ENGN2226 Portfolio

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Biometric Passport Authentication By Facial Recognition

Feasibility Study

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Introduction

The job of an engineer is often characterised as problem solving. While this may seem simple, and venerable, when it comes time to produce a solution, looking at a problem offers no potential for realisation of the inextricable nature of industry, the environment, humans, and the economy. In an interconnected world, we must afford a systems approach to thinking, and offer our designs input from a perspective that realises the complex relationships and possibilities of an integrated approach to engineering.

Throughout this paper, the task at hand is to analyse the feasibility of advanced facial recognition, or ‘SmartGates’ in passport authentication. In an engineering systems analysis, several tools will be used to inform a progressive development of design, through further analysis, data collection, and redesign. Each analysis technique can be integrated into another; data collection is used several times to build more comprehensive knowledge used in queue theory, human factors analysis, and system dynamics. The arrows linking these topics are more convoluted than in any Sankey, stock and flow, or energy-mass diagram.

The technical outcomes of the following analyses clarify areas needing attention in current biometric identification systems, and conclude that a key focus must be to gain accurate data on uptake of technology to ensure a smooth rollout, to avoid under- or over-supply of the right services. Multifactorial design and queue theory combine to influence system design into a clever balance between automated and human passport controllers. It is important to ensure an appropriate level of human presence in the process, to save face in the event of system failure. Technologies designed for humans that seem to be designed by non-humans suffer from adoption issues, and in a high paced environment, smart human interfaces need to be developed to facilitate a smooth journey through declaration and identity confirmation.

Viewing a system as a whole is not possible without some process and thought. Logical progression through various analytical techniques is highly useful in defining scope, and drawing a picture of a system from multiple perspectives. It is this ability to step back, to use tools to clarify analysis rather than convolute it, that sets a team of engineers on the path to a properly conceived technology of perfect functionality. Implementing SmartGates is a large task that will benefit from increased understanding and usage as it becomes more prominent across the globe. At the local level, 4 SmartGates should serve the flow of passengers through Brisbane’s international arrivals.

Summary of Analyses

Informed estimation provides engineers with initial system requirements, a platform for scoping further analysis, and an idea of the size and number of resources required for the problem at hand. Data collection of passenger numbers arriving at Brisbane airport suggests that the number of passengers utilising an intelligent facial recognition system at that airport would be approximately 6000 per day. Collection of data from multiple sources, and a broad range of contexts determines where a certain technology will find itself most useful; in this case, Brisbane airport was chosen as a model, but the same data collection and estimation can be performed for any destination for SmartGate technology. This initial estimation was an important starting point for much of the following analyses. The potential dynamical nature of the system at hand is highlighted when the number of stakeholders is realised through initial estimation and research. Back of the envelope estimation was used again in identifying how biometric technology could diffuse into an airport such as Brisbane, and analysis of its diffusion led to a broader understanding of the contributing factors to success in implementation - an intelligent passport system requires the cooperation of international governments and standards organisations to create a universal system that everyone can use, wherever they travel. This insight is especially important for queue theory, where the number of SmartGates servicing arriving customers not only directly affects processing time, but also affects customer perceptions of biometric technology, leading back to a consideration of system dynamics, to ensure that the technology's diffusion does not lead to slow uptake rates due to security concerns. Exogenous variables such as forced uptake of a technology have complex relationships with queue theory (when customers thrust into a situation are not sure how to act) and system dynamics. As the arrival to an airport is a very interactive, high paced process centring about people, one of the most important considerations in developing a system for this environment is human factors. To ensure smooth operation, designers must consider all variations in the customer base, using anthropometrics to build resilience into their software, and ergonomics to create easily navigable routes to logical machines that enhance, rather than detract from our natural ability. More data collection on deviation in facial types would ensure that every person that passes through our borders is compatible with a facial recognition system, but this can always be overshadowed by trivial user errors and peculiarities. Human intervention in the identification process seems to be inevitable in most cases, as even with SmartGates, every move is tracked for seasoned customs officers to analyse later if required.

Analysis

Informed Estimation

Figuring out a starting point for required system capacity is an important introduction to a successful design process. During the preliminary phase, and with a lack of data, simple *back of the envelope estimation* can assist with this initiation to the project. It will not usually provide useful statistics to following analytical processes, however, until more evidence is collected based on the scope provided by the initial estimation.

Brisbane airport will be used as an example in the following sections, and the analytical process will develop using it as a real-world example when necessary. The success of a new biometric passport processing system depends on several variables; incoming and outgoing passengers, the proportion of those requiring passport control, and whose passports are equipped for biometric authentication.

Performing a back of the envelope calculation without data for all these variables would probably not prove very useful. Given that statistical data is available for them, a short *data collection* process will inform a much more accurate estimation of current system parameters.

Data Collection

Before conducting data collection, it will be useful to define our system boundary, to avoid collecting unnecessary amounts of data, or making an estimation that is going to be irrelevant to later analytical processes. However, any care that is lacking in this process can be offset by the further definition, analysis and data collection throughout the systems analysis process. For this activity, data collection will be relevant to the boundary of a single airport, servicing all its international arrivals and departures requiring passport control. Over 2.23 million international arriving passengers passed through customs at Brisbane airport in 2012 (Commonwealth of Australia 2013), requiring identity confirmation by customs officers. The airport operates 365 days a year, 24 hours a day, and experiences its heaviest passenger demand on weekdays, between 7 and 9 am, and 5 to 8 pm (Willey 2013). Dividing the total number of passengers over 365 days is a simple way of finding an average arrival rate, but fails to consider seasonal fluctuations in travel activity, from holiday-makers to international and local sporting events. To understand the full required capacity of the airport's international arrival system, a consideration of reasonable fluctuations in passenger numbers would benefit our estimation of maximum expected passenger flow. The arrival rate is also restricted by the airport's runway capacity, and traffic control ability. An increase in aircraft traffic delays flight arrivals, saturating the flow of passengers to the terminal (Willey 2013), so higher aircraft arrival rates should not drastically affect the requirements of a passport control system. Using the data collected, the expected rate of passengers flowing to international passport control can be estimated. The mean daily arrival rate is 2 230 000/365 ≈ 6000 passengers.

Time of day	Arrivals (% of total)	Arrivals (passenger number) per hour
0 to 400 hrs	5%	75
400 to 800 hrs	17.5%	262.5
800 to 1200 hrs	17.5%	262.5
1200 to 1600 hrs	20%	300
1600 to 2000 hrs	25%	375
2000 to 2400 hrs	15%	225
Total	100%	6000

Table 1: estimated international arrivals by time of day at Brisbane airport

The estimated required capacity of the international passport control system system is 375 passengers per hour. Adding 10% to account for future increases in passenger flow, and rare events of high traffic, this will be rounded up to 400 per hour.

Given that the system under analysis requires passengers to have a biometric passport to utilise it, it will not experience the full passenger load, as not all passengers will have a biometric passport. International standards for facial recognition and contactless passport technology have existed since 2006 (ICAO 2006), with international passport authorities issuing new passports with the technology since at least that time (Reid 2006). An Australian adult's passport lasts for 10 years (Department of Foreign Affairs and Trade 2013), so by 2016 any Australian who purchases a new passport will be able to utilise biometric security. Australia has been an early adopter of biometric passport technology and the "SmartGate" (Australian Customs and Border Protection Service 2012), and will soon allow Chinese passport holders to navigate customs through a SmartGate by 2015 (McDonell & Woodley 2013). From 2013 to 2015-16, the estimated percentage of international arrivals able to use biometric passport authentication could rise to 90% or more, but some countries will still not support it until the technology's security is further verified. Given the expiry time of passports, the number of countries adopting biometric authentication, and number of international arrivals, the proportion of international arriving passengers able to use a facial recognition system in Brisbane airport may be estimated at 60%, or 240 persons per hour, increasing to over 350 persons per hour by 2016. A number of considerations may change this estimate: though a SmartGate is available to passengers, some may prefer to navigate customs the normal way through personal interaction due to fear of technology failing, or being slower than a human. Without proper diffusion of biometric authentication throughout other airports, knowledge and adoption of the system may be poor amongst potential users. These dynamical system behaviours can be understood by looking at the *diffusion of innovations.*

Dynamical Systems

Diffusion of Innovations

A few major stakeholders will influence the adoption of a biometric passport control system. Users can be airline passengers, as well as airport staff. These groups will benefit from improvements the system offers in efficiency, and ease of use, and so will the airport's management. Governments responsible for issuing passports greatly influence the way in which biometric security is rolled out. While a citizen may be able to choose when to update their passport, it is often not their choice to take part in biometric identification. This creates two separate drivers for diffusion of the technology, one influenced by forced adoption of biometrics by authorities, and another created by demand for biometric authentication by users choosing between a SmartGate and a traditional customs officer when passing through security. Figure 1 details the complex interactions between users and developers of the technology once the user is inside the airport, waiting to be processed. Green arrows indicate a positive effect of one variable on another; the number of active users will increase the demand on biometric processing. Red arrows indicate a negative effect; as security concerns grow, the number of active users will shrink. The increasing demand of either processing technique affects the active number of users of the new technology. Interpreting this stock and flow diagram allows us to see the detailed process of adoption when someone enters the choice between using a SmartGate or traditional passport processing official. The stock in this case comes from users of the latter, who flow through the complex processes outlined, to become active users of the former. The reduced demand on the old system creates opportunities to reduce resource use, and rethink the management of queues.

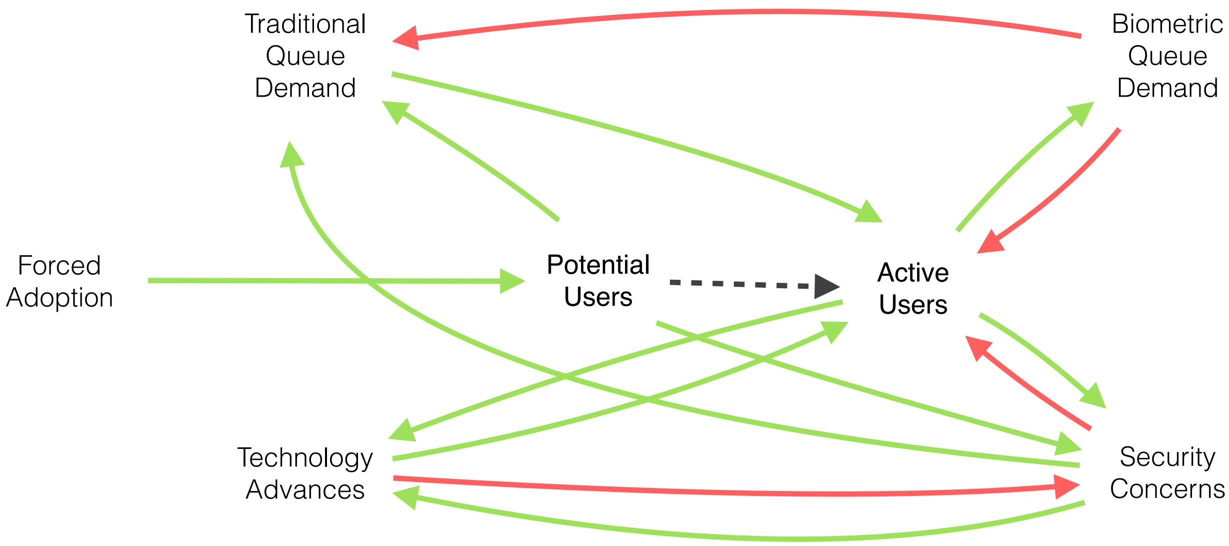

Figure 1: Stock and Flow diagram for users of customs processes.

This analysis is a useful way to uncover areas of potentially high impact on technology adoption. Positive feedback loops help to speed up the process exponentially, for example, between improving the technology and its security, creating more users, encouraging further improvement. It broadens a systems engineer's outlook on a system, and encourages logical deliberation on priorities, and naturally integrates ideas of queues and further development as key considerations. It is a short- and long-term map of a system's dynamical nature, that informs analyses of life-time costs, and possible future changes in customer demand. The complexity of modern engineering systems lends itself to a rigorous approach in analysing system dynamics. This field has only seen recent improvement (Forrester 1971) and is key to successful diffusion of innovations.

Queue Theory

Single and Multi-channel Design

This section will first determine the capacity of a human official to process arriving passenger's passports, to compare the the capacity of a computer-based biometric passport authentication system. The nexus of changing service channels, service time, and arrival rate will be examined to determine the fastest possible combination of these that effectively processes an incoming passenger.

For some parts of this, informed estimation may be required to find approximate service times. Queues to navigate customs can be enormous, with JFK Terminal 4 in the U.S. presenting customers with a 93 minute queue on average, in 2012 (Skift 2013). To reach a realistic estimation of actual processing time once at the front of the queue, the following process may be assumed:

Walk from queue to desk, hand over passport	20 seconds
Officer confirms face and scans passport	5 seconds
Checks arrival documents	20 seconds
Officer stamps appropriate page	10 seconds
Total	55 seconds

For a SmartGate (Australian Customs and Border Protection Service 2012):

Find and place passport on kiosk reader	5 seconds
Answer declarations and receive ticket for biometric gate	15 seconds
Proceed to biometric confirmation	5 seconds
Insert ticket and wait for confirmation from scanner	5 seconds
Total	40 seconds

These estimations are based on the currently low traffic at SmartGates in Sydney airport. However, this analysis is restricted to the processing stage, to identify queue characteristics. One conclusion from the above statistics is that one SmartGate replaces 55/40 ≈ 1.4 humans. To find what the reduced processing time really means, consideration of arrival rates must be included. Figure 2 depicts expected arrival numbers to a SmartGate system at Brisbane airport, based on the estimations from table 1. A number of humans will still be required to ensure smooth operation of a SmartGate system, and a successful application of queue theory will offer a system that reduces staffing costs while optimising the wait time and service time of incoming travellers. The following section will quantitatively compare the service capacity of a variety of combinations of SmartGates and traditional processing queues.

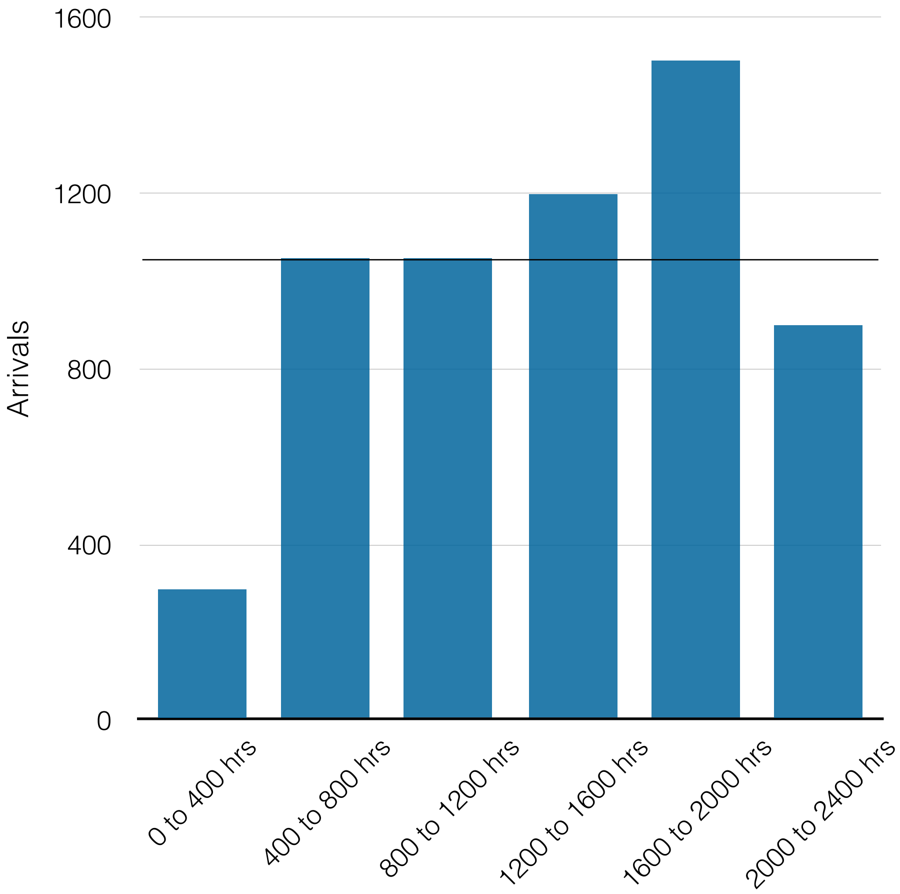

Figure 2: arrival rates at Brisbane airport on an average day (data from table 1).

The average arrival rate to immigration processing is shown in figure 2, at around 1050 every 4 hours, or 260 per hour. The arrival rate is not constant, but proper application of queue theory should ensure that no one is left waiting forever due to an imbalance in service and arrival rates.

A SmartGate combines two processes, for a short arrival declaration, and to receive a ticket to proceed to facial recognition. It is a two-phase, single- or multi-channel queue.

Traditional processing is single phase, as the process happens all at the one location, and can likewise be single- or multi-channeled.

		Expected service completions per minute (μ)		Average length of queue (m_m)		Average waiting time for service (w_m)	
Number of Channels	Arrivals per minute (λ)	Human	SmartGate	Human	SmartGate	Human	SmartGate
1	4.33	1.09	1.5	143	98	33.3 minutes	25 minutes
2	4.33	1.09	1.5	76	44	14 minutes	9 minutes
3	4.33	1.09	1.5	30	0	8 minutes	0 minutes
4	4.33	1.09	1.5	0	0	0 minutes	0 minutes
5	4.33	1.09	1.5	0	0	0 minutes	0 minutes
6	4.33	1.09	1.5	0	0	0 minutes	0 minutes

Table 2: predicted queue lengths and wait times for human and biometric systems at Brisbane airport.

Queue theory suggests that a SmartGate is an ideal solution for customer waiting time. Economic analysis allows queue theory to be used to implement the right number of more costly service channels, while considering the cost of waiting for a certain period to each service user. The cost of a development, implementation, maintenance, and updates for a single facial recognition kiosk can vary from $5 000 to $20 000 or more (Gupta et al. 2010). Employing a customs officer for the service period of one of these devices at an average wage of $60 000 per annum (Australian Bureau of Statistics 2013) becomes much more of an investment than a single kiosk machine. The reduced wait time when using a SmartGate also increases its economic merit. A cost analysis of waiting time could be conducted here, but given that users of both a kiosk and a human immigration system will be waiting in identical queues, it would be unnecessary. Of key importance to the economic merit of a SmartGate is its reliability: a successful arrival system will deal with the possibility and frequency of maintenance or failure, to ensure reliable and predictable performance throughout a technology's life time.

Multifactorial Design

The Pareto Principle

Products deployed in high-intensity environments need to carry some sort of guarantee that their service will not fail during their expected useful life-time. In the real world, failure cannot be 100% predictable, and measures must be taken to ensure a product can provide a service as predictably as possible, and be maintained efficiently to ensure ongoing utility.

A queueing theory analysis tells us what the most efficient way is to manage incoming customers, but must be combined with considerations of reliability to ensure that when a component of a biometric authentication system fails with a large queue behind it, a human or another backup device needs to effectively replace it with little detriment to those waiting in line.

Biometric identification has its flaws, as peoples faces can change, be obscured by hair or glasses, or a software glitch can cause the system to fail to recognise someone's face (Commonwealth of Australia 2013).To reduce the number of failures of this nature, facial recognition systems must not operate in 2D, and instead must draw details of nasal and eye-socket contours, bone structure, distance between the eyes, and other 3 dimensional details to ensure that no matter what condition, angle, or height a person's face is at, their face can be recognised at least 80% of the time. Facial recognition systems have improved in reliability significantly over the years, with 3D systems touting up to 98.3% success rates, with a false acceptance rate of 0.1% in controlled environments (Crawford 2011). A large number of problems come from unusual facial features, and obscuring jewellery and other items, such that in the 2.5% of failures in advanced systems, of several standard types of failure (obscured face, bad lighting, wrong angle, wrong expression, and aged photographs), one fifth (obscured face) causes about 80% of failed acceptance. In such a high risk application as aviation security, it is not sufficient to only consider one method of major failure and address it over others, however. Careful methods of ensuring reduction in all modes of failure is the only way to ensure a biometric authentication system is viable.

Bathtub Failure

Three modes of failure; early, constant and end-of-life, exist for most engineering systems. A system that relies on software as well as hardware, especially hardware that exists on a personal item like a passport, has more opportunity for failure than a self-contained system. A facial recognition system experiences an expected rate of false rejections, and (hopefully never) false acceptances, which affect the flow of queues, and demand on other services that require investment (like backup staff). These form the middle, constant failure rate of the bathtub curve. In addition to software failure, hardware failure can occur at any stage during the system's life-time, and can often be unpredictable. Consideration of the bathtub curve can inform decisions in queue theory. Service rates and simultaneous queues can reduce the impact of a single, high performing part failing. Instead of a large delay, other service channels can bear some of the load while the failed channel is repaired. Constant monitoring of failure, and continuous repairs will ensure that the fleet of SmartGates and their supporting staff can remain efficient throughout the demanding 24 hour airport schedule. During the period of constant failure, it is important to note that the system is most likely to fail to perform due to user error, or other exogenous variables. To avoid a system that is poor at recognising faces in a variety of circumstances, the SmartGate must be developed with a constant understanding of human factors, ergonomics, and a relevant set of principles to ensure its operation in a busy, interactive environment is unproblematic.

Human Factors

Anthropometrics

A biometric facial recognition system relies entirely on anthropometric data to store images of faces, and to efficiently match 3D camera data to data stored on a traveller's passport. Variations in bone structure, size, height, complexion, expression and other physical dimensions and anomalies have to be carefully included in the software and hardware implementation that is used in the final system. Figure 3 shows a certain implementation of anthropometric face recognition, using key points present on most faces.

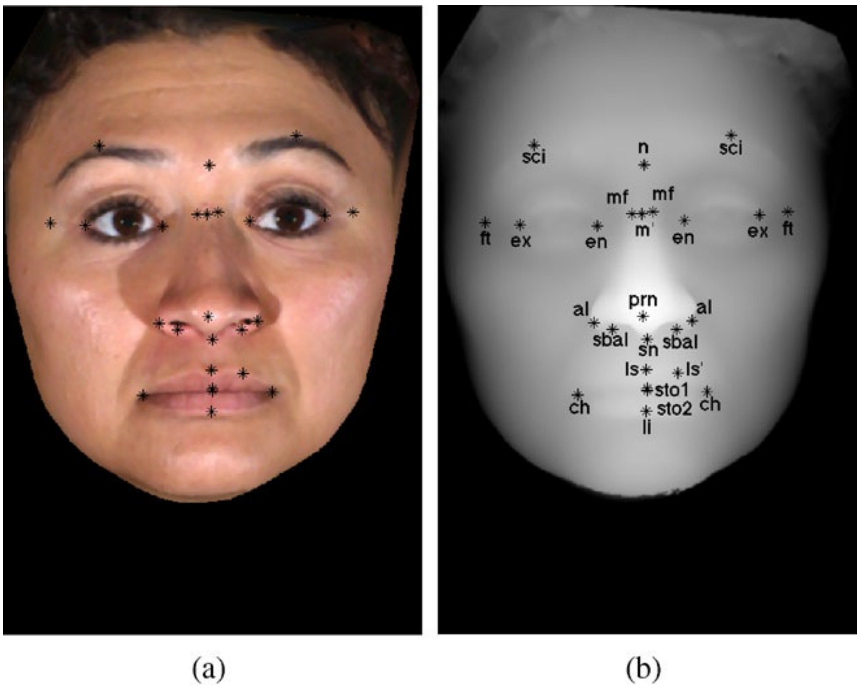

Figure 3: points on the face used for anthropometric facial recognition (Gupta et al. 2010).

These points have been identified by researchers to have high accuracy and relatively low standard deviation, as shown in table 2. This allows programmers to develop software that caters for all faces that have been measured in their study. It is important to note that the diversity of humans means that not all faces will fit into the dispersion in data encountered in initial tests, but use of standard deviation allows us to prepare for the majority of cases in the real world.

Dispersion in Population Data

The largest standard deviation found here is important in the implementation of facial recognition systems in the high volume environment of international travel. An economic analysis might present trade-offs and opportunities to reduce the system's complexity, thus requiring more manual overrides of failed recognition, but the combination of this with queue theory may offer a result that balances accuracy with processing time, and sends unnecessarily complicated cases to another, human moderated queue, freeing up a basic SmartGate for regular users that do not present with anomalous or incompatible characteristics. An entirely automated immigration system seems untenable at this time due to the still immature understanding between computers and humans. More advanced anthropometric analysis could inform highly intelligent human recognition systems in the future, though some level of human interaction and empathy is a requisite in all service industries, regardless of technological performance.

Anthropometric Proportion	σ
$O3=(ex-en,l)/(en-en)$	7.75
$O10 = (en - en)/(al - al)$	8.29
$O12=(en-en)(ch-ch)$	6.02
$F32=(n-sto1)/(ex-ex)$	5.3
$N1=(al-al)/(n-sn)$	5.81
$N2=(mf-mf)/(al-al)$	7.08
$N4=(sbal-sn,l+r)/(al-al)$	8.8
$N6=(ex-m'_{sag},l)/(mf-mf)$	14.6

Table 2: dispersion in population data for a selection of anthropometric variables used in modern 3D facial recognition systems (Gupta et al. 2010).

Conclusion

This report has analysed the feasibility of implementing biometric passport authentication in Brisbane airport. The Australian government's 'SmartGate' has provided useful information on current technologies, and several improvements have been identified. Data collection provided a platform for informed estimation of passenger numbers, allowing the process of dynamical systems analysis to draw conclusions on expected uptake and other effects of biometric technology adoption. Feedback loops between users and passport issuers, and worries about security will initially hinder uptake, but once more advanced facial recognition, faster processing times, and better reliability are realised, successful biometric identification may experience an enhanced uptake. These earlier analyses informed queue theory, and based on initial estimates that were improved by analysis of system dynamics, an number of queues required for passport control at Brisbane airport was calculated, reducing it from 4 with traditional methods, to 3, with SmartGates. Methods to improve the efficiency of SmartGates were realised in a human factors analysis, where ergonomics and anthropometrics align deeply with the technical operation of a facial recognition system. With clear boundaries as well as strong links between the factors studied in this paper, an engineering project can be viewed holistically, splitting workloads, reducing tension on designers. A systems approach ensures the inclusion of all human and technological factors to form truly sensible design.

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