signing and wayfinding process has a wayfinding problem on its hands, or at best, one in the making. This paper considers the basic question of how to recognize whether one's airport has a wayfinding problem. Discussion includes steps to follow in analyzing the problem in both a reactive and proactive manner. Understanding the importance of proven wayfinding principles such as consistency, the backbone of any wayfinding system, will help airports develop effective wayfinding solutions. Acknowledging the key principle of any wayfinding strategy is to value it. For wayfinding to be successful, the wayfinding system must be treated as an integral part of the airport's building systems. The net result will provide airport customers with a wayfinding experience that yields positive results not just for the airport and its customer, but also the airport's bottom line.

Frontex Agency (2012). **Best Practice Technical Guidelines for Automated Border Control (ABC) Systems**. Warsaw: 62p.

The present document constitutes a compendium of best practice guidelines on the design, deployment and operation of automated border control systems with a focus on their technical dimension. Automated Border Control (ABC) is defined as the use of automated or semi-automated systems which can verify the identity of travellers at border crossing points (BCPs), without the need for human intervention. The term Best Practice Guidelines (BPG), on the other hand, refers to knowledge, typically based on experience, which can be shared in order to achieve improved results towards specific objectives. These BPG have been drafted by the Frontex Working Group (WG) on ABC in an effort to promote harmonisation of practice, similar traveller experience, and consistent security levels at the different BCPs where ABC systems have been deployed. The intended audience are technical experts involved in the design and implementation of ABC systems in the EU Member States (MSs), including project managers and system architects from border management authorities. While these ABC Best Practical Technical Guidelines have been conceived as a standalone resource, ideally they should be read in combination with the Frontex "Best Practice Operational Guidelines for ABC Systems".

Frontex Agency (2012). **Best Practice Operational Guidelines for Automated Border Control (ABC) Systems**. Warsaw: 65p.

The present document constitutes a compendium of best practice guidelines on the design, deployment and operation of automated border control systems with a focus on their operational dimension. Automated Border Control (ABC) is defined as the use of automated or semi-automated systems which can verify the identity of travellers at border crossing points (BCPs), without the need for human intervention. In general, an ABC system consists of one or two physical barriers (e-Gates), document readers, a monitor displaying instructions, a biometric capture device, and system management hardware and software. The term Best Practice Guidelines (BPG), on the other hand, refers to knowledge, typically based on experience, which can be shared in order to achieve improved results towards specific objectives. These BPG have been drafted by the Frontex Working Group (WG) on ABC in an effort to promote harmonisation of practice, similar traveller experience, and consistent security levels at the different BCPs where ABC systems have been deployed. The intended audience are decision makers, project managers and practitioners involved in the design, implementation and operation of ABC systems in the EU Member States (MSs). While these ABC Best Practical Operational Guidelines (BPOG) have been conceived as a standalone resource, ideally they should be read in combination with the Frontex "Best Practice Technical Guidelines for ABC Systems".

Felkel, R. and D. Klann (2012). "**Comprehensive Passenger Flow Management at Frankfurt Airport**." Journal of Airport Management 6(2): pp 107-124.

This paper describes Fraport's practical approach towards the implementation of a comprehensive passenger flow management solution. The combination of data preparation, forecasting and simulation, in conjunction with real-time information regarding the terminal situation, helped to improve passenger service. An approach, not used before at airports to forecast the distribution of passengers within terminal buildings in almost real-time, is introduced. Further extension of the programme, in the future, could be to use derived data to provide information to passengers directly, eg by the use of smartphones.

Chiang, P.-N. and K. Taaffe (2012). **Estimating Corridor Occupancy and Passenger Flow in Airport Concourses with Moving Walkways**: 17p.

The successfully designed airport concourse must perform at a level that meets the needs of its passengers. One key element for airport designers and planners to consider is the concourse congestion created as a result of terminal use. One method for assessing concourse performance is to set and attempt to meet an appropriate level of service (LOS) for airport passengers based on congestion. A simulation model is developed to estimate the occupancy of zones within a concourse. Specifically, factors such as the flight frequency, aircraft size, gate configuration, and passenger walk speed are considered in the simulations. Zones inside the concourse are introduced and examined for how various diversions (concessions, restaurants, etc.) within the concourse, the capacity of departure lounge in each gate, and moving walkways affect passenger flow in each zone. A finger-pier concourse with 12 gates along its perimeter and four sets of moving walkways is considered as an example to estimate passenger occupancy in each zone and the resulting percent of time a day the concourse attains LOS B for three cases, 1) concourse without moving walkway, 2) concourse with wide moving walkway, and 3) concourse with narrow moving walkway. This research provides insight into how various concourse operation strategies affect when and how passenger congestion forms within the terminal. The results indicate that a concourse with sufficient corridor width and departure lounge capacity could further benefit from installing moving walkways.

Yildirim Yayilgan, S., A. Hovstø, et al. (2011). **Group identification at Border Crossing Points.** Special Interest Group on Biometrics and Electronic Signatures, BIOSIG 2011. Darmstadt: 291-295.

Increasing Passenger flow at Border Crossing Points is an important issue at today's border crossing points (BCPs) of land, sea and airport. Group Access Control and utilizing biometrics information will help increase passenger throughput and reduce human error in handling passengers erroneously. Using multi modal information for (biometric) group id can provide more robust handling of passengers. On the other hand, connecting various BCPs will help solve some problems related to illegal entries from non-Schengen to Schengen space, laws and health. This paper presents the first relevant concepts and issues of using (biometric) group idea and connecting BCPs.

Wheeler, R. and D. Schneider (2011). **"Guiding the Customer."** Airport Business 25(6): 14-15.

The article offers information on providing airport customers with a comprehensive wayfinding signage system in airports. It states that giving air travelers with good wayfinding signage systems allows the travelers to be confident that they will be safe when going to their destination. It mentions that the Modular Curved Frame Technology (MCFT) is a signage system offering a broad selection of solutions to have easy changes of graphics and cost effective approaches to serve air travelers.

Tam, M. L. (2011). **"An optimization model for wayfinding problems in terminal building."** Journal of Air Transport Management 17(2): pp 74-79.

Passenger orientation (wayfinding) is one of the important factors for the layout design of airport terminals. It is common that some people have difficulties in locating their destinations in spite of availability of wayfinding aids. Visibility index is commonly used to evaluate the ease of wayfinding. However, there is a lack of studies for the determination of the appropriate locations for setting up wayfinding aids in airport terminals so as to enhance the ease of wayfinding. In this paper, a binary linear program is proposed for better allocation of directional signs for wayfinding. The proposed model can be widely applied to practical situations so as to improve the design of signage system in various enclosed environments including airport terminals, multi-function railway stations, and shopping malls.

Mijksenaar, P. (2011). **"Leading the way."** Airport World 16: p. 51.

Wayfinding pioneer, Paul Mijksenaar, provides his thoughts on how good signage can reduce the 'hassle factor' of air travel and make for a smoother journey for passengers.

MacLeod, V. and B. McLindin (2011). **Methodology for the evaluation of an international airport automated border control processing system.** L. C. Jain, E. V. Aidman and C. Abeynayake. 338: 115-145.

Biometrics are increasingly being used as a tool for identification and verification and are currently being implemented in access control situations, such as for border control. Biometrics are often used for such purposes on the assumption that it provides greater accuracy and security than humans performing these tasks and that there is the potential for greater efficiency in terms of processing times and resources. Nevertheless, the introduction of a biometric system, particularly where there are potential security implications, warrants considered evaluation before the system becomes operational. Preliminary evaluation may involve factory-acceptance testing, user-acceptance testing and scenario-based trials to determine likely operational performance. However, the most accurate assessment of system performance is obtained by an operational trial involving real travellers. This assessment should seek to determine: the operational performance of the biometric algorithm; how users (novice and experienced) interact with the system; and whether this interaction may impact on current and future business processes, as well as on the quality of the biometric samples obtained. This chapter presents a systems approach for evaluating traveller processing systems in the operational environment when implementing a new system or comparing an old with a new system. A system-level approach, that takes into account both technical performance and the impact of human factors issues, is recommended to provide a complete understanding of overall system performance, as well as identify potential improvements to enhance performance and/or useability. © 2011 Springer-Verlag Berlin Heidelberg.

Lee, A. J. and S. H. Jacobson (2011). **"The impact of aviation checkpoint queues on optimizing security screening effectiveness."** *Reliability Engineering & System Safety* 96(8): 900-911.

Passenger screening at aviation security checkpoints is a critical component in protecting airports and aircraft from terrorist threats. Recent developments in screening device technology have increased the ability to detect these threats; however, the average amount of time it takes to screen a passenger still remains a concern. This paper models the queueing process for a multi-level airport checkpoint security system, where multiple security classes are formed through subsets of specialized screening devices. An optimal static assignment policy is obtained which minimizes the steady-state expected amount of time a passenger spends in the security system. Then, an optimal dynamic assignment policy is obtained through a transient analysis that balances the expected number of true alarms with the expected amount of time a passenger spends in the security system. Performance of a two-class system is compared to that of a selective security system containing primary and secondary levels of screening. The key contribution is that the resulting optimal assignment policies increase security and passenger throughput by efficiently and effectively utilizing available screening resources.

Harding, J. R., M. Elizer, et al. (2011). **Wayfinding and Signing Guidelines for Airport Terminals and Landside** Airport Cooperative Research Program (ACRP), Department of Transportation Federal Aviation Administration.

There are many definitions of wayfinding, but in the most basic terms it is simply the act of finding your way to an intended destination. Therefore, by extension, the purpose of this guideline is to provide airports with the tools necessary to help passengers find their way in and around the airport. The content contained in this guideline is based on research, surveys from airports and design professionals, existing guidelines, and case studies.

Frontex Agency (2011). **Best Practice Guidelines on the Design, Deployment and Operation of Automated Border Crossing Systems**. Warsaw, Poland: 81.

This document presents a compendium of best practice guidelines on the design, deployment and operation of automated border crossing (ABC) systems. These have been elaborated in an effort to achieve at the different border crossing points: harmonization of practice, similar passenger experience and consistent security levels. The intended audience are the different stakeholders in automated border checks, namely practitioners, technical bodies, and decision makers. Current and prospective practitioners, i.e. border guards, will benefit from a wealth of practical information on what to do, and what to avoid too, in order to run an ABC system in an effective, efficient and user-friendly way. System architects and project managers from border authorities will find detailed technical information in order to specify and implement a fully compliant system that performs up to standards while staying away from previously known risks and dead-end streets.

Brown, J. R. and P. Madhavan (2011) **Examining Passenger Flow Choke Points at Airports Using Discrete Event Simulation**. 7p

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110012091_2011012530.pdf

The movement of passengers through an airport quickly, safely, and efficiently is the main function of the various checkpoints (check-in, security, etc) found in airports. Human error combined with other breakdowns in the complex system of the airport can disrupt passenger flow through the airport leading to lengthy waiting times, missing luggage and missed flights. In this paper the authors present a model of passenger flow through an airport using discrete event simulation that will provide a closer look into the possible reasons for breakdowns and their implications for passenger flow. The simulation is based on data collected at Norfolk International Airport (ORF). The primary goal of this simulation is to present ways to optimize the work force to keep passenger flow smooth even during peak travel times and for emergency preparedness at ORF in case of adverse events. In this simulation the authors ran three different scenarios: real world, increased check-in stations, and multiple waiting lines. Increased check-in stations increased waiting time and instantaneous utilization while the multiple waiting lines decreased both the waiting time and instantaneous utilization. This simulation was able to show how different changes affected the passenger flow through the airport.

Bauer, D., M. Ray, et al. (2011). **Simple sensors used for measuring service times and counting pedestrians: Strengths and weaknesses** Transportation Research Record, National Research Council, 500 fifth street, NW, Washington, DC 20001: 77.

Sensors composed of light barriers and switching mats are used to continuously measure service times at security and border checkpoints in an airport setting. The service times in combination with the number of service checkpoints operating in parallel determine the passenger flow. Checkpoints are a major bottleneck at airports and hence determine the capacity of the whole airport system. The results show that at the considered locations both light barriers and switching mats after initial calibration are able to provide continuous information of acceptable accuracy on the distribution of service times. In addition, the technology can be used to inexpensively measure the flow of passengers with reasonable accuracy compared with other pedestrian counting technologies. As such it provides valuable input to the airport operations management.

An, R., H. X. Ma, et al. (2011). **Research on terminal facility optimization in large airport.** 1st International Conference on Transportation Information and Safety: Multimodal Approach to Sustained Transportation System Development - Information, Technology, Implementation, ICTIS 2011. Wuhan: 2085-2090.

This paper formulates the queue network model and the cost model that helps to assure maximal service level and economic benefit. In addition, the queue network model and the cost model had been set up during the operation of airport according to the passenger flow. The passenger waiting cost was applied into the simulation and optimization of the terminal system. The simulation for the process of international departure in Beijing capital international airport terminal T2 is performed, which provides the best reasonable allocation of check-in counters and security facilities during different periods. Finally, the paper examines the feasibility of the application of simulation technology for airport terminals of passenger flow optimization. © 2011 ASCE.

Frontex Agency (2010). **BIOPASS II: Automated biometric border crossing systems based on electronic passports and facial recognition: RAPID and SmartGate.** Warsaw: 51.

To evaluate the concept of automated border crossing, Frontex has previously studied automated border crossing systems in Europe. The first volume of the BIOPASS study [FRO07] covered systems for registered travellers at the four largest European airports: Amsterdam Airport Schiphol; Frankfurt Airport; Paris Charles de Gaulle and London Heathrow. All systems are fully working and enable the passengers to cross the border in a convenient way, however they are limited to specific airports, offer no interoperability –using different tokens for different systems – and require prior enrolment. Since ABC systems are being taken up and increasingly tested and used by Member States, and endorsed by the European Commission to improve passenger facilitation and border security, Frontex carried out a subsequent – BIOPASS II – study on two automated biometric border crossing systems which do not require enrolment and are based on electronic passports and facial recognition: RAPID (Portugal) and SmartGate (Australia). The intent of the study is to examine how such systems operate in the EU and outside of it. More specifically, it aims to examine state of the art technology, its performance, strengths, and limitations; and how such systems complement the larger (integrated) border control process.

Yang, S. and M. Hu (2009). "**Combination forecasting for airport passenger throughput.**" Wuhan Ligong Daxue Xuebao (Jiaotong Kexue Yu Gongcheng Ban)/Journal of Wuhan University of Technology (Transportation Science and Engineering) 33(2): 231-233.

To improve the accuracy of airport passenger throughput forecasting, a combination method is presented. The combination method is based on the econometrics method and the time series method. The multiple linear regression model determines the weight of each method. The combination method is used to fit the annual throughputs of Beijing Capital International Airport from 1994 to 2004. The average error is 3.36%. The result shows that the combination method accurately fits the actual data, and is better than the econometrics method and the time series method. The combination method provides a new way to forecast airport passenger throughput.

Yang, M. and J. Stephens (2009). "**The front line.**" *Military Engineer* 101(658): 41-42.

The Customs and Border Protection Airport Technical Design Standards (ATDS) are newly design standards applicable for all international airports, formulated by the Department of Homeland Security (DHS), Immigration and Naturalization Service (INS) and U.S. Customs and Border Protection (USCBP) in collaboration with private firms. The regimented facility enable the passenger movement while simultaneously controlling illegal entry into the U.S. thereby detailing everything as signage, processing areas, booths, holding rooms, remote monitoring control rooms and security requirements. The design of an international airport require to separate the passenger processing facility, physically and visually from the domestic meet and greet area, domestic passenger operational and other outside areas. Such standards and facilities created play a vital role in helping those on the front line of the homeland security mission to do their jobs.

Vogel, B. (2009). "**Two terminals test MFlow passenger monitoring.**" *Jane's Airport Review* 21(8): 36-37.

An undisclosed major UK airport has concluded a 16-month trial at two terminals of an innovative system designed to monitor and manage the flow of arriving passengers.

Schofield, A. (2009). "**Flow Control.**" *Aviation Week & Space Technology* 170(7): 40-40.

The article reports on the passenger self-service program of the International Air Transport Association (IATA). Automated boarding gates, similar to those used in subway stations, will be introduced at several airports in 2009, as part of a global airline initiative to streamline passenger flow and reduce costs, according to the author. Automated gates allow passengers to scan their own tickets when boarding flights, with a barrier retracting when a bar-coded ticket is passed over a sensor, according to the author.

Price, J. (2009). "**The Future of Airport Kiosks.**" *Airport Magazine* 21(1): p 44.

The author discusses enhanced airport check-in kiosk capabilities now on the horizon. These enhancements should provide better customer service and passenger flow. In addition to allowing passengers to check in, select their seats, pay for baggage, and proceed to a baggage drop, kiosks may also be used for changing seats, entering passport information for international flights, prepaying baggage fees, and accessing frequent flyer mileage upgrades. Future options focus on convenience and passenger rebooking when flights are missed or canceled. Another possibility is paying for amenities such as food and beverages. Kiosk operations by US Airways are profiled.

Paul, J. A., L. Lin, et al. (2009). "**Airport Security System Design: Passenger Flow Analysis and Simulation.**" pp 184-206.

This paper focuses on the screening of passengers and carry-on luggage, which is a crucial security function performed by the Transportation Security Administration (TSA). The paper has developed and tested a simulation model using data collected at a mid-sized U.S. airport with a combination of direct observations and historical records. The data collection plan was formulated in two steps. First, statistical analysis of randomly collected samples and historical records identified distinct day-patterns for passenger volume at the security screening checkpoint. Second, characterization of passenger volume into high, medium and low levels for each of the identified day-patterns allowed a comprehensive data collection to be devised. The process and layout of the security system were taken into consideration while developing the simulation. The research behind this paper aimed to define the process used in security checkpoint operations, collect and analyze passenger flows and operational control policies, and build a comprehensive simulation model of the passenger screening system to evaluate its potential for improvement.

Logarta, M. T. (2009). "**Streamlining security.**" Business Traveller (Asia-Pacific Edition): 13-13.

The article offers information on the Centralised Security Screening (CSS) System at the Suvarnabhumi Airport in Thailand, which is aimed at a faster passenger flow. Passenger security screening points have been reduced to six by the CSS. According to the article, airport managers are optimistic about travellers being able to manage their time better before boarding, through the CSS.

Kaffa-Jackou, R., M. R. Brochado, et al. (2009). "**A multilevel approach for airport security resource allocation.**" World Academy of Science, Engineering and Technology 38: 822-828.

In this communication, the problem of optimizing the allocation of equipments and work teams to control flows of passengers in an airport terminal is considered. The main objective is to minimize the possibility of dangerous situations inside the passenger terminal including dubious passenger being admitted on board aircraft, but another objective is to insure a minimum quality of service to passengers. This communication introduces a general mesoscopic modelling approach for passengers flows in an airport terminal which should be compatible with the formulation of relevant short term optimization problems for the allocation of available security equipment and staff. The adopted network approach displays the dynamic interdependencies between the different flows and queuing systems while the degree of detail adopted allows the definition and quantification of detailed performance indexes. Different instances of global optimization can be proposed but when considering that upstream (check-in) and downstream (boarding) processes follow specified operations rules, the resulting optimization problem concentrates on the optimization of security operations. An overall optimization problem is formulated but its complexity leads to decompose it in two optimizations problems: one devoted to the optimal assignment of airlines resources to check-in and boarding and one dedicated to the optimal assignment of passengers control resources. The coordination of the solutions of the two problems is insured by two ways: by taking into account the predicted effect of decisions on current sub-system to the others and by improving these predictions through repeated overall simulations. © 2009 WASET.ORG.

Matas, M. and A. Novak (2008). "**Models of processes as components of air passenger flow model.**" Komunikacie 10(2): 50-54.

The paper presents the model of air passenger processes at airports for single source and two source processes. It shall be used as a component for the development of passenger flow model. In the paper the single source model is applied on passenger check-in process. It is based on deterministic queuing model where cumulative diagrams of the flow are used for calculations. As input data the model requires the arrival and service profile of passengers at the check-in. The arrival profile is a cumulative number of passengers arriving to the server during the time. The service profile is a cumulative number of passengers which can be served by the check-in process. The calculation of average waiting time and average length of the waiting queue is presented in the paper. In latter part of the paper the case of two source process is discussed.

Kellerman, A. (2008). "**International airports: Passengers in an environment of 'authorities'.**" Mobilities 3(1): 161-178.

This article looks at airports from the passengers' perspectives. It shows that international airports are, above all, spaces of highly explicit expressions of several authorities. The article first distinguishes between airline and airport geographies, followed by a conceptual analysis of authority, power and airports. Then, the article describes the several airport authorities and their responsibilities, spelling out their control of the physical elements of airport terminals, with special attention to signage. This is followed by discussions of airport terminal operations and resulting passenger flows, once again focusing on the role of multiple authorities. These discussions lead, finally, to expositions of travelers' socialities while at international airport terminals and under an authoritarian regime, focusing on passengers' disembodying and dialectics.

Fayez, M. S., A. Kaylani, et al. (2008). "**Managing airport operations using simulation.**" Journal of Simulation 2(1): 41-52.

Airport terminals have dramatically changed after September 11th, primarily due to the tightened security measures. These changes had a major impact on passenger arrival patterns, passenger flows, space allocation, processing times, and waiting times. In turn, it impacted a terminal's performance, levels of service, and the overall passenger experience. Airport planners and decision makers required a decision support tool that can quickly evaluate the impact of the often changing security regulations and the decisions to counterpart these changes on the airport's level of service. The intellectual focus of this paper is to present the methodology and the generic tool that will quantify and assess passenger flow in airport terminal functional areas and relate these requirements to the airport's key performance indicators and level of service.

Churchill, A., E. Dada, et al. (2008). "**Quantifying and validating measures of airport terminal wayfinding.**" Journal of Air Transport Management 14(3): pp 151-158.

The paper is concerned with passenger orientation, commonly called wayfinding, in airport terminals. Previous work has built on theoretical models of connectivity to quantify visual connections. The paper incorporates empirical findings of the effects of the number of decision points and level changes on the ease of wayfinding into a new model of the visibility index that is compared with an existing model. The level of service for wayfinding as experienced by users is examined using questionnaires. Comparisons of measured and reported ease of wayfinding are employed to develop a new level of service scale.

Bartlett, D. (2008). "**Wayfinding**." *Design Week* 23: 19-19.

The article reports about the British Airport Authority's Heathrow Terminal 5 wayfinding. David Bartlett, design director of Heathrow Terminal 5 describes how the basic systems in the airport work its importance to travelers as it features digital signage, single RFID with zonal and departure beacons greeting at the lounge.

9.5 Technology Readiness Levels – Assessment Data

Table 10. Technology Readiness Levels – Biometric Technologies – Assessment Data

Biometric Technology	Number of Publications	Treatment	Affiliation Types	Top Affiliations	Number of Patents	Assignee Type	Top Patent Assignees	Ratio Pubs:Patents	TRL Level
DNA matching	77	Practical [34]; Experimental [18]; Product [6]; Prototype [3]	Academic [56]; Government [9]; Corporate [8]	National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA [2]; University of Milan, Italy [2]; University of Seville, Spain [2]; Nanyang Technological University, Singapore [2]; Forensic Science Service Ltd., Birmingham, UK [2]; Institute for Experimental Mathematics, Essen, Germany [2]; Plymouth State University, Plymouth, NH, USA [2]; University of Porto, Portugal [1]; South China University of Technology, Guangzhou, China [1]; University of Miami, FL, USA [1]; 114 more items with [1]	0			n/a	Not enough data
Ear recognition	68	Experimental [47]; Practical [16]; Prototype [5]; Product [2]	Academic [67]; Government [7]; Corporate [1]	Beijing University of Science and Technology, China [14]; Indian Institute of Technology, Kanpur, India [4]; Shenyang University of Technology, China [3]; Cairo University, Giza, Egypt [3]; University of Southampton, UK [3]; West Pomeranian University of Technology, Poland [3]; West Virginia University, Morgantown, WV, USA [3];	0			n/a	Not enough data

				Shijiazhuang Institute of Railway, Shijiazhuang, China [3]; Amirkabir University of Technology, Tehran, Iran [2]; Darmstadt University of Applied Sciences, Germany [2]; 4 more items with [2]					
Emotion recognition	31	Practical [13]; Experimental [13]	Academic [28]; Corporate [2]; Government [2];	Zhejiang University, Hangzhou, China [3]; Bogazici University, Istanbul, Turkey [2]; Chinese Academy of Sciences, Beijing, China [1]; Samsung Telecommunications America, Richardson, TX, USA [1]; Pécs University Medical School, Hungary [1]; Imperial College London, UK [1]; Université Catholique de Louvain, Louvain-la-Neuve, Belgium [1]; University of Massachusetts, Lowell, MA, USA [1]; National University of Singapore, Singapore [1]; Masaryk University, Czech Republic [1]; 30 more items with [1]	0			n/a	Not enough data

Face recognition	1318	Practical [651]; Experimental [641]; Prototype [64]; Product [25]	Academic [1157]; Government [174]; Corporate [58];	West Virginia University, Morgantown, WV, USA [26]; Michigan State University, East Lansing, MI, USA [25]; Carnegie Mellon University, Pittsburgh, PA, USA [20]; Harbin Institute of Technology, China [20]; Chinese Academy of Sciences, Beijing, China [20]; University of Salerno, Italy [17]; University of Calgary, AB, Canada [15]; University of Las Palmas de Gran Canaria, Las Palmas, Spain [15]; Nanyang Technological University, Singapore [15]; Yonsei University, Seoul, South Korea [15]	401	Corporate [98]; Academic [30]; Government [12]	IBM [10]; SAMSUNG [6]; S1 [5]; BEIJING BAIXIANG NEW SCIENCE [5]; HANVON [5]; GOOGLE [5]; TOSHIBA [4]; VISION [4]; BEIJING WEISHEN DIGITAL TECHNOLOGY [4]; CHINESE ACAD SCI INST AUTOMATION [4]; 3 more items with [4]	3.28:1	4-Product
Fingerprinting	1185	Practical [1088]; Experimental [665]; Prototype [61]; Product [18]	Academic [955]; Government [109]; Corporate [46]	Michigan State University, East Lansing, MI, USA [23]; Gjovik University College, Gjovik, Norway [20]; University of Magdeburg, Germany [15]; RMIT University, Melbourne, VIC, Australia [15]; King Saud University, Riyadh, Saudi Arabia [15]; State University of New York (SUNY), Buffalo, NY, USA [14]; Tsinghua University, Beijing, China [14]; Multimedia University, Melaka, Malaysia [12]; University of Twente, Enschede, Netherlands [11]; University of Milan, Italy [11];	3608	Corporate [938]; Academic [269]; Government [121]	IBM [48]; NEC CORP [40]; FUJITSU LTD [37]; GOOGLE [36]; SYMANTEC [35]; HITACHI [34]; MICROSOFT CORP [33]; MITSUBISHI [24]; LG [22]; SONY CORP [22]	1:3.04	4- Product

				3 more items with [11]					
Footstep recognition	8	Practical [5]; Experimental [5]; Product [1]	Academic [7]; Government [1]	Universidad Autonoma de Madrid, Spain [3]; Dongguk University, South Korea [2]; Swansea University, Swansea, UK [2]; U.S. Army Research Laboratory (ARL), Adelphi, MD, USA [1]; Yonsei University, Seoul, South Korea [1]; University of Maryland, College Park, MD, USA [1]; Yildiz Technical University, Istanbul, Turkey [1]	0			n/a	

Gait recognition	220	Experimental [133]; Practical [80]; Prototype [12]; Product [5]	Academic [206]; Government [30]; Corporate [6]	Darmstadt University of Applied Sciences, Germany [8]; Osaka University, Japan [8]; University of Canberra, ACT, Australia [7]; Shandong University, Jinan, China [6]; University of Southampton, UK [6]; Kyushu University, Fukuoka, Japan [5]; Indian Institute of Information Technology and Management, Gwalior, India [5]; University of Technology (UTS), Sydney, NSW, Australia [5]; Universidad Autonoma de Madrid, Spain [5]; Gjovik University College, Gjovik, Norway [5]; 1 more items with [5]	13	Corporate [3]; Government [2]; Academic [1]	ZEBRIS MEDICAL [2]; ROCKWELL AUTOMATION [2]; HOSSAIN S M EMDAD [1]; INDUSTRY ACADEMIC COOPERATION FOUNDATION [1]; VALTION TEKNILLINEN [1]; KAUPTHING BANK HF [1]; NAT SAFE DEPOSIT CTR S [1]; CHAND SUJEET [1]; MICROSOFT CORP [1]; OSSUR NORTH AMERICA [1]; 2 more items with [1]	18:1	1- Experimental
Hand geometry	101	Practical [49]; Experimental [47]; Product [3]; Prototype [3]	Academic [93]; Government [12]; Corporate [1];	University of Las Palmas de Gran Canaria, Las Palmas, Spain [10]; Hong Kong Polytechnic University, Hong Kong [5]; Polytechnic University of Madrid, Spain [3]; King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia [3]; International Institute of Information Technology, Hyderabad, India [3]; Universidad Autonoma de Madrid, Spain [3]; Escola Universitaria Politecnica de Mataro, Barcelona, Spain [2]; Cairo University, Giza, Egypt [2]; Shenyang University of Technology,	0			n/a	Not enough data

				China [2]; Carlos III University, Madrid, Spain [2]; 7 more items with [2]					
Handwriting recognition	48	Practical [25]; Experimental [12]; Product [1]; Prototype [1]	Academic [37]; Corporate [1]; Government [1];	Technical University of Cluj-Napoca, Romania [3]; University of Kent, Canterbury, UK [2]; Mandsaur Institute of Technology, Mandsaur, India [2]; Hannam University, Daejeon, South Korea [2]; Medicaps Institute of Technology, Indore, India [2]; King Faisal University, Saudi Arabia [2]; University of KwaZulu-Natal, Durban, South Africa [2]; NMIMS University, Mumbai, India [1]; Université du Québec à Montréal (UQAM), Montréal, QC, Canada [1]; University of Magdeburg, Germany [1]; 37 more items with [1]	44	Corporate [13]; Academic [5]; Government [1]	BEIJING BAIXIANG NEW SCIENCE [6]; IBM [3]; JIANGSU HUA AN IND TECHNOLOGY [3]; WELLS FARGO BANK [2]; SHANGHAI LINGRUI INFORMATION [2]; BROADCOM CORP [2]; MITEK SYSTEMS [2]; UNIV BEIJING TECH CN [2]; HEWLETT PACKARD [2]; MICROSOFT CORP [1]; 20 more items with [1]	1.09:1	2-Practical
Iris recognition	667	Experimental [306]; Practical [257]; Prototype [22]; Product [11]	Academic [576]; Government [93]; Corporate [29];	University of Salzburg, Austria [19]; University of Notre Dame, South Bend, IN, USA [15]; Chinese Academy of Sciences, Beijing, China [14]; West Virginia University, Morgantown, WV, USA [14]; Hong Kong Polytechnic University, Hong Kong [12]; Harbin Institute of Technology, China [11]; University of Kent, Canterbury, UK	250	Corporate [68]; Academic [23]; Government [8]	HONEYWELL [8]; SRI INTERNATIONAL [6]; MORPHOTRUST [6]; SAGEM [6]; BEIJING BAIXIANG NEW SCIENCE [6]; AOPTIX TECHNOLOGIES [6]; RETICA SYSTEMS [5]; MORPHO [4]; EYELOCK [4]; SARNOFF [4];	2.68:1	4-Product

				[10]; Shandong University, Jinan, China [9]; Nanyang Technological University, Singapore [9]; Shenyang University of Technology, China [8]; 2 more items with [8]			3 more items with [4]		
Odour recognition	15	Experimental [6]; Prototype [2]; Practical [2]	Academic [12]; Government [4]; Corporate [1];	Macquarie University, Sydney, NSW, Australia [2]; Florida International University, Miami, FL, USA [2]; University of Padova, Padua, Italy [2]; Netaji Subhas Institute of Technology, New Delhi, India [1]; CNRS, Orsay, France [1]; University of Florida, Lake Alfred, FL, USA [1]; Chinese Academy of Agricultural Sciences, Beijing, China [1]; Maharaja Agrasen Institute of Technology, Delhi, India [1]; Monsanto Company, Ankeny, IA, USA [1]; University of Pennsylvania, Philadelphia, PA, USA [1]; 15 more items with [1]	0			n/a	1- Experimental

Palmprint recognition	151	Experimental [103]; Practical [87]; Prototype [5]; Product [4]	Academic [140]; Government [17]; Corporate [2]	University of Las Palmas de Gran Canaria, Las Palmas, Spain [5]; Tsinghua University, Beijing, China [5]; Hong Kong Polytechnic University, Hong Kong [5]; King Saud University, Riyadh, Saudi Arabia [5]; Shenyang University of Technology, China [4]; Nanjing University of Science and Technology (NUST), China [4]; Harbin Institute of Technology, China [4]; University of Science and Technology of Houari Boumedienne, Algiers, Algeria [4]; Vel Tech Dr. RR and Dr. SR Technical University, Chennai, India [3]; Southwest Jiaotong University, Chengdu, China [3]; 3 more items with [3]	63	Corporate [22]; Academic [15]; Government [8]	FUJITSU LTD [7]; UNIV HONG KONG CN [4]; CHINESE ACAD SCI INST AUTOMATION [3]; INDUSTRIAL RES INST HSINCHU TAIWAN [2]; LUMIDIGM [2]; RUMI DIME [2]; BOLISON ASSETS [2]; NEC CORP [2]; TOSHIBA [2]; HARBIN INST OF TECHNOLOGY CN [2]	2.39:1	2-Practical
Periocular recognition[44]	44	Experimental [20]; Practical [10]; Product [1]	Academic [36]; Government [6]; Corporate [1]	University of Notre Dame, South Bend, IN, USA [5]; Carnegie Mellon University, Pittsburgh, PA, USA [3]; West Virginia University, Morgantown, WV, USA [3]; Shandong Normal University, Jinan, China [2]; Clemson University, SC, USA [2]; Islamic Azad University, Tehran, Iran [2]; Central Mechanical Engineering Research Institute, Durgapur, India [2]; Hong Kong Polytechnic University,	0			n/a	Not enough data

				Hong Kong [2]; Shandong University, Jinan, China [2]; Halmstad University, Halmstad, Sweden [1]; 32 more items with [1]					
Retinal recognition	21	Practical [11]; Experimental [10]	Academic [18]; Government [2]; Corporate [1]	University College Dublin, Ireland [4]; Mehran University of Engineering and Technology, Pakistan [1]; Department of ECE, NERIST, Nirjuli, India [1]; Agriculture and Food Science Centre, Belfield, Dublin 4, Ireland [1]; Karadeniz Technical University, Trabzon, Turkey [1]; Chinese Academy of Sciences, Beijing, China [1]; TAK Co., Ltd., Japan [1]; Chinese Academy of Sciences, Chengdu 610209, China [1]; Deemed University, Arunachal Pradesh, India [1]; Sukkur Institute of Business Administration, Pakistan [1]; 16 more items with [1]	90	Corporate [21]; Academic [3]; Government [2]	BEIJING BAIXIANG NEW SCIENCE [5]; IBM [3]; QUALCOMM INC [2]; INNOVATIVE GLOBAL SYSTEMS [2]; MICROSOFT CORP [2]; BOLISON ASSETS [2]; RETICA SYSTEMS [2]; ROCKWELL AUTOMATION [2]; MORPHOTRUST [2]; JPMORGAN CHASE BANK [2]; 1 more items with [2]	1:4.28	4-Product

Tongue print	5	Experimental [2]; Practical [2]	Academic [5]	Mody Institute of Technology and Science, Laxmangarh, India [1]; Oita National College of Technology, Japan [1]; Graz University of Technology, Austria [1]; Shanghai University, China [1]; University of Sao Paulo, Brazil [1]; University Center of the Octavio Bastos Educational Foundation, São João da Boa Vista, Brazil [1]	0			n/a	Not enough data
Vein matching	76	Experimental [46]; Practical [42]; Prototype [3]; Product [1]	Academic [65]; Government [9]; Corporate [3];	Dongguk University, South Korea [7]; Harbin Engineering University, China [4]; Gjovik University College, Gjovik, Norway [4]; Civil Aviation University of China, Tianjin, China [3]; Harbin Institute of Technology, China [3]; Peking University, Beijing, China [3]; Shandong University, Jinan, China [3]; Universiti Teknologi Malaysia, Skudai, Malaysia [2]; Chongqing University, China [2]; National Defense University, Taoyuan 335, Taiwan [2]; 8 more items with [2]	44	Corporate [11]; Academic [8]	HITACHI [4]; FUJITSU LTD [3]; CHENGDU XINRUAN SCIENCE TECHNOLOGY [3]; SOUTH CHINA UNIV OF TECHNOLOGY [2]; UNIV SHENZHEN CN [2]; JASON R D [1]; RICOH [1]; INFOSYS [1]; UNIV HONG KONG CN [1]; CINSOFT [1]; 20 more items with [1]	1.72:1	4-Product

Voice recognition	199	Practical [92]; Experimental [80]; Prototype [13]; Product [2]	Academic [161]; Government [23]; Corporate [14];	Zhejiang University, Hangzhou, China [4]; Idiap Research Institute, Switzerland [4]; University of Balamand, Koura, Lebanon [4]; Darmstadt University of Applied Sciences, Germany [4]; University of Vigo, Spain [3]; King Saud University, Riyadh, Saudi Arabia [3]; Queensland University of Technology, Brisbane, Australia [3]; University of Surrey, Guildford, UK [3]; National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA [3]; University of New South Wales, Sydney, Australia [2]; 19 more items with [2]	336	Corporate [101]; Academic [13]; Government [4]	IBM [16]; AT AND T CORP [14]; BEIJING BAIXIANG NEW SCIENCE [6]; MICROSOFT CORP [6]; NUANCE COMMUNICATIONS [5]; BCE [4]; UNIVERSAL SECURE REGISTRY [4]; SYMBOL TECHNOLOGIES [4]; VERIZON [4]; AOPTIX TECHNOLOGIES [4]	1:1.68	4-Product
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Table 11. Technology Readiness Levels – Baggage/Passenger Screening – Assessment Data

Screening Technology	Number of Publications	Treatment	Affiliation Types	Top Affiliations	Number of Patents	Assignee type	Top Patent Assignees	TRL
CT scanning	68	Practical [46]; Experimental [36]; Prototype [6]	Academic [46]; Corporate [16]	Cranfield University, Cranfield, United Kingdom [9]; Tufts University, Medford, MA, USA [7]; Tsinghua University, Beijing, China [5]; University of Texas, San Antonio, TX, USA [5]; Analogic Corporation, Peabody, MA, USA [4]; China Institute of Nuclear Information and Economics, Beijing, China [2]; University of Manchester, United Kingdom [2]; University College London, United Kingdom [2]; Rapiscan Systems Ltd, Surrey, Redhill, UK [2]; University of Erlangen-Nuremberg, Germany [2]; 3 more items with [2]	10	Corporate [8]; Academic [2]; People [1]	TSINGHUA UNIV [2]; MORPHO DETECTION [2]; L3 COMMUNICATIONS SECURITY DETECTION SYSTEMS [2]; IHI ISHIKAWAJIMA HARIMA HEAVY IND [1]; REVEAL IMAGING TECHNOLOGIES [1]; PERKINELMER [1]; ANALOGIC [1]; BBH CAPITAL III [1]; NUKTEK KOMPANI [1]; NUCTECH [1]; 3 more items with [1]	4-Product
Gamma radiography	15	Practical [12]; Experimental [9]; Prototype [2]	Government [7]; Corporate [5]	Tsinghua University, Beijing, China [1]; Medical College of Georgia, Augusta, USA [1]; Soreq NRC, Yavne, Israel [1]; National Academy of Sciences of Ukraine, Kharkov, Ukraine [1]; Pacific Northwest National Laboratory, Richland, WA, USA [1]; Los Alamos National Laboratory, Los Alamos, NM, USA [1]; National Institute of Standards and Technology, Gaithersburg, MD, USA [1];	12	Corporate [10]; Academic [2]; Government/RTO [2]	TSINGHUA UNIV [2]; INNOVATIVE AMERICAN TECHNOLOGY [2]; NUCTECH [1]; NUKTEK KOMPANI [1]; TELESECURITY SCIENCES [1]; STEREO SCAN SYSTEMS [1]; SAGE INNOVATIONS [1]; PERKINELMER [1]; INST NAT OPTIQUE CANADA [1]; ASPEKT [1]; 4 more items with [1]	4-Product

				Morpho Detection GmbH, Hamburg, Germany [1]; L-3 Commun. Security & Detection Syst., St. Petersburg, FL, USA [1]; China Academy of Engineering Physics, Mianyang, China [1]; 17 more items with [1]				
Millimeter wave	24	Practical [19];Experimental [9];Prototype [1]	Government [14];Academic [11]	Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR), Wachtberg, Germany [8];Fraunhofer Institute for Applied Solid State Physics (IAF), Freiburg, Germany [3];Pacific Northwest National Laboratory, Richland, WA, USA [3];Manchester Metropolitan University, UK [2];Maxonic GmbH, Gimmersdorfer Str. 75a, D-53343 Wachtberg, Germany [2];Goethe-Universität Frankfurt, Germany [1];SynView GmbH, Glashütten, Germany [1];French-German Research Institute of Saint-Louis, France [1];Fraunhofer Institute for Communication, Information Processing and Ergonomics, Wachtberg, Germany [1];ENAV SpA, Roma, Italy [1];15 more items with [1]	3	Corporate [2];People [1];Academic [1]	GE HOMELAND PROTECTION [1];FRIEDRICH ALEXANDER UNIVERSITAET ERLANGEN NUERNBERG [1];SMITHS HEIMANN [1];UNITED TECHNOLOGIES [1];L3 COMMUNICATIONS SECURITY DETECTION SYSTEMS [1];MORPHO DETECTION [1]	4-Product

Neutron detection	27	Experimental [17]; Practical [17]; Product [5]	Government [12]; Academic [7]	Lawrence Berkeley National Laboratory, Berkeley, CA, USA [2]; Pacific Northwest National Laboratory, Richland, WA, USA [2]; Helmholtz Zentrum München, Germany [2]; Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany [1]; Health Canada, Ottawa, ON, Canada [1]; Prairie View A&M University, Prairie View, TX, USA [1]; NASA Johnson Space Center, Houston, TX, USA [1]; L-3 Communications Security and Detection Systems, St. Petersburg, FL, USA [1]; Medical College of Georgia, Augusta, GA, USA [1]; Varian Medical Systems, Mountain View, CA, USA [1]; 26 more items with [1]	28	Corporate [25]; Government/RTO [2]; Academic [2]	OPTOSECURITY [4]; L3 COMMUNICATIONS SECURITY DETECTION SYSTEMS [4]; INNOVATIVE AMERICAN TECHNOLOGY [2]; TSINGHUA UNIV [2]; IHI ISHIKAWAJIMA HARIMA HEAVY IND [2]; MORPHO DETECTION [2]; FAJ INTERNATIONAL HOLDINGS [1]; FEDERAL NOE GUP RF JADERNYJ TS [1]; ASPEKT [1]; AIRPORT SECURITY BUSINESS CTR [1]; 16 more items with [1]	3-Product
Terahertz scanning	11	Practical [8]; Experimental [4]	Academic [7]; Government [3]	Maxonic GmbH, Wachtberg, Germany [1]; Manchester Metropolitan University, UK [1]; Max-Planck-Institut für Radioastronomie, Bonn, Germany [1]; Nanjing University of Science and Technology, China [1]; Zurich State Police, Zurich, Switzerland [1]; SynView GmbH, Glashütten, Germany [1]; Saratov State University, Saratov, Russia [1]; Newcastle University, Newcastle upon Tyne, UK [1];	1	Corporate [1]	MORPHO DETECTION [1]; UNITED TECHNOLOGIES [1]; GE HOMELAND PROTECTION [1]	1- Experimental

				Military University of Technology, Warsaw, Poland [1]; University of Canberra, Canberra ACT, Australia [1]; 3 more items with [1]				
X-ray	172	Practical [97];Experimental [76];Prototype [26]	Academic [102];Government [41]	University of Applied Sciences and Arts, Northwestern Switzerland (FHNW), Olten, Switzerland [10];University of Zurich, Switzerland [7];Civil Aviation University of China [5];Center for Adaptive Security Research and Applications, Zurich, Switzerland [5];Tufts University, Medford, MA, USA [5];Cranfield University, Cranfield, United Kingdom [5];Trent University, Peterborough, ON, Canada [4];Commissariat de l'energie atomique (CEA), France [4];University of Texas, San Antonio, TX, USA [4];Zurich State Police, Zurich, Switzerland [3];8 more items with [3]	29	Corporate [23];People [4];Academic [2]	L3 COMMUNICATIONS SECURITY DETECTION SYSTEMS [5];OPTOSECURITY [4];MORPHO DETECTION [3];JIN XIANHUI [2];IHI ISHIKAWAJIMA HARIMA HEAVY IND [2];TSINGHUA UNIV [2];UNITED TECHNOLOGIES [2];ANNA LOGIC [1];NUCTECH [1];NUKTEK KOMPANI [1];15 more items with [1]	4-Product