A Novel Concept for Airport Terminal Design Integrating Flexibility

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Abstract

Airport terminals go through frequent transformations to accommodate technological advancements as well as changes in regulations. The ever growing aviation industry requires airport terminals to be planned, designed and constructed in a way that should allow flexible operating conditions. The significance of "flexible design" has been identified by various researchers and architects, and a number of flexible design techniques have been applied to residential and some other utility buildings such as hospitals and educational building. However, the flexible design concept has attracted limited attention for application in airport terminals, which may benefit from this design approach to address the ever changing functional requirements. The current research proposes a design framework to develop flexible layouts of departure areas in an international airport.

A flexible design framework for airport terminals (FlexDFA) has been developed based on a number of hypotheses extracted from literature. Business Process Models (BPMs) available for airport terminals were used as a tool in the current research to uncover the relationships existing between spatial layout and corresponding passenger activities, explicitly highlighting the significance passenger activities. The proposed technique uses a novel concept of obtaining rational adjacency information from BPMs.

An algorithm has been developed as part of the current research demonstrating the applicability of the proposed design concept by obtaining spatial layout for preliminary design based on passenger activity. The generated relative spatial allocation assists architects in achieving suitable alternative layouts that are required to meet the changing needs of an airport terminal. A set of design parameters has been finally proposed to identify for choosing a suitable layout that will provide due flexibility in uncertain situations.

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Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature:

Date: 17/11/2015

Chapter 1

Introduction

1.1 BACKGROUND

An airport terminal needs to accommodate a wide range of allied operations and facilities where the performance of any operation influences the other. Airport terminals are composed of large-scale, multi-stakeholder buildings that require an innovative design approach to tackle a number of strongly interacting services and stakeholders (de Neufville & Odoni, 2003; Kazda & Caves, 2007). Airport terminal design approach entails an appropriate recognition of the relationship between all interdependent activities to ensure smooth operation and a high level of passenger satisfaction. The aviation industry is growing rapidly – in the past decade air travel has grown 7% per year (MIT, 2013) with travel for both business and leisure purposes showing strong growth worldwide. This ever-increasing growth in air transport propagates into the need for providing more-efficient airport terminal services that can accommodate growth in demand along with the changing needs of an airport environment.

The random transformation in airport terminal environment is driven by numerous factors; technological advancements, changes in regulation, and changes in terminal facilities are the ones that affect most. The traditional concept of airport design and planning is typically driven by long-term point forecast, fixed standards and established clients. This concept is gradually changing to that of recognising great forecast uncertainty, more than one standard, and changeable clients (Chambers, 2007; de Neufville, 1995) to cope with the ever-changing nature of airports. Current forecasting models, typically used in designing airport terminals to predict the growth of traffic volume, could fail to grasp many future uncertainties. In reality, most instances permit the creation of several conflicting forecasts depending on the forecast method, and no single forecast can be entirely correct because of the small differences in assumption can yield large differences in outcomes (Chambers, 2007). New design concepts are required that could accommodate these uncertainties with possible design alternatives to tackle emerging challenges in airport terminal design.

Airport terminal is a complex 'building' whose usage could change widely during its lifetime. Provisions to accommodate such changes should be one of the most important factors in determining economic efficiency and performance of this building. The concept of 'flexible design' is intended to respond specifically to changing situations and operations. Continuous and rapid changes required in airport management to incorporate technological advancements clearly warrant new approaches of design to allow for short to long-term flexibility in airport terminal development. A number of researchers (de Neufville, 2008; Edwards, 2005; Kincaid & Tretheway M., 2012) identified that incorporating flexibility in terminal design will help reducing the risk of high costs of change, both financial and material, and will reduce uncertainties in adopting new technologies. Appropriate integration of flexibility within the standard design process has, therefore, been identified as an efficient way of dealing with uncertainties.

Considerable studies are available in literatures that provide guidance towards planning and design of airport terminals. Previous research related to airport design were primarily aimed at designing passenger terminal buildings and their optimum configuration, wayfinding, Level of Service (LOS) space requirements, terminal performance analysis etc. (Andreas, 2011; Andreatta et al., 2007; Correia & Wirasinghe, 2004, 2007; de Barros & Wirasinghe, 2003; IATA, 2004; King & Yun, 1998). Modelling of airport terminal operations and their performance evaluation also attracted considerable attention from researchers (Tosic, 1992). Variety of models and tools were proposed to highlight the importance on airport terminal decision-making dynamics, where the ultimate objective is to facilitate decision-making for airport terminal planning, design and operational management (Mumayiz, 1990; A. R. Odoni, 1991). However, very limited attention has been given highlighting the importance of flexibility in airport terminal design (Chambers, 2007; de Neufville, 2008). The concept of flexibility in terminal design is a relatively new initiative; limited number of preliminary rules, guidelines and principles are available for designers to incorporate flexible design elements. Flexible design strategies presented by de Neufville (2008) are considered as a paradigm shift in low-cost airport terminal design, whilst Edwards (2005) emphasised the separating of building layers (Brand, 1995) to accommodate inevitable changes over the life cycle of a terminal building. Butters (2012) proposed that the adaptable environment of airports should depend on embedding flexibility in four key stages of development or refurbishment: master planning, building design, space planning, and components.

The current research primarily investigates the suitability of flexible design approach for airport terminal design. The research developed a design framework for the departure terminal of a typical Australian airport. Departure area involves relatively complex activities, and hence is chosen to demonstrate the concept developed in this research. Available flexible design strategies are utilised to develop a hypothetical framework, which will assist designers in developing flexible spatial layouts at the early stage of a design process. A systematic development plan is considered as an integral part of the proposed framework that will allow identifying common obstacles or uncertainties. The proposed conceptual framework brings the following three particular fields of knowledge together:

- Flexibility in design.
- Airport terminal design process with specific emphasis on departure area.
- Layout development for the departure area based on passenger processing activities.

1.2 RESEARCH QUESTIONS

Design flexibility in airport terminal layout has not been thoroughly investigated despite its obvious advantages demonstrated in other design fields such as housing, hospitals and educational buildings (de Neufville et al., 2008). The primary objective of the current research is to fill in this knowledge gap through developing of a theoretical design framework for the departure terminal of an airport to illustrate how flexible design elements could be integrated in the design process. This leads to the following main research question:

- How can the concept of flexibility be incorporated into airport terminal layout development?

Development of a flexible design layout will be driven by passenger-terminal activities and associated spatial requirements; identification of the relevant relationships between various passenger activities and their spatial adjacency are paramount in flexible layout development. Hence, to achieve the primary objective, the following questions require appropriate answers:

- Can Business Process Model(s) be used to determine spatial adjacency for airport terminals?
- How can spatial adjacency information as obtained from BPM analysis be to develop spatial layouts?

Answers to these research questions are sought through comprehensive investigation of passenger processing activities as well as through examination of spatial relationships between various operational activities in departure terminal. Qualitative analysis techniques are primarily used in the current research to answer the aforementioned questions. Any design strategy would require a set of design guidelines; this raised the final question in the current research that eventually helps to achieve the primary objective.

- Is it possible to define a set of design parameters to evaluate flexibility of departure layouts?

The first research question addresses the main objective of this research, whilst appropriate answers to the following three questions allow achieving that goal through various qualitative analysis techniques.

1.3 SCOPE OF THE CURRENT RESEARCH

Development of a new conceptual framework to incorporate flexibility in airport terminal layouts is the primary objective of the current research. The proposed conceptual framework specifically targets incorporating flexible design elements during the preliminary phase of a design process. This proposed design approach should cope well with ever-changing needs of an airport with minimum interruption. It should be noted that the scope of the proposed design framework was limited to departure activities in a typical Australian airport considering time and resource constraints for this particular PhD project. As part of the "Airports of the Future (AotF)" project, the researcher was allowed to visit the passenger activities but no real passenger data were made available for this particular project; this prompted the current research to be carried out through 'qualitative analysis' of passenger activities.

A set of design parameters (presented in details in Section 7.4.2) with an associated qualitative scale is also proposed herein to facilitate designers in achieving flexibility. The proposed parameters are identified through careful investigation of available literature, and by inspecting actual airport facilities. However, the suggested measure of performance should be verified through performance analysis of an airport terminal using actual data related to passenger activities. It is worth noting that the scope of the current research is limited to proposing a design framework and relevant guidelines based on flow of passenger activities as obtained from the process models.

1.4 RESEARCH SIGNIFICANCE

Current research provides a significant contribution towards understanding of flexibility in airport design, and proposes a new design framework to integrate flexibility in departure terminal for new construction (Greenfield site) as well as for re-construction (Brownfield site). A number of researchers highlighted the importance of flexibility in airport design, but no specific efforts are made in currently available literature for its implementation. The current research is the first of its kind that offers a rational integration of a number of existing fields of knowledge to be incorporated within a flexible design framework. Following are the four major contributions to the current field of knowledge:

- A Flexible Design Framework for Airports (FlexDFA) is proposed that combines the knowledge of flexible design elements with those specific to airport terminal design.
- Spatial adjacencies of terminal facilities are obtained from passenger processing analysis. Useful passenger activity flow patterns extracted from Business Process Models (BPMs) are exploited in the design process in an innovative way.
- An automated floor plan generation technique has been proposed based on spatial adjacency and passenger movement. The developed algorithm

demonstrates how initial layouts can be generated using passenger activity models.

- A set of design parameters has been proposed to help designers in assessing flexibility for airport terminal layouts. The proposed design parameters are considered as performance indicators to measure the level of flexibility achieved through an adopted layout.

Overall, the research outcome provides a new perspective in the field of airport terminal design process. The proposed design framework includes various steps such as identifying the areas of uncertainty in design, activity analysis using BPM, and development of design rules to incorporate flexible design elements at the preliminary stages of design.

1.5 INFORMATION OBTAINED FROM AIRPORTS OF THE FUTURE (AOTF)

The current research is part of a multidisciplinary research project Airports of the Future (AotF), which is composed of seven different research teams exploring the complexity of airport terminals, and addressing the conflicts between aviation security and passenger experience. Out of the seven research teams, Business Process Management team developed Business Process Models (BPM)s (Mazhar, 2009a, 2009b) for a number of Australian airports.

The current research specifically selects two airports for case study analysis – Brisbane International Airport and Gold Coast Airport. The adopted process models for these two case study airports were qualitatively analysed to identify the relative levels of importance to form appropriate passenger activity groups prior to obtaining spatial adjacency for passenger terminal processing areas. Use of process models in identifying spatial relationship between activities and subsequent spatial allocation is one of the key approaches developed in the current study.

1.6 RESEARCH METHODOLOGY

The current research primarily relies on qualitative research techniques; Figure 1.1 presents a flowchart of the overall research methodology, which is thoroughly explained in Chapters 4 to 7. Various qualitative research techniques are used throughout the current research such as development of the conceptual framework in Chapter 4, extraction of useful information related to spatial adjacency from Business Process Models in Chapter 5, and comprehensive investigation of interactions among all stakeholders in the departure terminal. Results obtained through the analysis of BPMs are used to formulate logical decisions to propose rational techniques for determining appropriate spatial adjacencies; this eventually leads development of initial layouts for departure terminal. Development of a computer algorithm is presented in detail in Chapter 6, which demonstrates generation of floor plan layouts using the adjacency

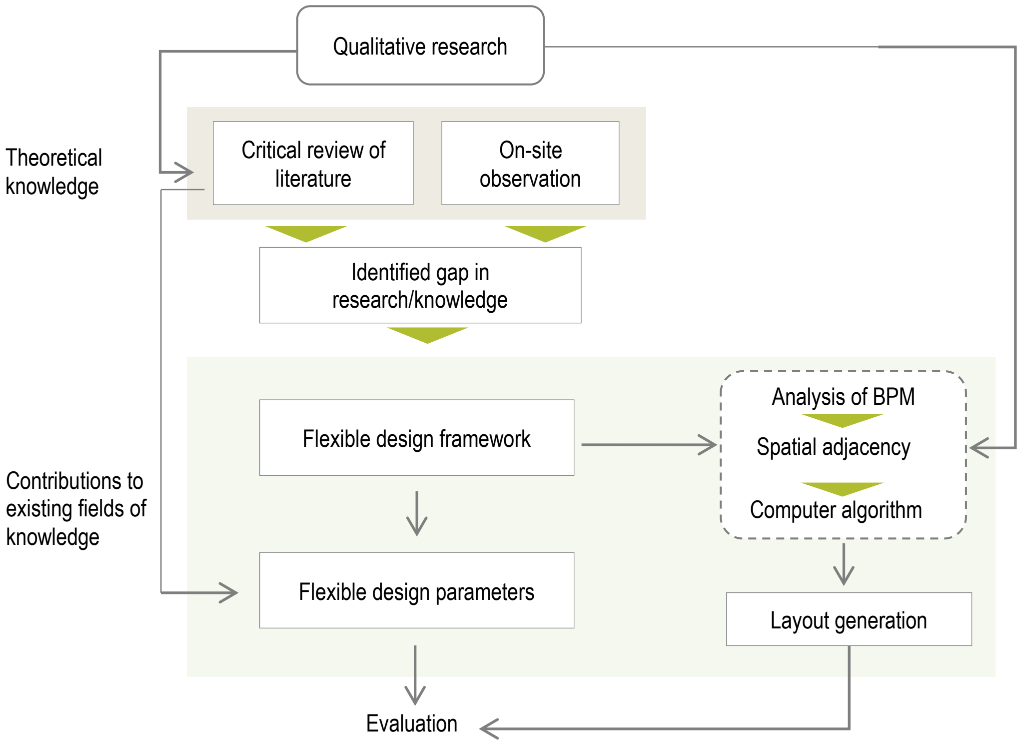


Figure 1.1: Overview of the research methodology

information and the hypothetical data assumed for activity analysis. This technique will allow generating alternative layouts using real passenger data to combat changing scenarios in airport terminals. Finally, a set of design parameters are proposed in Chapter 7 to evaluate flexibility of the developed layouts.

1.7 OUTLINE OF THE THESIS

The outline of the research activities (presented in Figure 1.2) carried out as part of this project is briefly discussed in the following paragraphs.

Review of relevant literature is always one of the most important aspects of any research project; this helps to investigate the current state-of-the-art as well as to identify research gaps. A comprehensive review of relevant literature has been undertaken, and is presented in Chapters 2 and 3 to provide appropriate definitions, useful case studies, and current design practices related to flexible design concept. Chapter 2 is primarily focused on presenting available design approaches to achieve flexibility in building design. The notion of design flexibility is reviewed in wider context such as housing, hospitals and educational premises with a view to paving the way for its suitability in airport terminal design. A theoretical basis for flexible design concepts is briefly discussed with relevant historical overview of key factors and strategies used in achieving flexibility in building layout as well as in passenger terminal layout.

Chapter 3 presents the elements and issues related to design process and also discusses the characteristics of BPMs. The relationships between architectural design process and the space layout planning theory are also investigated for an appropriate understanding of the new conceptual method, which is the core contribution of this research.

In Chapter 4, a new theoretical framework – 'Flexible Design Framework for Airport (FlexDFA)' – is proposed. The development of FlexDFA takes place in four stages – Stage 1 explores the systemic generation of the process; Stage 2 integrates BPM in the design process to obtain adjacency requirements of terminal processing areas; Stage 3 develops the initial layout generation, and finally Stage 4 examines the developed layout against a set of proposed parameters to evaluate the level of flexibility achieved.

Chapter 5 presents an innovative technique for obtaining spatial adjacency from BPMs. Comprehensive analysis of BPMs lead to development of rational layout planning based on extracted information.

Chapter 6 presents the layout automation technique developed as part of the current research. Adjacency information obtained from BPM and assumed passenger movement information were utilised to develop an algorithm that integrates useful features of Eclipse, Rhinoceros and Grasshopper (a plug-in within Rhinoceros) to generate automated layout for a typical airport departure terminal. This algorithm clearly demonstrates that the proposed technique could be applied for designing airport terminals as a whole using real passenger activity data.

Chapter 7 presents the final step of the proposed FlexDFA; the outcomes of the aforementioned chapters are utilised in a rational way to complete the proposed design technique. A comprehensive and careful investigation was performed to propose a list of design parameters, and each of those parameters is briefly discussed to demonstrate their role in achieving flexibility in airport terminal design.

Chapter 8 integrates all major contributions of the current research project highlighting the research techniques adopted to propose the flexible design framework for airport terminal design. The current research proposes a novel technique, which has significant potential for further extensions; future scopes for research in the relevant field are also identified in this chapter to take this research field to the next level.

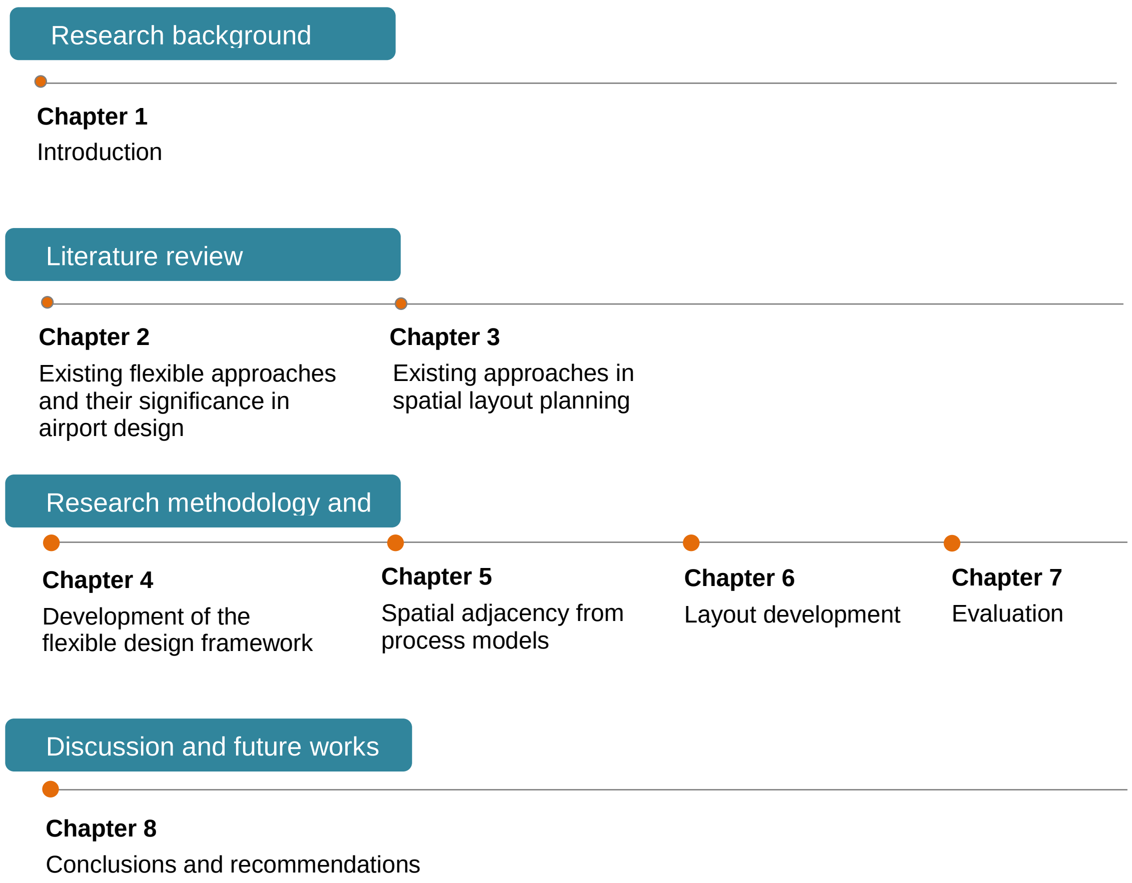


Figure 1.2: Overall thesis outline

Chapter 2

Existing flexible design approaches

2.1 INTRODUCTION

The review of relevant literature and critical reflection on findings are essential for the current research to develop a new design concept integrating flexibility in airport terminal layout. The literature review is presented in two chapters to provide a thorough insight into relevant research. Chapter 2 presents a brief overview of airport terminal design process with primary focus on the current measures of design flexibility in airport terminal design. However, there is limited literature available on flexible airport design; hence, available literature in generic principles of flexibility, flexible design strategies and flexible design elements have been studied comprehensively. The relationship between architectural design process and space layout-planning theory is investigated with a brief overview on Business Process Models (BPM) in Chapter 3.

The first step of literature review was to fully understand the typical design process of an airport terminal and to get a clear idea of terminal operations, facilities and passenger processing. The notion of design flexibility is investigated herein; stretching from housing to hospitals, leading up to its suitability for airport terminals. The key contribution of this chapter is a theoretical understanding of flexible design concepts so that the knowledge could be utilised in devising a flexible design framework for the departure terminal of an airport. Literature review presented in this chapter is comprised of the following six sections:

Section 2.2 recognises theories behind airport terminal design process and operations. This section presents an overview of passenger processing activities, airport terminal configurations and corresponding space requirements.

Section 2.3 presents definitions and meaning of flexible design, highlighting its importance in the design process.

Section 2.4 identifies the importance of flexibility in the field of airport terminal design, with an overview of the concept as reported by various researchers. This section also presents some case studies of both flexible and inflexible airport designs.

Section 2.5 presents is a review of flexible design practices reported in various design fields such as residence, hospitals and educational buildings. A number of key factors and strategies for achieving flexibility in building design are also thoroughly discussed in this section.

Section 2.6 presents the summary and findings from literature.

2.2 AIRPORT TERMINAL DESIGN: AN OVERVIEW

An airport is comprised of a number of strongly interacting services and stakeholders, where the terminal building is the major interface between an airfield and other areas of an airport. While the main function of an airport terminal is to provide a convenient transfer facility from ground to air and vice-versa, the terminal building should have a suitable layout to facilitate a convenient travel experience for passengers. At the same time, airport operations should provide a functional and safe transition from landside to airside, complying with the most stringent aviation regulations, legislation and requirements. Airport passenger buildings serve various needs of different types of passengers including arriving, departing and transferring passengers. The design of an airport terminal is affected by the types of passengers and their needs (Kazda & Caves, 2007; Odoni & de Neufville, 1992), where essential objectives for efficient design are sharing of facilities, performance objectives and management operations (Odoni & de Neufville, 1992). However, the design perspective differs substantially among different airports so there is no single set of design standards that is valid for all airports. The overview of airport terminal design covers a brief understanding of design process, passenger processing facilities, relationship between terminal design and configuration, and spatial planning in terminal design process.

2.2.1 Understanding airport terminal design process

The primary users of airport terminals are airlines, air travellers, well-wishers, and a wide range of employees of airport management, government regulatory authorities, air carriers, concessionaires, and other airport tenants (ACRP-25, 2010). The design process of an airport terminal is the determination of optimal capacities for different areas of airport terminal, the uncertainty of future demand and the costs of expansion (Chambers, 2007; de Neufville & Odoni, 2003; Solak et al., 2009). The ever-evolving complex system of an airport terminal design requires the fulfilling a multitude of safety, operational, commercial, financial and environmental considerations (ACRP-25, 2010; Ashford & Wright, 1992; de Neufville & Odoni, 2003).

Like other building design processes, a typical airport design process is also more or less a standard planning process. The design requirements, however, are guided by many stakeholders making it relatively complex in nature. The standard design process of an airport terminal building could be defined using the following steps (Odoni & de Neufville, 1992).

1. Forecasting traffic levels for peak hours
2. Specification of level of service standards
3. Flow analysis and determination of server and space
4. Configuration of server and space

The terminal design process starts with gathering existing information and parameters that will affect determination of future forecasts. Passenger forecasts are informed predictions for future aviation activity that are supported by careful assessment and analysis of historical trends in traffic demand, projected economic growth, and any other relevant factors that may affect growth in local aviation (ACRP-25, 2010). Once forecasts have been finalised, airport planners focus on creating different strategies for accommodating the predicted levels of activity. The quality and accuracy of a forecast depend on tools, data and methodology adopted in the forecasting process (Ashford &

Wright, 1992). As past trends are constantly changing for various reasons, forecasting has been identified as ‘inaccurate’ by many authors like, Odoni and de Neufville (2003), Ashfold (1998), Edwards (2005).

The objective of specifying Level of Service (LOS) standards is to translate a forecast into an actual design process. The levels of service are usually described in terms of flow, delays and level of comfort, where the standards of space are usually defined in terms of “space conversion factors” giving an appropriate space per occupant (Neufville and Odoni 2003). Higher LOS standards imply more space and inevitably more cost (Correia & Wirasinghe, 2004).

Analysis of passenger flow and determination of space requirements are regulated by the formal application of queuing theory, graphical analysis, or with application of detailed computer simulation. Determination of space requirement leads to the conceptual planning process – this typically involves an iterative process of developing initial layouts, and then progressively leading to a more refined terminal design concept. The formal application of classical queuing theory (Lee, 1966) has not been proven particularly effective for design (Odoni & de Neufville, 1992). Formulae for translating number of traffic into space requirements are arithmetically simple, and depend on several equations specifying the floor area per passenger for various activities. Many researchers (Andreatta et al., 2007; Hee King & Zeph Yun, 1998; Solak et al., 2009; Tosic, 1992) conducted investigations in the area of modelling airport terminal operations and performance evaluation. Researchers have identified that, although queuing models have been used for passenger flow analysis, a steady-state theory is not valid for airport terminals due to high variability in the number of arrivals and departures during a typical day. However, none of these simulations suggested a generic model that can capture the complexity of terminal process reflecting the configuration and operational characteristics at the same time (Manataki & Zografos, 2009).

2.2.2 **Airport terminal passenger processing**

The current research uses passenger flow characteristics to determine layout of processing areas following a new concept. The prime objective of an airport terminal design is to provide smooth and efficient passenger movement (Edwards, 2005). Passenger processing can be classified under three major components – access interface, processing system and flight interface (Horonjeff et al., 2010). Access interface of a terminal enables originating and terminating passengers, visitors and baggage to enter and exit a terminal. This includes circulation, parking, and kerbside loading and unloading of passengers. Processing system refers to the processing of passengers and baggage during arrival and departure activities in a terminal, which includes ticketing, check-in, customs, security, immigration etc. The flight interface consists of the departure lounge or hold-room, security facilities used for the inspection of passengers, airline operation space used for airline personnel, equipment and activities related to arrival and departure of aircrafts.

Various domains that a passenger must pass through to board on their flights (departure) or after getting off (arrival) from the flight are presented in Figure 2.1. Between these processing domains, a passenger can undertake discretionary activities such as shopping, use washroom facilities or get something to eat, etc.

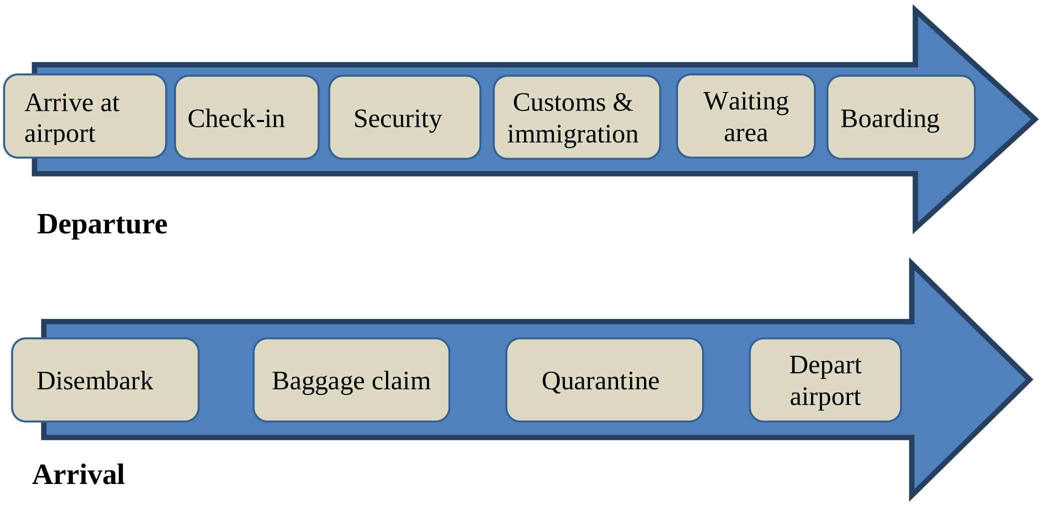


Figure 2.1: The various domains of landside and airside facilities at airport terminal (Kirk 2013).

The sequence of passenger processing shown in the Figure 2.1 is not universal as this varies among airports; for example, positioning of security and immigration can be interchanged, depending on the country and the airport (Kazda & Caves, 2007). Passengers are considered to be on the 'landside' unless they pass through the security/customs area of departures, or unless they have gone past the customs/quarantine area of Arrivals. 'Airside' is the sterile area after security/customs in departures, or the area before the passenger leaves the customs/quarantine area of Arrivals. The layout of an airport terminal has a significant role in achieving efficient passenger processing. The landside and airside facilities at each airport are unique, but passenger processing techniques are somewhat similar. Departure facilities include checking in, security screening, customs and immigration, boarding and various discretionary facilities. The following paragraphs provide a brief description of the various domains of departing passenger facilities.

Check-in

In addition to check-in counters, check-in domain includes the queuing area and some basic facilities such as flight information counter, telephone, toilets, cafe and waiting area for greeters (Kazda & Caves, 2007). A fast and efficient check-in process is very important in passengers processing where poor layout of queuing could lead to congestion. The standards for the design of check-in facilities are undergoing rapid changes due to security concerns, rapid electronic development, and radical changes in ticketing systems. For example, the use of electronic ticketing and online check-in facilities reduce the processing time at the airport, which eventually should result in a reduction in number of check-in positions. Self-service kiosks together with fast bag-drop facilities are the preferred choice for newly developed airport terminals as observed in Canberra Airport (Figure 2.2). These technological changes may transform the notion of traditional check-in and could make the conventional check-in hall obsolete in the future.

Figure 2.2: Self-service check-in kiosks at Canberra Airport (by the author)

Security

The security interface is arguably the most important aspect of airport operations which must be balanced with efficient management of passenger flow. Since the 1960s, security has evolved into a vital aspect of the airport planning and design process. Recently, the complexity of this domain has greatly increased, particularly security; the past 10 years have seen dramatic changes due to the terrorist attack on the Twin Towers in New York on 11 September 2001 (9/11) (Australian-Government, 2009). This attack led to significant changes in the previous perception of the terrorist threat (Kirk, 2013). Screening processes vary at different airports, but usually include the following devices: a walk-through detection device, an X-ray machine for carry-on baggage, and space for manual searches and recovery of the X-rayed items. Processing speed at Security Screening Checkpoints (SSCPs) also varies significantly with the overall size of the airport, and its corresponding traffic.

Customs and immigration

At international airports, when passing through customs, passengers have to present their passport, boarding card and Outgoing Passenger Cards (OPC) to a customs officer. The passenger's details are checked and their 'right-to-fly' is confirmed (Kirk, 2013). Customs and security are tightly bound as passengers proceed directly from one domain to the next (Kazda & Caves, 2007).

Boarding

All boarding areas have seating arrangements for passengers allowing them to arrive early and wait for boarding. However, the layout of the boarding domain varies among different airports. Some airports have specifically allocated waiting space for every flight, whereas, other airports use a common open space for passengers waiting to board various flights (Kirk, 2013). Boarding cards and passports are checked by airline staff at the gate, and then passengers allowed boarding the plane. There is a conflict in this domain between the airline's desire to have passengers wait in close proximity to the gate, and the passengers' aversion to being confined in an area with few facilities for what could be perceived as an indefinite period of time (Kazda & Caves, 2007a).

Discretionary/concession space

Passengers spend around two thirds of their total airport experience in these areas. During departure, there are three periods where the passenger has discretionary time: pre-check-in landside, post check-in landside and airside (Kirk, 2013). During these periods, passengers are provided with the opportunity to eat, shop and rest.

2.3 DEFINING FLEXIBILITY

Flexibility is the ability to adapt continuous changing requirements and conditions of the environment (Cowee & Schwehr, 2009) and respond to changing situations (Kronenburg, 2007). According to Schneider & Till (2007) the history of flexibility in architecture is dominated by a list of experiments that play directly with the rhetoric of flexibility: parts of the building that actually move or buildings that signify the potential of change. The concept is not only limited to building design, it comes in many forms, each enabling different kinds of responses (de Neufville & Scholtes, 2011). Kronenburg (2007) stated that changes in human living, environment and the ability to adapt the changes need to be responded with contemporary living where new forms of flexible architecture will fulfil the functional, cultural and collective needs. However, according to Saari and Heikkila (2008), until now the problem of flexibility is an ambiguous concept, and it has different meaning to different interest groups. Following are some definitions of flexibility in various fields as obtained from literature:

- In the system design literature, flexibility is the ability to modify the mode of operation or the attribute of a system (McConnell, 2007).
- In manufacturing design, flexibility is the ability to change the manufacturing line volumes, change delivery rates, the speed of delivery or to add new product lines (McConnell, 2007).
- In network design, flexibility creates the ability to add new nodes or to make new connections between nodes.
- In building design, flexibility allows to create spaces that anticipate complex and changing requirements of human needs (Edwards, 2005).

Although the definition varies based on the field of interest, the underlying theme of all definitions is to allow a system to undergo changes at relative ease and to lower costs if possible. The current research develops a framework for airport terminal design process to accommodate changing requirements of passenger needs in an efficient manner, and hence, the current research adopted Edwards (2005) suggested definition of flexibility.

2.3.1 **The value of flexible design**

Flexibility in design generally enhances performance in complementary ways (de Neufville & Scholtes, 2011), it can also reduce downside consequences, and could increase upside opportunities of a design. Flexibility that is inherent to a system allows adaptation to unexpected circumstances in a relatively efficient manner (Cardin, 2007). de Neufville and Scholtes (2011) presented an overview of the concept and methods of flexibility, and also examined the value of flexibility in design practice in sufficient details. Flexibility in design leads to significant improvements in overall expected benefits. Design flexibility does not necessarily provide the best design solution to fit all circumstances; including flexibility criteria in design could add extra cost to some projects – although de Neufville and Scholtes (2011) suggested that flexibility in design could increase the expected value by up to 80%. Benefits of adding flexibility in design process are briefly explained in the following paragraphs.

Flexible design helps managing uncertainty

In our everyday life we observe rapid changes in technology; today's technology could quickly become obsolete because new developments are continuously taking place to replace established technologies. Yesterday's state-of-art can be out-of-date tomorrow as a result of faster technological changes. By mitigating the impact of future uncertainty, flexibility increases investment value, and reduces the level of uncertainty (Fawcett & Krieg, 2011). Standard design practice uses a set of deterministic objectives and constraints that do not reflect uncertainty (de Neufville & Scholtes, 2011). If we do not consider ranges of possible outcomes into account from the beginning of a project the future assumptions might be misleading. The future assumption is based on forecast where all forecasting methods are based on some extrapolation of past trends into the future. However, past trends are constantly changing due to economic, technical, political reasons. Unreliable forecasting and unanticipated changes in technologies and regulations make an airport terminal a complex entity for the design field; hence an efficient way to cope with this ever-changing scenario is to allow the designed space to be flexible.

Flexible design is 'eventually' less expensive

A better understanding of the value of flexibility or the ability to change will help reducing the risk of high cost of renovation by accommodating changing circumstances. Flexibility could also help to reduce the cost of adopting new technologies. In flexible design, all likely future changes of a building are taken into consideration during planning, and the resulting infrastructure is better equipped to deal with future changes. This perspective can reduce financial risks and achieve significant cost savings over the life cycle of a structure. According to de Neufville and Scholtes (2011), flexibility leads to a less-expensive solution as it allows phases to build.

Flexible design extends the life cycle of building components

Adaptability/flexibility refers to the capacity of a building to accommodate substantial changes. Over the lifetime of a building change is inevitable, both in the social, economic and physical surroundings, and in the needs and expectations of occupants (Schneider & Till, 2007). A building that is more flexible will be utilised more efficiently, and will stay in serviceable condition for a longer period as it can respond to changes in various stages of its life cycle. Longer and more efficient service life of a building may, in turn, translate into improved environmental performance over the life cycle. For example 'kit of parts' approach (Edwards, 2005) in Stansted Airport, UK encourages replaceability and small-scale flexibility.

2.4 NECESSITY OF FLEXIBILITY IN AIRPORT DESIGN

An airport is comprised of a number of strongly interacting services and stakeholders, which requires a 'complex systems' approach (Ashford & Wright, 1992; de Neufville & Odoni, 2003) towards design and operations. Airport infrastructure is typically designed for 20 to 50 years lifespan. Edwards (2005) compared the growth of airports with the growth of cities, postulating that the airport behaves like the city it serves. Even though the airport expands gradually and systematically, the expansion is constrained by space and environmental factors. User flexibility or adaptability in building design, in relation to residential buildings, is a widespread concept, whereas the need for flexible design for airport passenger buildings is only recently gaining recognition (ACRP-25, 2010; Butters, 2010; de Neufville, 2008; de Neufville & Odoni, 2003; Edwards, 2005).

The current terminal buildings of airports are far different than those of a decade or two ago. A terminal needs to adopt undergoing rapid management and technological changes. Increased use of information technology systems, advanced fuelling systems, passenger tracking, self-tagging and check-ins, wireless communications, common-use baggage systems are examples of technology advancement. At the same time, current economic turmoil has also generated uncertainty in the level of investment (Butters, 2010) in airport infrastructure. The other reasons behind rapid changes in air transport industries are unexpected traffic growth, privatisation, introduction of low-cost carriers, and terrorist attack of 9/11. Planners and designers are encouraged to design for flexibility to cope with all aforementioned issues (ACRP-25, 2010; Edwards, 2005).

Traditional design methods are mostly based on forecast models that cannot deal with every aspect of rapid change in an airport terminal, and hence define a single master plan for the development of airport facilities. de Neufville (2008) points out:

> *'Airport planning paradigm is shifting from traditional pattern, which is determined by high standards, established customers and long term forecast , to that of recognizing great uncertainty at forecast, broad range standards and potential for a rapidly changing customer's base.'(p35)*

de Neufville (2008) provided a number of examples on how traditional design processes lack in adapting rapid unforseen changes. As a result, ongoing design changes cause severe financial and operational difficulties. For example, the inability to adjust to low-cost development stalled the opening of the new Bangkok international airport for two years. Terminal 2 in Frankfurt Airport was underused because it could not adapt to the hubbing needs of Lufthansa. Kansas City Airport failed to adapt to the needs of its main client, TWA, creating huge financial losses. Kwakkel *et al*. (2010) also recognised that airports around the world operate in an increasingly uncertain environment where a traditional rigid master plan performs poorly. This increasing recognition of uncertainty in forecasts is driving airport planners to seek other means to balance. Inaccurate passenger forecast models have a crucial implication in airport planning, which prompts the designers to create flexible planning and design that could easily accommodate future uncertainties. This flexible approach allows rescheduling decisions according to time that helps managers to optimize decision making (Magalhaes et al., 2012). The need for flexibility in design is also largely reinforced by the prospect of future aircraft manufacturers; airports with enough flexibility to accommodate A380 aircraft with 90m wing spans could only enjoy the benefit of this latest enormous carrier.

2.4.1 **Previous research approaches**

Traditional planning methods led to several costly failures which resulted in over-designed airports, which didn't have the ability to adapt to changing traffic levels, technologies and customer demands (Chambers, 2007). Despite the practical evidences of the need of flexible development in airport design, researchers haven't thoroughly explored this field. The concept of flexibility was studied by few authors (ACRP-25, 2010; Butters, 2010; Chambers, 2007; de Neufville, 2008; de Neufville & Belin, 2002; de Neufville & Odoni, 2003; Edwards, 2005; Gil & Tether, 2011; Kwakkel et al., 2010) in various fields of airport planning and design. de Neufville and Belin (2002) studied shared-use facilities to achieve flexibility in airport operations; de Neufville and Odoni (2003) studied uncertainty; de Neufville (2008) also researched on flexibility in low-cost airports; Edwards (2005) discussed about shearing layers of change in terminal design; and Chambers (2007) studied how to tackle uncertainty in airport design. Extracts of these research findings are presented in the following paragraphs.

de Neufville and his co-authors

Richard de Neufville is one of the pioneers and the most diversified researcher in the field of airport design. He has several research publications offering the concept of flexibility in airport terminal design covering various aspects. Since 2003, de Neufville and his co-authors identified several issues related to flexibility. Choosing of appropriate terminal configuration should be given initial priority to handle various types of passenger need, where 'hybrid' design is highly encouraged (de Neufville, 1995). According to de Neufville and Odoni (2003), the primary flexibility in terminal buildings can be achieved by choosing an appropriate configuration that helps to expand and contract according to the activities performed. Also the major design possibilities for adopting flexibility can be achieved with connected buildings, shared-use and temporary facilities.

Connected Buildings

Connected terminal buildings allow operators to shift operations more easily and assist expanding better than separate terminal buildings. For example, Amsterdam/Schiphol (Figure 2.3), San Francisco International and Singapore Changi Airport are good working examples of connected terminals. On the other hand, separate terminal buildings may lead to split operations that confuse both passengers and airline operations.

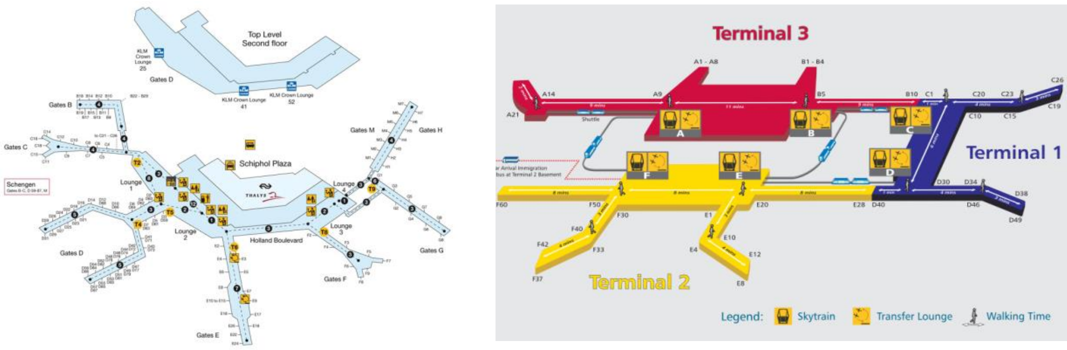


Figure 2.3: Connected terminal buildings at Amsterdam Schiphol (left) and Singapore Airport (right)

Temporary facilities

Temporary facilities limit financial exposure to a volatile environment. In an airport terminal context, temporary facilities indicate the capacities used for tackling unpredictable traffic, such as use of a transporter to connect passengers to the aircraft or inflatable structures used in Boston/Logan Los Angeles/International to provide capacities for passengers or maintenance facilities until they could formulate a definitive plan.

Shared use facilities

In general, if two or more clients share a space that helps reducing design load is called a shared-use space. For example, when peak international and domestic traffic do not coincide, the same boarding and waiting areas can serve both international passengers and domestic passengers at different periods in a day. Shared use facilities significantly increase flexibility of a terminal building (de Neufville and Belin 2002; de Neufville and Odoni 2003; Edwards 2005; de Neufville 2008). Sunshine Coast Airport/Australia provides a good example of shared-use facilities, where check-in counters are shared by airlines at different periods of the day. de Neufville and Belin (2002) proposed a comprehensive guide to design shared and multifunctional facilities. They discussed specific types of shared-use facilities: waiting lounge in front of aircraft gates; swing-gates between international and domestic operations; and gates at the airport. They also presented a range of concepts and analytical tools required to execute efficient shared-use designs. Edmonton international Airport in Alberta, Canada, is designed to serve three distinct types of traffic for many airlines by using a system of corridors with access points that can be locked or opened to channel passengers as required.

Two main obstacles have been identified that delay the extensive integration of shared and multifunctional facilities in airport passenger buildings. One is tradition: typical practice has focused on single-use facilities. The other is the lack of a comprehensive analytical approach to the design of multifunctional spaces. Single-use facilities are practised worldwide because historically passenger buildings were considered relatively inexpensive compared to runways and other investments, and designers did not perceive much opportunity to reduce costs by sharing. But a number of researchers (de Neufville & Scholtes, 2011) identified that shared facilities could reduce capital expenditure by up to 30%. The two factors that motivate the use of shared use space are: peaking of traffic at different times; and uncertainty in the level of traffic. The time between the distinct peaks of traffic influences both types of analyses and design of the shared spaces.

The flexible design process described by de Neufville (2008) is considerably different from the traditional design process which usually depends on forecasts and ignores inevitable uncertainties. A flexible design strategy for low-cost airport terminals presented by de Neufville (2008) is a paradigm shift to deal with uncertainties. The core component of the strategy is to build ‘real options’ into the design, which allow the airport owners to match the development in such a way that traffic demand unfold in the decades ahead. Using Portugal as an example, the author illustrated the risks and points out how flexible design strategies could manage uncertainties while maximizing expected value.

Brian Edwards

Brian Edwards in his book *The Modern Airport Terminal* discussed the importance of flexibility in airport design. According to his point of view, the need for flexibility in airport design is the result of complex interactions between airline companies, aircraft design and airport authorities. Airport terminals are functionally turbulent spaces; different parts of an airport change at different rates. The design of airport terminal is not just about facility planning, a terminal should be designed in such a way that separate layers can be renewed without undue disruption. For example, frequent interior revision reflects the commercial pressure, but is less visible and allows slower changes made to the skin, structure and services. Recognising the separate layers, as proposed by Edwards, helps in understanding the process. Each layer is on a distinct timescale so concurrent changes in each layer tend to disrupt the whole. Recognising separate layers and allowing some disconnection between them (such as separating structure from 'skin', interior space separate from 'service') is necessary to allow the terminal building to renew itself. This deliberate disjunction between structure (usual life considered for 50 to 60 years) and skin (20 years life) would allow accommodating inevitable changes over time. Figure 2.4presents the principal layers in a conceptual sense proposed by Edwards (2005). Each of these layers is on a distinct timescale and is expected to renew each layer without disrupting the whole; these shearing layers of change should, however, be managed by good design.

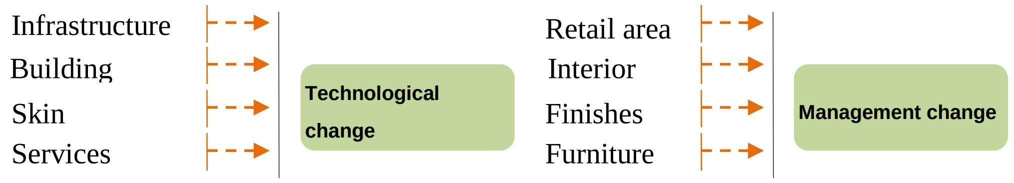


Figure 2.4: Airport terminal layers by Edwards (2005

Butters (2010) investigated flexibility in airport design, and offered solutions for optimising airport design based on his experiences at Dublin Airport terminal 2. To adapt to the changing environment at airports, four key stages of development or refurbishment should be embedded: master planning, building design, space planning and component design. Flexibility in master planning stage could be achieved by identifying a series of components; for example, a simple layout with unobstructed floor plan (open plan) allow enormous amount of flexibility for later extension. Importance of buffer spaces was also identified; appropriate incorporation of such spaces in layout and space planning for future expansion keeps possibilities for converting spaces from non-operational functions to operational. Use of construction sequence with detail planning grid and zoning of services is important for future modification and to overcome uncertainty. Converting adjacent spaces from non-operational space to operational is another strategy to add flexibility in space planning.

The work of Gil and Tether (2011) explores how risk management and design flexibility interplay in major infrastructure projects. Their research focused on the expansion project of London Heathrow Terminal 5. The key contribution of their study was a theoretical understanding of the conditions under which risk management and design flexibility may complement each other to manage the pressure between efficiency and effectiveness in large projects. Their investigation figured out that the developers invested in a flexible architecture to mitigate the design fluidity, and the risk of progressing with limited flexibility can be balanced with risk management. The balance between flexibility and risk management helps to reconcile efficiency and effectiveness.

Recently Magalheas L. et al. (2012) reported a literature review on the concept of flexibility and analysed different levels of flexibility. They suggested that "multiairports" should also consider flexibility levels along with the four key stages defined by Butters (2010). Another aspect of flexible design mentioned by Magalhaes et al (2012) is time. Based on the level of flexibility they proposed a framework which represents a characterization of fundamental variables of flexibility (levels) and the casual relationships linking the variables among themselves and with consequences (performance variables). The framework also considers exogenous variables, such as demand, technology, regulation and financing.

2.4.2 **Case study: flexible and inflexible airports**

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within a real life context especially when phenomenon and context are not clearly evident or when there is a lack of relevant information. A case study can provide the opportunity to find out more than just the outcomes, *i.e.* it can explain why certain outcomes might occur. Case study analysis illustrates, explains and provides more detailed qualitative findings for the development of a theory (Yin, 2003). Information was collected on each case study of this section by reviewing backgrounds and current situation of the considered airports. Lessons learnt from each case study in both successful and unsuccessful instances are discussed later in this section.

Amsterdam Schiphol International Airport – Europe's fifth-largest airport opened in 1919 and is still running successfully with addition of new terminal buildings. On the other hand New York City's John F. Kennedy International Airport (JFK) opened in 1962, which was highly praised as an architectural masterpiece but was eventually closed in 2001. Now the question is why do some airport terminal buildings become redundant or inflexible, whereas the other remains functional or adjust to the changing demand over time? A very simplistic explanation would be that the design was insufficient/inadequate compared to the other one. The rehabilitation was either too expensive or difficult to address larger passenger volumes, bigger aircraft, new security requirements, and infrastructure needed to install information-technology requirements. Nevertheless, this explanation is not enough to cover the long-term view of understanding the changing pattern of air traffic growth and passenger needs. Flexibility could provide an indication of what works and what doesn't in these instances. But what elements make an airport terminal flexible? To find out an appropriate answer to this question, a number of airports around the world are analysed in the following paragraphs.

Schiphol International Airport, Amsterdam

Amsterdam Schiphol International Airport – Europe's fifth-largest airport opened in 1916 as a military airbase consisting of a few barracks and a field, which eventually started to serve as a civil airport from 1919 (Schiphol-Group, 2011). The current airport terminal building was opened in 1967 and is still running successfully with several extensions. The number of passengers had grown to more than five million in 1970, from under 1.4 million in 1960. The arrival hall was therefore extended in 1971, and in 1975 an even larger extension of the terminal building was completed. The new airport opened with the arrival hall on ground floor and a departure hall above it with three piers, located within a four-runway system surrounding a central zone that has the ability to process around six million passengers annually. The terminal's capacity has more than doubled over time.

Schiphol now has capacity for 55 million passengers annually (Schiphol-Group, 2012). Figure 2.5 shows the gradual development Schiphol Airport, which has successfully evolved through a number of adaptation and expansion schemes to respond to the continuous increase in passenger demand.

Schiphol has gradually evolved from an airport to an airport city. This success is a positive example of designing an airport with the ability to adapt to demands from all directions. The inherent flexibility of the design layout allowed this airport to operate for nearly a century. The reasons which made Schiphol a successful airport are:

- A flexible master plan that allowed to accommodate various changes over the period
- A steady and constant growth undertaken in various phases
- There was no site constraints

1920 **1967** **2001**

Figure 2.5: Development of Schiphol International Airport, air field to airport city (Schiphol-Group, 2011, 2012)

Stansted Airport, London, United Kingdom

Stansted airport is the UK's third-busiest airport; a single-storey terminal building with evenly spaced grid column creates a particular interest for the airport designers. The design concept was based on an idea of creating an elegant and directionally neutral terminal. Design of a single-storey airport terminal building is usually encouraged in terms of cost, flexibility, passenger convenience and passenger convenience (Edwards, 2005). The transparency of the building structure is an added advantage for passengers, who can see where they are heading with the logos on the tail of aircraft seen at a distance. This visual link between landside and airside was a central goal of design philosophy. This spatial clarity is accompanied by straight line passenger processing through the terminal so that passengers never feel confused or disorientated (Clarke & Ainsworth, 1991). The over-sailing roofs protect the external walls from the solar gain, and also being a single storey with highly glazed and roof-lit conditions eventually help reducing energy costs. The aerial view and the interior and exterior are presented in Figure 2.6.

London's Stansted Airport was designed with an open-plan interior but the choice of configuration made it inflexible for future passenger accommodation. The design of the terminal is locked in the configuration because it is difficult to alter for future traffic (Edwards, 2005). Alteration in interior layout is also made more difficult by the column grid system(Clarke & Ainsworth, 1991).

Left: Interior of the terminal showing column, middle: Arial view of the airport

Figure 2.6: Stansted Airport, London (Foster and Partners)

Dublin Airport, Ireland

The design approach of Dublin Airport was based on identification of a series of 'components' for the development strategy with each of the components having specific characteristics. It was anticipated that the components can be developed independently or combined; for example terminal 1 and 2 are both designed for different passenger types but can be developed independently according to the increased traffic demand (Butters, 2010). The design development considered the advantages of layering concept as obvious on the layout planning. The visually striking building (Figure 2.7) also makes maximum use of natural daylight and creates bright and airy spaces.

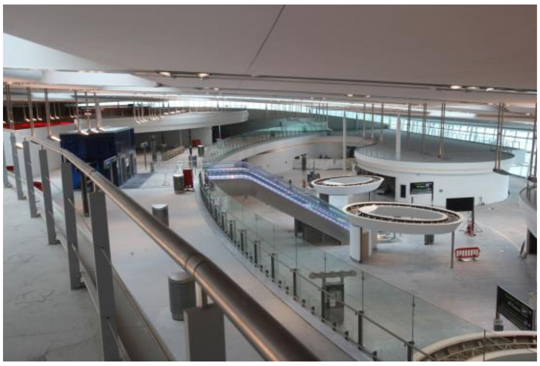
 

Figure 2.7: Ariel view and interior of Dublin Airport Terminal 2 (Passenger-Terminal-Today, 2015)

The key considerations for a spatial layout development are as follows (Butters, 2010):

- Incorporate buffer areas that can be expanded in future.
- Annex adjacent facilities to convert those facilities from non-operational to operational functions.
- Remote locations should be identified to relocate non-core functions to create bigger operational area.

Vancouver International Airport, Canada

Vancouver International Airport is Canada's second-busiest airport and provides a notable example of flexible space for international and domestic passengers. It consists of a large, open hall (Figure 2.8), divided by interior panels that splits the hall into spaces which can be connected in different ways using escalators and elevators. The airport is notably efficient in using flexible space for international and domestic passengers. It uses glass partitions and doors that allow aircraft gates or passenger lounges to be secured for either use. This airport can easily accommodate both short- and long-term shifting patterns of traffic (de Neufville, 2008) demonstrating a good example of flexible design.

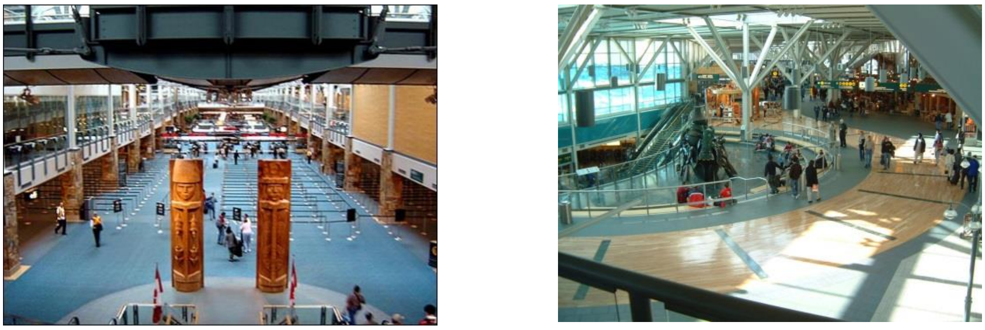
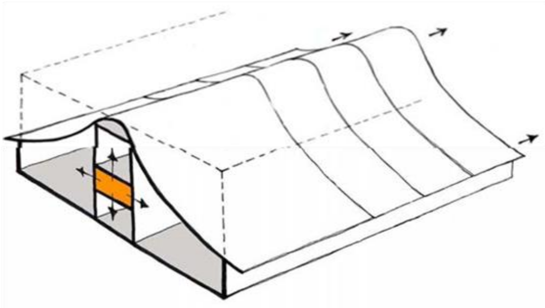


Figure 2.8: Open interior at Vancouver airport (Airportia)

Southampton Airport, United Kingdom

Southampton Airport is a small regional airport designed by London architects Manser Associates in 1990. The concept of modular airport (Figure 2.9) assists designers to develop expandable and flexible facilities that can meet airline requirements in a cost-effective manner. The regional airport at Southampton, UK (MPD, 2009) is an elegant example of modular airport terminal concept. The building form facilitates the ease of future expansion, where the required expansion could be easily achieved without disruption to existing operations. Modular techniques offered more rapid construction time due to the commonality of building elements.



Left: Modular structure showing the direction of expansion; Right: Light and airy interior: Below: Cross section of the terminal building

Figure 2.9: Modular terminal at Southampton, UK (MPD, 2009)

The terminal building is designed with passenger facilities in one level with a three-storey spine of offices at the centre. The wide band of roof lights between the central offices, and arrival and departure concourses – arranged as aisles at either side. Rather than creating a double-height space over the whole area, the roof height lowers at the edge whilst still providing a comfortable height in public areas (MPD, 2009). Structurally the form is simple, and the interior is a column-free space with wide spans providing operational flexibility for retailers and facilities managers. This relatively cheap and adaptable regional terminal costs half the amount for a typical multistorey terminal. The adopted form provided economical solution; the target price was 50% of the unit rate normally required on the development of typical gateway terminals. According to the 2006–2015 development plan (BAA Southhampton, 2006) new aircraft parking stands will be required for commercial aircrafts, and more check-in facilities will be added to meet passenger demand.

Madrid Barajas Airport, Madrid

A flexible, loose-fit system employing large-scale modular repetition on an 18 x 9 m structural grid was chosen as the best solution to accommodate the multitude of uses in the terminal (presented in Figure 2.10), including check-in desks, security checks, retail units, toilets and baggage reclaim (Partners, 2014). A simple palette of materials and the use of a kit-of-parts approach to detailing reinforce the direct simplicity of the architectural concept as well as facilitating the ultra-rapid construction programme and maximising the potential for flexibility.

Figure 2.10: Interior of Madrid Barajas Airport (Partners, 2014)

Bangkok Suvarnabhumi Airport, Thailand

Bangkok Suvarnabhumi Airport in Thailand is another example of flexible design concept. The terminal is comprised of a series of large modular terminals, each served by wings of airside corridors with aircraft gates on either side. The terminal and concourses were constructed in five phases. The long-span, lightweight steel structures along with lightweight building materials helped reducing construction cost (e-architect; Palmer, June, 2006). When Thailand decided to build the airport, the authority, however, did not consider the market for low-cost tourism. As a result, the low-cost airlines are using the old airport which is inexpensive and convenient for them (de Neufville, 2008).

TWA Terminal, JFK International Airport, US

The unique architectural design of terminals at JFK dates back to the 1960s, and was one of the first larger airports to accommodate jet airplanes. TWA Flight Centre (Terminal 5) was opened in 1962 and was highly praised at the time for its innovative beauty and creative design. As a work of architecture, the TWA Terminal (called ‘Bird in Flight’) was an unparalleled success, but as a passenger terminal building it proved over time to be functionally deficient (The-Huffington-Post, 2011). The radial and compact plan, as shown in Figure 2.11, of the terminal was inefficient when compared with other linear-planned terminals. The terminal was eventually closed in 2001 after the American Airlines bought TWA. Now the Port Authority of New York and New Jersey is looking for developers to turn the vacant TWA Flight Center at JFK Airport into the centrepiece of a small, high-end hotel that would allow the agency to reopen the terminal and recoup some of the money it spent restoring it. This clearly demonstrates unfortunate consequences for not having inherent flexibility to adapt to the future demand.

The TWA Flight Centre was initially challenged by three important factors:

- The high cost of restoration,
- A tight construction schedule for the JetBlue terminal, and
- Limited options for alterations

Figure 2.11: TWA Terminal (The-Huffington-Post, 2011)

The newly expanded Ottawa Airport, Canada, has developed a system that enables it to adjust the number of gates provided for domestic and international air service, simply by opening and closing partitions, moving the wall that separates two types of traffic. In Heathrow Airport Terminal 5, the concept of flexibility was initially achieved in some areas; the floor plate of the retail area was physically decoupled from the building shell (Gil & Tether, 2011).

2.5 FLEXIBILITY IN BUILDING DESIGN

Currently available literature recognises that the usage of a building and its key design parameters typically change widely during its lifetime, and hence provision to accommodate such changes could prove to be one of the most important factors in determining economic efficiency and performance. Though the concept of flexibility started to grow around developing flexible dwellings, the main philosophy behind creating flexible space was to anticipate complex and changing requirements of human needs. Kronenburg (2007) in his book *Flexible Architecture that Responds to Change* defined:

> *'Flexible buildings are intended to respond to changing situations in their use, operation and location.' (p10)*

The notion of flexibility in architecture first emerged from the Second Congress Internationaux d'Architecture Moderne held in Frankfurt in 1929 (Schneider & Till, 2007), where the debate for reduced space standards led to the concept of flexibility; this ideally means if there is less space available to use, then the space should be used in an efficient and flexible manner. This led architects in developing new plan types for housing, many of which incorporated flexible elements (Schneider & Till, 2007; Till & Schneider, 2005). In building design concepts, the terms 'flexible' and 'adaptable' are sometimes confusing and, in many cases, these terms are used to describe the same thing. The following definition was drawn by Steven Groak (Groak, 1992) – 'adaptability' is capable of different social uses, which means designing a particular space that can be used in a variety of different ways, whilst 'flexibility' provides the capability of different physical arrangements that can be achieved by altering the physical fabric, by joining, extending or through sliding or folding walls and furniture. Diverse building types can respond to various design strategies. The area of such diverse solutions is not easy to categorise, and multiple methods are available for achieving flexibility (Schneider & Till, 2007). This section discusses commonly used key factors/strategies as identified in literature.

2.5.1 **Previous design approaches**

Flexibility in residential buildings is a broadly accepted perception. 'Open building' concept proposed by Habraken (1961) is widespread and accelerating to achieve. The core idea of open building is to respond to various needs of individual users through the phasing of design and implementation process. The main goal of Open Building is to achieve independency between different parts, so buildings can be created that are able to adapt to new user requirements. Considerable literature is available on flexible building design as well as housing, healthcare infrastructure and educational sectors. However, the current review will only cover a fraction of the flexible building design literature that is relevant to develop a conceptual flexible design guideline for airport terminal design process.

Schneider and Till (2005) carried out a comprehensive analysis on past, present and future of flexible houses and examined more than 150 case studies at different scales, starting from blocks of buildings to individual rooms offering a range of tactics and strategies. They came up with a simple method of division to achieve flexibility – soft and hard. ‘Soft’ refers to the techniques that allow users to adapt the plan according to their needs, whereas, ‘hard’ refers to the elements that specifically determine the way the design should be used. The research findings from Till and Schneider (2005) explained three fundamental ways of achieving flexibility in residential building design:

- Through simple construction,
- Appropriate technological consideration, and
- Suitable use of space.

They recommended flexible design solutions which are divided into two basic components – plan (building level, unit level and room level) and construction. Planning mainly refers to the particular ways to promote flexibility that adapt to changes in terms of designing the plan. Construction refers to the way a house should be structured and constructed to accommodate uncertain changes of the future. The key elements of the design recommendation by Till and Scheinder (2005) are summarised in Figure 2.12.

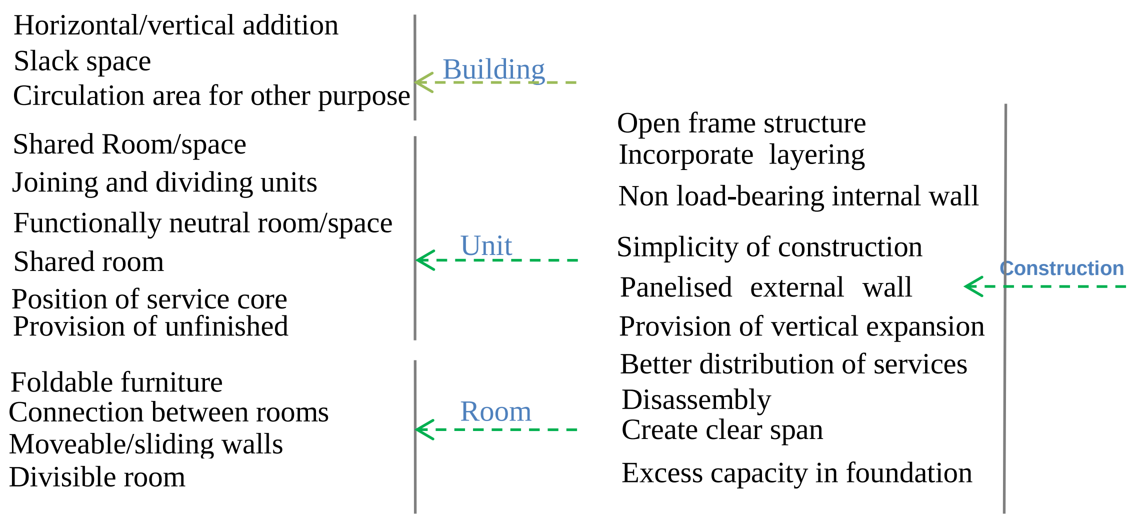


Figure 2.12: Design elements of flexible housing adopted from Till and Schiender (2007

Other than housing sector flexibility has been considered as a growing concern in healthcare design in recent years. Demand for flexibility in healthcare design is driven by lifestyle changes, rapid advances in medical technology and rapid regulatory changes. According to de Neufville and Lee (2008) the main design features that make hospital buildings flexible is the shell space, where the areas are already built but are not equipped with medical facilities, or suitable structural foundation of a building to allow for expansion in future. de Neufville and Lee (2008) categorised flexibilities as strategic, tactical and operational. Operational flexibility refers to use on daily or weekly basis to deal with short-term unpredictability of infrastructure usage. Use of tactical flexibility is somewhat slower, and requires a more significant commitment of capital making it more difficult to achieve. Strategic flexibility deals with the lifetime of an infrastructure.

In educational sector, recognition of the importance of flexibility was outlined as early as 1968. Following four distinctive subcategories of flexibility were identified (Finch, 2009) such as expansible space, convertible space, versatile space and malleable space. Expansible space allows for ordered growth by the use of flexible construction. Convertible space is the part of adoption of relocatable partition. Versatile space creates to serve for multiple functions and malleable space creates flexibility by open learning space. Hertzberger's (1991) concept of flexible school design transformed the notion of traditional hierarchical order of space (*i.e.* teacher at the front on a podium and children at a lower level sitting behind rows of desks) into a more informal arrangement of classroom areas to provide better learning environment for team teaching. The 'Freeform Modular School Project' by Cartwright Pickard (2004) provided the opportunity of arranging various sized classroom areas to create a variety of zones and open learning (Kronenburg, 2007). Table 2-1 summarises the examples of flexibility discussed in this chapter.

Table 2-1: Typology of flexibility obtained from literature

Authors/researchers	**Building type/process**	**Types/subcategories of flexibility**
Gross and Murphy, 1968 adapted from Finch (2009)	Educational building	Expansible space Convertible space Malleable space
Kronenburg (2007)	Any	Adaptation Movability Transformation Interaction
Schneider and Till (2007)	Residential building	Soft method Hard method
Saari and Heikkila (2008)	Any	Service flexibility Modifiability Long-term adaptability
Cowee and Schwehr (2009)	Any	Extension flexibility Internal flexibility User flexibility Planning flexibility

Ways of achieving flexibility

According to Saari and Heikkila (2008) a building may response to three types of flexibility: a) service flexibility – important for the building's users; b) modifiability – specifically related to the owner's interest and c) long-term adaptability – to satisfy urban and cultural environment. Cowee and Schwehr (2009) evaluated flexibility based on typologies and suggested that the main building flexibility types are: (1) extension flexibility, which is related to analysis and classification of various types of extension and retrofit involved in building design; (2) internal flexibility, which is the adaptability of building related with time, risks and degree of modifications influencing extensions of a building; (3) use flexibility which refers to the way a specific design responds with a change in use; and (4) planning flexibility of a building responds during the entire planning and construction phase

Kronenburg (2007) carried out a thorough overview of flexible architecture which explored the historical context that has shaped today's contemporary design. He identified four different ways that a particular building can respond in creating flexibility such as adaptation, transformation, movability and interaction.

The buildings that are designed to adjust with various functions, users and climate are known as adaptable buildings (Kronenburg, 2007; Schneider & Till, 2007). Provision of multi-use space is the simplest strategy that can be used to achieve adaptability in buildings such as meeting rooms that become teaching rooms in school, and hotel conference suites can become wedding, exhibition and show venues. Adaptable architecture encourages users to take design decisions. The key principle for enhancing adaptability appears to be the independence of building elements (shearing layers of change). The more each feature is separated from the others, the more adaptable a building becomes. There is a long history of using movable interior elements, such as moving screens and temporary dividers in vernacular dwelling, mainly in traditional Japanese houses. Within a fixed framework of a building, design flexibility can be achieved by incorporating moveable elements. The idea of movable elements in flexible dwelling was first demonstrated in 1931 by Carl Fieger at the Building Exhibition in Berlin showing transformation of spaces related with operational features. Spaces that are normally dedicated to specific functions can be used to support different methods of use. In general, furniture or furnishings are the most usual customisable components that dramatically alter the appearance of a building (Kronenburg, 2007). For example, a small theatre with transformable elements such as movable seating, or an extendable stage helps to support various types of performances.

2.5.2 **Flexible design strategies**

A flexible option is a means of realising a strategy, which can be applied to deal with uncertainties. Flexible Strategic Planning (FSP) has been suggested by de Neufville (2008) as an alternative solution to the traditional traffic forecasting. de Neufville (2008) also presented the key differences between the traditional airport master planning and his proposed flexible strategic planning. This section congregates some principles of flexible design strategies used in various design fields to help the development process of a new conceptual framework, which will allow utilising flexible design principles specifically targeted for the departure terminal of an airport building.

Design strategies in engineering system

The following four steps for developing design flexibility are suggested by de Neufville and Scoltes (2011):

Step 1 *Recognise the major uncertainty of a project*

Dealing with uncertainty presents a major challenge for the designers in long-term engineering systems (Chambers, 2007) as well in building design. Future cannot be predicted precisely, which makes a design difficult to expect how it will respond during the total life cycle of a project. Moreover because of the unpredictable future, long-term forecasting is not reliable (de Neufville, 2008; de Neufville et al., 2008; de Neufville & Scholtes, 2011). Forecasts are fundamental to port planning and design as most ports rely on detailed cargo forecasts based on analysis by commodity of historic trends, international, national and local developments, and their competitive position (Taneja et al., 2012). Considering the uncertainties that affect their accuracy in forecasting long-term futures, de Neufville and Scoltes (2011) suggested to adopt a new paradigm focusing on the range of circumstances that might occur, and tackle those scenarios through flexible design approach.

Step 2 *Identify specific areas 0f uncertainty within a system/design*

This stage identifies the specific area of a whole design or system that needs to deal with uncertainties. It is obvious that flexibility will add value to a project but it depends on many interacting factors such as the nature of the design/system, the intensity of uncertainty as well as the types of uncertainty that will arise during its total life cycle, and the cost of implementing measures to tackle uncertainty.

Step 3 *Evaluation of alternatives*

At this stage of the design process, evaluation of different alternatives is suggested based on range of scenarios. The complete evaluation needs to consider several factors, with economic value is given one of the top priorities. It should be noted that de Neufville & Scholtes (2011) added more importance on choosing ‘preferable’ rather than ‘best’ solutions.

Step 4 *Implementation of flexible design.*

Designing flexibility into a system is not enough, designers have the responsibility to ensure a systematic plan for implementation and adapt the system with future circumstances.

Design strategies to meet the expansion of low-cost airport terminals

de Neufville (2008) proposed a flexible design strategy to deal with the uncertainty and suggested the following three basic elements of a flexible design process:

Recognition of the range of uncertainty:

It helps to find out wide variation of possible outcomes, from the least favourable to the most advantageous.

Definition of flexible design opportunities:

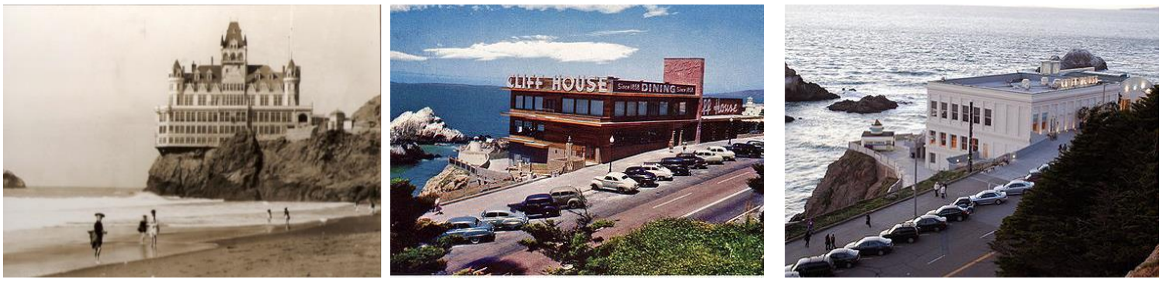
A key part of the flexible design process lies in the identification of design solutions that minimise irrevocable commitments that may be premature, and that simultaneously provide easy pathways to the development of the range of facilities that might actually be needed in the future.

Analysis of the development strategies:

The final part of the design for flexibility is to think through how alternative initial designs could adapt to future circumstances.

2.5.3 **Influence of shearing layers in design**

Most buildings undergo substantial changes during its lifespan. There are large numbers of events that have different impacts on the performance of a building over its lifetime. Brand (1995) presented the famous Cliff House in San Francisco as a prime example of how the performance of a building changes throughout its lifetime. A series of owners invested in this particular house over the last 140 years in order to take the advantage of site's spectacular view (Flager, 2003). The cliff remains constant but the structures come and go (presented in Figure 2.13). Large numbers of incidents affected the performance of a building over its lifetime, and various components of a building change at different timescales (Till & Schneider, 2005), which requires diverse design strategies. A brief overview of shearing layers of building design is presented herein considering its possible implications on airport terminal design.



In 1900, the eight-storey Cliff House was completed with art galleries, dinning and ballrooms

In 1954, it was drastically remodelled and extended to the left

Remodelled again 1971 – this is the current condition

Figure 2.13: Evolution of San Francisco's Cliff House (Brand 1995)

The expected life of a building, the scale, the number of components involved and the mutual relationship with its contextual surroundings combine a building as a complex product in the rapid changing world (Schmidt iii et al., 2009). Duffey and Henney (1989) argued that there isn't such a thing as a Building; rather stated the following:

> *'A building properly conceived is several layers of longevity of built components.'*

Duffy (1989) proposed the concept of building layers, where he identified four layers of commercial buildings in time descending order: the *Shell*, the *Services*, the *Scenery* and the *Set*. Shell is the structure that lasts the lifetime of a building, services refer to cabling, plumbing, elevators etc. *Scenery* is the layout of partitions, dropped ceiling etc., and *set* is the furniture layout. His concern was to provide internally adaptable buildings so that the building can be separated from a long service life to a short service life. In other words, when a building are no longer able to provide services to meet the contemporary requirements, the whole building does not have to be upgraded or replaced, only the specific part of that service area can be renewed. Duffy's layering concept towards interior works in commercial building was expanded by Brand (1995) into a slightly revised and a more general-purpose 'Six S' concept, i.e. *Site*, *Structure*, *Skin*, *Services*, *Space plan* and *Stuff*. Figure 2.14 presents Brand's (1995) "Six S" concept with assigned expected service lives.

1. The *Site* is eternal; it is defined as the ground on which the building sits.

2. The *Structure* is the foundation and load bearing components of the building and expected to last from 30 to 300 years depending on the type of the building.

3. The *Skin* of the building is the cladding and roofing system that can last up to 20 years due to maintenance, changing technology and style.

4. The *Services* are comprised of heating, ventilating, air conditioning and moving parts like elevators or escalators. The services have an expected life from 7 to 15 years.

5. The *Space* plan would require changing every 3 years in commercial buildings and up to 30 years in residential buildings.

6. The *Stuff* corresponds to change in daily to monthly basis.

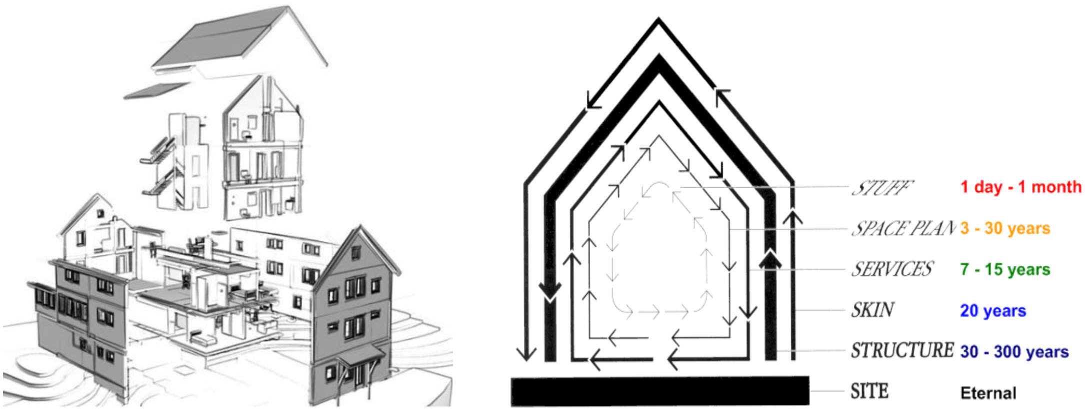


Figure 2.14: Shearing layers of change (Brand, 1995)

It should be noted that the layered construction will not lead to flexibility unless the given layers are separable (Crowther, 2003; Edwards, 2005) The proposed building decomposition model by Brand (1995), hinges around the principle that a building is constructed from components with varying service lives, which requires changing or replacing at different rates. Slaughter (2001) reported that nature of interaction within a building system can influence the flexibility of a building to respond to different types of changes. System interactions can be grouped into three general categories: physical, functional and spatial interaction. Physical interactions in building systems can be done through a connection, intersection or adjacency; for example, a roof element can be mechanically connected to the structure, interleaved through the structural elements, or simply rest upon the structure. These types of interactions can be easily identified and verified through direct observation at design, construction, and during operational life.

Table 2-2 presents building decomposition or layering system proposed by a number of researchers avaiable in literature.

Table 2-2: Building decomposition systems from literature

Duffy (1990)		Brand (1994)		Slaughter (2001)	
Layers	**Lifetime**	**Layers**	**Lifetime**	**Layers**	**Lifetime**
Shell	50 yrs	Site	Eternal		Not specified
		Structure	30–300 yrs	Structure	
		Skin	20yrs	Envelop	
Service	15 yrs	Services	7–15 yrs	Services	
Scenery	5–7 yrs	Space plan	3–30 yrs		
Set	15–30 days	Stuff	1–30 days		

The concept of building layers could play a major role on both the analysis and the design process of airport terminals. The interfaces between the layers could be considered as the primary points for a flexible terminal layout. Like other buildings, the functional life of an airport terminal has a different timescale from its structural life. Edwards (2005) highlighted the importance of incorporating the layering concept in terminal design. He mentioned that terminal design should allow separate layers that can be renewed without any significant disruption. Appropriate recognition of separate layers within a typical terminal should allow the terminal to be renewed as required. This will also allow the designer to anticipate changes even without knowing the exact configuration. Edwards (2005) divided terminal buildings in two basic conceptual layers i.e. technological change and management change (more detail discussion is presented in section 2.4.1). This concept plays an important role in the current research and will be thoroughly explained in the subsequent chapters.

Essential design elements to achieve flexibility

From an airport planning perspective, flexible terminals will easily adjust to capacity reduction or expansion as well as will accommodate new technologies into facility design. Modularity is a simple yet effective tool in design that could help reducing costs by increasing flexibility. Appropriate recognition of likely future changes during planning will result in an infrastructure that is better equipped to deal with unforeseen future. Another key principle to achieve flexibility is simplicity in spatial layout where selection of an appropriate terminal configuration is an extremely important factor. Following are the key flexible design elements for an airport terminal as identified from literature:

- Design should be based on functionality
- Simplicity in terminal configuration and geometry
- Open-plan design
- Use of standard design components will help easy replacement or relocation, if required
- Use of modular approach in layout
- Repeatable module allows to create incremental expansion
- Easily removable partitions can quickly respond to the change in level of traffic
- Shared used facilities reduce design load
- Shared used facilities also increase economic performance
- Maintain a hierarchy of functions
- Minimize level change for cost reduction and simple circulation
- Allow room to expand in all directions if possible.

2.6 **SUMMARY**

The term ‘flexibility’ adopted herein defined as the ability to alter an infrastructure in time to respond to its capacity needs. Flexibility enhances performance in complementary ways; initial cost of incorporating flexible elements could be easily outnumbered by the value added to a design. Unexpected scenarios that cannot be dealt with conventional design process could be accommodated by adopting appropriate flexible design. The conventional building designs are rigid in nature, and therefore do not have the capacity to adapt frequent and unforeseen changes. To accommodate processing facilities in an airport terminal, such as check-in, security scanning etc., a terminal building must be capable to cope with the frequent changes in technology as well as changes required for incidental security concerns. To accommodate changes in the lifecycle of an airport terminal, flexible design strategies have been identified based on their frequency of alteration requirements such as strategic, tactical and operational.

Design flexibility depends on interactions between building and its users where decomposition of several ‘layers’ of a building affects its whole life cycle. The concept of ‘shearing layers’ identifies the importance of independency between different building layers so that any modification required for a specific layer could be addressed without affecting other layers; appropriate adoption of this concept will allow achieving flexibility in design. Early practices of flexibility concept in housing utilized the form of 'open building' concept to achieve independency of building parts to allow easy adaptability to user requirements. Simple construction technique, appropriate technological consideration and suitable use of space are identified as fundamental principles to achieve flexibility in building design. Therefore, it is suggested that if designers can incorporate flexible design elements at the early stage of a design process, it will be possible to deal with uncertainties over the lifecycle of an infrastructure.

Chapter 3

Previous Approaches to Spatial Planning in Design

3.1 INTRODUCTION

The previous Chapter presented background information available on the context of flexible design in various fields. To achieve the research goal of developing a conceptual flexible design framework for the departure terminal of an airport, a comprehensive review of available literature is required on spatial layout generation. This chapter presents a discussion on elements and issues related to architectural design process. In addition to investigating the relationship between an architectural design process and space layout planning theory, a brief overview on Business Process Model (BPM) is presented showing its possible application in design.

Section 3.2 presents definitions and meaning of design process, emphasising how the design process could uncover the relationships that exist between space and their relevant functions. The aim is to identify possible areas within the course of the design process where space adjacency analysis could help in planning spatial layout.

Section 3.3 presents an overview of spatial layout planning approaches with a critical reflection on the use of graph theory in architectural design layout. It provides a review on how computational spatial layout planning could be used to develop floor-plan layouts.

Section 3.4 reviews definition of process models and modelling notations used in the current research. The importance of using process models in defining design problems and spatial adjacency is also identified in this section.

3.2 THE ROLE OF DESIGN PROCESS

Design is considered as a generic activity where the real differences appear in the end product created by designers in various domains (Lawson, 2005). This section explains the meaning of design process, and reviews various definitions with a brief examination of the phases of the "map of a design process". The 'map of a design process' is defined as a problem-solving activity where space adjacency analysis is considered as a tool to support and serve design problems. Process mapping allows understanding of a process visually, shows what is involved, and how the inputs of a process are translated into outcomes or deliverables.

3.2.1 Overview of design and design process

In exploring the role of a design process, it is fundamental to understand the meanings and assumptions of 'design'. Over the past half century, the theory and practice of design has evolved and the role of design has undergone significant transformations (Franco & Geraldine, 2013). Many attempts are available in literature to come up with an appropriate definition of design in countless essays, journal papers, conferences and publications; yet the concept of design among design practitioners remains ambiguous. Alexander (1964) defined design as:

'Finding the right physical components of a physical structure.' (P45)

From his point of view, design patterns are more or less independent, yet they complement each other with a coherent language. Design could be viewed as an activity that translates an idea into a plan for something useful, whether it's a car, a building, a graphics, a service, or a process. According to Asimow (1962) each design project is unique and has an individual history, but as a project it initiates and develops a sequence of events unfolded in a chronological order, forming a pattern which is common to all projects. Design has widely been identified as a 'problem-solving activity' (Asimow, 1962; Lawson, 2005; Rowe, 1998; Simon, 1969). Some researchers defined design as a process making artefacts that have desired properties (Grason, 1971; Simon, 1969).

A process is either an unintended or a planned sequence of actions or procedures which produces desired outcomes (Franco & Geraldine, 2013). It consists of a series of steps which is performed through systemically defined methods. The design process is a generic method that reveals how things are created and architectural design process is the scientific study of existing ideas to get some detailed solution(s). A design process is divided into two separate phases: problem definition and problem solution. Architectural design is a combination of graphical and analytical solution to a problem, such as residential, industrial, institutional, religious or commercial design. (Idi et al., 2011). An essential feature of architectural design process is the use of diagrammatic representations, particularly in the early phases (Bertel et al., 2004). The main feature of a design process resembles problem solving (Simon, 1969), but in deeper meaning this is an analytical tool which carries process through *analysis, synthesis* and *evaluation* and *decisions*. (Asimow, 1962; Lawson, 2005).

3.2.2 **Traditional maps of design process**

Traditionally the process of building design follows some individual phases starting from initial concept drawings through to final detailed design into construction (Asimow, 1962; Lawson, 2005). Although design can be described as a generic activity, the real differences appear at the end product created by designers in various fields. For example, a structural engineer uses the word 'design' to obtain suitable beams and columns to sustain the calculated loads on structural elements, whilst an architect uses the word to find an appropriate layout of a building. The common idea behind all design process consists of sequences of distinct and identifiable activities occurring in some predictable and logical order, which is typically termed as the 'map of design process'.

Lawson (2005) stated that design practice is a bidirectional process, where each problem enables the designer to learn from guiding principles. He identified design as a kind of research, offering the designer an option to shape, test, evaluate and reconsider an initial design through an action-based method of advancing knowledge. Every design project is unique, yet the process of making it and the methods used are somewhat similar (Oyen, 2007). RIBA *Architectural Practice* and *Management Handbook (1965)* offers the following four possible phases of design process (Architects, 1965):

(i) Assimilation is the first phase, which accumulates general information related to a design problem.

(ii) General study investigates the nature of a problem using the accumulated information and also leads to a possible solution or means of a solution.

(iii) Development stage emphasises refinement of one or more of the tentative solutions and focuses more on the technical aspects of materials and building systems.

(iv) Communication is the final phase, which shares the possible solutions among the involved design teams.

Figure 3.1 presents widely accepted 'map of design process' by RIBA plan of work. It is worth mentioning that these four phases are not necessarily sequential, and there could be unpredictable transitions between these phases. For example, it is not possible to gather all accurate information on the problem until there are some investigations done in phase 2. Similarly, detail development (phase 3) of design solution rarely goes smoothly to a single inevitable decision and often requires returning to phase 2 activities. Lawson (2005) argued that in some situations clients fail to describe the problem in sufficient detail at an early stage and hence the designer has to go back to phase 1 from phase 4. The RIBA map of design process, however, did not propose any return loop from Phase 4 to Phase 1.

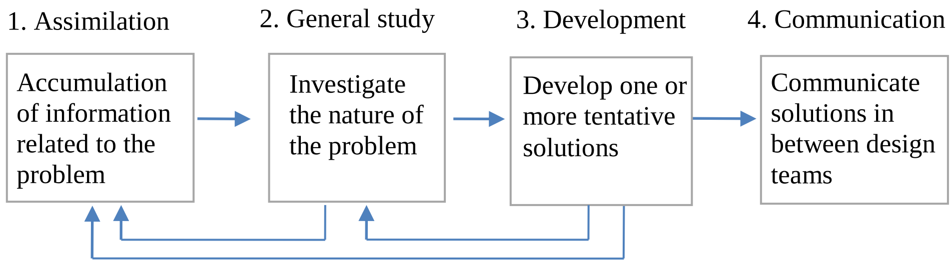


Figure 3.1 : Map of RIBA design process (Markus, 1969b)

Markus (1969b) and Maver (1970) elaborated the maps of the architectural design process (Markus, 1969b; Maver, 1970), as shown in Figure 3.2, where they argued that a complete picture of design method requires both 'decision sequence' and 'design process'. They suggested that designers need to go through analysis, synthesis, appraisal and decision at detail levels of the design process; this corresponds to stages 2, 3 and 4 in the RIBA handbook as outline proposal, scheme design and detail design respectively.

Analysis, synthesis, appraisal and decision of a design process map are required to allow return loops from one activity to another. Analysis helps exploring the relationships, seeks available information, and defines the problem. Synthesis creates a response to the problem leading to the generation of solutions. Appraisal helps critically evaluating the suggested solution against the objectives obtained in the analysis phase. This model describes an iterative process, going back and forth in loops, generating a progress of the object of design, analysis, synthesis and evaluation/decision of a design process.

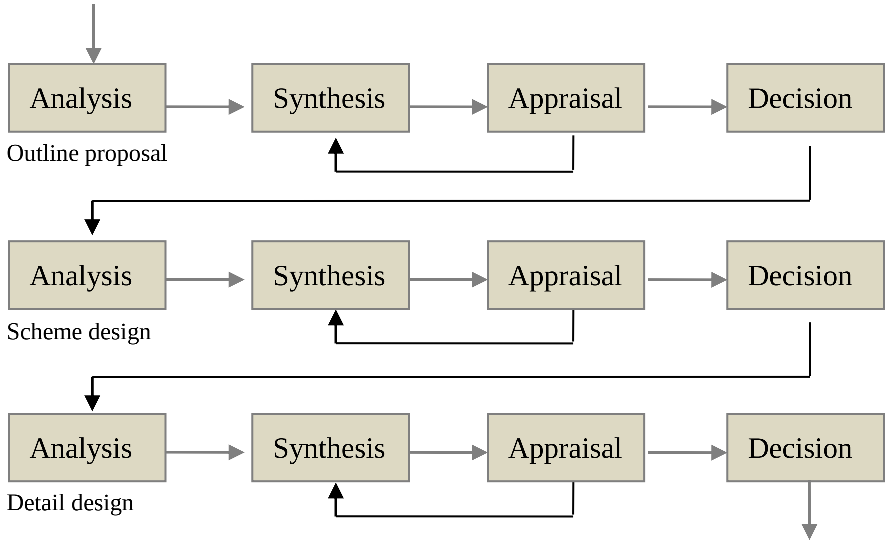


Figure 3.2: Markus (1969) /Maver (1970) map of design process

Finally, Lawson (2005) suggested a generalised map of the design process, which concluded with a process map that shows a return loop from each function to all preceding functions. Figure 3.3 illustrates a more generalised design process map where designers also need to go back to the evaluation stage to analysis stage. This process map suggests that the early stages of design will be more focussed towards the overall organisation and disposition of spaces (such as, explore relationships between spaces) and the later stages will deal with the detailing (such as, selection of material used in the

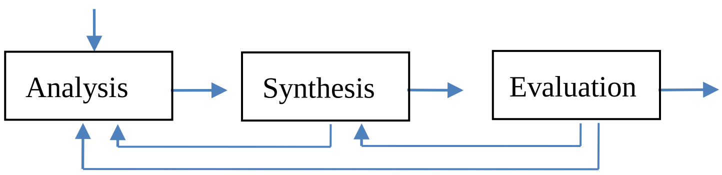


Figure 3.3: A generalised map of design process (Lawson 2005)

construction).

This generalised map of design process provides a significant influence in the current research. The proposed flexible design framework, which will be presented in Chapter 4, seeks to integrate flexibility in the design process of an airport terminal. "Identifying uncertainties" of a design problem is added to the map of design process to make it more adaptable to changing working environment.

3.2.3 **Design problem through space adjacency analysis**

A well-coordinated design integrates architecture, engineering, interior design and infrastructure through a design process. The problem definition of a design includes needs, issues, requirements, constraints and opportunities of the project. The complexity of a project is determined by its size and functional requirements. The design of a building requires responding to a range of issues, such as climate, cost, energy, client's requirements etc. Each of these issues has a unique set of analytic tools for entering into the design problem. White (1986) stated:

> *'To understand and define the problem, we use our analysis tool and to respond the problem with a building design we use our synthesis tool'. (p9)*

According to White (1986), space adjacency analysis provides one way of entering into a design problem. It explores the opportunities to find out links between spaces, it also provides insight into desired spatial and workflow relationships (Augustin & Coleman, 2012). During a design process, architects have to satisfy a set of adjacency constraints between spaces, and dimensional constraints over each space element (Homayouni, 2007). Requirements for a new house or a new building generally come from a client or a user. This declaration of requirements is called the Space Program, and it is a translation of the needs (human activities) of the client or the user into an architectural language. The words and numbers specified by the client/user is transformed by the architect into appropriate rooms, sizes, and some relationships are established among various rooms, which are known as adjacency requirements (Lobos & Donath, 2010).

Space adjacency analysis works as a tool to support and serve the building design process, it facilitates design decisions to organise and enclose client activities. White

(1986) defined space adjacency analysis as a ‘pre-design study tool’ that reveals building space location according to adjacency. It also serves as a facilitator for bridging between analysis and synthesis to solve the design problem. He used three graphic tools; matrix, bubble (Figure 3.4) and zoning diagrams for approaching space adjacency analysis. These graphic tools not only help the designers to understand important aspects of client’s operations but also help anticipating appropriate design concepts to meet client’s requirements.

It should be noted here that when two spaces need to be separated for any reasonable purpose then it also should be presented in adjacency matrix as ‘negative adjacency’. Adjacency requirements are usually presented with an appropriate relative importance. The common ‘words set’ (White, 1986) used to express relative importance are mandatory, critical, important, desirable, neutral and negative. These terms are used in an adjacency diagram to indicate the importance of adjacency between spaces while designing a building.

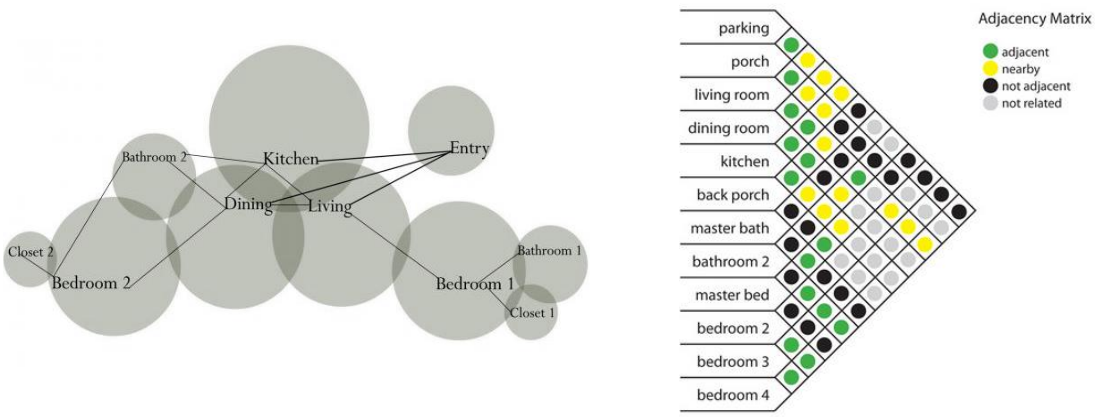


Figure 3.4: Bubble and matrix diagram from White (1986)

Overall, space adjacency analysis can influence the following aspects in a building design process:

- The placement/position of spaces in a building
- Space cluster and grouping
- Distribution of spaces to various floors

- The selection of the circulating geometry
- Size and shape of building spaces
- Number of floor levels
- The overall shape of the building plan
- Furniture and furnishing
- Overall building form

In the current research, space adjacency analysis is used to find out initial design requirements by analysing the relationships between airport passenger and their associated activities. Figure 3.5 shows a simple schematic showing influence of space adjacency analysis in diagram.

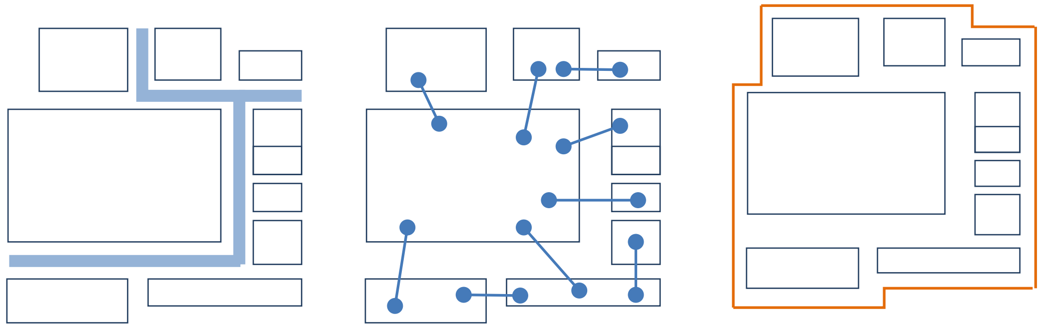


Figure 3.5: Circulating geometry, placement of spaces, overall shape of geometry

3.3 SPACE LAYOUT PLANNING

Architectural design can be specified as a two-step, problem solving process. The first step is to determine the current state of the problem and then identify the design conditions to be fulfilled to satisfy the design problem. The second step deals with the act of designing, which means to create layouts and then to evaluate it under diverse criteria (Boehme, 2006). A theoretical foundation is presented in this section to understand the process of space allocation from a design problem.

The process of arranging various spaces according to their design requirements is the core activity of a building design. New design of a building is required to respond to a range of issues such as site climate, client's operation, energy, costs, codes and regulations. Each of these requirements responds in a unique way in different situations, and has major influence in determining the building form and space layout. Formally the process of organising separate spaces according to the requirement of a user is considered as Space Layout Planning (SLP) (Jo & Gero, 1998). If floor-plan layout is generated using computing devices and techniques, then the process is known as automated Space Layout Planning (Lobos & Donath, 2010). SLP is one of the most interesting and complex of problems in architectural design, which has been examined by many researchers over a long period of time (Eastman, 1973; C. M. Eastman, 1975; Jo & Gero, 1998; Kalay, 2004; Liggett, 1985; Nassar, 2010). Various researchers have defined SLP in different words. According to Jo and Gero (2006):

> *'Space layout planning is the assignment of discrete space elements to their corresponding locations while the space elements have relationships among each other'. (p2)*

The statement implies that space elements which are closely interrelated will tend to be located nearer to each other. Space layout planning is also defined as 'spatial allocation problem'. It is the assignment of discrete space elements to their corresponding locations while the space elements have relationships among each other (Jo & Gero, 1998). Liggets (1985) defined the space layout problem as algorithms to aid solutions for large class of problems. Kalay (2004) defines the problem of space allocation as,

> *'For a given set of spaces (or activities) and the desired adjacencies between them, find the layout that minimizes distances between spaces that ought to be close to each other.'(p241)*

In general all space planning problem consists of a set of activities to be located; a space in which to locate them; and a method of evaluating a particular arrangement of activities in the space (Liggett, 1985). Nasser (2010) mentioned that although space planning problem cannot be defined as an independent problem, the importance of space layout planning is considered more in the context of design process itself, *i.e.* exploring the topological options of the design. There are no universal rules that can describe to put rooms straightaway into a shape; the famous quote by Louis H. Sullivan "form follows function" is often considered as a basic inspiration for finding the initial shape of rooms. Ching (1996) also made efforts to explain some 'techniques', (rather than steps or rules) to distribute a room into a specific shape.

3.3.1 Space layout planning approaches

Automated floor plan layout creation is a well-known research field in artificial intelligence, but space layout problems tend to be ill-defined (Yoon, 1992) and over constrained. Since the early 1960s, numerous computer programs have been developed for automated solutions of architectural spatial allocation problems. The objective and scope of these programs varied widely with various expert systems. (Arvin & House, 2002; C. M. Eastman, 1975; Galle, 1981; Grason, 1971; Gross, 1985; Hashimshony et al., 1980; Jo & Gero, 1998; P.H. Levin, 1964; Mitchell et al., 1977).

Automated space planning methods can provide good solutions from a large set of possible solutions, and allow a designer to modify a set of design constraints to continually refine the problem definition (Arvin & House, 2002). Some approaches to automated space layout planning generate a large number of possible designs within a design space (Liggett, 1985), whilst some employ evolutionary design techniques (Jo & Gero, 1998; Lee, 1979; Nassar, 2010).

Kalay (2004) categorizes computational design synthesis methods as *procedural methods, heuristic methods, and evolutionary methods.* Procedural approach attempts to specify all possible arrangements of floor plans for a given set of rooms, and the architect can choose the most appropriate one from those alternatives. Heuristic methods are the computational design methods that are inspired by analogies and guided by the designer's previous experiences. Evolutionary approaches investigate the fundamental form generating tools in architecture, where space, structure and forms are expressed in generative rules. This approach considers architecture as a form of artificial life and proposes a genetic representation in a form of DNA-like code-script, which can then be subject to developmental and evolutionary processes in response to the user and the environment.

The network method (Whitehead & Eldars, 1965) is known as one of the early attempts of using computers as a generative design layout. The relationship between two spaces was represented by the number of journeys between them. The group of elements forming whole activities were presented in a relationship matrix and the final step of the process is outlined with a diagrammatic theoretical workable form layout. Jo & Gero (1999) used the evolutionary design method to solve a certain class of design problems. Arvin & House (2002) used physically based space planning program and created a space plan by specifying and modifying graphic design objectives rather than using geometry. Spatial networks appear in many different fields but the current research is concentrated on layout representation in building design.

3.3.2 Graph theory in space layout

Use of graph theory in space layout planning and the value of utilising graph theory in representing architectural layout have been investigated by several researchers (Carrie et al., 1978; Foulds & Tran, 1986; P. H. Levin, 1964; Roth et al., 1982; Ruch, 1978). The current research uses graph theory to suggest a conceptual interactive approach in obtaining flexible departure layouts in an airport terminal. Grason's (1971) method of producing solutions to the floor plan problem based on dual graph representation technique, and March and Steadman's (1971) theory of electrical network are extensively used in the current research. Hence, a brief overview of space planning problems from a graph theoretical approach with relevant definitions is discussed in the following paragraphs.

Swiss mathematician Euler is acknowledged as the father of the 'theory of graph' (March & Steadman, 1971). A graph is a series of nodes or vertices, and edges joined by pairs of nodes. Graphs have been used in the theory of electrical networks, in representing the structure of human organisations, in social group – or even the scientific study of decision making. Euler's problem of the Konigsberg Bridge with graph theory is very closely related to solving the problem of architectural layout and town planning (March & Steadman, 1971).

A number of common terminologies used in graph theory (Harary, 1969) are briefly explained in the following paragraphs to facilitate better understanding of the subsequent discussions and analysis presented in the current research.

Isomorphic graph

When two graphs contain the same number of graph vertices connected in the same way are said to be isomorphic. Often, two graphs may look completely different on paper, but are essentially the same from a mathematical point of view.

Planar and non-planar graph

In graph theory, a planar graph is a graph that can be embedded in a plane, *i.e.* it can be drawn on a plane in such a way that its edges intersect only at their endpoints. In other words, it can be drawn in such a way that no edges cross each other. The graph that cannot be drawn without edges that intersect within a plane is called a non-planar graph. According to Kuratowski's theorem, a graph is planar, if and only if, it does not contain a sub-graph that is a subdivision of K_5 (the complete graph on five vertices) or of $K_{3,3}$ (complete bipartite graph on six vertices) and isomorphism.

There are several mathematical theorems (Kuratowski's theorem, Wagner's theorem and Eurler's formula) and proven algorithms available in literature that can be used to prove planarity of a graph.

Dual graph

The dual graph of a plane graph *G* is a graph that has a vertex corresponding to each face of *G*, and an edge joining two neighboring faces for each edge in *G*.

Consider the blue planar graph G in Figure 3.6 that has five nodes and seven edges creating three triangular internal faces, as shown by three red nodes in the figure. There is a fourth red node outside the blue graph representing the surroundings, which is adjacent to all three faces denoted by the previous three red nodes. Red dotted lines show their adjacency and the resulting graph G′ is the dual graph of the original blue graph G.

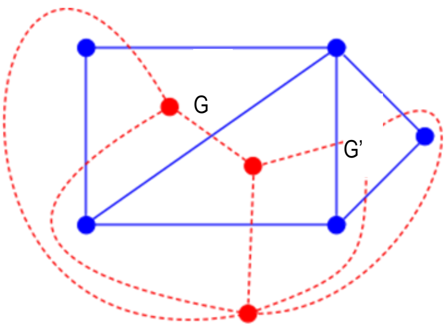


Figure 3.6: The red graph (G') is the dual graph of the blue graph (G)

Plan graph

In a plan graph, as shown in Figure 3.7, the connections between walls are represented as nodes, and the walls themselves are represented as links. The representation of 'wall' is not restricted to physical barriers alone, but includes other divisions of space as well. A plan graph of a set of spaces is related to its adjacency graph; one is called the dual of the other (Mahalingam, 2003). A plan graph, however, is not the same as a planar graph.

Adjacency graph

If each enclosed space is assigned a vertex and the adjacency relationships between them are considered to be the edges joining the vertices, the result is a simple graph generally known as an 'adjacency graph'. In an adjacency graph, each separate space is represented as a node and spaces that are in contact with another are connected by links. In this representation, spaces that are connected only at corner points are not considered adjacent. Adjacency graphs and their alternate form of representation, adjacency matrices, have been used in architectural design to establish proximal relations between spaces (Mahalingam, 2003).

Plan graphs and adjacency graphs can be integrated with other graphs, which can be embedded in them. The example shown in Figure 3.7 illustrates the modelling of a way out pattern in the floor plan of a building. Each way out element, a door or a window, is represented as a node. This node is embedded in the link between nodes that represent spaces in an adjacency graph of the plan. The way out node is also embedded in the plan graph of the floor plan.

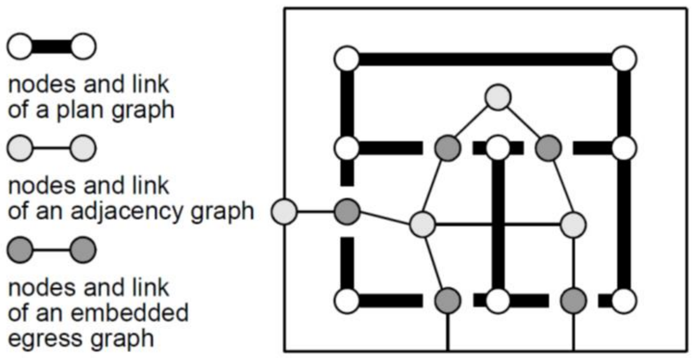


Figure 3.7: Plan graph, adjacency graph and embedded graph (Mahalingam, 2003)

Weighted Graph

If a relative weight is assigned to each edge of a graph using a number then the graph is called a weighted graph. Such weights might represent relative costs, lengths or capacities, etc., depending on the purpose. Weighted graphs are sometimes called networks.

3.3.3 Space layout representation using graph theory

Network-based space layouts cover the concept of representing spatial relations in space layouts as graphs or networks. Graph theory (Harary, 1969) is a branch of mathematics, and its implication in architectural design problem has an extensive research history. The possible application of graph theory in architectural design was first presented by Levin (1964); since then many researchers attempted developing systemic methods to transform graph representation into a physical floor plan (Foulds & Tran, 1986; Grason, 1971; Gross, 1985; Roth & Hashimshony, 1988; Roth et al., 1982).

The following paragraphs present various approaches of space planning, based on dual graph theory, which are relevant to the current research.

Dual graph representation in floor plan layout

Grason (1971) proposed a computerised space planning technique by implementing an experimental computer program called GRAMPA (GRAph Manipulating PAckage). The proposed method depends on a special linear graph representation for floor plans called dual graph representation. The main objective of the program was to solve two-dimensional floor plans for a special class of buildings, such as rectangular buildings with rectangular rooms. Grason considered the following sets of design considerations as an input to the program.

- *Location requirements to specify the adjacency of rooms, one with another or the outside wall of the buildings*
- *Size requirements to specify the allowable range of physical dimensions for each room.*

As a part of specifying the problem, Grason assumed that a set of room is given with activities assigned to them. The room with its given adjacency is presented in the first Figure 3.8(a). Adjacencies between rooms are indicated by drawing lines (edges) connecting the nodes to the corresponding rooms. In the floor plan graph, ‘edges’ and ‘nodes’ were called ‘wall segments’ and ‘corners’ respectively. A special dual of the floor plan graph Figure 3.8(b) was obtained by placing a node inside each space and constructing edges to join the nodes of adjacent spaces. The general idea of its application was to first set down the four nodes and four edges of the dual graph that represent the corresponding outside walls of a building. Then nodes and edges were added one by one to the dual graph in response to design requirements and other considerations until a completed dual graph is obtained.

Dual graph representation allows a relatively independent treatment of adjacency and size requirements. Adjacency between rooms is denoted by edges and the nodes of the dual graph correspond to rooms. The room sizes are indicated by assigning weights to these edges, which correspond to the wall segments separating adjacent rooms. This approach allows fulfilling two requirement types more directly and independently in the dual graph representation, when compared against the literal diagrammatic representations usually used in floor plan design. Grason produced incomplete dual graphs as partial design solutions. In addition, a planar graph grammar was introduced to test planarity of a graph and to generate geometric realisation of any planar graph. Edges in Grason's space adjacency graph or network are directed and weighted. Edge weights correspond to lengths of wall segments.

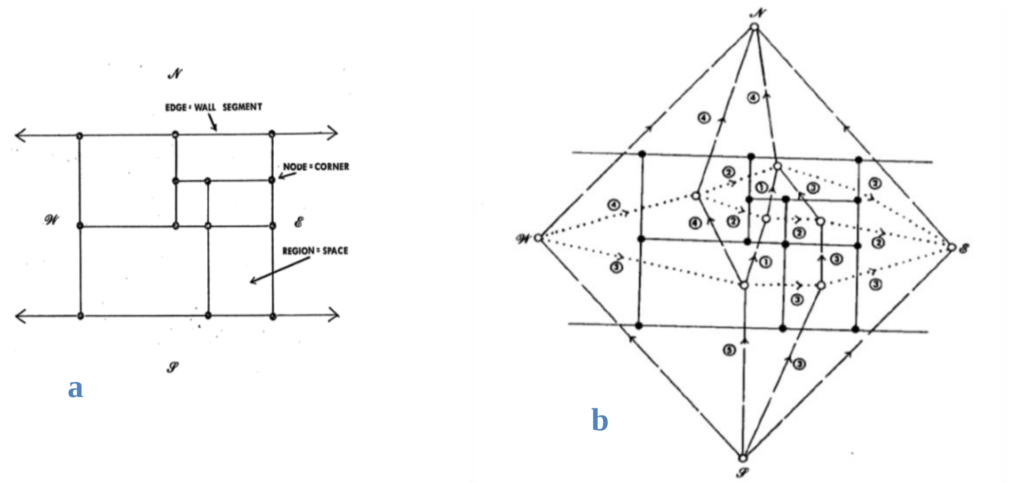


Figure 3.8: Floor plan graph with dual graph representation (Grason, 1971)

The ultimate goal of Grason's design procedure was to produce a dual graph that corresponds to a physically realisable floor plan satisfying the various design requirements. Theoretically, the proposed program is capable of producing floor plans up to a specified number but Steadman (1976) reported that the program fails for the problems with more than five rooms. Homayouni (2004) identified that the relatively long run time of the program hampers the possibility of fixing the input data in multiple times in an effort to reach to a solution.

March & Steadman (1971) also developed a similar type of network representation for building layouts. Space adjacency and space access graphs form the basis for several space layout planning systems that have been developed since.

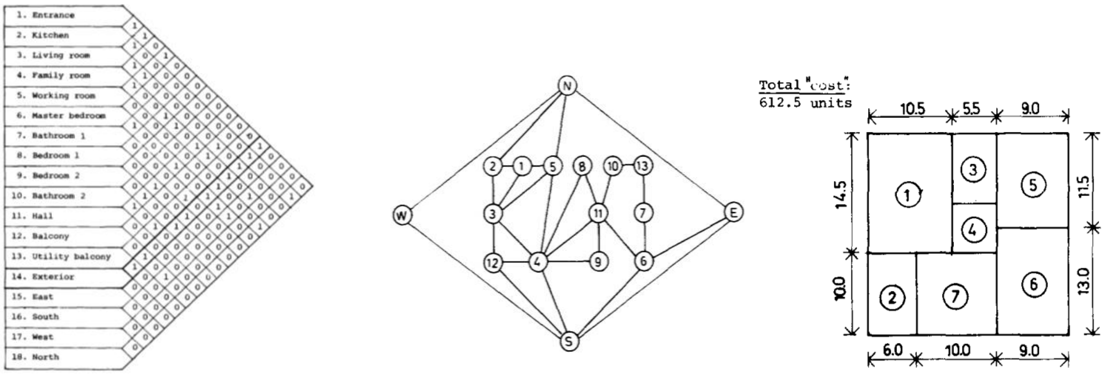
3.3.4 Transformation of graph representation into rectangular floor plan

Roth *et al.* (1982) presented a systemic pathway of reaching a dimensioned plan from adjacency graphs. The lists of cells (each room/space) and their dimensions as well as the matrix representing the required adjacencies between them were considered as inputs to the problem. A step-by-step procedure was proposed where at stage 1 authors translated the given adjacency matrix into a planar graph; each vertex representing a cell and each edge connecting two vertices that represents a required immediate adjacency. This adjacency graph is planar because it contains no intersections of edges. A non-planar graph will have to be converted into a planar graph for this technique to be applied.

At stage 2, the adjacency graph is separated into two sub graphs (one in the X direction and the other in the Y direction) by using the colouring techniques described by Grason (1971) and Roth & Wachman (1985). The next stage is to convert the colored graph into

Figure 3.8: Floor plan graph with dual graph representation (Grason, 1971)

lges between them represent distances between the walls. This method is similar to that of March & Steadman (1974) method, although the edges represent length of walls. The translation of the two dimensioned sub-graph into a physical plan was the last step of the procedure. The minimum and the maximum dimension for each cell were already defined in the problem and all possible dimensions of rooms were listed as obtained from the graph. It is worth noting that not all obtained combinations allow feasible realisations, but this method can deal with a great number of cells and can generate a large number of alternatives to fulfill the desired adjacency. The transformation of adjacency matrix to a dimensioned floor plan layout is presented in Figure 3.9.



Adjacency matrix Adjacency graph Plan layout

Figure 3.9: adjacency matrix to dimensioned floor plan layout (Roth et al., 1982)

3.3.5 Design constraints

Design is a problem solving process where designers need to deal with constraints originating from different sources. Design constraints might come from a multi-dimensional region where each dimension represents an independent design attribute; each point represents a variant or an alternative solution (Gross, 1986). Constraints are fundamental part of design, it is actually fundamental to all creation. Design constraints of a building include structural constraints, architectural constraints, environmental constraints, surface-material constraints, and many more. The spatial arrangement depends on the objective requirements, which are typically expressed by constraints. Generally, dimensional constraints and topological constraints are used to express the design objective requirements. The current research has also considered dimensional and topological constraints in the process of developing an algorithm as proposed in Chapter 6.

Dimensional constraints:

It is often defined as geometrical constraints and considered over one space such as constraints on surface, length or width, or space orientation.

Topological constraints:

Topological constraints allow specifying adjacency, non-adjacency or proximity of a space with another space or with the contour of the current floor. The topological constraints relate to the desired configuration of spaces relative to each other. These adjacency requirements can also be negative, *i.e.* objectives that require separation of spaces (Medjdoub & Yannou, 2000).

Dimensional constraints are applied to the attributes of a single architectural object whereas topological constraints are applied between two or more architectural objects. Dimensional constraints are associated with setting a minimal or maximal domain value, especially width, length and surface area. Designing a building layout is largely linked with defining the adjacency between rooms and circulations or defining the distance between two rooms as defined by topological constraints. Most topological constraints are derived from 'generalised adjacency' constraint, which is not restricted to direct contact (adjacency) but allows relative positioning of two spaces.

Prioritising constraints

In a design problem, prioritising the constraints should be considered as an integral part. Constraints in design largely result from required or desired relationships between two or more elements. According to Gross (1985), addition of constraints is as much a part of design as the search for solutions. The design process consists of adopting constraints and then exploring for 'good' alternatives within the region bounded by the constraints. A design task is not a single solution to be determined, but rather a potentially large variety of alternative solutions that may fulfil the conditions of the design specification.

3.4 PARADIGM OF BUSINESS PROCESS MODEL

A business process is a group of activities or series of tasks designed to produce specific outputs for a particular stakeholder. It implies a strong emphasis on how the work should be planned within an organisation. Business Process Model (BPM) provides a conceptual network diagram of the processes within a facility using formal Business Process Modelling Notations (BPMN) (The Enterprise Architect, 2004). The current research aims to develop a conceptual method where passenger processing activities will be used from available BPMs for Australian airports to capture the spatial requirements. This unique technique of extracting design related information from business process models requires a general understanding of the Business Process Modelling approach. Following sub-sections briefly explains BPM and BPMN using available literature.

3.4.1 **Business Process Model**

A process is a specific order of activities across time and place, with a beginning, an end, and clearly defined inputs and outputs. Every human endeavour, from planning a holiday to managing a complex manufacturing production, is governed by a process. Process models describe how activities within a process are connected, ordered and structured (Lee et al., 2007). It also illustrates activities and states logical information flow of various activities within a process. A business process is a collection of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how the work is to be done within an organisation (The Enterprise Architect, 2004).

Business Process Management is a concept that emerged in the early 20th century essentially finding ways to improve how ‘work’ is managed. BPM is a comprehensive system for managing and transforming organisational operations, as well as managing business performance (Hammar, 2010). BPM is considered as an essential phase of business process management lifecycle. It is a method to represent how organisations conduct their business and to simplify the business from its complexities (Nagra et al., 2011).

Process thinking looks at the chain of events in a company from purchase to supply, from order retrieval to sales and so on. The traditional modelling tools, such as flowchart, Gantt chart, control flow diagram etc. were developed to illustrate time and costs, while modern methods focus on cross-function activities. Unified Modelling Language and Business Process Modelling Notation (BPMN) are now the most popular notations to be used in BPM; the current research adopts BPMN to define activities within airport terminals.

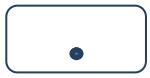
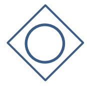
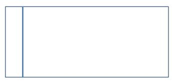
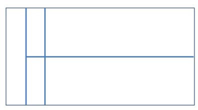
3.4.2 **Business Process Modelling Notations**

BPMN is a graphical representation for specifying business processes in a process model. It is the new standard of model business process flows and web services. Created by the Business Process Management Initiative (BPMI), the first goal of BPMN is to provide a notation that is readily understandable by all business users (Owen & Raj, 2003). BPMN provides a vocabulary for drawing business processes similar to a flowchart. The graphical notation facilitates the understanding of the performance collaboration and business transactions between organisations (C. Eastman et al., 2008). Consequently, BPMN serves as a common language and bridges the communication gap that frequently occurs between business process design and implementation (White, 2006). Diagrams produced using BPMN are called the Business Process Diagram (BPD), which has been designed to be easy-to-use and understandable but has the ability to model complex business processes. The elements in BPMN are designed to be distinguishable from each other and the adopted shapes are familiar to most modellers.

The process models of airport terminals examined in this research were produced using BPMN. Modelling a business flow starts with an event which is known as start event, then the processes are launched, and finally there is an end of the process flow. Business decisions and branching of flows are modelled using gateways. A gateway is similar to a decision symbol in a flowchart. Furthermore, a process in a flow may contain sub-processes, which can be graphically shown by another Business Process Diagram connected via a hyperlink to a process symbol. Alrashed et al. (2011) provided a detailed understanding of all notations used in airport process models documented by the Business Process Management team of the Airports of the Future research group (AotF, 2010). Their report provides a 'BPMN toolkit' that is specific for the Airports of the Future project, and the notations are described using examples taken from Brisbane International Airport. This section provides an insight into some of the core modelling notations used in the airport process models (Mazhar, 2009a) examined in this research. Table 3-1 displays a list of the core modelling elements with corresponding brief explanations.

Table 3-1: Core modelling elements used in BPMN.

Elements	**Descriptions**	**Notations**
Event	An event starts a process flow, or happens during a process flow, or ends a process flow. There are three types of Events, based on when they affect the flow: Start, Intermediate, and End. *Start Event* indicates where a particular process will start. *Intermediate Event* happens during the course of a process flow and *End Event* ends a process flow (Specification, 2008). The Start Event shares the same basic shape of the Intermediate Event and End Event, a circle with an open centre so that markers can be placed within the circle to indicate variations of the Event.	

Activity	Activity is a generic word used when a work is performed. The types of activities that are a part of a Process Model are: Process, Sub-Process, and Task. Tasks and Sub-Processes are rounded rectangles. A process is a network of 'doing things', it is a rounded rectangle. A Sub-Process is a rounded corner rectangle that MUST be drawn with a single thin black line. (Nagra et al., 2011).	 Process  Sub-process
Gateways (decisions)	A Gateway is used to control the divergence and convergence of Sequence Flow (Specification, 2008). Gateways are depicted by diamond shapes. There are four types of gateways; *parallel, inclusive, exclusive and event based exclusive*. In parallel gateway all options from this gateway must be performed. Inclusive gateway is used in a situation where or more alternatives could be taken. In exclusive gateway there are two or more options are available but only one path can be taken. It is also referred as XOR gateway. Event based exclusive gateway is similar to XOR gateway but the followed path is based on the external decisions.	 Parallel  Inclusive  Exclusiv  Event-based
Sequence Flow	A Sequence Flow is used to show the order that activities will be performed in a Process.	 Sequence flow
Message Flow	A Message Flow is used to show the flow of messages between two participants that are prepared to send and receive them. The BPMN business process diagram augments the Sequence Flow line with a Message Flow line, so that you can model people or machines sending messages to one another (Owen & Raj, 2003).	 Message flow
Lane	A Lane is a sub-partition within a Pool and will extend the entire length of the Pool, either vertically or horizontally Lanes are used to organize and categorize activities.	 Lane
Pool	A Pool represents a Participant in a Process also acts as a "swimlane" and a graphical container for partitioning a set of activities from other Pools (Specification, 2008).	 Pool

Group	A box around a group of objects within the same category. This type of grouping does not affect the Sequence Flow of the activities within the group.	
Message flow	Start Message event is a trigger of a process when a message is received. This message may be phone call, email or submission of a form.	

3.4.3 Process model used in other areas

Business Process Modelling is primarily used by the business managers and analysts to organise documents and to improve their business processes. However, BPM has also gained importance for studying operations within organisations mainly in planning and re-engineering. Most of the research works covered in the current literature review are focused on business process reengineering in the area of construction process (Eastman et al., 2008; Lee et al., 2007; Lee et al., 2011; Smith & Tardif, 2009) Business process re-engineering is the analysis and design of workflow process within an organisation, which involves rethinking and redesigning of an organisation's existing resources. According to Smith & Michael (2009), construction scheduling and business process modelling is not much different as both outline work activities with defined durations and a critical path for its workflow. They also considered process modelling as a vital tool for changing management.

Business process modelling has been used to define the functional requirements of a Building Information Modelling (BIM) standard for architectural precast concrete (Eastman et al., 2006). Lee et al. (2008) explored ways of making effective use of process model (data model) information in deriving product model (information model) and identified a logical gap between process modelling and product modelling methods; the existing process modelling methods do not support extraction of information that can be used in various activities. After examining several process modelling methods, a new formal approach was proposed called Process to Product Modelling (PPM), in which process and product modelling can be logically linked. The research project developed within the North American Precast Concrete Industry (Lee et al., 2011) aimed to integrating information within the companies that produce precast concrete and among its suppliers, consultants, contractors and clients.

Available literature shows that process models could be used in understanding the actual activity flow. But its potential in facilitating architectural design has not been investigated; this gap paved the way for the current research. Business process models developed for airports will be used to understand the complex interactions among services, technologies and stakeholders, and hence rational design philosophies are developed to obtain appropriate layout for airport departure terminals.

3.5 SUMMARY

To understand an architectural design problem this chapter presents an appropriate theoretical insight of design process. Iterative design processes are required for appropriate analysis as well as for synthesis of the obtained results to come up with a solution and, finally, for evaluating the design solution against specified criteria. In architectural design, adjacent rooms or spaces allow people to directly access from one to the other, which is commonly referred to as ‘adjacency requirement’. The layout of the spaces according their required adjacency is a core activity in a design process.

Space adjacency analysis is a useful tool in supporting building design process as facilitating design decisions to coordinate various activities performed by stakeholders by influencing the placement, clustering and distribution of spaces within a building. However, space layout planning is still considered as a ‘black box’ and obtaining an optimum solution is never straightforward. Graph theory has a long history in designing space layout; it helps to identify appropriate adjacencies, space requirements, and dimensional or geometrical constraints. BPMs have the potential to be used in identifying spatial requirements through activity flow analysis, although this feature has not been explored in literature. The current research uses BPMs to extract adjacency information as well as special requirements for airport departure terminals.

Chapter 4

Flexible Design Framework

4.1 INTRODUCTION

The importance of flexibility in building design as well as in airport design has been thoroughly discussed in literature review (Chapter 2), highlighting the necessity of further research to develop rational framework to incorporate flexibility in airport terminal design process. Limited literature available in the field of flexible airport terminal design briefly discussed previously suggested design strategies but available literature do not provide any systematic guideline. This identified research gap formed the very basis of the current research, which is primarily aimed at proposing a design framework to incorporate flexibility with specific reference to the departure terminal layout. Thorough review of flexible design philosophies, using various case studies representing different infrastructure types, paved the way for the development of the proposed conceptual design framework, which is named as Flexible Design Framework for Airports (FlexDFA).

Currently available concepts of flexibility in airport design, which are seemingly scattered, have been put together in a rational way in the current research to come up with a design strategy that will allow incorporating flexibility. The schematic development process adopted to propose the framework is presented in Figure 4.1. The proposed framework answers the first research question (Section 1.2) by incorporating flexibility in airport departure terminal design.

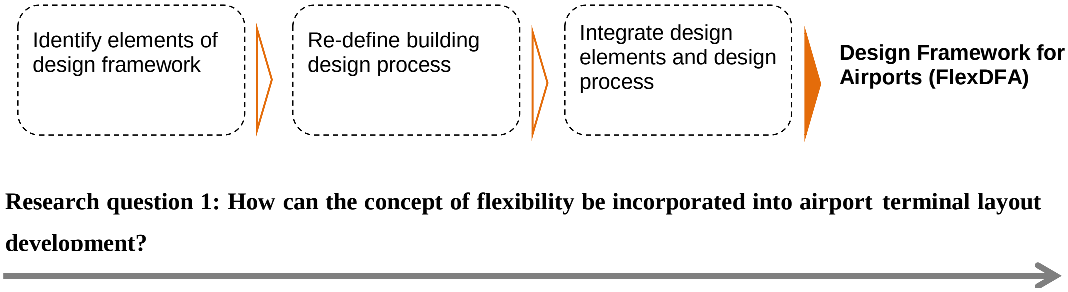


Figure 4.1: Development process of the conceptual framework

Section 4.2 presents a systemic process for collecting all relevant information that will underpin the proposed framework.

Section 4.3 identifies the design elements that contribute to the development process of the proposed framework,

Section 4.4 re-defines the traditional building design process and integrates design elements and design process together to incorporate flexibility in the design process.

And finally **Section 4.5** proposes the Flexible Design Framework for Airports (FlexDFA). This section presents the preliminary concept of the four step development processes. The detail exploration of each of the four steps will be presented in following chapters.

4.2 BUILDING A CONCEPTUAL FRAMEWORK

A conceptual framework is considered as a product of qualitative processes of theorisation (Jabareen, 2009). To explore the process of building a conceptual framework the terms ‘concept’ and ‘conceptual framework’ should be defined. According to Jabareen (2009), every concept has a history and usually contains ‘bits’ or components where all concepts are related back to the other concepts. A conceptual framework sets the stage for presenting a specific research question that drives the investigation being reported. It incorporates pieces borrowed from elsewhere, but the structure, the overall coherence, is something that is built by the researchers, not something that exists ready-made. The framework to be proposed in the current research uses the generic principles of flexibility and flexible design strategies identified in Chapter 2.

The development procedure of the proposed conceptual framework includes the following activities:

Data selection

As part of the current research, useful concepts are collected from previous literature regarding airport and building design process and also from case study observations. Those concepts are collated to propose a rational design framework allowing a step-by-step process to incorporate, implement and evaluate flexibility in the early stage of an airport terminal design process. The key design elements selected herein to ensure a systemic progression of the proposed framework, integrate three fields of knowledge i.e. flexible design strategy, level of flexibility and shearing layers of change.

Identifying and integrating the concepts

Once appropriate sources of data are identified, the research performs comprehensive qualitative analysis to integrate related concepts. Reported literature review clearly identified that there is currently no comprehensive concept of flexibility covering all aspects of airport terminal design. A limited number of researchers proposed some hypotheses that are applicable for some specific design aspects. After identifying the research gap, available ideas and strategies that have similarities are integrated in a rational way to formulate the concept of flexibility for airport terminal design. The design strategies have been re-structured to achieve this goal, and the outcome has been presented in a way that could be used to positively influence the design process of airport terminals. The aim at this stage is to interpret the relevant data and synthesise the corresponding ideas into a theoretical framework.

Analysis and evaluation

At this stage available concepts are thoroughly analysed through an iterative process, which includes repetitive synthesis actions until the proposed framework makes an appropriate sense. The research proposes a modified design process integrated with relevant design elements to produce a conceptual basis for achieving flexibility in airport terminal design. The term ‘evaluation’ is very subjective and offers different meanings to other researchers; qualitative measure are used in the current research for evaluating the proposed theoretical framework.

4.3 ELEMENTS OF DESIGN FRAMEWORK

This section presents an integration of various fields of knowledge for the development of the proposed framework. The following three fields of knowledge underpin the development of FlexDFA, which is specifically designed to cater for the design process of airport terminal buildings starting from the initial phase up to the evaluation of the adopted design.

1. Flexible design strategy
2. Level of flexibility
3. Shearing layers of change

4.3.1 Flexible design strategy

‘Strategy’, in a broad sense, is a plan for how to achieve a goal, whilst flexibility means maintaining future alternatives. Design strategy enables a design system to organise automatically to meet its requirements (Stone, 2013). A four-step strategy (presented in Section 2.5.2) is suggested by de Neufville & Scoltes (2011) for developing design flexibility in complex engineering design. Design strategies identified by de Neufville & Scoltes (2011) to achieve flexibility in engineering design are restructured and presented in a way so that those techniques could be used to positively influence the design process of airport terminals. The current research partially adopts their proposed design strategies to come up with those specifically targeted for airport terminal layout design. Following paragraphs briefly explain the steps of the proposed strategy.

Identification of major uncertainties

Dealing with uncertainty presents a major challenge because of the unpredictable future. The research suggests adopting a new paradigm focusing on the range of circumstances that might occur in a departure terminal processing. It is observed from the literature that the optimal layout largely depends on traffic level, transport technologies, and modes of managing the expected queue and so on. The expansion mechanism of an airport terminal, when required, highly influences the design process and the way an airport could adapt to incorporate the future needs. It is, therefore, extremely important to identify the associated uncertainties, as much as possible, at the very beginning of a project.

Identification of areas of uncertainties

Once the design uncertainties are identified, the next stage is to find out specific areas within a design or system that mostly have to deal with those uncertainties. Passenger activities influence the identification of appropriate areas, and the associated uncertainties. Uncertainties could originate from a number of sources throughout the life span of a departure terminal. It is envisaged that the proposed design strategy will facilitate in recognising the areas where more flexible options are required in an airport terminal.

Development of design alternatives

Any design process typically involves an iterative process by considering a number of alternatives to satisfy the given design requirements. Available alternatives would require appropriate evaluation against a range of scenarios to meet the design constraints and to fulfil the required functional requirements.

Evaluation of design alternatives

Once various layouts are developed for a departure terminal, a preferable layout which is flexible enough for a certain context should be identified. Evaluation of design alternatives is hence considered as an integral part of the proposed FlexDFA. A complete evaluation process needs to consider various factors. It is, however, worth noting that this evaluation process will depend on the project and the determining factors will change accordingly. In the case of the current research, it is envisaged that choosing a 'preferable' solution rather than the 'best' solution should get more importance at the preliminary stage. Airport terminal involves several stakeholders or decision makers, and hence, early design decisions depend on relative benefits of each of the stakeholders.

4.3.2 Level of flexibility in design process

Prior to proposing the steps of FlexDFA, a level of flexibility is defined in this section to support the development process of the proposed concept. An airport is a part of several systems those run simultaneously which reflect the performance of a terminal design process. In the present context, the level of flexibility refers to the pace of changing/ rearranging terminal layout according to time. de Neufville (2008) categorised flexibility as strategic, tactical and operational for hospital infrastructure; largely depended on how fast one would expect to use the change. The levels of flexibility suggested in the current research for airport design process follows the same terms: operational, tactical and strategic flexibility, which essentially deals with short, medium and long-term development issues for airport infrastructure.

Operational flexibility

Operational flexibility deals with frequent and potentially disruptive changes expected in an airport terminal. It refers to the ability to adapt recurrent and quick changes in an airport terminal on a daily or weekly basis such as changes in furniture or other fittings of a terminal to deal with short-term volatility. Operational flexibility should be fast, and reversible to accommodate frequent and recurring changes. For example, day-to-day operational changes occurring in ticket counters, check-in desks, signs etc. are considered under operational flexibility. Sunshine Coast Airport in Queensland, Australia provides a good example of operational flexibility through shared-use facilities, where check-in counters are shared by airlines for domestic and international flights at different periods of the day. It is worth noting that airport terminal facilities are open all year round, and therefore, operational changes should be given the greatest emphasis in flexible design.

Tactical flexibility

This category refers to relatively less frequent changes than operational changes within a structure, which mostly focuses on specific aspects of progression, suitable objectives and assessment outcomes. Tactical flexibilities may be linked to medium to long-term plan, which predicts and frames the opportunity for both tactical and strategic level of progress. The use of tactical flexibility requires a significant commitment of capital, therefore, more difficult and expensive to revert. Generally it affects the areas where changes are slower in pace than the operational, for example, changes in building services such as heating, ventilation, lighting etc.

Strategic flexibility

Airport Strategic Planning (ASP) focuses on the plans for both medium and long-term development of an airport (Kwakkel et al., 2010). Alternative approaches for the treatment of uncertainty in ASP identify a robust policy across a set of probable future that could substantially increase the lifetime of an infrastructure. Strategic flexibility allows changes in various services, building structure and building envelop. Strategic planning focuses over a long period of visible or slower changes made to the airport terminal services, skin and structure.

4.3.3 **Layering concept in airport design**

The complex network of goals and ideas, that span all layers from furniture layout to structural system, raises the dilemma between identifying terminal building layers and the implication of flexibility. The basic design philosophy of Shearing layers (Brand, 1995) will allow individual layers to be altered without affecting others, and hence different layers could be altered at different rates. Edwards (2005) suggested that changes in a terminal could be done in two basic conceptual layers – technological change and management change. Each of these layers is on a distinct timescale, where frequent interior revision reflects the commercial pressure. Relatively less-visible and less-frequent changes made to skin, structure and services represent technological change (Edwards, 2005). The literature recognises the importance of a relationship between flexibility and building layers, although no specific guidelines are available to link the theory of time-related building layers with the design of an airport terminal.

The current research integrates Brand's (1994) concept of six shearing layers for a building and Edward's (2005) two conceptual layers of change for airport terminal structure. The proposed integration of level of flexibility and shearing layers of change is presented in Figure 4.2. The changes in spatial layout have effects on stuff, space plan and service layers, and changes in physical structure influence on service, skin and structural layers. Hence, both spatial layout and physical structure have their influence on the service layer. The current research categorise pace of change as operational, strategic and tactical flexibilities. These are largely dependent on how fast the facilities of an airport terminal would require appropriate changes.

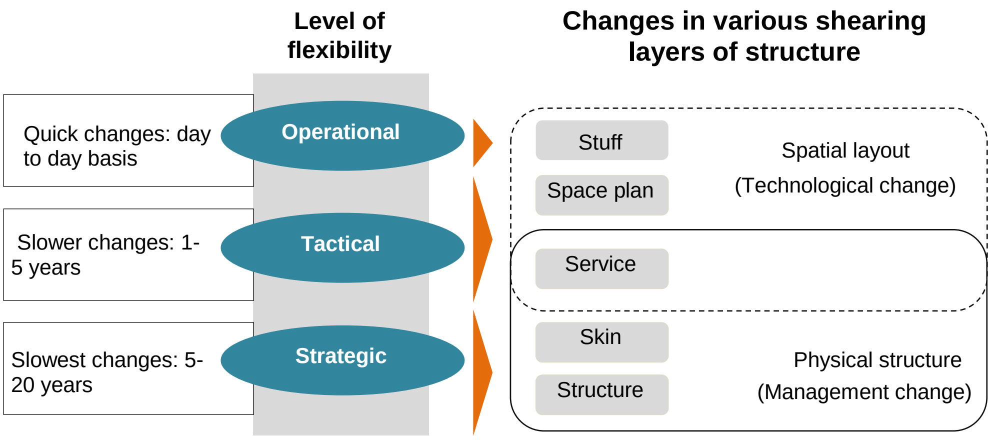


Figure 4.2: Proposed flexibility level with shearing layers of change

4.4 REDEFINING THE TRADITIONAL DESIGN PROCESS

Literature review presented in Chapter 2 provides a theoretical background of the design circumstances under which flexibility can complement in managing uncertainties at the early stage of a design process. The map of traditional design process proposed by Lawson (2005), as presented in Section 2.3.2, has three main phases: analysis, synthesis, and evaluation. The research requires recognising the inevitable uncertainties to understand the range of circumstances that might occur for a design solution. Hence, the design process needs to engage with a range of circumstances and their probabilities to appreciate the context. Identifying uncertainties of a design problem suggests redefining the traditional design process. As a result, the research suggests adding a phase that will help the designers to identify the uncertainties at the early stage of a design process. Within the traditional map of design process, a new term 'improbability' is suggested herein to be added. As shown in Figure 4.3, the design process is redefined and it is composed of actions and interactions of four dependent decision phases where uncertainty is taken as the initial course of action to be identified before going further into a design problem.

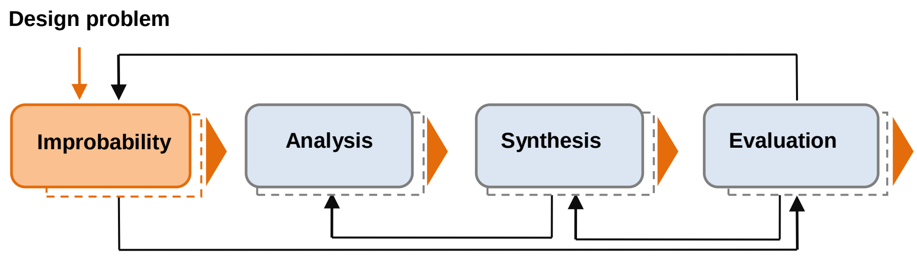


Figure 4.3: Design process redefined

The proposed design process suggests identifying uncertainties related to a specific airport at the preliminary stage of a design. This will allow designers to focus on the unlikelihood of a design, and will encourage considering various design options. Adding ‘improbability’ at the traditional design process is a significant challenge within the design framework to find out uncertainties even before commencing a design process. If a designer prepares himself to tackle some uncertainties he might face for a specific design, he will produce different solutions than a usual one. Like the traditional design process, the re-defined design process is also represented as a continuous network composed of return loops from analysis to synthesis and synthesis to evaluation. The return loops between analysis, synthesis and evaluation were proposed by Lawson (2005), whilst the current research recommends a direct link between improbability and evaluation. Identified areas of uncertainties will have direct influence on the evaluation stage.

4.5 DEVELOPMENT OF ‘FlexDFA’

Flexible design strategy, layers of airport terminal and level of flexibility are considered as three key elements of the proposed framework. Appropriate application of FlexDFA is believed to reduce uncertainty and increase adaptability in new development as well as in redevelopment process. Figure 4.4 presents the interrelation between the design elements and the design process. The flexible design strategy helps to redefine the design process to achieve flexibility and the core outcome obtained from this cognition is the proposed flexible design framework.

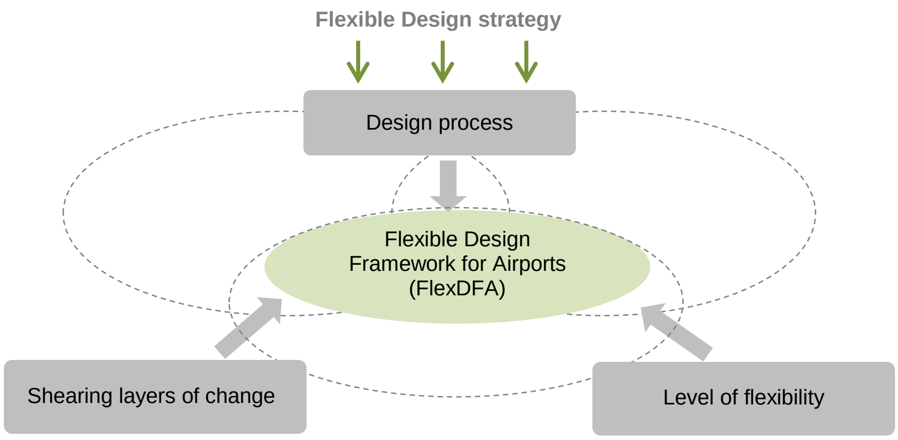


Figure 4.4: Elements of Flexible Design Framework (FlexDFA)

The conceptual framework presented in Figure 4.4 involves a four-step process to achieve flexibility in layout generation. Step 1 of the framework identifies uncertainty of the design problem; Step 2 analyses passenger processing activities to identify spatial adjacency; Step 3 is the design development stage that presents the process of initial layout development based on the information acquired from previous steps; and Step 4 outlines the determining factors to develop various layouts and discusses the process of evaluation under identified flexible design parameters. The proposed framework is a preliminary step towards developing a flexible design concept for the departure terminal layout design. The following Section 4.5.1 explains the logical development process of Step 1 and the following chapters present the various steps of FlexDFA. Finally a detailed and elaborated framework will be presented in Chapter 7.

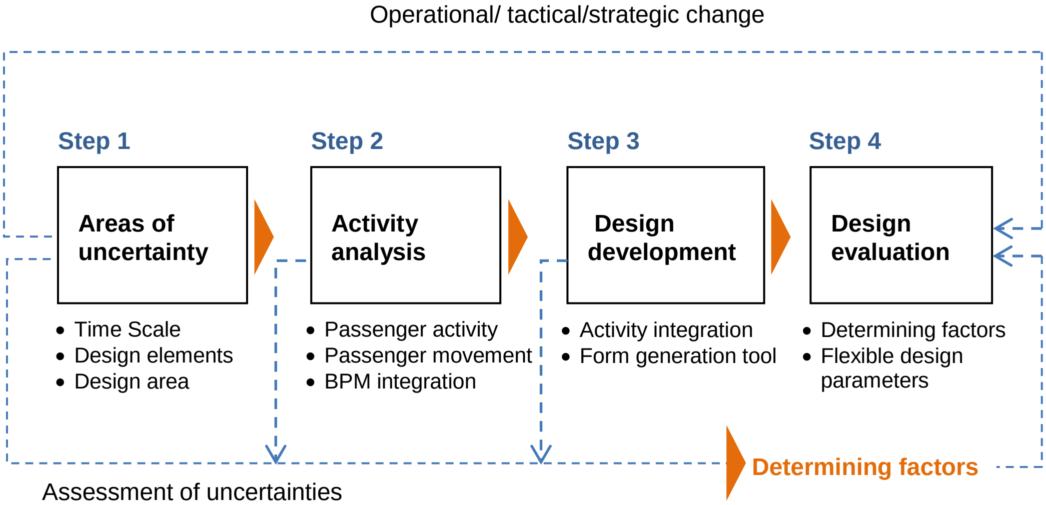


Figure 4.5: Flexible Design Framework for Airport (FlexDFA)

4.5.1 **Step 1: Identify areas of uncertainties**

In traditional design process, uuncertainty is either caused due to a lack of knowledge of the designer (de Neufville & Scholtes, 2011) or due to changes or irregularities in planning phase of a building. The implementation of the proposed FlexDFA aims to develop spatial layouts to enable an airport to respond easily and effectively to a range of uncertain scenarios without major interruptions. Under uncertainty, taking decisions become more difficult, and hence the first stage of FlexDFA seeks to identify the areas where inevitable uncertainties could occur. It is actually not possible to predict exactly what the future will bring over the life cycle of a system. However, if we do not consider ranges of possible outcomes into account from the beginning of a project the future assumptions might be completely misleading.

The theory of time-dependent layer is considered as one of the fundamental concepts, and is combined with uncertainties at the starting point of the FlexDFA. Uncertainties in every stage of a design system are very different. The current research suggests that uncertainty may occur under two main layers – physical structure and spatial layout. Based on these two categories, design decisions will be discussed in short, medium and long-term perspectives which are already classified respectively as operational, tactical and strategic flexibility. The proposed framework works as a provocative mechanism, examines uncertainty through the notions of 'spatial flexibility' as well as 'structural flexibility'.

Spatial Layout

Identification of future improbabilities in spatial layout is a way to gain control with unfamiliar changes. The changes in spatial layout relate to the changes in stuff (primarily in furniture layout), space plan and services. These changes are more frequent than those in physical structure and hence are considered as more uncertain. The development of an airport terminal layout with spatial flexibility aims to help architects making changes in composition and arrangement of a space to cope with uncertain situations. Spatial flexibility considered herein is the capacity of change to tackle both short-term and medium-term periods. In conventional design approach, an architect has to reflect the functional requirements of the client into a building plan. However, to achieve flexibility in spatial layout the main focus should be on the organisation and sequencing of spaces in a way that allows for differing compositional arrangements or makes use of space in a multi-functional way. Spatial layout in a departure terminal is significantly affected by capacity and flow of passengers.

Physical structure

Finding out uncertainty in physical structure helps to identify changes on the skin (external wall) as well as on the structure of an airport terminal. Changes in physical structure are slower than those expected in spatial layout. Typically, changes in structural life ranges up to 50 years and exterior surfaces change in every 20 years or so (Edwards, 2005) to keep up with fashion or technology. The current research is concentrated on developing flexible layouts for departure terminals, therefore changes in physical structure are not considered in the current research.

Identified areas of uncertainty

It is of high importance to identify all possible areas of uncertainty that could affect key design elements. Earlier detection of uncertainties will accomplish more efficient design process. Figure 4.6 presents the areas of uncertainty that an architect needs to investigate carefully to tackle unpredictable scenarios in a departure layout. For example, queuing areas are subject to frequent changes due to variation in passenger volumes during different periods of a day, which eventually requires changes made to the tape barriers used to organise the queuing areas. Changes in queuing areas are not only affected by the number of passengers, it is the outcome of rapid technological changes which will eventually influence on the tactical changes. For example, the introduction of self-service kiosks could significantly transform check-in layout. Operations in check-in counters are also subject to regular changes with the relevant changes in passenger flow. In most Australian International Airports, internet check-in facility and business/first class check-in facility are typically operated from dedicated counters for each category, whilst the other counters are used for regular check-in processes. This arrangement may change regularly depending on the volume of traffic or could see significant alterations due to some unusual circumstances.

The use of movable partition walls also assists in tackling uncertain situations and changing requirements of passenger demand. Changes in passenger waiting areas and in furniture arrangements are also subject to change to accommodate unusual as well as usual circumstances. If a terminal layout aims to accommodate the changing traffic volume, the furniture layout should be flexible to meet the changing demands. Arrangement of furniture and furnishing has an influence on both operational and strategic changes. Service core facilities should be updated in every three to five years to keep pace with the consequences of technological advancement and the increase in volume of passenger. Hence, changes in services are considered in tactical flexibility in the current research.

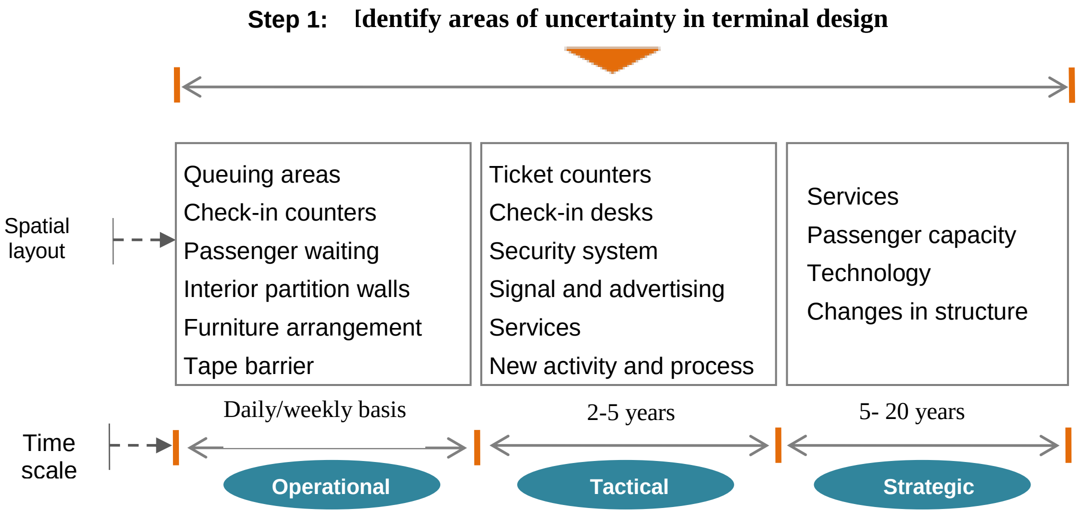


Figure 4.6: Areas of uncertainty

Tactical changes are more likely to occur in space planning and services. According to Edwards (2005), those are the resultant of technological advancements. The impact of advanced computational technology has substantial influence on the layout of today's airport design. Introduction of self-service technology increases efficiency in passenger processing, and at the same time reduces the space requirement for check-in services. Air transport guideline and security acts have seen significant changes since the terrorist attack on 9/11, and hence very careful considerations must be adopted whilst planning to implement tactical and strategic flexibility in airport terminal planning. Changes in service layout have significant influence on airport terminal development.

4.5.2 **Step 2: Activity analysis**

Airport terminal design process is dominated by passenger processing as well as passenger *vs.* airport personal interactions. The second stage of FlexDFA analyses passenger activities to gather adjacency information for initial spatial layout. The current research uses Business Process Models (BPMs), which are developed to capture the flow of airport terminal passenger activities, to obtain appropriate space adjacency requirements for various facilities. In particular, this stage of FlexDFA addresses the research gap of how passenger activities could be used as an integral part of terminal design process; and hence answers the research question 2. The relevant theoretical concepts and its usage for activity analysis are explained in Chapter 5.

4.5.3 Step 3: Design development

Design development phase, the third step of FlexDFA, provides a structured view on how airport-passenger interaction can possibly be supported in a departure layout development. Once activity analysis is completed, the next phase is to develop layouts using spatial adjacencies. The current research proposes an automated design layout generation technique using spatial adjacency obtained using BPMs. The development of an automation technique will help creating useful parametric layouts. All necessary details of the design development stage are explained in Chapter 6.

4.5.4 Step 4: Design evaluation

The final stage of the FlexDFA is the evaluation of design layout(s) against a number of proposed design criteria. Alternative design options, generated using the proposed automation technique are assessed against a set of proposed design parameters to find out whether the developed layouts are suitable to meet specified level of flexibility. The details are discussed in Chapter 7.

4.6 SUMMARY

A conceptually new design framework, Flexible Design Framework for Airports (FlexDFA) is presented illustrating the elementary concept, which is going to be elaborated in the following chapters to demonstrate the detail development steps of FlexDFA. The proposed framework combines the concepts of flexible design strategy, shearing layers of change and level of flexibility to ultimately produce an alternative design approach, especially suited for handling uncertainties in a departure terminal. Instead of developing a static plan, this framework presents how spatial adjacency from passenger activity analysis could directly influence the development of various layouts at the initial stage of design process.

The proposed framework has paved the way for a design process to exploit information obtained through passenger activity analysis. Appropriate implementation of FlexDFA should facilitate extending the longevity of an airport terminal by allowing it to accommodate changing circumstances. However, at this stage of research the use of the framework remains theoretical and is only limited to the departure terminal but it has the potential to be used as a definitive design tool for flexibility if accurately implemented using real life data. Further research is required for testing and validating the proposed FlexDFA through case studies of airport terminals. It is expected to facilitate various stakeholders to expand and to contract their activities easily and effectively as required.

Chapter 5

Spatial Adjacency from Process Model

5.1 INTRODUCTION

Passenger processing activities play a significant role in the terminal design process. Appropriate detailed analysis of such activities can facilitate the design process through identification of required spatial adjacencies. A novel conceptual approach is proposed in the current chapter to obtain adjacency information from Business Process Models to be used in the design process. The current chapter, hence, develops the 'activity analysis' step of the proposed FlexDFA (Figure 5.1) and answers the 2nd research question.

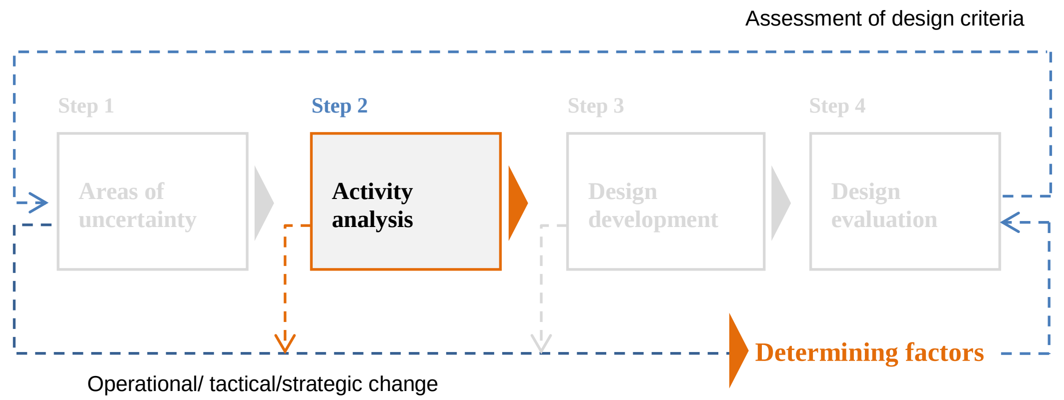


Figure 5.1: Flexible Design Framework (FlexDFA): Step 2

Section 5.2 presents an outline of the proposed integration process and discusses the research approach in brief.

Section 5.3 provides an overview of departing passenger activities and also identifies their relative level of importance to form passenger activity grouping.

Section 5.4 explains the transformation process of detail activity analysis to obtain adjacency information for space layout planning.

Section 5.5 demonstrates the development of graph representation based on the adjacency of passenger facilities. Finally, **Section 5.6** presents a summary of the chapter.

5.2 RESEARCH APPROACH TO ACTIVITY ANALYSIS

Within the existing design process, the presence and the necessity of information flow from the process models to the actual building design have been overlooked. Hence, utilisation of information obtained directly from passenger processing in the design process has been considered as an essential part of spatial allocation in the current research. Passenger processing involves an appropriate understanding of passenger activities, and finding out their relevant sequence of occurrence plays an important role in airport terminal design process. To get the required adjacency information, a list of detail processing activities is developed, and identified activities are consequently grouped together according to their spatial context. To reach the research goal, case study airports are selected first, for which available BPMs as well as the data collected from on-site observation enabled the research to obtain required adjacency requirements. The process models of departure activities are later redefined into modified Business Process Models (mBPMs) based on the proposed attributes.

5.2.1 Case study selection rationale

Case studies have been carried out both in international and domestic terminals around Australia, which aims to focus on collecting information from departure terminal operations and facilities. The case study analysis involves a number of airports across Australia. The selection of airports provides the potential to analyse different parameters of various types of airport terminals, including single-level and multi-level terminals, dedicated and common-user terminals, low-cost carrier terminals or airports with limited international/domestic capabilities. Initially, the case study airports listed in Table 5-1 have been selected. The research is carried out as a part of the ARC funded project, “Airports of the Future” (LP0990135) (AotF, 2010). The listed airports in the Table 1-1 was involved with the Airports of the Future project, due to their involved in the project, the researcher had full access to these airports. Therefore, case study airports were selected from the airports listed here.

Table 5-1: Case Study airport configuration from AotF projects

Separate International and Domestic Terminals	Integrated International and Domestic Terminals	Domestic-Only Terminals
Brisbane Perth	Gold Coast Townsville Melbourne	Sunshine Coast Rockhampton Canberra

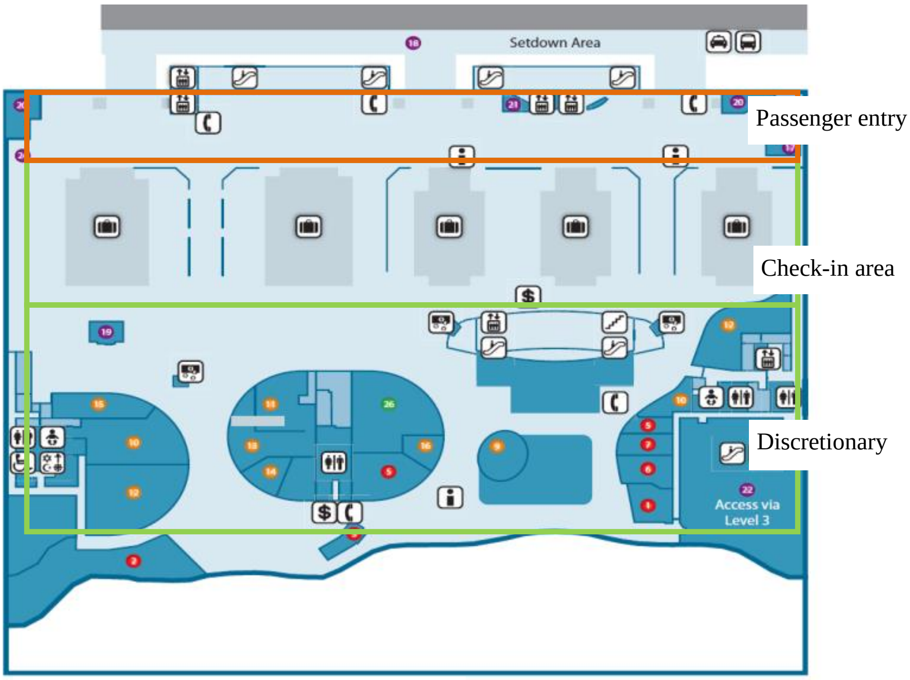
It is suggested that for a thorough understanding of the research purpose, at least one airport from the each different types of airport configuration should be selected as shown in Table 5-1. Initially, Brisbane, Gold Coast and Rockhampton airports were selected to collect detail passenger processing information. The selection included one regional airport with only domestic operations, one large airport with international services and one medium-sized airport with international services as well. The chosen airports provided an opportunity to cover a wide variety of passenger processing aspects to find out spatial requirements. Rockhampton airport, however, involves military operations and hence the airport terminal has some specific passenger activities other than usual departure terminal activities. Finally, two airports were selected for detail passenger activity analysis – Brisbane International Terminal (BNE) and Gold Coast Terminal (OOL). Brisbane International Airport is a large international airport which has separate international and domestic passenger facilities in separate floor. Gold Coast Airport is a medium-sized airport where international and domestic passenger facilities are processed on the same floor.

The current research concentrates on the experiences of departing passengers of the selected international terminals. The use of process models of the departing passenger allowed in-depth investigation for passenger activities as the processing facilities for the international departing passengers are more complex, and hence require more time to process. Departing international passengers are required to arrive two hours prior to their flight, whereas departing domestic passengers are requested to arrive 30 minutes before their flight time – this difference causes a considerable difference in passenger activities in the terminal.

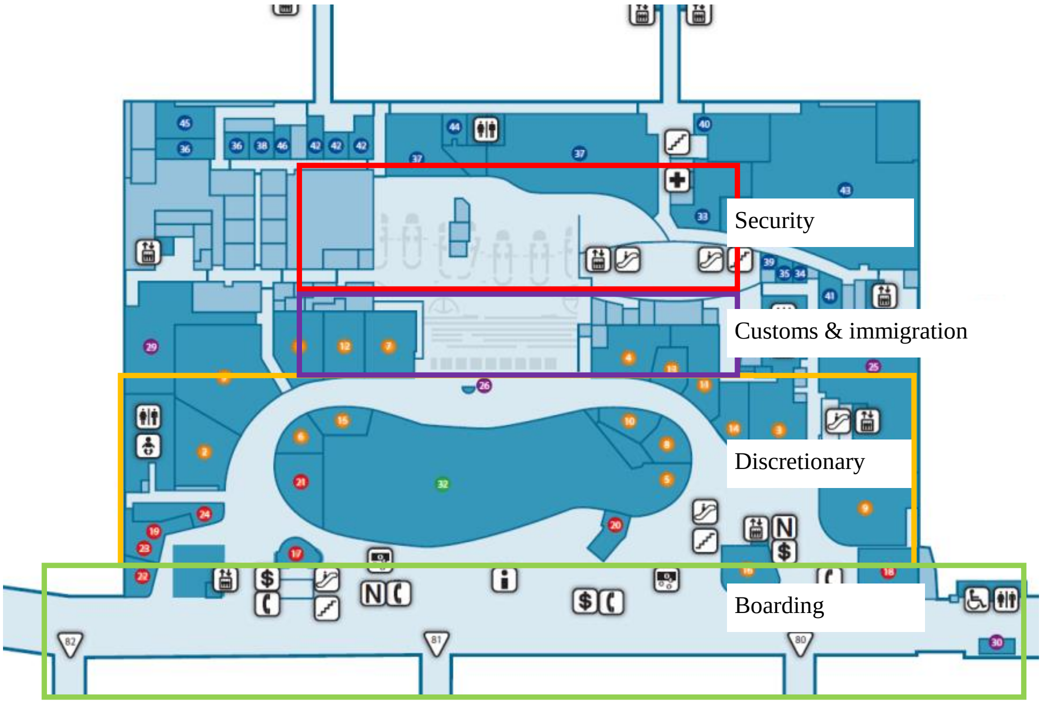
The process models developed by the Business Process Management research group of the Aotf (AotF, 2010) are examined to see how passenger processing activities could be used to get spatial adjacency for departure processing areas. Onsite observation of the case study airports are initially used to get familiar with the detail passenger activities of departure domains. The on-site observation procedure involved the researcher to closely observe each domain of activities. The researcher had permission to take photographs of passenger activities, however, security check and customs area were excluded from any kind of photographing. It is worth noting that passengers were not interviewed as part of the current research.

Case study 1: Brisbane International Airport

Brisbane Airport has separate domestic and international terminals. The International Terminal has 4 levels: Level 1 houses airlines, baggage handlers and tourism operators; Level 2 handles arrivals; Level 3 houses the departure lounge; and Level 4 houses departure check-in. The terminal has 10 check-in rows in total, where some check-in areas are designated for specific airlines and others for 'common use'. In security area, there are five security gates available to serve. In December 2012, the airport authority successfully installed and commenced operating one 'Full Body Scanner'; four additional scanners will be installed in due course. Figure 5.4 presents departing areas of Brisbane International Airport, which is spread over level three and level four of the terminal building. The departing passengers enter from level four and after finalising check-in process they move down to level three for security and customs check and finally board on to the plane.



Departure area Level 4



Departure area level 3

Figure 5.2: Brisbane International Airport departure layout (BNE)

Case study 2: Gold Coast International Airport

Gold Coast Airport (GCAPL) is the fifth busiest international airport in Australia and the gateway to one of Australia's premier tourist destinations. Gold Coast international airport is a single storey airport (Figure 5.3) handling over 5.6 million passengers per year. Both arrival and departure facilities are located on the same floor. The rectangle shown in Figure 5.3 indicates departure area.

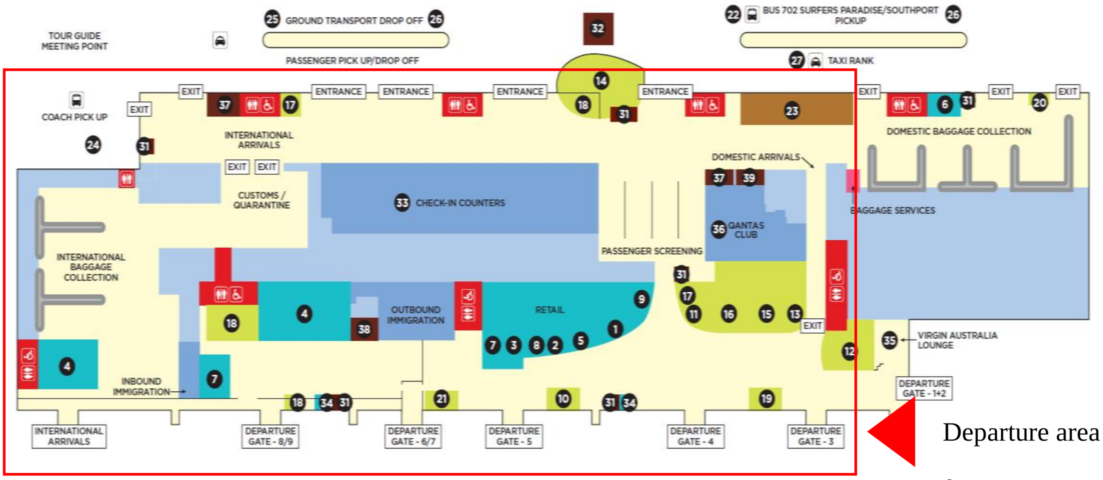


Figure 5.3: Gold Coast International Airport layout ("Gold Coast Airport," 2014)

5.2.2 Redefining BPM in articulating spatial allocation

A complete knowledge and understanding of the spatial requirement for various terminal facilities are considered as an integral part of developing departure layout in the current research. There are three common ways of mapping buildings and urban space: maps of the volumes, surfaces and edges of the built environment; networks formed by the communication, transportation and service channel; and movements and patterns associated with human activities (March & Steadman, 1971). The current research has adopted the third mapping technique as reported by March and Steadman (1971) *i.e.* activities are grouped in clusters so that each cluster represents certain common attributes.

To obtain spatial adjacency from passenger process models, available BPMs of airport terminal passenger process studied. The process models provided the sequence of activities, however, the objective the research is the associated areas. To get the spatial information the process models are redefined to determine the relationships among various departure activities. Adjacency information is subsequently transformed into network diagrams to generate spatial layout.

5.3 ANALYSIS OF BUSINESS PROCESS MODEL

The process models are obtained from the Business Process Management team of the AotF (AotF, 2010) project. They generated BPMs for several Australian airports using Business Process Modelling Notations (BPMN). The current research uses the BPM of Brisbane International Airport (Mazhar, 2009a) and Gold Coast Airport (Mazhar, 2009b) to study detailed passenger activities in the departure terminal. Brisbane and Gold Coast Airport provide different processing facilities, and hence the outcome of the current research is believed to represent a generic yet simple departure process model in the Australian context. To reach the objective of the research, a generic passenger facilitation process should be developed for the considered Australian airport terminals. The adopted process models from Business Process Management team are presented in Appendix A.

5.3.1 Generic model of departure activities

The departure process starts once a departing passenger enters into the appropriate terminal. Four main domains of departure activities are check-in, security, customs & immigration and boarding. Between these processing domains, passengers also undertake some discretionary activities such as using washrooms, shopping, getting something to eat or drink and many more. Discretionary activities and passenger entry hall are also considered as separate domains in the current research. BNE (Figure 5.4) have three areas for discretionary facilities available between terminal entry and check-in; check-in and security; and customs and boarding. The passenger processing for both airports start from check-in facility, and passengers then proceed to security check, customs and immigration, and finally board to the plane.

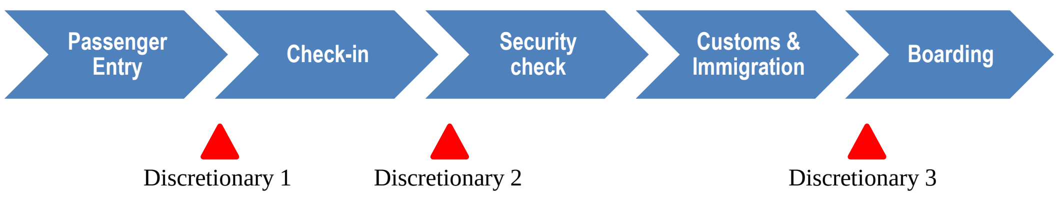


Figure 5.4: Departure facilities at Brisbane International Airport

The departure facilities in Gold Coast Airport are slightly different than those of Brisbane Airport. It has separate liquids, aerosols and gels (LAG) inspection area (Figure 5.5) and also has more discretionary facilities than BNE. The locations of four discretionary facilities are between terminal entry and check-in; check-in and security; security and LAG; and customs and boarding. In total, there are seven domains to complete departure facilitation process in Gold Coast airport.

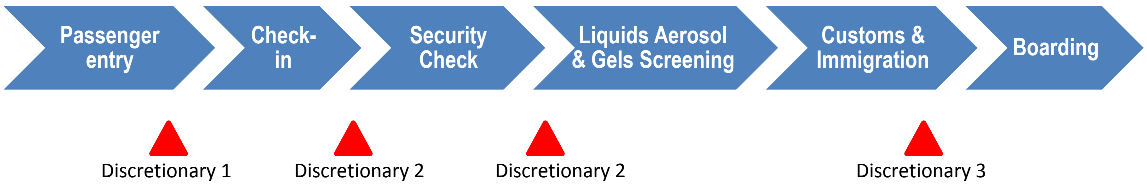


Figure 5.5: Departure facilities at Gold Coast International Airport

To reach the objective of the research, a generic passenger facilitation process should be developed for Australian airport terminals. By inspecting passenger processes of the considered airports, a macro-level description of generic international departure activities is presented in Figure 5.6 using BPMN 2 (the detail description of BPMN is presented in Section 3.4). The figure shows that once passengers arrive at the entry area they need to make a decision whether to take any discretionary facilities (such as eating, shopping, using toilet facilities or greeting people) first, or proceed directly to the check-in area. After completion of check-in there is another decision point; passengers may take any discretionary facilities available or may go straight to the security preparation area. Between security preparation to the customs and immigration process, there is no decision point, and hence passengers must proceed straight from the security preparation to the security check area followed by customs and immigration. In Gold Coast Airport passengers have options to experience discretionary facilities even between security and customs screening. Once customs and immigration process are finalised, passengers enter into another decision point – they may immediately join the boarding queue for a plane, or wait, or use discretionary facilities depending on the boarding time of his/her flight.

Figure 5.6 shows a generic process model developed for a typical departure terminal of an Australian airport. A colour code is used to identify “optional” activities; for example, discretionary activities were always marked with yellow and LAG screening in orange.

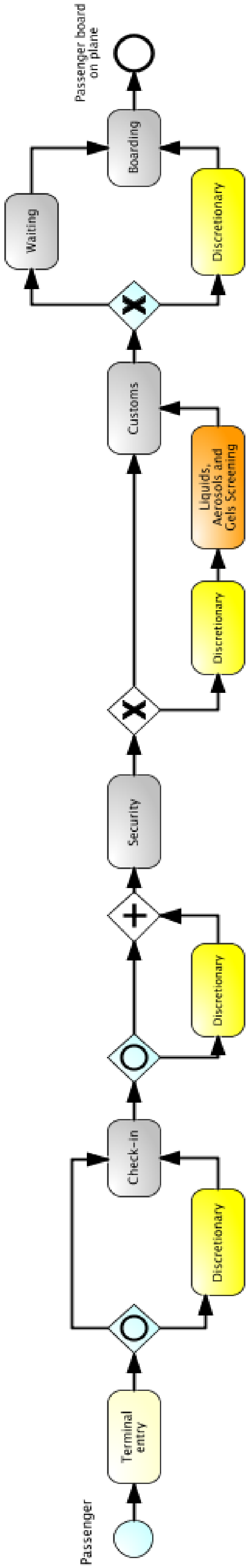


Figure 5.6: Generic process models of international departure facilities

5.3.2 **Identifying detailed passenger activities**

All passenger activities area as documented in the process models are listed under domains of departure facilities. All activities are undertaken by departing passenger classified under the following seven domains – Terminal entry, Check-in, Security Screening, LAG Screening, Customs & Immigration, Boarding and Discretionary. In BPM diagrams, each activity has a separate ID number, and there are several sub-processes to describe interactions of passenger and airport personnel in detail. For example, when a passenger comes to the check-in counter for preliminary check-in, he performs several activities and interacts with airport personnel in the check-in desk. In BPM, this activity is named as 'Perform preliminary check-in' and the detail of this activity is shown under a 'sub-process'. However, all activities of a sub-process occur in a specific area. Therefore, detail activities under all the sub-process do not need to explain here.

Table 5-2 presents departing passenger activities classified under various domains. All listed activities are identified from the available process models of Brisbane and Gold Coast Airport. Whilst preparing the list of departure activities, each of the departing passenger activities is also verified and cross-checked, while, field-study observations undertaken to make sure that no important activities are missed out in the process models.

Table 5-2: lists of departing passenger activities

Passenger activities	Activity domain
Arriving at appropriate terminal Rearrange luggage Manage liquids, aerosols and gels in belongings* Read flight information display Identify appropriate check-in row	Terminal entry
Go to regular check-in queue Go to internet check-in queue Go to business check-in queue Resolve booking /passport issue Initiate customs-specific activity by phone or in person Get tourist refund items checked* Get restricted items checked* Perform preliminary check-in* Perform luggage check-in* Go to repacking area Repack luggage Go to deposit luggage Finalise check-in* Pay fees for overweight luggage Go to service desk to deposit oversized/fragile luggage Deposit oversized luggage	
Go to security preparation area Perform preparation activities* Go to express passenger security queue Go to regular passenger security queue Undergo security metal checks* Return tray Undergo random pat-down check Undergo re-inspection* Undergo Explosive Trace Detection (ETD) screening* Receive denial of permission to board (issue found) Receive permission to continue to customs and security/sterile area	Security screening
Go to liquids, aerosols and gels screening area Perform preparation activities Undergo liquids, aerosols and gels screening* Provided with staff to private room for further check Undergo pat down check Undergo Explosive Trace Detection (ETD) screening Proceed with authorities (issue found with ETD) Continue to immigration check (no issue found with ETD)	Liquids, aerosol and gels screening
Go to queue for customs and immigration check Undergo customs and immigration check* Complete outgoing passenger card Receive permission that denied from travelling Receive permission to travel	Customs and immigration

Go to gate from main lounge Go to gate from amenities Go to gate from viewing areas Go to gate from shopping/food/beverage Go to gate from customs Proceed through boarding checks* Passenger boards on plane	Boarding
Seating/waiting Sales desks Luggage wrapping Currency exchange Unaccompanied luggage counter Restrooms ATM machine Telephone booth Tourist refund Water fountain Eating/drinking	Discretionary activities

*Indicates sub-process

5.3.3 **Grouping of passenger activities**

The passenger activities were grouped under seven domains of activity in the previous section. To obtain space adjacency from passenger activities, it is necessary to identify spatial boundaries for activities by considering the type of passenger interactions and their relevant significance. More detailed classification of activities is performed in the current research based on two criteria – importance of activity and spatial grouping of activities.

Importance of activity

In a typical airport terminal designed with several in-bound and out-bound facilities, some facilities ideally should be grouped in close proximity, whereas grouping of some other facilities is not essential. The passenger activities are categorised in this section according to their given relative importance – mandatory and auxiliary. The mandatory activities are those which must be performed to complete the departure process such as Terminal Entry, Check-in, Security, LAG Screening, Customs & Immigration and Boarding. Other activities including oversize luggage deposit, shopping, eating, using toilets, ATM machines, internet kiosks etc. may be considered as auxiliary activities. The optional activities are not an indispensable part of completing a departure process, but some optional activities are essential depending on passenger category.

Spatial grouping of activities

Passenger facilities from landside to airside are expressed using a series of areas, which are bounded or non-bounded by a physical volume. In airport terminals, several activities could take place in a single space, and hence the spaces accommodate similar activities are grouped. For example, a complete check-in procedure is more or less composed of check-in counters, queuing area, and area for some auxiliary activities, such as oversized baggage deposit, payment counter for the overweight luggage etc. Again, check-in counters and their corresponding queuing area are comprised with separate counters for various types of passengers, e.g. business class, economy class and counters for the passengers who have already completed check-in online. At the same time, passengers and airport staff interact around check-in counters.

Figure 5.7 presents passenger and airport staff interactions at check-in counter showing the level of detail activities captured in a process model. Preliminary check-in activities are recorded in one lane (see section 3.4.2 for modelling notations) and interaction with airline passengers are recorded in a parallel lane of the same pool. In order to group activities according to their spatial relationship, all check-in activities and passenger interactions, recorded in the check-in counters, are considered as a single entity: the ‘check-in counter’. The simple concept used herein for grouping passenger activities is summarised as follows: all activities and interactions taking place in a shared area are considered as a single space in the spatial grouping.

The spatial groups are identified from the general guideline of passenger terminal design available in the literature (de Neufville & Odoni, 2003; Kazda & Caves, 2007). Passenger interactions within various activity domains are associated with some specific activities. Though the activities vary in different airport terminals, the research has observed that each of the domains consists of some secure activity areas. Terminal entry is considered as a single area. Check-in facility consists of check-in queue, check-in counters, and overweight luggage counter. Security screening has security preparation, security queue, and security check counters. LAG screening is a single entity, customs and immigration checking has a checking queue and checking counters. A boarding area is consists of waiting area, boarding queue, and final boarding checking.

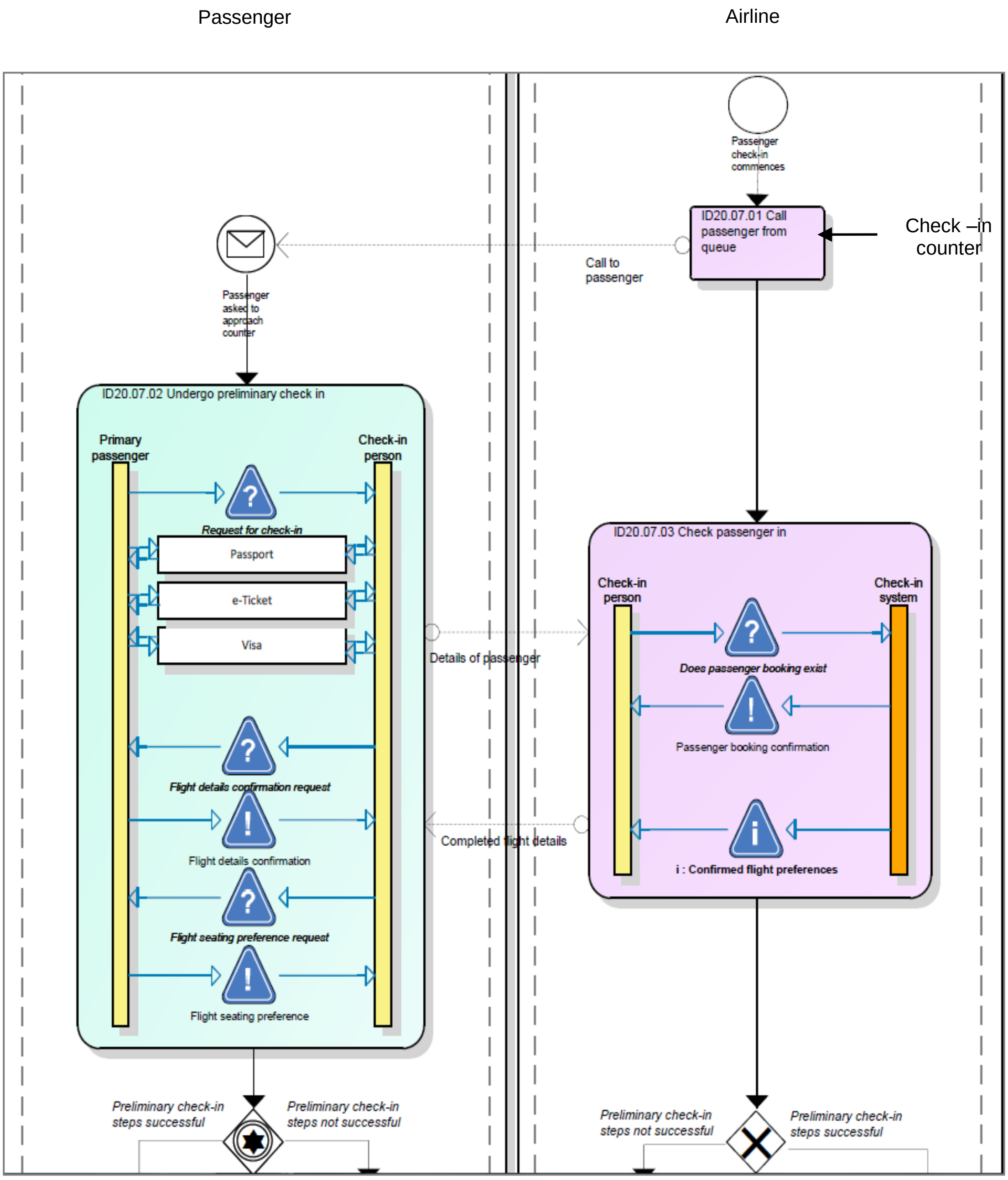


Figure 5.7: Passenger interaction at check-in counter

Table 5-2 are now listed based on their perceived importance (mandatory or optional) and their corresponding spatial groups.

Table 5-3: Grouping of activities for spatial requirements

Passenger activities	**Activity domain**	**Importance of activity**	**Spatial group of activity**
Arriving at appropriate terminal	Terminal entry	Mandatory	Terminal entry
Rearrange luggage Manage liquid, aerosol and gels in belongings* Read flight information display Identify appropriate check-in row		Optional	
Go to regular check-in queue Go to internet check-in queue Go to business check-in queue Resolve booking /passport issue Perform preliminary check-in*	Check-in	Mandatory	Check-in queue Check-in counter Overweight luggage counter
Initiate customs specific activity by phone or in person Get tourist refund items checked* Get restricted items checked* Perform luggage check-in* Go to repacking area Repack luggage Go to deposit luggage Pay fees for overweight luggage Go to service desk to deposit oversized/fragile luggage Deposit oversized luggage		Optional	
Finalise check-in*		Mandatory	
Go to security preparation area Perform preparation activities* Go to express passenger security queue Go to regular passenger security queue Unger go security metal checks* Return tray Undergo random pat-down check Undergo re-inspection* Undergo Explosive Trace Detection (ETD) screening* Receive denial of permission to board (issue found) Receive permission to continue to customs; and security/sterile area (no issue found)	Security screening	Mandatory	Security preparation Security queue Security check
Go to liquids, aerosols and gels screening area Perform preparation activities Undergo liquids, Aerosols and Gels screening*	Liquids, aerosol and gels screening	Mandatory	LAG check

Provided with staff to private room for further check Undergo pat-down check Undergo Explosive Trace Detection (ETD) screening Proceed with authorities (issue found with ETD) Continue to immigration check (no issue found with ETD)			
Go to queue for customs and immigration check Undergo customs and immigration check* Complete outgoing passenger card Receive permission that denied from travelling Receive permission to travel	Customs and immigration	Mandatory	Customs queue Customs desk
Go to gate from main lounge Go to gate from amenities Go to gate from viewing areas Go to gate from shopping/food/beverage	Boarding	Optional	Waiting area Boarding queue Boarding
Go to gate from customs Proceed through boarding checks* Passenger boards on plane		Mandatory	
Seating/waiting Sales desks Luggage wrapping Currency exchange Unaccompanied luggage counter Restrooms ATM machine Telephone booth Tourist refund Water fountain Eating/drinking	Discretionary activities	Optional	Discretionary area

*Indicates sub-process

Dedicated and non-dedicated areas

After identifying the level of importance, it is also observed from the onsite case study that some optional activities are performed in dedicated spaces, whilst others do not require, or have not been provided with, any dedicated space in a terminal layout. For example, some passengers re-arrange their luggage just after entering the terminal, some may rearrange their luggage while performing check-in activities near the check-in counter (such as, for taking out overweight items) or some passenger do not need to rearrange their luggage at all. In first two cases, the activity could be performed anywhere at the departure terminal, at the entry hall, or at the circulation area. On the other hand, optional activities such as shopping, eating, toilet facilities have dedicated space provided. The activity areas are therefore classified under dedicated and non-dedicated space requirements.

5.4 MODIFIED BUSINESS PROCESS MODEL (mBPM)

The next step of achieving space adjacency requires the information of passenger facilitation processes in a modified way so that the modified version of the process model presents the activities in terms of space. The transformation process of BPM to a concise process model has been carried out by applying appropriate spatial logics; obtained process model is named as Modified Business Process Model ‘mBPM’ in the remainder of the thesis. The aim of developing mBPM is to define the relative positioning of spaces, rather than identifying the allocation of activities or the detailed interaction between airport staff and passengers.

5.4.1 Developing an algorithm for mBPM

The term ‘algorithm’ originally referred to any computation performed via a set of rules applied to numbers written in decimal form. (Mahdi, 2013). With the help of algorithm complex problem that is difficult to solve could be approached as a series of small and solvable sub-problems. The transformation process of BPM to mBPM is going to be established through a set of rules, which manipulates well-defined passenger activity data to produce spatial relationships.

Algorithms can be written with the use of natural language, flowcharts and pseudo code (Mahdi, 2013). The current research adopts flowcharts to explain the transformation steps of BPM to mBPM. A flowchart is quite helpful in understanding the logic of lengthy problems. The reason behind writing an algorithm using flowchart is that, if the conceptual method required converting into programming language then this flowchart will help the computer programmer to edit valid procedures in terms of grammar. Figure 5.8 shows some of the basic flowchart symbols used in this project and the following paragraphs explain the symbol in brief.

Terminal: An oval flow chart shape indicates the start or end of a process, usually containing the word ‘Start’ or ‘End’.

Process: A rectangular flow chart shape indicates a normal/generic process flow step.

Decision: A diamond flow chart shape indicates a branch in a process flow. This symbol is used when a decision needs to be made, commonly a Yes/No question or True/False test.

Arrow: used to show the flow of control in a process. An arrow coming from one symbol and ending at another symbol represents that control passes to the symbol the arrow points to. It is also known as flow line.

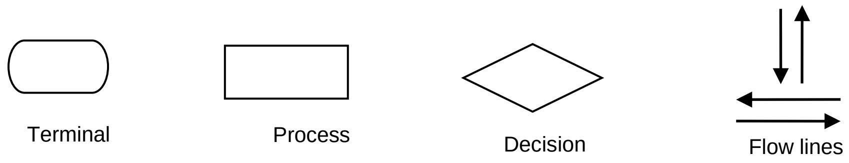


Figure 5.8: Basic symbols of flowcharting ((Mahdi, 2013))

5.4.2 **Transformation of BPM to mBPM**

A flowchart represents a series of logical operations to satisfy specific requirements, and hence, the transformation process of the existing process model to mBPM is based on a proposed logic set. The basic concept is to assign appropriate attributes to each activity so that the selection process for spatial grouping can be optimised. To assign an attribute to the activities, some logics have been developed which are assigned manually to each activity. Each of the passenger activities is listed in Table 5.2 followed the logics for the transformation process:

- Assign level of importance: mandatory/optional.
- Identify passenger activity domain: Terminal entry/Check-in/Security/LAG Screening/ Customs and immigration//Boarding/Discretionary.
- Classify space requirement: dedicated/non-dedicated.
- Identify an appropriate spatial group for each activity.
- Complete spatial grouping of all activities.

Figure 5.9 presents how the proposed logics are used for each activity to identify spatial grouping. For example, an activity ‘Check if LAG (Liquid, Aerosol, Gel) items need to be packed' is chosen from existing process model. The first step is to assign an 'importance level', whether or not the activity is mandatory for a passenger to complete the departure process. The selected activity is a 'mandatory' task for departing passengers. The next step towards spatial grouping is to identify an appropriate passenger domain. Both identifications of 'importance level' and 'passenger' domain are selected from Table 5-3. Once a passenger domain is identified, the next task is to classify whether or not the activity needs a dedicated area to be performed. At this instance, the selected activity does not require any designated area for packing LAG items and hence this goes to 'non-defined space' category. Finally, an appropriate spatial group is to be identified. For the considered activity Table 5-3 shows that 'Check if LAG items need to be packed' should be categorised under security preparation.

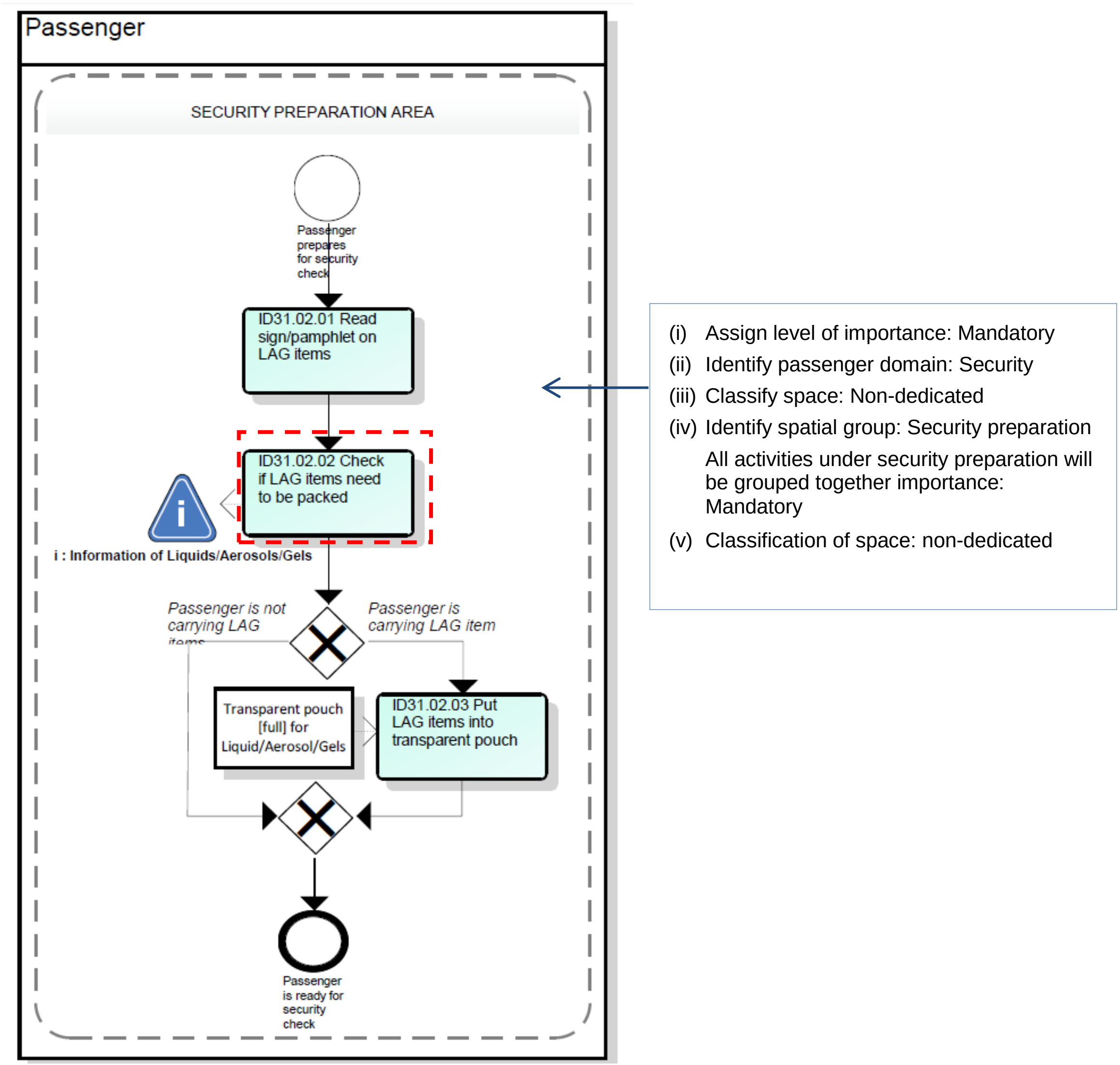


Figure 5.9: An example of passenger activity following the proposed logic

The proposed logics are now presented in the form of a flowchart in Figure 5.10. The process of obtaining spatial grouping begins with defining a passenger activity from BPM; the first step is to select each of the passenger activity from Table 5-3 and then define its importance, *i.e.* mandatory or optional. Mandatory activities should be assigned to the appropriate 'activity domain', whilst optional activities should be checked whether or not they belong to a discretionary category. Optional activities, which do not belong to a discretionary category, are also required to be assigned to an appropriate 'activity domain'. Discretionary activities, on the other hand, would require separate areas. Once an activity is assigned to a specific 'activity domain', the next step is to check whether or not this activity requires dedicated space. Finally, if the activity requires a dedicated space then it should be assigned to an 'identified terminal activity group', otherwise activities not requiring dedicated space should be put into 'auxiliary group'. Yes

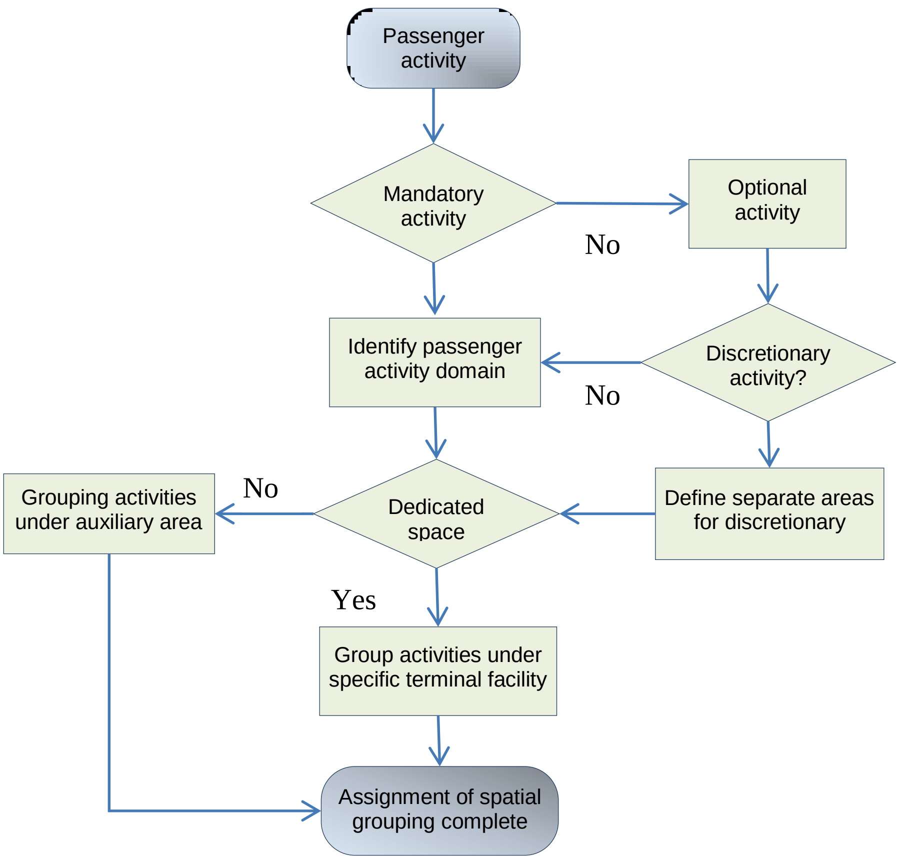


Figure 5.10: Identify spatial allocation using proposed flowchart

Table 5-2. The current research is not going to present the long lists of finding spatial grouping for all activities. Figure 5.11 presents two examples to explain how the proposed flowchart is used to find an appropriate spatial grouping for each activity. For example, two random activities are selected: Return tray and Re-pack luggage. The figures are self-explanatory and clearly demonstrate that a logical sequence is achievable to identify spatial grouping for each activity.

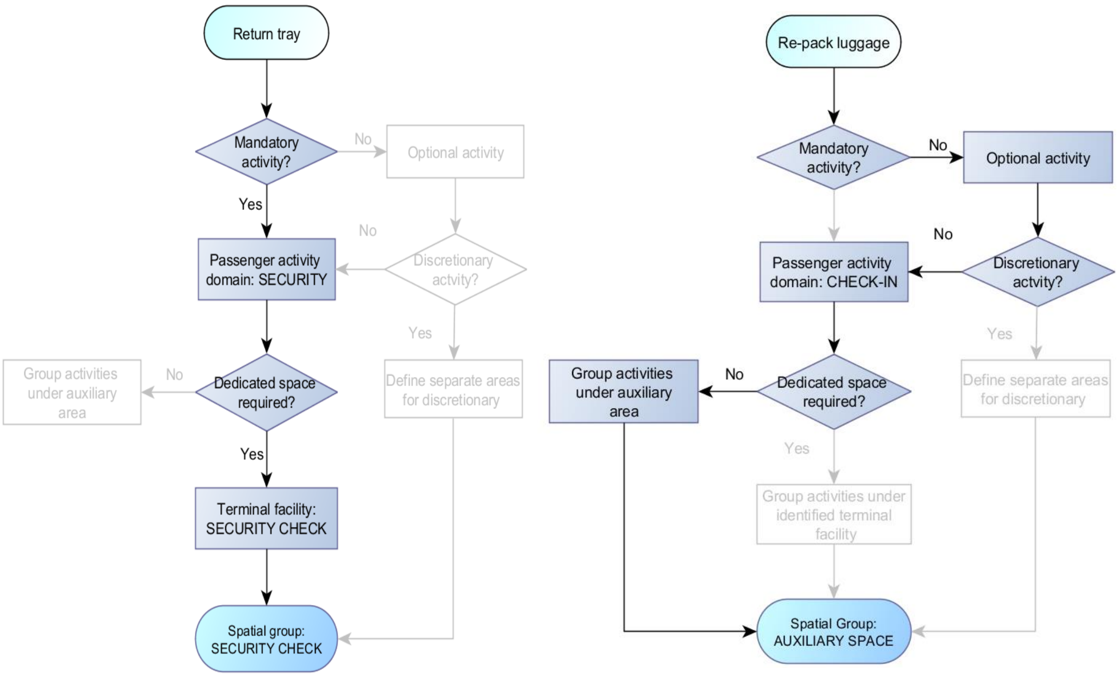


Figure 5.11: Identifying spatial allocation following the flowchart

Once all passenger activities are assessed using the proposed logics the allocation of spatial grouping for each activity is finalised. All activities are now expressed in terms of their spatial requirements. Hence, the necessary information required for the transformation process of BPM to mBPM is gathered. Now to develop the mBPM all departing passenger activities listed in Table 5-3 identified under spatial requirements. A generic departure process of Australian international airport is presented in Figure 5.6. The developed mBPM is the detailed process model of various complex activities that follows the generic process model of departure processing presented in Figure 5.10. The mBPM has been generated using ‘Signavio Process Editor’ version 4.6. Signavio’s Process Editor is the intuitive platform for professional process modelling. It offers a web-based solution for modelling business processes using BPMN 2.0 (Signavio, 2013). All departure activities are now presented here in terms of area in the figure 5.12.

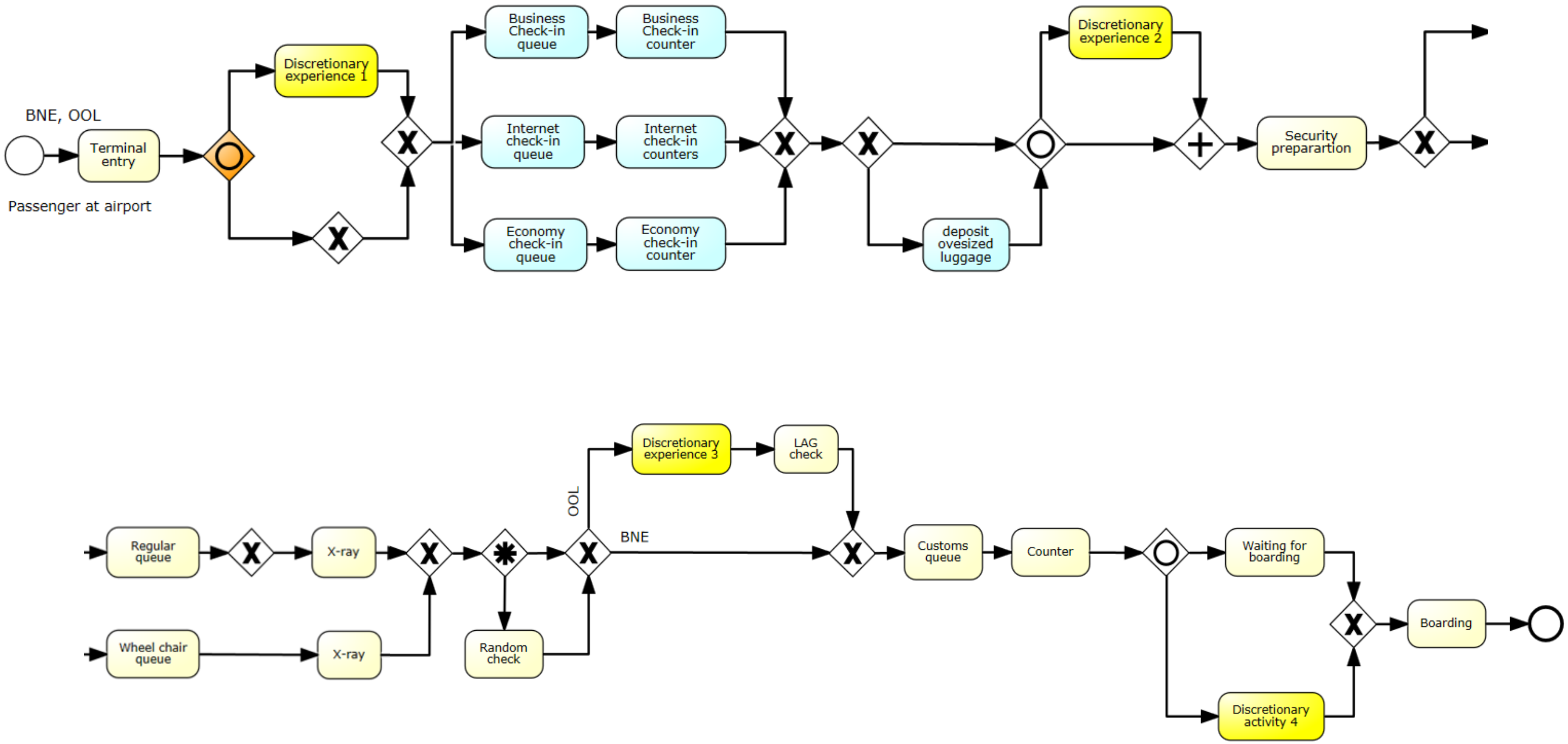


Figure 5.12: mBPM of passenger activities in Australian airports

The mBPM presented in Figure 5.12 shows that once a passenger enters into the departure area an ‘event’ starts, and then he enters into a decision point, which is represented as ‘inclusive gateway’ used in a situation where one or more alternative could be taken) in the model. From that area, the passenger can either join the check-in queue or take a discretionary act, and then can join at one of the check-in queues. After completing check-in procedure from a check-in counter, the passenger comes to another decision point, where he can go straight to the discretionary facilities or may move on to the security preparation area but if the passenger needs to deposit any oversized luggage he goes to the oversize luggage counter. When the security preparation is complete, the passenger enters into another decision point, which represents ‘exclusive gateway’ (when two or more alternative path is available, however, only one path should be taken); from that area the passenger has to join in one of the following queues: the regular queue or the express queue. After finalising customs and immigration, there is another decision point for the passenger on whether to join the boarding queue, to take a discretionary act, or to wait in the waiting area.

5.4.3 **Space adjacency analysis**

The developed mBPM provides a set of requirements for an airport terminal layout in terms of spatial adjacency. The group of passenger activities identified in mBPM expresses the relative position of functional spaces as well as the proximity of functionally of related spaces, and hence, it answers research question 2. For example, check-in counters and check-in queue should be located at close proximity; but at the same time depositing oversized luggage may be part of check-in process and it could be located in a separate location because it does not need to be immediately adjacent to check-in counters. The space adjacency analysis from the mBPM provides the following information to obtain initial terminal layouts.

Placement of spaces

The developed mBPM creates links between spaces through passenger activity grouping. It should help appropriately locating certain activities in layout planning based on the obtained spatial relationships.

Zoning and separating conflicting activity

The activities that belong to the same facility are treated as one internal mass of space in the modified model. The identification of zoning and the division of spaces according to the zoning will influence the organisation of the terminal layout and corresponding circulation system.

In a case of passenger terminal layout, each of the passenger domains should be positioned according to the processing order. For example, security check must come after check-in process, therefore, in mBPM, security area is separated from check-in as well as from other facilities that are associated with the check-in.

Selection of circulating geometry

When the placement and location of activities are determined the spaces requiring contiguity, their size and the extent to which they will share terminal facilities have a major influence upon the selection of the circulation geometry. Placement of the activity areas is identified from mBPM, which will have influence on the determination of initial circulation pattern of passengers, as well as the geometry of the circulation area.

Overall shape of the terminal layout

The adjacency requirements of passenger processing will help to determine sizing of spaces which must be integrated into the terminal configuration.

Selection of furniture layout

Once the initial layout of the passenger terminal is developed, the space adjacency identified in mBPM will affect the decisions about the detail furniture layout and the placement of required windows and doors.

At this stage, no restriction on size and shape of room/area has been placed in the current research. mBPM identifies the requirement to define which activity areas should be adjacent to each other, and hence the need to share some length or boundary of the other activity area.

5.5 GRAPH REPRESENTATION

The use and importance of graph theory in architectural layout have been already discussed in the literature Section 3.3.2. The current research develops a graphical layout using the adjacency requirements obtained from the developed mBPM. The graph representation uses graph theory (Harary, 1969) where further simplification may be necessary to produce a planar graph to achieve a suitable layout. The obtained planar graph is then elaborated into a physical layout adding dimensions in Chapter 6.

5.5.1 mBPM to adjacency graph

Each activity involved in the passenger process presented in is considered as a vertex/node and the connections between those activities are considered as edges/links. The discretionary activities are grouped together and placed in four positions; between passenger entry and check-in process, check-in process and security process, security and customs and the fourth one in between customs and boarding. Each of the activities with the given acronym presented in Table 5.4.

Table 5-4: Notations used in graph layout

EN	Entry
DS1, DS2, DS3, DS4	Discretionary activities
DH1, DH1, DH3, DH4	Departure hall
ECQ	Economic check-in queue
BCQ	Business check-in queue
ICQ	Internet check-in queue
LC	Regular check-in counter
BC	Business check-in counter
IC	Internet check-in counter
OL	Over weight luggage deposit
SP	Security preparation
RS	Regular screening queue
ES	Express screening queue
X1, X2	X-ray
RC	Random check-in
LS	LAG Screening
CQ	Customs and immigration queue
CI, C2	Customs and Immigration counter
WA	Waiting area for boarding
BD	Boarding

The obtained mBPM presents passenger processing activities in terms of space. Each 'Task' identified in the mBPM (each task represents passenger activities combined in terms of area requirement) is considered as a node and the 'Sequence Flow' between activities are connected as links. Figure 5.13 presents adjacency graph mapped from mBPM showing the adjacency requirements of departing terminal facilities. This adjacency graph is presented as an adjacency network could be used for a series of required plan relationships. It is worth noting that the adjacency graph does not necessarily represents the complete picture of all considerations to be taken into account when planning such a complex design like an airport terminal. According to the spatial requirements, some of the areas should be placed in close proximity and some do not.

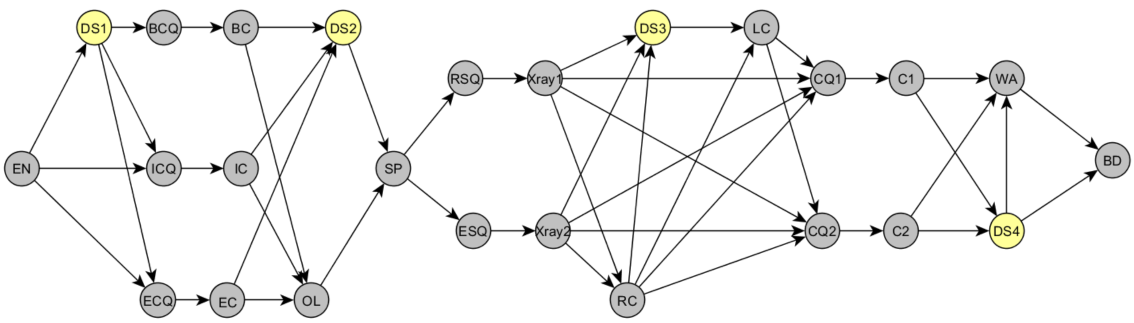


Figure 5.13: Adjacency graph obtained from mBPM

5.5.2 **Checking planarity of the adjacency graph**

A graph can only be converted into a realisable floor plan if it is planar and hence planarity should be checked for the obtained adjacency graph. The graph presented in Figure 5.13 has several intersections, from the definitions of graph theory this is a non-planar graph (see section 1.4.2 for graph theory). If all areas of a required graph have to be realised in a single level then the adjacency graph should be a planar one. As the current research is considering that all departure activities are occurring in the same level, it requires testing the planarity of the adjacency graph and should be converted into planar graph if required.

There are several mathematical theory and proven algorithms available in the literature to verify the planarity of a graph. However, with the help of computer programs it is also possible to check the planarity of a graph without going into any explicit mathematical theorem. The current research used yEd, a graph editor (yWorks) to draw and test planarity of a graph. Using yEd the adjacency graph was tested for planarity . Using yEd, the developed adjacency graph is a non-planar one (screenshot presented in 5.14. To meet the research purpose, the graph now should be now turned into a planar graph.

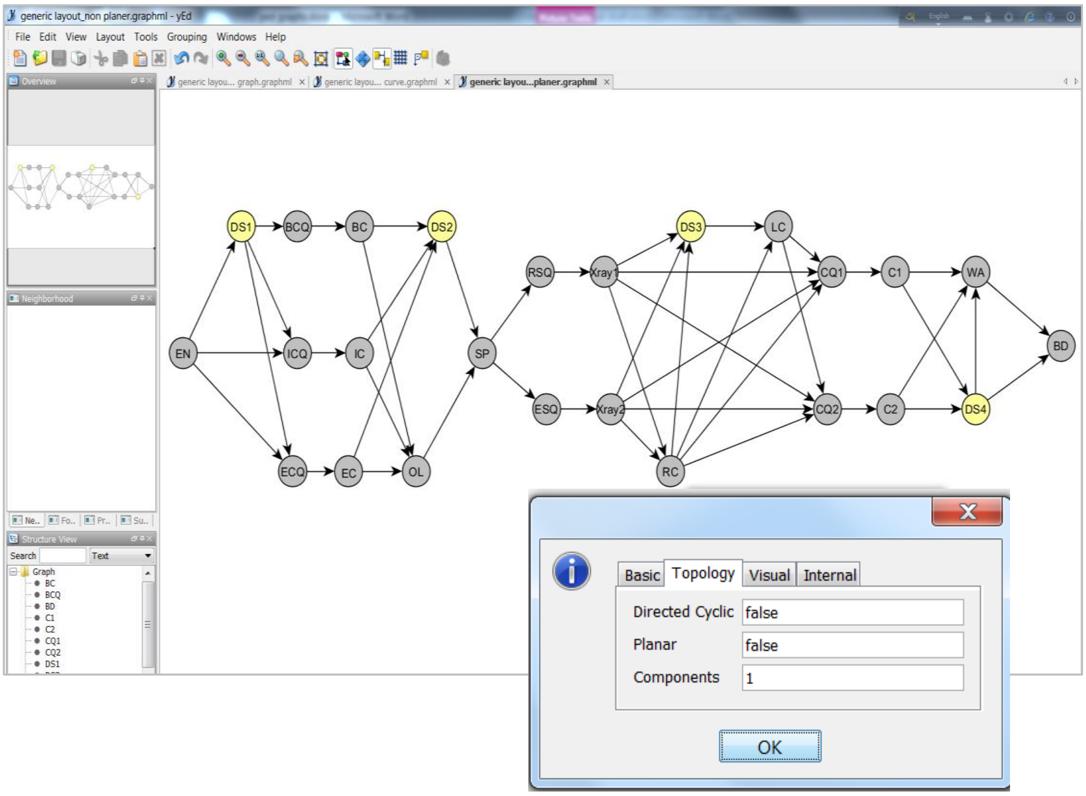


Figure 5.14: Adjacency graph showing the planarity test result

A non-planar graph can be turned into a planar one by using following methods (Hashimshony et al., 1980):

1. Adding vertices instead of unavoidable crossing links.

2. Cancelling some of the links forming at the unavoidable crossings.

The adjacency graph in Figure 5.15 shows four unavoidable crossing links and the current research work adopts the first method to overcome this situation. Adding vertices to a graph suggests an additional functional unit in a plan. The addition of an extra vertex in the current context considers addition of a circulation area inserted between nodes connected by crossing links.

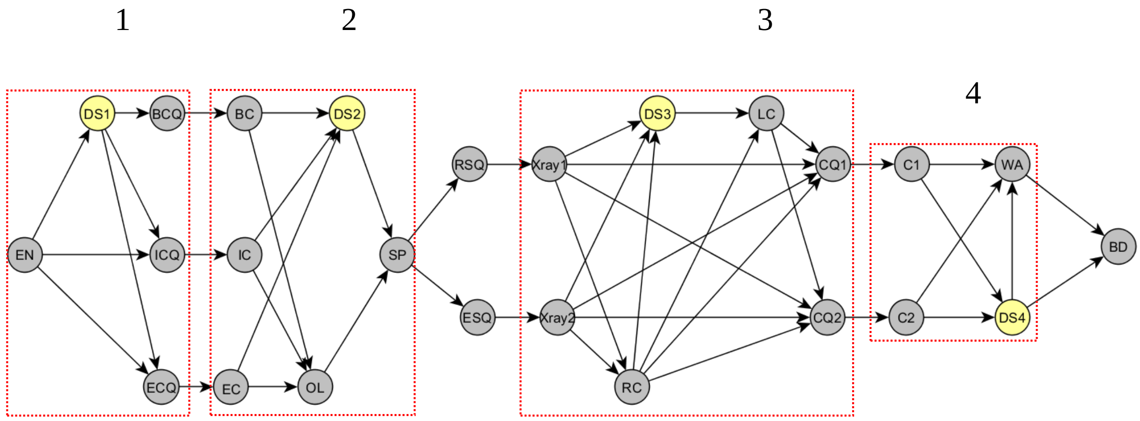


Figure 5.15: locations of crossing links

Four vertices have been added one by one between the cells connected by crossing links. After adding each vertex to the unavoidable crossings, the graph is analysed in yEd to check the planarity. After adding three extra vertices DH1, DH2 and DH3 at the crossing links the graph is analysed as a ‘planar’ graph (presented in Figure 5.16), although one crossing link is still apparent between four nodes (C1, C2, WA & DS4). However, this crossing is easily avoidable when the link from C1 to DS4 is redrawn along the outer skirt of the graph, which makes the graph into an obvious planar graph as required to proceed to the next step. However, in terms of spatial adjacency a straight circulation is required in between customs and immigration counters to the discretionary and waiting area. Hence, an additional vertex is added to avoid the visible crossing whilst maintain the required adjacency.

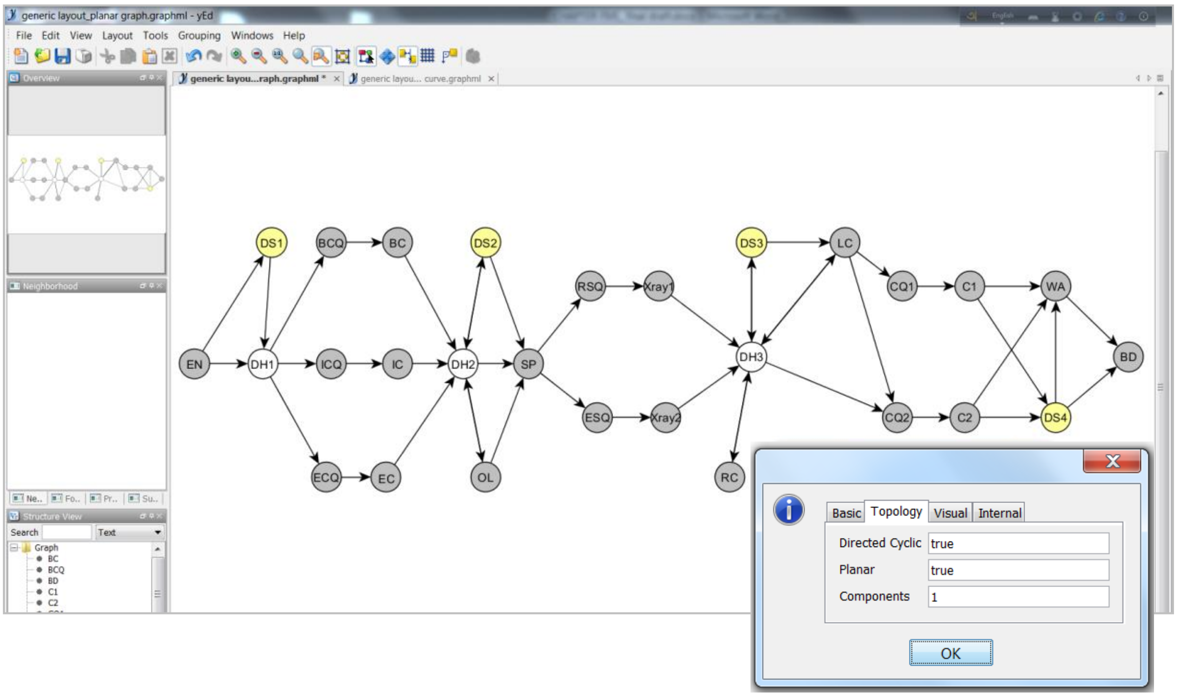


Figure 5.17: Planar graph showing a crossing link

The final graph with four additional vertices is presented in Figure 5.17. This adjacency graph has four added circulation area in terms of departure hall, named, DH1, DH2, DH3 and DH4. The planar graph shows the topological relationships in terms of spatial adjacency among terminal facilities which should be satisfied in an airport terminal layout. It should be noted that the obtained adjacency graph does not represent a unique plan, and hence the designer/architect has the freedom to work with great

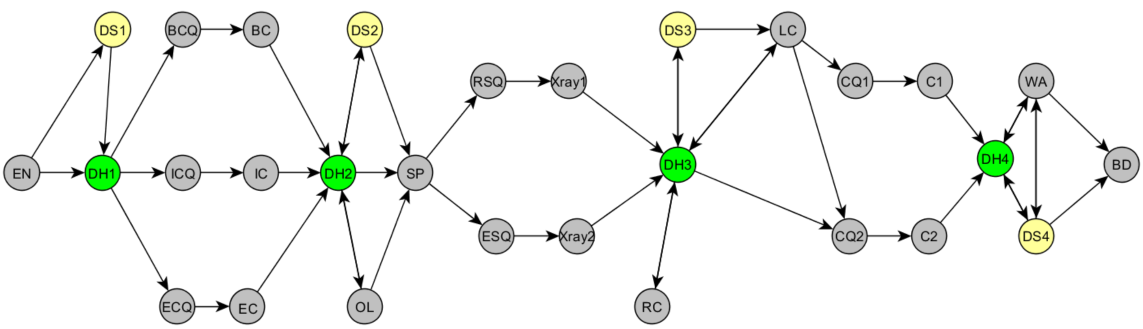


Figure 5.16: Planar graph showing required adjacency

variety of possible architectural plans that meet adjacency requirements.

5.6 SUMMARY

An airport is a process-driven building, where the design depends on the planned work processes that enable an airport to operate 365 days a year. The research method proposed herein for obtaining spatial adjacency from process models of passenger activities is a novel approach. The on-site observation and retrospective analysis of the BPM, developed a modified process model in a unique way to represent spatial relations of various passenger domains. Detail passenger activities have been categorised under seven domains and then the activities are grouped based on their spatial requirement and relative importance. Analysis of passenger activities in process models provides information on passenger movements and spatial requirements of corresponding terminal operations and facilities.

The proposed transformation method provides a structured view of airport-passenger interaction and shows the potential to support the decision-making process in layout design. In general, a layout deals with objects (building facilities, rooms etc.) and their relationships, where the use of graph theory has been employed to utilise the initial space allocation data from the modified process model. The developed mBPM provides a set of requirements for an airport terminal layout in terms of adjacency.

The benefit of applying this approach is that a range of adjacency networks can be generated to match various options for a new or existing terminal building. When planning for a new building, this can ensure that the selected design can accommodate a range of process configurations before it is documented. This method can also be applied to existing airport terminals to assess how existing processes are accommodated, or to assess how a revised process network will impact on the use of existing facilities.

Chapter 6

Layout Development

6.1 INTRODUCTION

Development of space layout planning follows a series of procedures, each with their own set of steps for generating the required information. Space adjacency analysis, which is an integral part of the early stage of a design process, is considered here as a prime research objective. This stage of the proposed design framework develops spatial layouts from the adjacency graph developed in Chapter 5. In particular, the development process of the spatial layout is achieved with the help of an automation technique. The proposed automation technique demonstrates a concept that can eventually be developed as a useful tool to achieve flexibility in the layout development process. Automation technique creates a direct link between the number of passengers being processed through departure terminal and the area required for each activity.

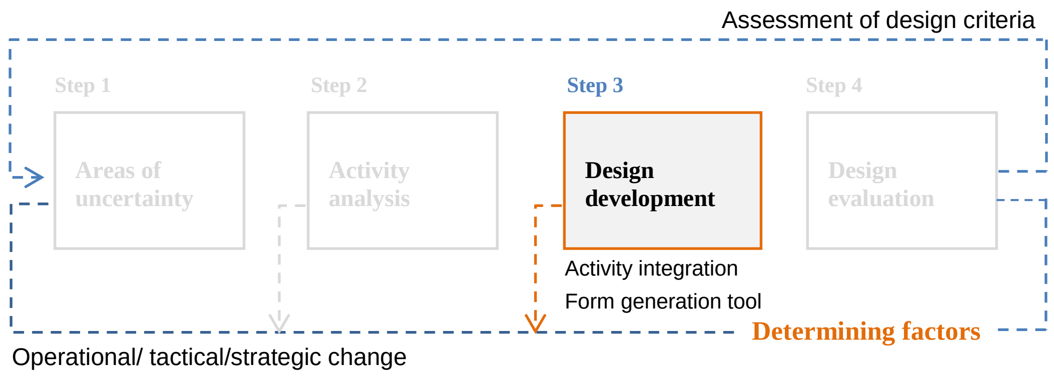


Figure 6.1: Flexible Design Framework (FlexDFA): Step 2

The process of layout development has been carried out in four steps. The outline of the design development process is presented in Figure 6.2.

Section 6.2 develops the floor plan dual of the adjacency graph (as explained in Chapter 5) as a design requirement.

Section 6.3 demonstrates the assignment of relative weights to the nodes of the dual graph from passenger activity count.

Section 6.4 develops a computer plug-in ‘Flowgraph’, which serves as the ‘input model’ for the ‘Floor Plan Generator’.

Section 6.5 presents the ‘Floor Plan Generator’, an algorithmic code written within ‘Grasshopper’ (a plug-in tool for parametric software Rhinoceros) to obtain automated spatial layouts.

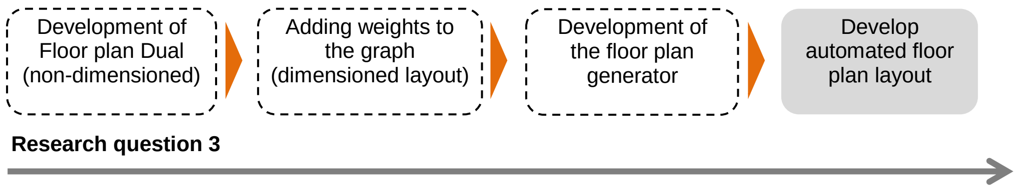


Figure 6.2: Phases of design development

6.2 ADJACENCY GRAPH TO FLOOR PLAN LAYOUT

Graph realisation is a process that allows generating floor plan from an adjacency graph; each layout corresponds to a single graph but each graph may correspond to several floor plans. Available methods for achieving spatial layouts using graph theory were described in the Section 3.3.2. The current research aims at developing a new concept using the very basic theories related to graph analysis. This led the researcher adopting Grason’s (1971) research method to obtain floor plan dual, and March and Steadman’s (1971) method to add relative weights to the dual graph. Despite being proposed in more than 4 decades ago, these concepts are still being used in relevant research and form the very basis for layout generation from adjacency relationships. The current research also demonstrates their suitability in obtaining flexible floor plan layouts in airport departure terminal. The adjacency graph obtained from Chapter 5 is uniquely defined by nodes and edges where each node corresponds to a spatial activity group and an edge between two nodes represent the adjacency between two activities. Grason (1971) selected a formal class of floor plan diagram and obtained dual of the floor plan graph by placing a node inside each space and constructed edges to join the nodes of adjacent spaces. Chapter 5 illustrated the suggested process of obtaining a planar graph from the adjacency requirements, and now the planar needs to be transformed into a physically realisable plan layout.

According to March and Steadman (1971) a given set of data only acquires significance when we map it onto a pattern of some kind, and the context of the data is important in regards to the kind of mappings is identified as appropriate. A graph can be mapped in different ways (graph isomorphism) maintaining the same properties. Hence, the same graph can be mapped in a number of different plans providing some flexibility in layout generation.

The present research makes a simple assumption that the area of the terminal building and the associated activities are rectangular in plan, and hence the adjacency graph is converted into an orthogonal rectangular dual. In the adjacency graph, the nodes stood for areas for passenger activities and the edges stood for adjacencies between spaces. The dual graph representation is comprised with nodes, edges and regions. A rectangle is placed around each activity graph and the edges of the adjacent rectangles are placed in such a way that the connecting nodes could share the area. The resultant floor plan dual represents the followings:

- The plan is composed of some reasonably identifiable rectangular areas.
- It maintains all required adjacencies.
- The plan provides continuity and has no overlapping.

The developed floor plan dual presented in Figure 6.3 is a robust and yet simple layout that can be mapped in a great variety of possible layouts. The floor plan dual mapped the adjacency requirements directly into rectangular spaces. It should be noted that the rectangular areas presented in floor plan dual provide a graphical representation to the designer showing how each of the activity areas should be placed in regards to required adjacencies. The rectangles do not necessary dictate that the activity areas have to be a rectangle in shape or the areas should be enclosed by some kind of partitions or walls.

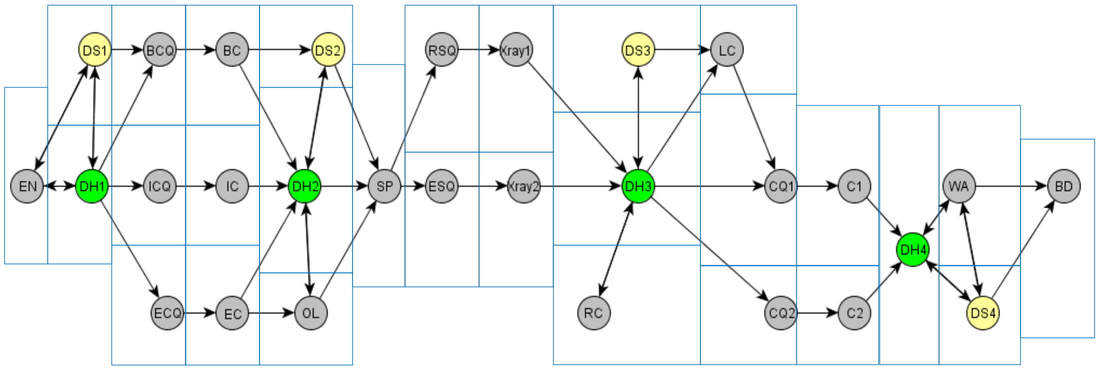


Figure 6.3: Possible floor plan dual from adjacency graph

6.3 ADDING RELATIVE WEIGHTS TO THE DUAL GRAPH

The floor plan dual presents an initial spatial layout, which could be transformed into dimensioned physical layout based on passenger processing activities. One of the basic principles of network flow, Kirchhoff's Current Law, KCL (Robbins & Miller, 2000), will be used in the current research to obtain relative weights based on passenger flow. The concept of KCL can be used to produce a graph representing adjacencies and relative positions of rooms in a plan with exact dimensions and shapes. The current research will exploit such network concept to obtain a rational layout for a departure terminal of an airport.

6.3.1 Dual graph representation

This section derives the sequential process of adding relative weights to the dual graph as presented in Figure 6.3, where nodes symbolise workspaces, and links joining the nodes refer to the shared boundary between adjacent spaces. To transform this dual graph into a layout, every link used to join the adjacent nodes must have an associated numerical value representing an appropriate weight. March and Steadman (1971) allocated the dimensional weights in terms of modules but the current research adopts a different approach. Passenger activity count in each processing activity is used to obtain relative weights from each node, where each node essentially refers to a space of one/more activities. The relative weight from each node is considered as the corresponding weight for the link connecting two nodes.

The flow of passengers in an airport terminal could be represented as an analogue to those observed in an electrical circuit and hence Kirchhoff's Current Law (KCL) could be used to determine appropriate weights to links used in a dual graph. KCL states:

At any node in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node, i.e. *the algebraic sum of currents in a network of conductors meeting at a point is zero*.

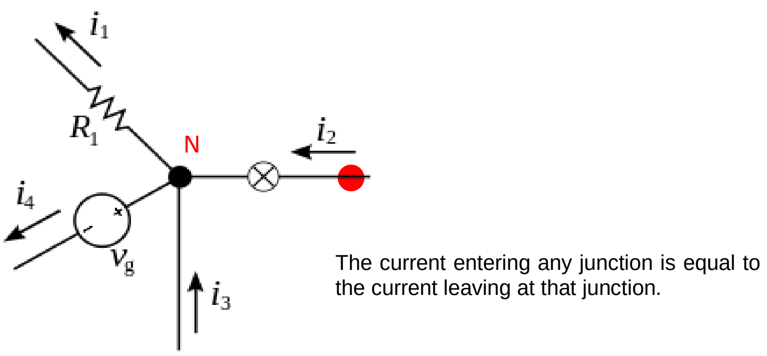


Figure 6.4: Kirchhoff's 1st law (Robbins & Miller, 2000)

Kirchhoff's Current Law states that the total 'current' entering to a vertex is equal to the total 'current' leaving that vertex. In Figure 6.4 at node 'N', the summation of incoming currents i_2 and i_3 must have the same magnitude as that for outgoing currents of i_1 and i_4. Application of this simple rule allows producing spatial layout using the developed dual graphs. Figure 6.5 presents a partial dual graph (only check-in area) to demonstrate the process of adding relative weights; this example provides an easy understanding of how passenger activity data could be implemented for floor plan generation, and this simple technique could be used in any dual graph using appropriate algorithms.

Australian airports, typically, have three types of check-in queues with associated check-in counters. In the partial dual graph as shown in Figure 6.5, two separate check-in counters, BCQ and ICQ, are allocated for business check-in and internet check-in respectively, whilst three additional check-in counters are considered for regular check-in. It is worth noting that the actual number of check-in counters will vary according to the size of an airport. It is a function of the number of passengers requiring check-in service at the 'peak' period of an airport. However, the number of active check-in counters is also variable and will depend on the average speed of passenger flow through check-in points as well as the average time required to serve a passenger.

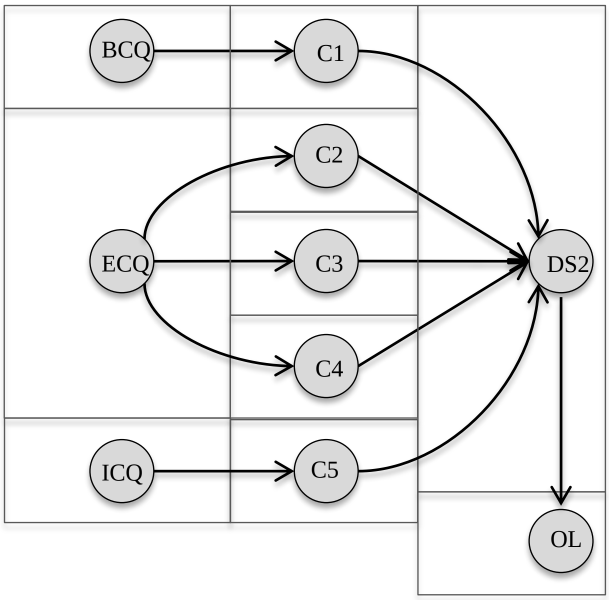


Figure 6.5: Partial dual graph (check-in area)

6.3.2 Adding relative weight to the partial dual graph

In partial dual graph, the nodes BCQ and ICQ have one outgoing link each, whilst node ECQ has three outgoing links. Only for demonstration purpose it is assumed that a total of 15 passengers are processing at a given instant with 3 passengers being served by each of the nodes. Hence, according to Kirchhoff's Current Law (KCL) it is obvious that ECQ will process 9 passengers when BCQ and ICQ process 3 passengers each. The number of passengers processed through a specific node is the 'weight' of the link between two adjacent nodes. The relative weight determines the vertical dimensions of the spatial layout. All passengers queuing at BCQ, ECQ and ICQ are processed through their relevant counters and they all join at discretionary area DS2 with a total 'weight' of 15 added to this space. The effects of these relative 'weights' showing different space allocations for various activities are presented in Figure 6.6.

Application of KCL generates a set of linear equations, which will facilitate defining the possible wall lengths across the entire layout. The actual output of passenger activity is shown by the solid horizontal links in dual graph, which determine the vertical dimensions of a work place. The horizontal dimensions, however, are shown using the dashed links. The ‘weights’ of these dashed links are purely assumed as they are not derived from activity analysis, and the input ‘weight’ of any dashed link must be equal to that of the outgoing dashed link for any given node. The aforementioned logics could be expressed using the following equation:

H1.2 = H2.2 + H2.3 + H2.4

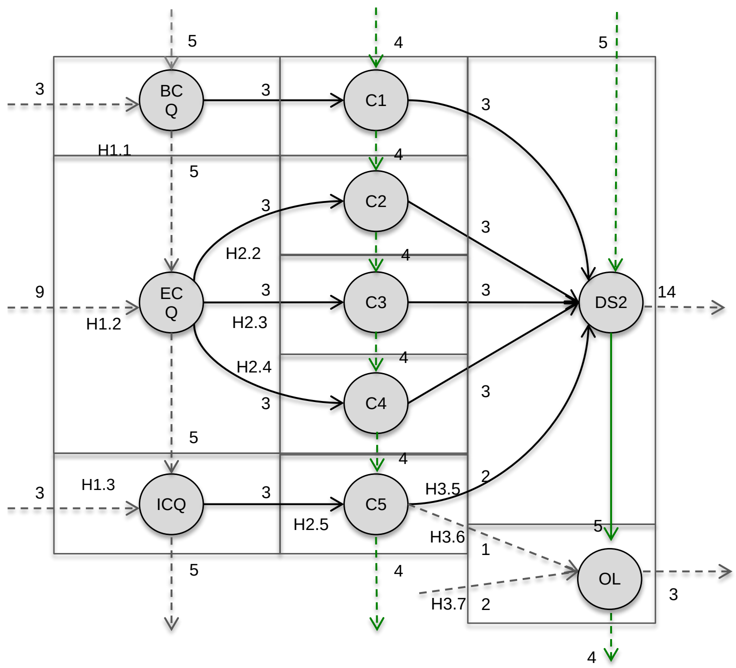


Figure 6.6: Adding weight to the dual graph

Figure 6.6 shows that H1.2 is given a weight of 9, and hence H2.2, H2.3 and H2.4 must add up to 9. Conversely, if H2.2, H2.3 and H2.4 are given a weight of 3 each, then H1.2 must be equal to 9. These relative weights obtained from passenger activity analysis allow obtaining a relative spatial allocation for a given floor area. In practice, the vertical distances are acquired from the space standard available from ‘IATA airport standards’ (IATA, 2004). When one of the dimensions is obtained following IATA guideline, the remaining dimensions could be determined using the relative spatial layout generated following the proposed technique.

6.4 CUSTOM PLUG-IN FOR LAYOUT GENERATION

A computer plug-in ‘FlowGraph’ was developed as a part of the current research to assist designers in customizing the dual graph and to add weights to links for automatically calculating flows at nodes. The Flowgraph utilises the concept of Kirchoff's current law to find out relative layouts from passenger activity, and movement from one departure facility to other. The advantage of using the current law in developing layouts is that a designer could consider fluctuating numbers of passenger movement and can easily get some initial layouts even before an actual design selection is commenced. It is worth noting that the logics behind the algorithm was conceived and demonstrated by the candidate, whilst the required computer codes were written by Joerg Kiegeland, who was a research assistant within the AotF team. The developed plug-in is named as 'FlowGraph', written using Eclipse Kepler software (Version 4.3).

FlowGraph

In computer programming, Eclipse is an Integrated Development Environment (IDE), which contains a base workspace and extensible plug-in system for customising an environment. FlowGraph uses tools adapted from Eclipse's plug-in mechanism. The research used Eclipse Kepler (4.3) distributions containing a stable version of Epsilon, which is particularly used to obtain the code of the FlowGraph. Epsilon is a family of languages and tools for code generation, model-to-model transformation and model validation/comparison/migration (Kolovos & Rose, 2009).

FlowGraph has a simple Graphical User Interface (GUI) (Figure 6.7), which consists of project explorer, model window, model outline, palette and model property. The following paragraphs present a brief description of the components.

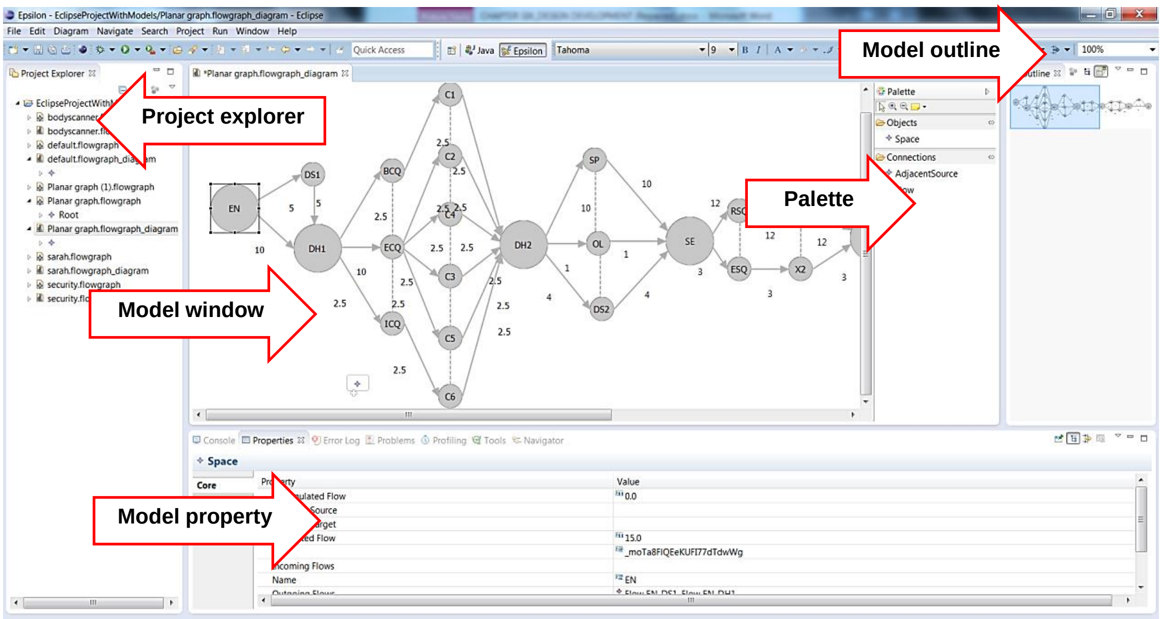


Figure 6.7: Graphical User Interface (GUI) of FlowGraph

Project explorer: the view of the project explorer provides a hierarchical outlook of the artefacts of the Workbench. This customised plug-in shares the typical Project Explorer installed within the Eclipse Package. The main function of this browser is allow the user to open and to close available files.

Palette: it consists of two properties 'Objects' and 'Connections'. Object property has 'Space' icon which creates 'node', the name of the node can be added while adding a space into the model space or can be edited later from the property window. Each node shows an incoming arrow and an outgoing arrow sign when computer mouse is toggled over a node. The Connections have 'Flow' and 'AdjacentSource' icons to create a connection between nodes and create the adjacency between nodes respectively. The connection between nodes can also be created by dragging an incoming or outgoing arrow from one node to another.

Model Window: the actual graph is drawn in this area with the help of the palette. The attributes of the graph can be changed and managed in this area. Objects and connections are selected from the palette and draw at the model area.

Model outline: it is a window panel where two icons are available for this plug-in located at the top of the panel: outline and overview. The outline shows the name of icons in the list that have been used to create a graph. The overview shows an entire model in a small scale and helps to locate any specific area of the graph in the model window if the graph is zoomed out.

Model Property: it enables to add/alter weights of a node and adjacent flow between two nodes. When a node is selected from a graph, the property panel shows the related attributes of that node. For example, in Figure 6.8, the node 'DS1' is selected and its corresponding attributes; ID, Calculated flow, Incoming flows, Name, Outgoing Flow, X-Input flow and Y-Input flow are shown in the properties panel. Calculated flow determines how many passengers are processed through that particular area. Incoming flow shows the immediate adjacency between two nodes. X-Input Flow is the horizontal distance between two nodes.

Figure 6.8: Attributes of 'Flow' in a graph

When a connection between any two nodes is selected then it shows the properties of that link. For example, at Figure 6.9 the connection between node 'EN' and 'DS1' is selected. It shows the 'weight' of the connection and the 'calculated weight' defines total average weight that is coming on to the target node. 'Source' defines the originating node (node EN) and 'Target' expresses the node it is going to connect (node DS1). A node must have at least one source node and one target node. When a graph is developed in the FlowGraph, each graph consists of one source code and one drawing file. The drawing file shows the illustration of the graph and it appears at the model window panel as well as the associated code developed for the Floor Plan Generator.

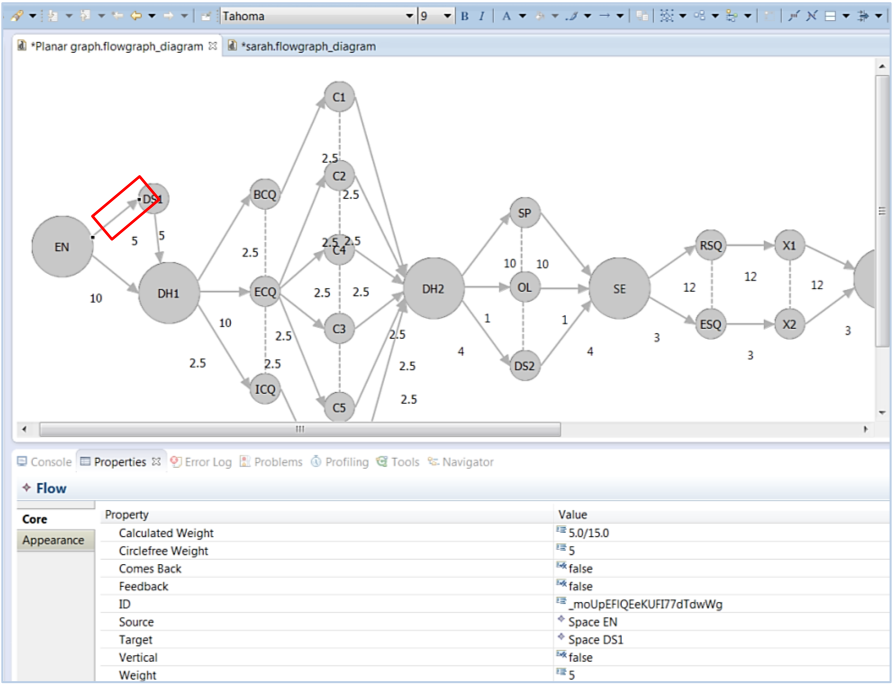


Figure 6.9: Attributes of a node

6.5 OVERVIEW OF THE FLOOR PLAN GENERATOR

The 'Floor Plan Generator' is a computer algorithm developed as a part of this research project to create automated spatial layouts from passenger activity count. The algorithm has been written for 'Grasshopper' which is a plug-in tool for computer-aided design environment called 'Rhinoceros'. Floor Plan Generator can develop some layouts with relative weighted dimensions to facilitate the preliminary design proc for the designers. at the early stage of design. This automation technique will allow designers to make some informed decisions for any future interruptions at early stages.

A brief description on Rhinoceros and Grasshopper are presented herein as they were used as integral parts of this research. Rhinoceros, which is also commonly known as 'Rhino 3D', is a parametric modelling software for designers, architects, engineers, artists and manufacturers. Grasshopper is a cutting-edge parametric modelling tool that works as a plug-in (add-in application) for Rhino 3D (Tedeschi, 2011). The graphical interface of Grasshopper provides an explicit representation of the geometric relationships and sequences used to generate a digital model. This enables designers to get immediate visual feedback as these relationships are manipulated by user-defined mathematical and geometric parameters (Guidera, 2011). Grasshopper utilises a separate interface window and the operations are saved in a separate file format from Rhino 3D. Rhino geometry is typically linked to Grasshopper using the Grasshopper Parameters panel, where single or multiple points or curves in Rhino are defined as geometry. Once a Rhino geometry is linked to Grasshopper, the relation between these two is activated.

6.5.1 **Design requirements for the Floor Plan Generator**

The algorithmic code written as part of the current study for Grasshopper utilises the generative design environment, and provides a substantial advantage for the proposed conceptual design process. Once the passenger flow is calculated and the relative weights are assigned to the graph, FlowGraph automatically calculates the relative flow at each link.

The development of Floor Plan Generator considers the followings to create automated spatial layouts:

- FlowGraph input model
- Geometrical constraints (Relative height and weight)

The design requirements for the Floor Plan Generator are presented in Figure 6.10. The input model obtained from FlowGraph in Eclipse is transferred to Rhinoceros using the developed algorithm, which is based on given geometrical constraints. In this research, topological constraints (adjacency requirements) have already been defined from the adjacency requirements. Additional geometrical constraints (heights and widths) are required to generate various layouts for the departure terminal under consideration.

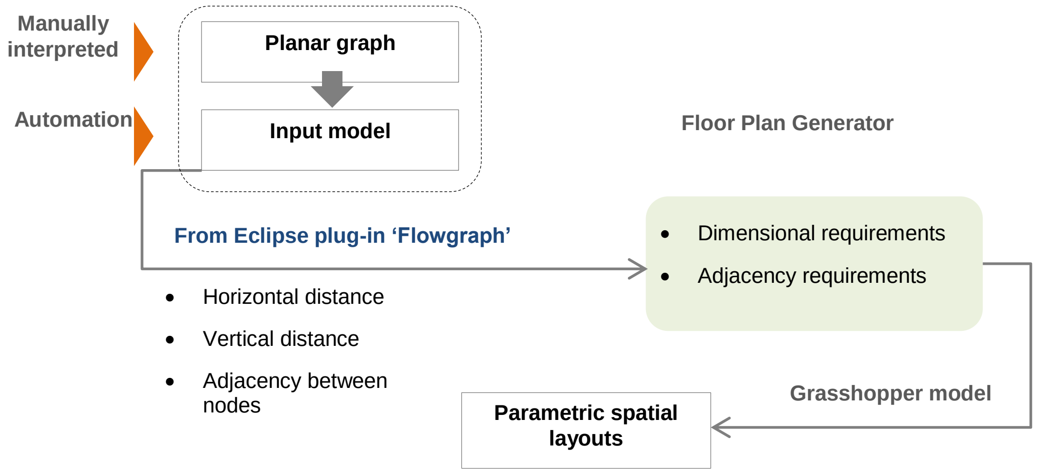


Figure 6.10: Requirements of the Floor Plan Generator

Flowgraph input model

The FlowGraph input model developed herein follows the process of adding relative weights to a graph as explained in Section 6.3.2. For the hypothetical case study, it was assumed that the total number of 15 passengers was being processed through the considered sub-segment of a departure terminal. This number is added to the first node 'EN' of the dual graph. In this case study, it is assumed that once passengers enter at the entry hall (EN), 1/3rd of the actual number of passengers experience discretionary facilities (DS1) before they move on to the check-in process. From the activity area 'EN', two immediate adjacent activity areas are available i.e. departure hall and discretionary facilities. It is therefore assumed that the rest 2/3rd of 15 passengers are going to join at the departure hall (DH1) for check-in process. Hence, out of 15 passengers, the connecting edge in between EN and DS1 is allocated 5 and the edge between EN and DH1 is allocated 10. All passengers then move on to the check-in process where each 1/3rd of the actual number of the passengers is assumed to be processed for business check-in and internet check-in queue, and the rest are assumed to queue for the regular check-in queue. From on-site adjacency requirements study, it was obvious that the queuing areas should be located next to each other. Dotted lines added between the nodes represent 'adjacency' between these activities. Figure 6.11 presents the FlowGraph input model for the Floor Plan Generator. The FlowGraph presents 'relative weights' of the links and required 'adjacency' between passenger activity areas. The next task is to transfer this FlowGraph model in Rhinoceros to validate the automation and create a departure terminal layout.

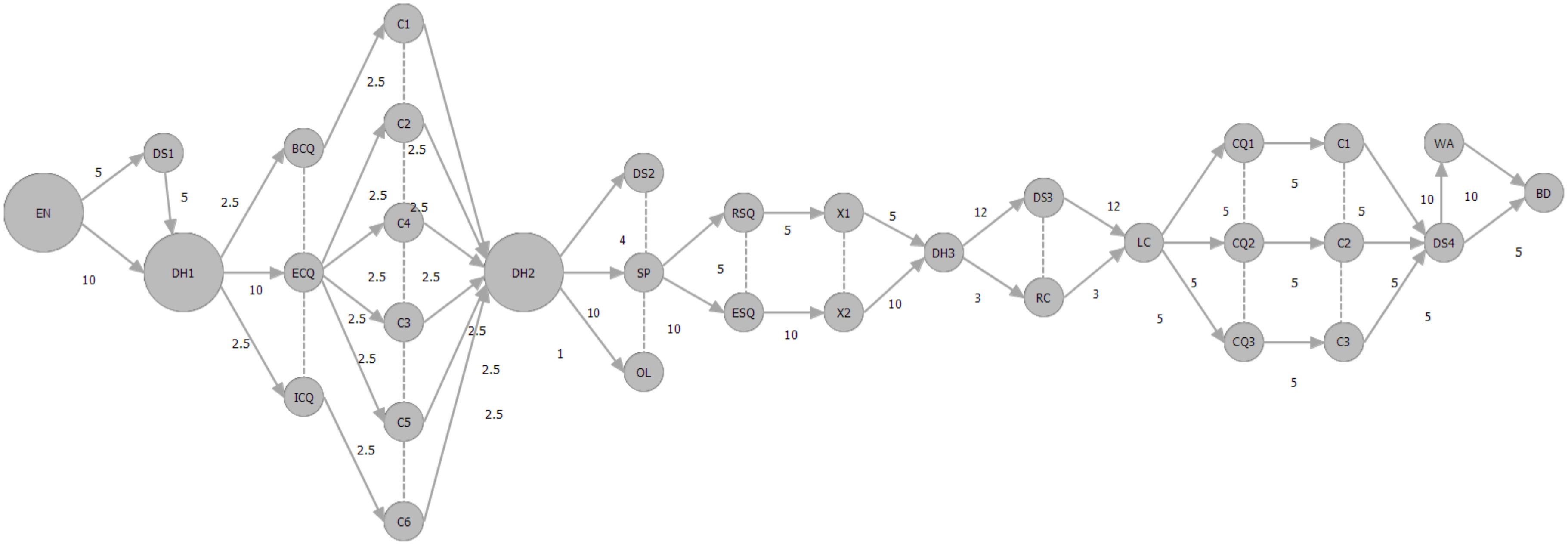


Figure 6.11: FlowGraph input model for layout generation

Geometrical constraints

At the early stage of layout generation, both geometrical constraints (length or width) and topological constraints (adjacency, non-adjacency or proximity of space with another space) are considered. The contact length and the distance between terminal activities are two considered geometrical constraints in the current research. For the case considered to demonstrate the applicability of the developed automated technique, the length and the width are assumed at 30 and 10 respectively. Assumed length and width provides relative dimensions and helps to develop a relative layout which can be easily altered depending on the actual dimensions of a real departure terminal.

The topological constraints are derived from adjacency constraints which are obtained from the adjacency graph.

6.5.2 **The Floor Plan Generator**

The developed code "Floor Plan Generator" has three main components (Figure 6.12): File paths, Read file and Floor Plan Generator, and these components develop an automated connection between the FlowGraph and its corresponding layout generated in Grasshopper.

File path: it represents a collection of file paths. The function of this component is to call a FlowGraph file from the specified stored location. Once the file is called the file path location automatically shows up in its associated panel.

Read file: once the file path is defined the 'Read file' component panel shows the contents of the FlowGraph file. This component is connected to both File path and Floor Plan Generator.

Floor Plan Generator: this component shows the custom notes and string values of the file. The main interface for algorithm design in Grasshopper is the node-based editor. Data is passed from component to component via connecting wires, which always connect an output grip with an input grip.

To create a layout, the Floor Plan Generator selects the file path in Rhinoceros, and the obtained spatial layout appears at Grasshopper interface window. When a specific

FlowGraph file is selected at the file path then the Rhinoceros geometry is linked to Grasshopper, their relationships are ‘piped’ – the input of one operation is channelled into a second operation or operations. Then the nodes are graphically represented by operation icons, and input and output curves connect the associated input and output parameters of the operation icons. The Floor Plan Generator component has a ‘Boolean Toggle’ operation icon, which needs to be flipped over to view the end result. Flipping the toggle input triggers the layout Generator.

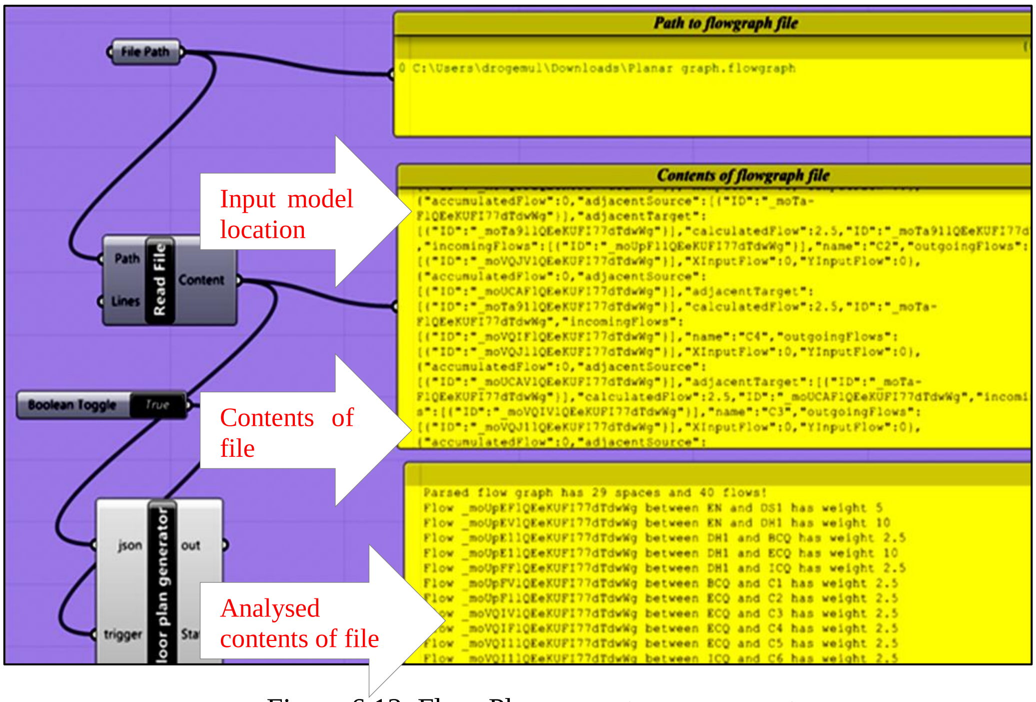


Figure 6.12: Floor Plan generator components

Figure 6.13 presents a number of screenshots from the Rhinoceros and the Grasshopper. The main three components of the Floor Plan Generator created the floor plan layout based on predefined ‘height’ and ‘width’ for the hypothetical case study. The height and width are easily configurable according to the actual requirements of the designed airport. In Rhinoceros, the resulting geometry from the FlowGraph is a three-dimensional volume manipulated by the number sliders. Each of the nodes presented in the Flowgraph (Figure 6.11) is now transformed into an area. The number slider associated with each of the areas is set for two numeric values, ‘upper limit’ and ‘lower limit’. Any numerical changes made to the layout are instantly propagated through all parts of the model, avoiding the need Grasshopper is saved in a separate file format from Rhino 3D.

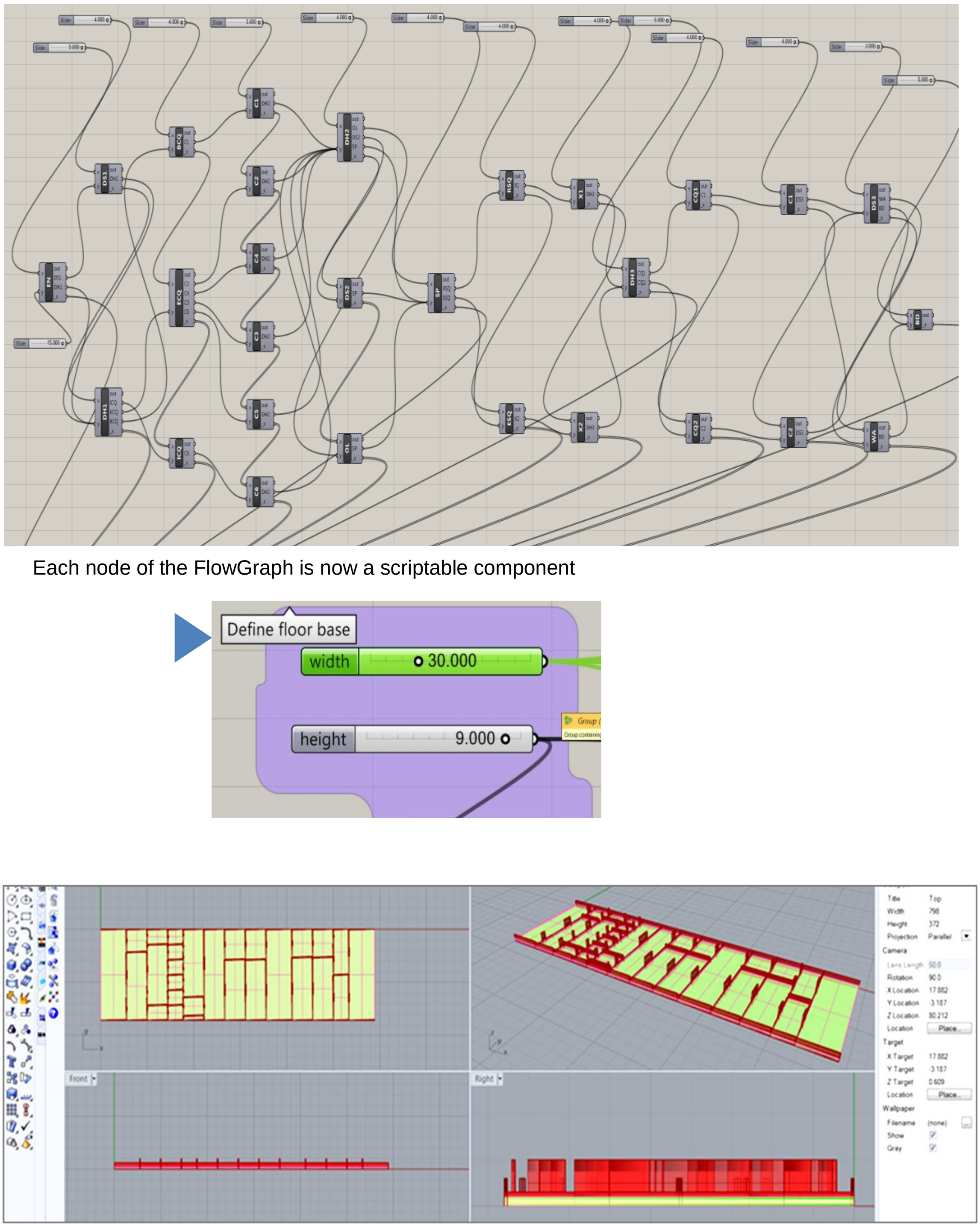


Figure 6.13: Layout generation in Floor Plan Generator

Relative layouts for new development (greenfield site)

A FlowGraph input model is now linked with Grasshopper and can develop relative layout for a departure terminal. Any changes made within the graph layout in the FlowGraph automatically made changes in the layout model, as the graph is automatically linked through the written algorithm. This model is able to generate several possible layouts by varying the initial values.

The developed parametric layout gives designers direct access to manipulate the relationships between various passenger activity areas and helps to generate alternative layouts under changing design requirements. Initially, the relative height and width of a new airport terminal are assumed to be 30 and 10 respectively. If the site of the airport is changed, but still keeps the same processing activities, then the changing geometric values automatically develop various layouts. Figure 6.14 presents four layouts that have same processing areas, but varies in height and width. In the top layouts (Figure 1 and 2) width of the airport is changed, while in the bottom layouts (Figure 3 and 4) both height and width have been changed. The figures clearly show that how the Floor Plan Generator can explore initial layout design as a responsive process where change of any design parameter affects the other.

A set of scriptable Grasshopper component (Figure 6.13) helps to make changes in the relative layouts. Geometrical parameters of the layout can be adjusted with the help of sliders, as well as through manual input at each node. As the relative layouts keep the same ratio of processing areas, the designers can easily get an initial idea of adjacent areas and an overall picture of the terminal.

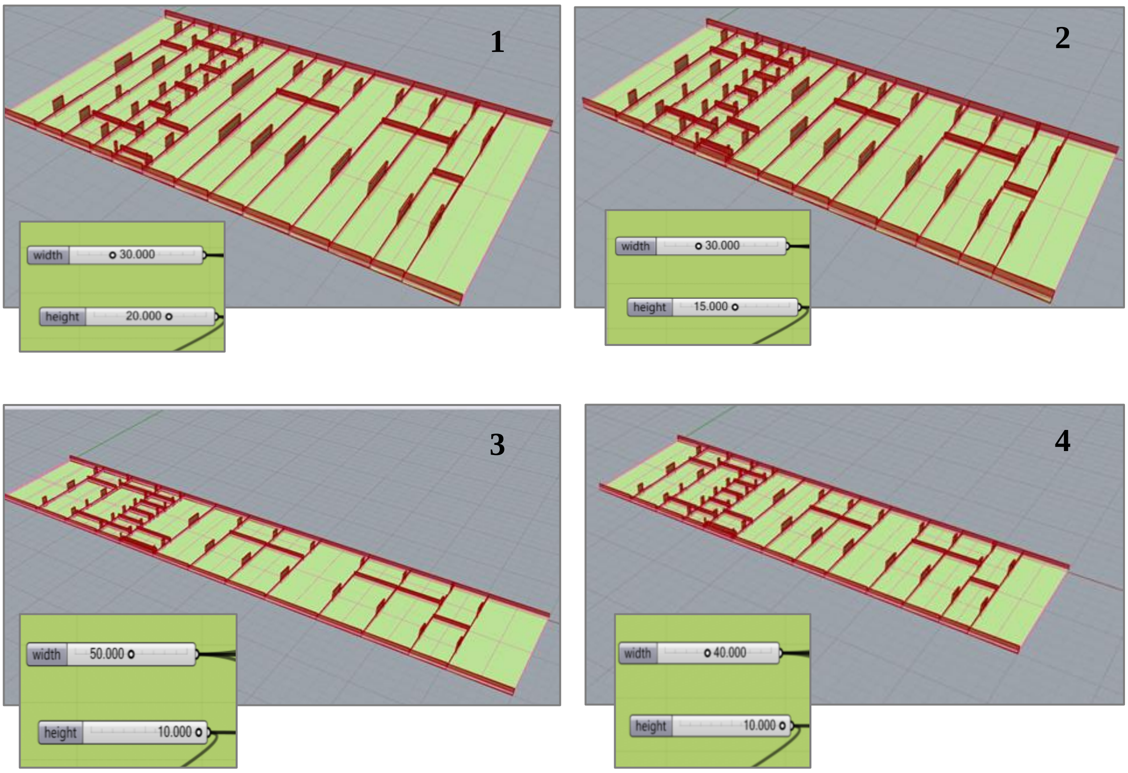
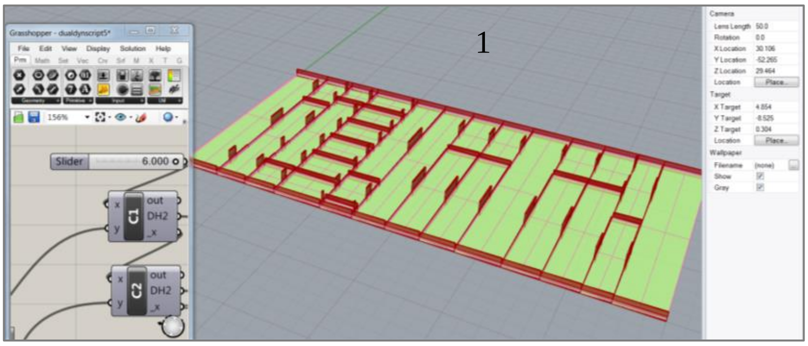


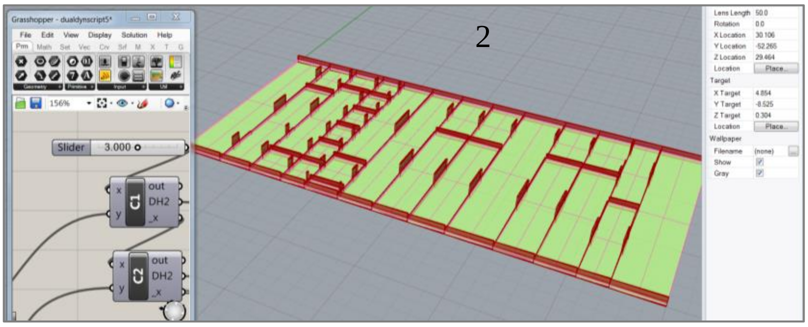
Figure 6.14: Various relative layouts for a new development

Relative layouts for re-development (brownfield site)

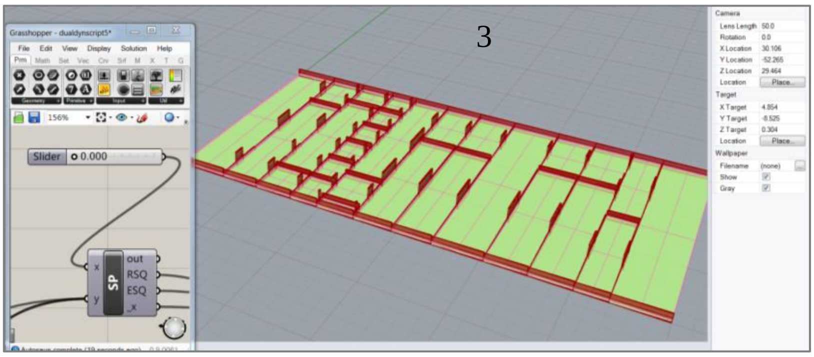
The overall aim of the current research is to develop the relative layouts not only for the new airport developments but also for making changes to already established terminals. Figure 6.15 presents a hypothetical scenario where variation in departure layouts were made to accommodate some modifications in passenger facilities.



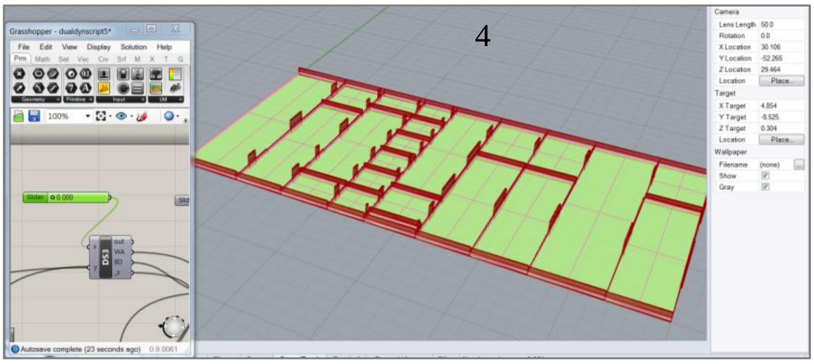
A typical check-in counters for a generic departure layout



Area of the check-in counters are reduced



Area of security preparation has been reduced



Boarding and security area has been reduced

Figure 6.15: Various relative layouts for new development

Layout with IFC model

Industry Foundation Classes (IFC) is used in the current research to create a neutral platform with open file format specification that is not controlled by a single user or group of users. IFC file format is a standard way of exchanging objects in the building industry to reduce loss of information when transmitting files between different applications. When combined with layers, this process, referred to as 'baking', can store any number of variations on discrete layers, so the options can be saved for future display and review. Figure 6.16 shows the spatial layout obtained from the adjacency FlowGraph with the corresponding static IFC model.

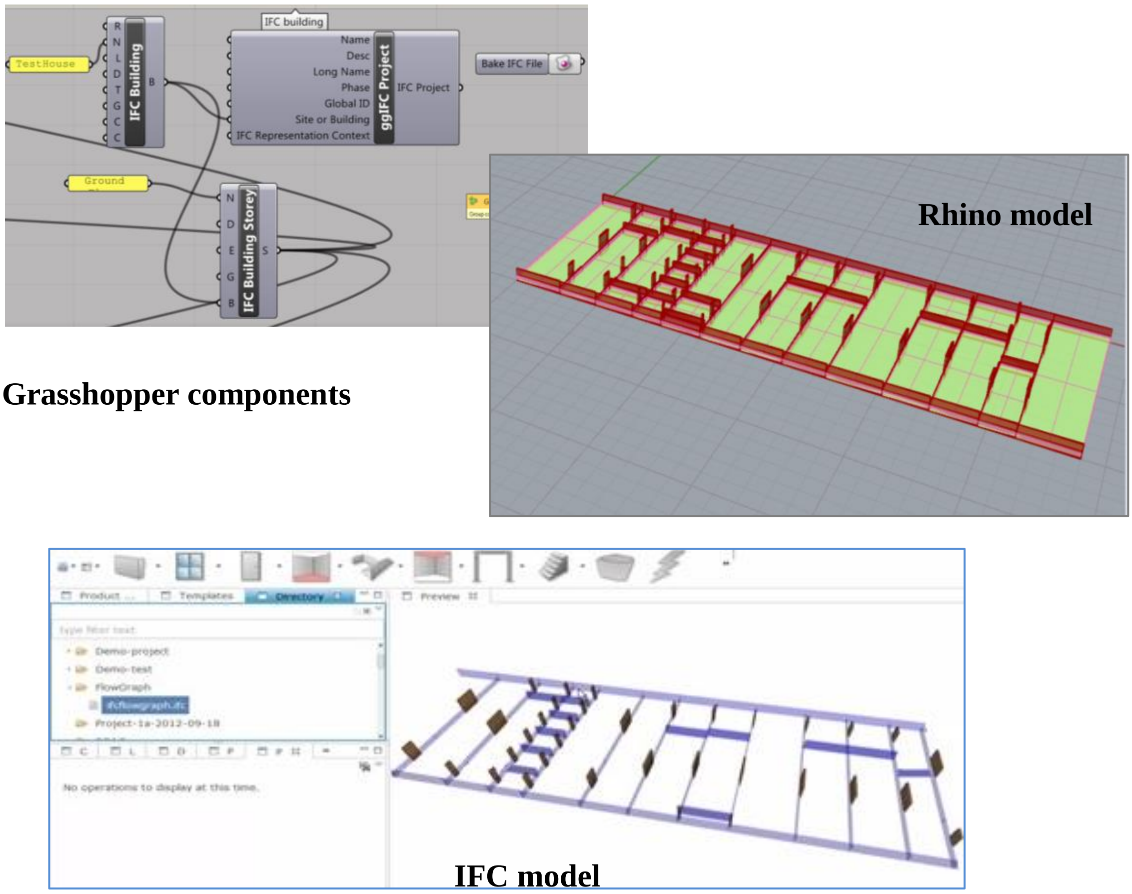


Figure 6.16: Spatial layout with IFC model

6.6 CONCLUSION

This chapter explains the basis and development the process of an algorithm to generate automated spatial layouts from passenger activity analysis. Appropriate development of the concept should all designers developing a number of alternative layouts at the early stage of design so that the most flexible design can be adopted to accommodate uncertainties. It is, however, worth noting that the spatial layouts developed herein are not detailed plans but have been used to demonstrate how spatial adjacency and number of processing activities can be used to develop relative layouts that can be easily changed to produce variants in a predefined geometrical structure. The primary achievement in this process is to identify a new design technique utilising information related to activity and adjacency.

Chapter 7

Design evaluation

7.1 INTRODUCTION

This chapter presents the final step 'Design Evaluation' of FlexDFA. At this stage of the design process, information obtained from Step 3 – Design Development and Step 1 – Areas of Uncertainty are used to get the outcome of the final Step 4. Figure 7.1 shows a schematic diagram of the proposed FlexDFA, where Step 4 – Design Evaluation stage is connected directly with Step 1 as well as there is a reverse loop from design evaluation to areas of uncertainty.

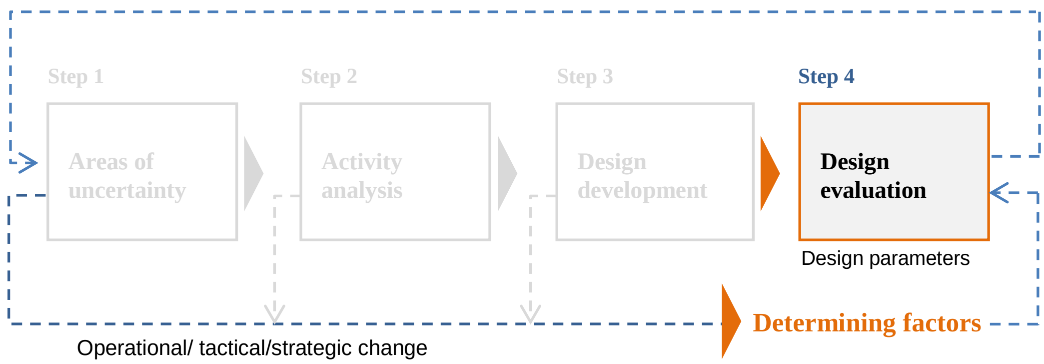


Figure 7.1: Flexible Design Framework (FlexDFA): Step 4

This chapter introduces the determining factors of flexible design criteria and identifies their role in the various layout development process. As explained in Chapter 6, an algorithm called Floor Plan Generator has been developed to get initial layout for a departure terminal, and this tool will be used to explore ways to incorporate design flexibility.

Section 7.2 introduces the desirable qualities and the required determining factors to develop various layouts.

Section 7.3 develops a number of layouts considering a hypothetical scenario for a greenfield site and also for a brownfield site.

Section 7.4 proposes a set of flexible design parameters to evaluate the initial layouts. A set of parameters is discussed in brief and each of the identified parameters is illustrated for its relevance to flexible design development.

Section 1.5 offers guidance on how to select a departure layout that will provide flexibility in a particular context.

Section 7.5 combines the thoughts and findings of the research within the proposed flexibility design framework FlexDFA and presents a detailed map of the framework.

Finally, **Section 7.7** presents the summary of the chapter.

7.2 **DETERMINING FACTORS**

A number of "determining factors" for flexibility is identified herein to facilitate developing layouts under changing situations using the hypothetical concept proposed in FlexDFA. The arrangement and configuration of different internal spaces as well as their usage have significant impacts on their facility, functionality and accessibility. Considering these aspects, this section discusses and identifies a number of factors that could determine the performance of a flexible layout, which will vary depending on its type as well as the volume of services provided at the airport. After careful considerations, the following three design factors are selected as key parameters for initial terminal layout development:

a. Processing activity
b. Spatial adjacency
c. Geometrical layout

The selected design factors attempt to contain closely related design variables within a single frame. Changes in processing activities depend on technological, regulatory and economical changes, whilst change is spatial adjacency is more versatile as this factor covers the frequent changes that take place during the life cycle of a terminal. The following paragraphs briefly present how the selected design factors can influence in obtaining various flexible layouts.

a. Processing activity

The current research shows the potential of passenger activity analysis to achieve terminal layouts at the early stage of a design process. Integration of passenger activity within the design process has led to the notion of 'activity-based' interaction. The developed initial layouts of the departure facilities showed that a parametric spatial layout defines a design with many available parameters that can be changed to produce variants in a predefined geometrical structure.

A hypothetical level of flexibility, as proposed in the first step of FlexDFA identified that flexibility in building layout should correspond to the following time scales – operational, tactical and strategic. Changes resulting from technology and other phenomena have influence on those from tactical and strategic perspectives as well as on operational changes originating from sudden incidents such as extreme weather and unwanted situations (volcanic eruption of Eyjafjallajökull left some 10 million air travellers stranded worldwide, and led most northern European countries to ground all planes for five days). Section 7.3 demonstrates two hypothetical scenarios, one developed for a brownfield site, whilst the other is for a greenfield site.

b. Spatial adjacency

During the initial layout design, an architect arranges individual spaces to meet the adjacency requirements specified in the functional program. Traditionally matrix, bubble and zoning diagrams are used to present adjacency relationships. The current research, on the other hand, has developed a novel approach of incorporating Business Process Models (BPMs) to obtain appropriate adjacencies. The adjacency information obtained by doing passenger activity analysis showed that a direct link can be created between activity and adjacency. Change in passenger terminal activities directly affects its layout generation; this process of automation has been justified and utilised in Chapters 5 and 6 accordingly. This section will demonstrate how some of these adjacency components could be implemented for flexible layout generation.

Space adjacency analysis explored the opportunities to identify relationships between terminal activities and their relevant placement. The need for separating activities that have conflicting characteristics also influences the shape of a terminal. Placement of spaces was discussed under the heading 'spatial group of activity' in Section 5.3.1; any change in a spatial group of activities is accompanied by a corresponding change in space/facility. Zoning or spatial grouping is also influenced by activities of occupants. Changes in zoning affect more on a strategic plan level, and the overall zoning plan dominates the shape and the form of an airport terminal. Zoning influences the organisation of circulation system as well.

c. Geometric layout

Available literature suggests that flexibility in floor layout encourages open-plan type of design, where geometrical complexity is less favourable. However, there are various reasons that require separating one space from another. In case of airport terminal design security, noise, radiation, visual clutter, etc. are some factors. The layout of an airport must be suitable for the shape and area of available land; and most importantly, it must satisfy the operational requirements of terminal processing activities. Depending on operational factors, certain geometric features would provide desirable enhancements for terminal configuration.

All three design factors are to some extent are dependent and are affected by each other. Initial geometric layout is determined by spatial adjacency, and spatial adjacency is achieved from processing activities. Influences of processing activities and spatial adjacency in flexible layout development are going to be demonstrated in the following sections.

7.3 DEVELOPING ALTERNATE LAYOUTS

The basic notion of generating alternative layouts is to allow designers analysing and evaluating all possible options at a preliminary design stage. Passenger flow in an airport terminal is extremely dynamic; it varies within a day, as well as within a month or a year depending on weather, public holidays, special events etc. The current research proposes that the designer will generate all possible spatial layouts considering real passenger activity data; this will allow analysis of the variation required in space allocations so that the designer can choose the most suitable layout that can efficiently accommodate the changes in passenger flow.

The Floor Plan Generator develops relative spatial layouts based on activity analysis, if the activity variables are changed, the developed algorithm generates corresponding layouts reflecting the proposed changes. Alternate layouts of security and check-in areas are developed in the following Sections 7.3.1 and 7.3.2 considering short, medium and long-term perspectives – which are classified as Operational, Tactical and Strategic Flexibility respectively. The following two scenarios are considered to develop alternate layouts considering the proposed determining factors.

Scenario 1: The layout for the Security Screening Checkpoint (SSCP) of Brisbane International Airport is developed herein to show the spatial impact of a newly installed full-body scanner on this typical spatial layout.

Level of flexibility: Tactical and Operational

Design factor: Processing activity

Scenario 2: A generic layout for check-in area is developed, where passenger activities are closely observed to identify strategic changes.

Level of flexibility: Strategic

Design factor: Spatial adjacency

7.3.1 **Scenario 1: Security Screening Checkpoint (SSCP)**

Every airport and airport terminal building is unique in physical design and operational requirements. In order to demonstrate how processing activities help to develop flexible layouts, a hypothetical case-study scenario has been developed surrounding Security Screening Checkpoint (SSCP). The SSCP layout incorporates queuing areas for both regular passengers and for wheelchair users, screening for X-rays with an associated conveyor belt and a dedicated space for re-inspection.

Security screening area includes spaces for passenger processing through a number of security screening devices. The screening checkpoints are designed to meet the criteria of Transport Security Administration (TSA) for operational space and equipment support as specified in TSA's Security Checkpoint Design Guide, February 2006 (Transportation, 2010). Since the terrorist attacks on September 11, 2001, it has been mandated by law to appropriately screen air travellers to ensure that a person carrying certain items is prohibited from flying. Passenger checkpoints have changed since the creation of the TSA, and are now becoming larger than previous installations. SSCP has been chosen as a case study since this area is subject to continuous modifications to facilitate ever-changing technical and operational needs; to ensure design and functional flexibility in this area is essential.

The technique of obtaining adjacency graph from spatial grouping of security activities is not thoroughly discussed herein as Chapter 5 presented the relevant process in detail. Table 7-1 presents the detail spatial grouping of passenger activities in SSCP, obtained from BPM.

Table 7-1: Spatial grouping of activities in the current SSCP area

Domain of activity	Status of activity	Passenger activities	Spatial group of activity
Security screening (Mandatory activity)	Security preparation	Perform preparation activities	Security preparation **(SP)**
	Security queue	Proceed to regular queue	Security queue for regular passenger **(SQ)**
		Proceed to the queue for wheelchair users	Security queue for wheelchair user **(SQW)**
	Security check-point for wheelchair user	Collect trays	Tray collection **(TC)**
		Place items on belt	X-ray machine **(X1, X2….Xn)**
		Proceed through to wheelchair door	Wheelchair door **(WCD)**
		Collect items and return tray	Return tray area **(RT)**
	Security check-points for regular passengers	Proceed to an available check-point	Checkpoint 1/2/3
		Collect trays	Tray collection **(TC)**
		Place items in belt	X-ray machine **(X1, X2…Xn)**
		Proceed through to detection passage	Metal detector arch **(MDA)**
		Selected passengers undergo random pat-down check	Random pat-down check **(RC)**
		Collect items and return tray	Return tray area **(RT)**
	Re-inspection area	Random pat-down check for re-inspection	Re-inspection area **(RI)**
	Security check complete	Complete security check and move to Customs & Immigration	Security check complete **(SC)**

Once the spatial grouping of an existing SSCP area is complete, the corresponding adjacency graph is developed using the proposed logical transformation process of BPM to mBPM. The 'Flowgraph' input model is then developed to obtain an automated layout using Rhinoceros. In this case-study scenario, the layout for SSCP area is developed according to the map of a generic airport terminal activities presented in Section 5.4.2**.** The adjacency graph, Flowgraph input model and spatial layout of SSCP obtained from Grasshopper is presented in Figure 7.2.

Design alternatives: Full-body Scanner introduced at the security area

Body scanners are being introduced as an additional layer of security that includes walk-through metal detectors, explosive trace detection, and restrictions on the carriage of liquids, aerosols and gels. There are multiple layers of security in place at airports in these days to facilitate safe movement of people and commerce throughout the airport transportation system. These layers are barriers to potential terrorist actions because they are equipped to detect and minimise threats that could occur within the system. Full-body scanner screening, aimed at enhancing security at airports, commenced in December 2012 at Australia's eight international gateway airports, which are Adelaide, Brisbane, Cairns, Darwin, Gold Coast, Melbourne, Perth and Sydney Airports (Development, 2013). This change raises a whole set of new challenges in terms of how and where to position this new equipment for efficient and effective operations at new as well as at existing, which is even more challenging, terminal buildings.

A number of possible layouts are developed in this section using the Floor Plan Generator to study spatial changes because of the introduction of full-body scanners in an airport terminal re-development. Table 7-2 lists the additional passenger activities that are required to be accomplished due to the addition of full-body scanners at the Brisbane International Airport. Initially, only one full-body scanner will be added to the schematic plan as observed in Brisbane International Airport. Eventually, five full-body scanners will be incorporated into the layout to investigate the resulting changes in passenger flow as well as to identify the effects in spatial allocation.

Table 7-2: Activities added to SSCP with the full-body scanner

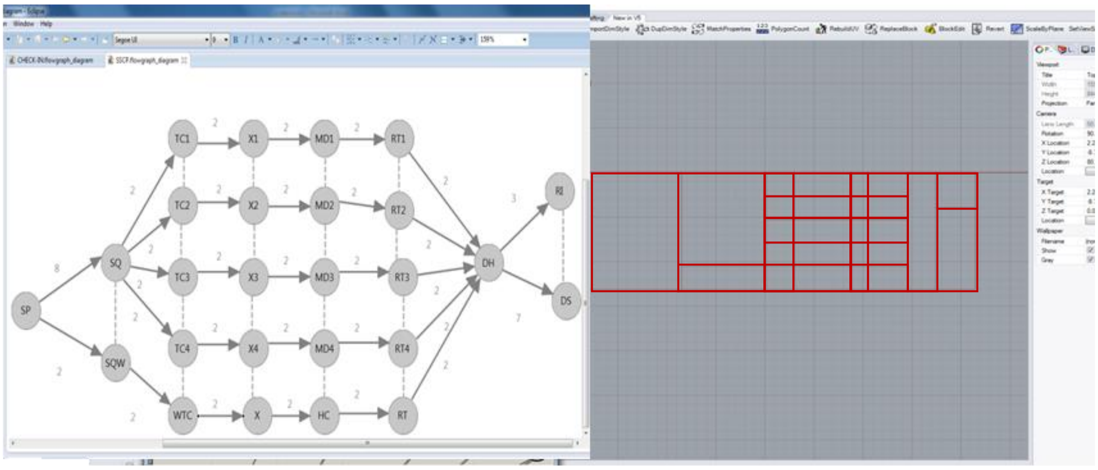
Departure facility	Proposed spatial grouping	Passenger activities	Detail spatial grouping
Security screening	Full-body scanning area (FS)	Selected passenger goes through the passage	Passage to scanner **(PS)**
		Passenger went through the scanner	Full-body scanner **(FS)**

Full-body scanners are currently designed to perform a thorough security scan for passengers alone and, therefore, meant to replace the metal detection gates. It is, however, worth noting that the luggage will have to be scanned using the traditional scanners, which is a bottleneck in the full-body screening system. Moreover, full-body scanners are considerably larger than the metal detection doors, and hence replacement of the doors with full-body scanners will require more space to be allocated in the security screening area. The introduction of full-body scanner is a time-consuming process and can't be altered overnight. Hence, this will affect both the tactical and the strategic planning of departure layout.

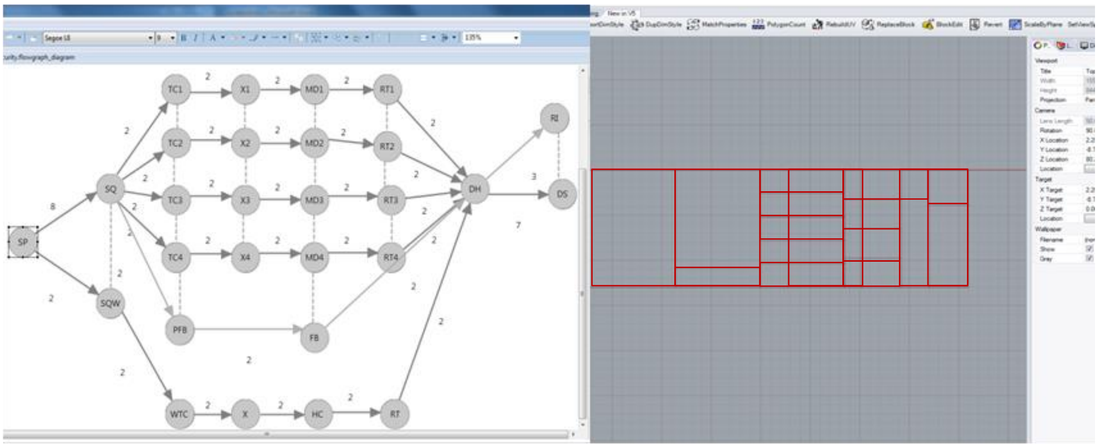
The second diagram of Figure 7.2 represents the screening system with the introduction of one full-body scanner at Brisbane International Airport. The figure shows that the installation of only one full-body scanner, while keeping the previous arrangement of security screening, doesn't affect much at the current layout.

When five full-body scanners are installed (third diagram at Figure 7.2, the metal gates are no longer required as well as area for random checking becomes redundant. Since the traditional luggage check-in still needs to be in place, the use of full-body scanners provides an extra level of security. As the space for random checking will be eliminated, the new layout leaves more space. However, it may not help to speed up the security-check processes. To have a real positive impact on the security scanning process, a new scanning technology will be required to scan the luggage and the body of the passenger at the same time. In that case, the traditional, slow process of luggage check could be removed and passengers will be able to experience a much faster screening process.

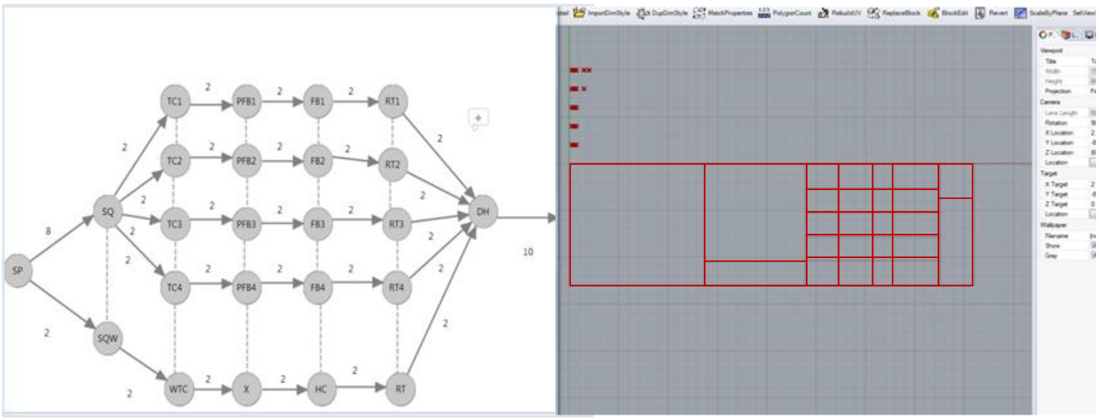
Security checkpoint design is an integral part of a terminal design process and any change made to security checkpoint for a brownfield site (redevelopment) could result in corresponding changes in public space, lobby space at the ticket counters, concessions placement, security queuing space, and throughput prior to the checkpoint. To some extent, changes in checkpoint area can also affect layouts after screening area, depending on the checkpoint locations with respect to departure gates and their rates of throughput.



Current SSCP Area



SSCP area with one -full-body scanner



SSCP area with five full-body scanners

Figure 7.2: Spatial layouts of SSCP with full-body scanners

7.3.2 Scenario 2: Check-in area

The emergence of new technologies is one of the major driving factors in demanding changes in airport design. The required processing systems for check-in are commenced once a passenger enters into a functional area allocated for check-in. Passengers may use some discretionary facilities before starting the check-in process. The check-in area includes spaces for passenger check-in queues, check-in counters and some additional space for luggage alternations, if required.

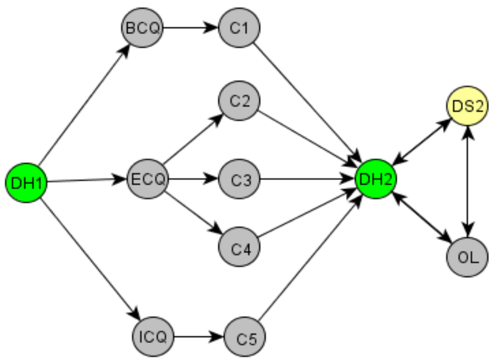
A hypothetical case-study scenario is developed surrounding the check-in area in the current case study. The considered scenario involves activities taking place in check-in area, and the associated discretionary activities.

Table 7-3 presents the proposed spatial grouping of passenger activities at the check-in area.

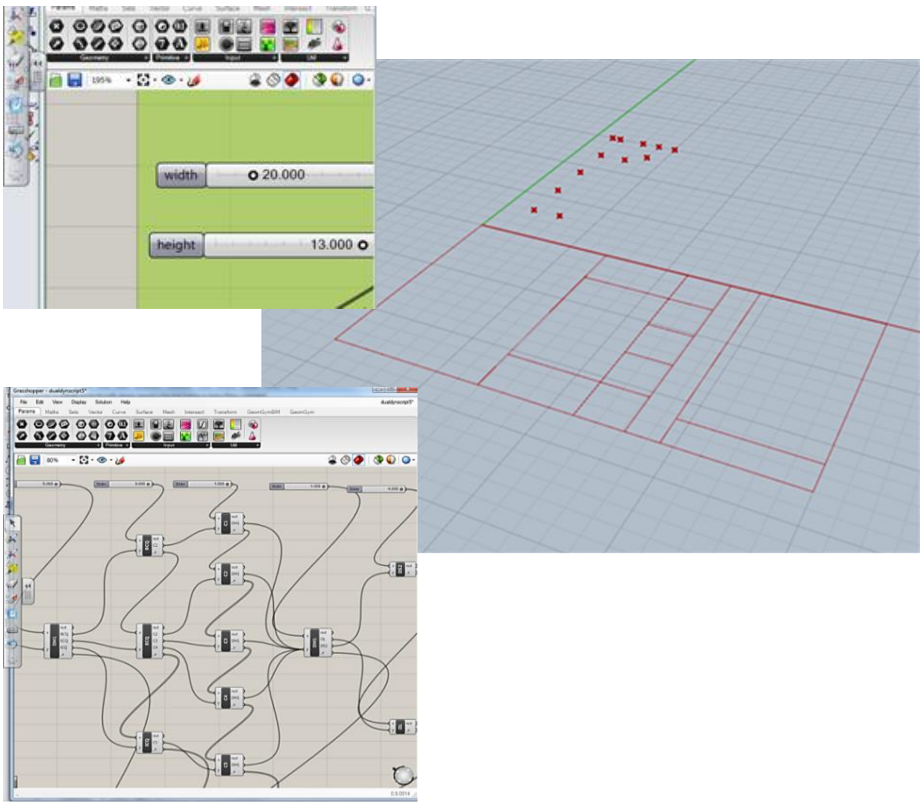
<table>
<tr><th>Activity domain</th><th>Passenger processing</th><th>Passenger activities</th><th>Spatial group of activity</th></tr>
<tr><td rowspan="11">Check-in (mandatory facility)</td><td rowspan="3">Terminal entry</td><td>Arriving at appropriate terminal</td><td rowspan="2">Terminal entry (EN)</td></tr>
<tr><td>Re-arrange luggage
Manage liquid, aerosol and gels in belongings*
Read flight information display</td></tr>
<tr><td>Discretionary facilities 1</td><td>Discretionary 1 (DS1)</td></tr>
<tr><td rowspan="8">Check-in facilities</td><td>Go to regular check-in queue</td><td>Regular queue (RQ1, RQ2 RQx)</td></tr>
<tr><td>Go to internet check-in queue</td><td>Internet queue (IQ)</td></tr>
<tr><td>Go to business check-in queue</td><td>Business queue (BQ)</td></tr>
<tr><td>Regular check-in counter</td><td>Regular counter (RC)</td></tr>
<tr><td>Internet check-in counter</td><td>Internet counter (IC)</td></tr>
<tr><td>Business check-in counter</td><td>Business counter (BC)</td></tr>
<tr><td>Deposit oversized luggage</td><td>Overweight luggage counter (OL)</td></tr>
<tr><td>Discretionary facilities 2</td><td>Discretionary 2 (DS2)</td></tr>
</table>

Table 7-3: Spatial grouping of passenger activities in check-in area

According to the spatial grouping of activities presented in Table 7-4, the 'Flowgraph' input model and its corresponding spatial layout obtained from Grasshopper is presented in Figure 7.3.



Adjacency graph of existing check-in



Spatial layout obtained from Grasshopper

Figure 7.3: Flowgraph input model and spatial layout of check-in area

Alternative layouts: introducing smart check-in system

The evolution to the 'Check-in point of the Future' can be achieved using options tailored to meet the specific needs of government and passenger growth. The introduction of e-ticketing and smart check-in system enables moving away from the traditional manual counter check-in queue. Frequent flyers and passengers who are familiar with the airport check-in process are now taking advantage of the self-service check-in options to bypass the hassle of standing in a long queue in standard check-in counters. In a self-service check-in kiosk, a passenger can choose his seat and print the boarding card and then take the baggage to the baggage drop-off facility. This allows saving a significant amount of time in the check-in process, as well as helping to reduce the number of regular check-in counters.

Table 7-4: Smart check-in system added to traditional check-in layout

Activity domain	Passenger processing	Passenger activities	Spatial group of activity
Smart check-in system	Kiosk with backdrop	Queue for bag drop	Queuing area for bag drop (**QBD**)
		Drop bags at the kiosk	Kiosks for bag drop (**KBD**)

Figure 7.4 presents the Flowgraph input models and the corresponding spatial layouts of the check-in area. Initially, five manual counters are considered for passenger processing in a traditional check-in system. In the second scenario, one of the traditional check-in counters is replaced by smart check-in kiosks. Three smart check-in kiosks are accommodated within the space occupied by one traditional check-in counter; this clearly should make the check-in process significantly faster. In the third case, two check-in counters are replaced by smart check-in kiosks, which eventually leave additional spaces in the check-in counter area. This additional area will allow operational flexibility within the check-in facility to tackle any unforeseen circumstances.

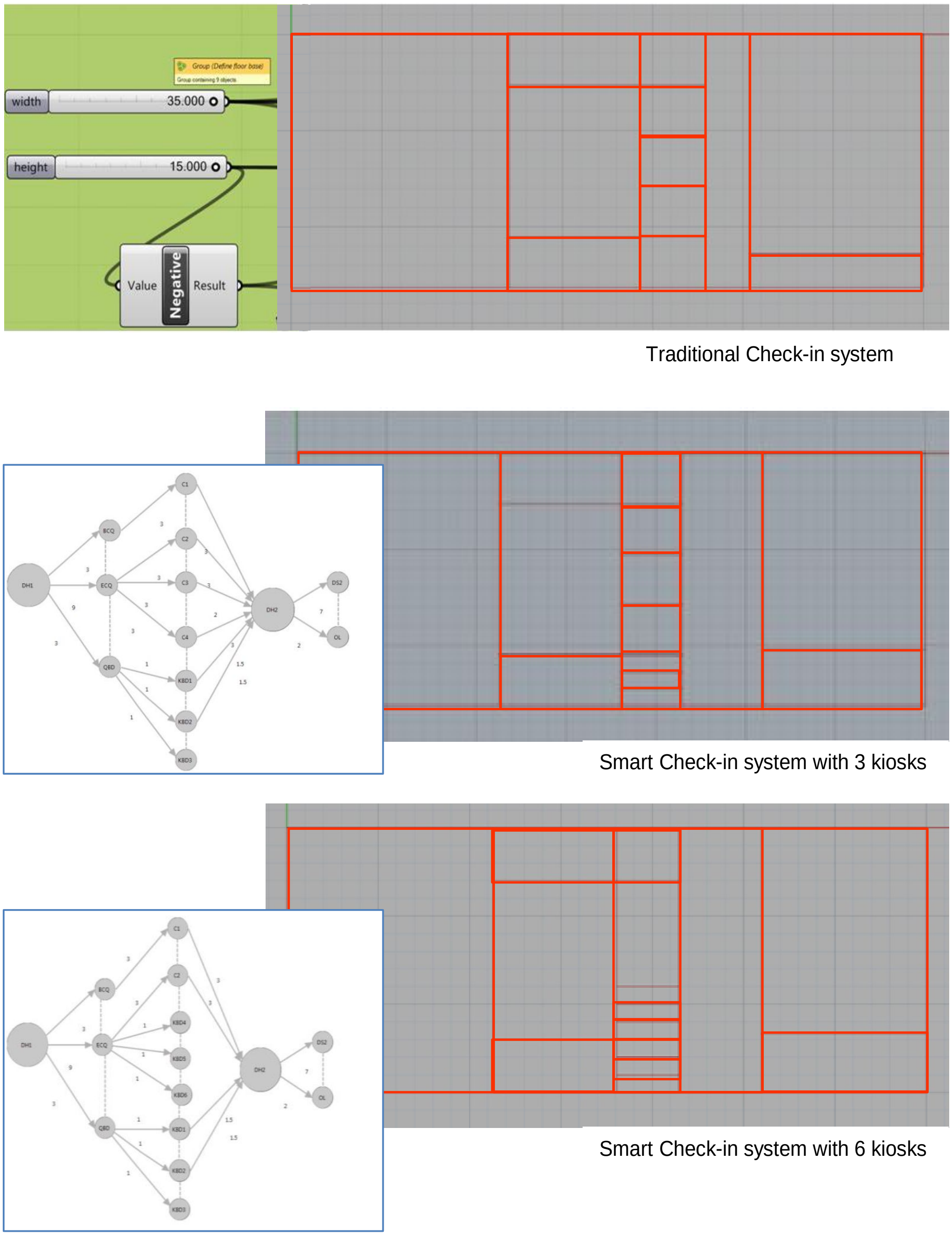


Figure 7.4: Spatial layouts of smart check-in system

7.4 PROPSED DESIGN PARAMETERS FOR FLEXIBLE LAYOUTS

Once various layouts are developed for either a new development or for re-development, the next step is to adopt a suitable layout so that the selected layout can ensure an appropriate level of flexibility is achieved. Currently, there is no standard set of design parameters to justify a flexible layout. There are, however, various related sources of information available in literature. Critical reflection on such current practices, knowledge, and research, has identified a number of explicit design parameters. The current research gathered the related information and developed a set of design parameters that may be used by the designers to assess an existing design or a new design.

The proposed set of design parameters are going to be assessed under some selected design criteria to ensure an appropriate level of flexibility is achieved in the process. The proposed design parameters are dynamic in nature; depending on each case, one parameter could be more important than the other.

7.4.1 **Selection criteria to assess design parameters**

The current research proposes a set of design parameters from the in-depth literature review and relevant analysis from various fields of flexible design. To assess the importance of each design parameters, a number of selection criteria is proposed. The underlying criteria make it possible to evaluate various layouts which can be characterised by different weight, dimension and direction of layout optimisation. The criteria selected here are layout generation, volume of passengers, and technological adaptability.

(i) **Layout generation**

The selection of a suitable layout depends on a large number of factors, and hence performance matrices are required for designing terminal layouts. The obtained alternative layouts should be evaluated at the early stage of a design process to achieve a given set of objectives. Therefore, layout generation has been given top priority in determining the best possible design option from the obtained alternative solutions.

(ii) Volume of passengers

It is difficult to quantify exact passenger growth in future, and hence, critical reflection on current knowledge from several fields has identified that the change in the volume of traffic is one of the vital issues in terminal design. Almost every aspect of an airport layout design varies according to the increase or decrease in number of passengers. Therefore, proposing the importance levels for each design criterion with regards to the volume of passengers is arguably important.

(iii) Technological adaptability

In our everyday life we observe rapid and frequent changes in technology. Use of new technologies both in an existing layout or in a new layout should be carefully assessed for optimising performance and efficiency. In the case of finding flexible layouts for an airport terminal, there is a great reliance on technology to satisfy evolving needs

7.4.2 **List of design parameters**

Design parameters proposed herein are aimed to facilitate in analysing the departure layout flexibility and to understand its performance due to changes in usage. The proposed parameters are considered as performance parameters which will be used to measure a level of satisfaction achieved by the adopted layout in regards to functional requirements.

Source of information

The available literature from the following flexible design fields provide a significant background knowledge to propose the design parameters; a range of strategic and tactics to achieve flexibility in housing by Schneider and Till (2007), de Neufville and his co-authors identification of flexible design possibilities for airport, Edwards (2005) identification of terminal building layers and their importance in flexibility, Butter (2010) proposed design elements for a flexible master plan.

Fifteen design parameters have been proposed in this section and are reviewed under three selection criteria using three different levels of relevance – high, medium and low. The scale of relevance is presented with a review of information sources, some parameters are highly relevant to all levels of flexibility and some are only highly relevant to only one level of flexibility. The highest level of relevance represents with three numbers of filled squares, and the lowest is one filled square. It is, however, worth noting that the proposed technique of assigning relevance for each of the selection criteria should not be regarded as an absolute measure – rather, level of importance is considered as a rational way of giving importance.

1. Ease of expansion:

Layout generation	Technological adaptability	Volume of passengers
■■■	■■■	■■■

The basic notion of flexibility in design is dependent on the expansion capability of design elements. Whether or not a design element has the potential for expansion should be identified at the early stage of a design process so that an initial plan can anticipate the prospect of any future extension. If a layout can be easily adapted to changing situations, then the design is more flexible. Hence, the importance level for 'ease of expansion' has been given the highest priority

Technological changes play a significant role in our everyday life, and airport terminals have to keep pace with these changes. Rapid technical changes have a massive impact on the expansion ability of an airport terminal. From the innovation of new aircraft to the invention of a new technology in the check-in process or security system, everything has to be compromised with the ease of expansion ability of an airport layout. Recent innovations in information technology have significantly reduced the pressure on traditional large check-in area; this has made check-in process a lot easier and faster without requiring any expansion to tackle increasing traffic volumes. Overall, ease of expansion is one of the most important selection criteria for evaluating flexibility in an airport terminal.

This parameter is also highly dependent on the volume of passenger for obvious reasons – increase or decrease in passenger volume will affect the total volume of traffic in an airport terminal. This will consequently affect all relevant activities and will, therefore, require expansion (or contraction) of the original design layout.

2. Terminal configuration

Layout generation	Technological adaptability	Volume of passengers
■■■	■	■■■

The overall configuration of a terminal building plays a very important role in determining whether or not the terminal is flexible. Passengers perform a series of tasks before boarding an aircraft. Maintaining the walking distance among services at a minimum will help speeding up passenger processing. According to de Neufville (2003), primary flexibility in terminal buildings could be achieved by choosing an appropriate configuration that has the ability to expand and contract according to the activities performed. For example, ACRP report (ACRP-25, 2010) suggests that a linear terminal capable of lateral expansion (extrusion) is preferable to other types, and hybrid configuration is suggested more flexible by de Neufville and Odoni (2003).

From a technical point of view, any adopted configuration must have the capability to accommodate any important technological advancement. However, technological adaptability and terminal configuration do not directly influence each other, and does not influence as much on choosing appropriate configuration as it is affected by other selection criteria.

Changes in the volume of passenger and its relevance to the passenger service period, expansion capacity of a terminal, etc. have been studied by many researchers. According to de Neufville and Odoni (2003), the initial plans should ensure that changes in the volume of traffic over time should respond flexibly to changing needs – hence, it is highly relevant to adopt flexibility in the basic configuration.

3. Moveable/folding partitions

Layout generation	Technological adaptability	Volume of passenger
■■■	■■	■■■

One of the most common features of a flexible structure suggested by most of the researchers (ACRP-25, 2010; Butters, 2010; de Neufville & Odoni, 2003; Kronenburg, 2007; Schneider & Till, 2007) is the use of moveable, foldable and/or sliding partitions. Various types of moveable and/or foldable partitions are used in airports around the world to achieve in fulfilling various needs of airport operations (examples available at 2.4.2). Quickly after 9/11 many small airport terminals used semi-permanent barriers (shown in the 1st picture of Figure 7.5) for separating arrival and departure passengers. The use of folding partitions also helps to attain acoustic separation if necessary. This simple technology has already proven its effectiveness in providing flexibility according to functional requirements especially in airport terminals and hence the importance of this parameter is considered highly relevant. Typically, a more open-plan type layout works better with a moveable partition system, as it opens the opportunity of creating spaces to meet specific needs.

Change in volume of passenger heavily affects any temporary modifications, *i.e.* expansion, contraction or re-orientation of service areas using moveable partition walls. The new expansion of Ottawa Airport, Canada (ACRP-25, 2010) has developed a system that enables it to adjust the number of gates provided for both domestic and international air services simply by opening and closing partitions, or moving the wall that separates two types of traffic.

Technological advancement, however, indirectly affects service areas as passengers might need to be regrouped to accommodate technical changes. It is now common to see separate check-in queue for web check-in passengers – which is typically organised using movable partitions. It is, hence, recognised that movable partitions are moderately affected by technological advancements in the current scenario. Sliding/ folding walls can take on a wide variety of forms (some are shown in Figure 7.5).

Semi-permanent barriers at Guam Airport, US

Moveable partition walls

Figure 7.5: Moveable or folding partitions

4. Connectivity among facilities:

Layout generation	Technological adaptability	Volume of passengers
■■■	■	■■■

Connection between rooms, whether it is permanent or temporary via sliding walls or doors, allows users to make connection between various activities. They are also considered by researchers to be extremely important in ensuring efficient passenger processing ((ACRP-25, 2010; Butters, 2010). Functionally related facilities are often connected using moveable or demountable walls to tackle rapidly changing passenger patterns in special situations. Appropriate, yet temporary, connectivity arrangements could be used to gain operation flexibility, and therefore reduce costly alterations. In airport terminal, connectivity between various terminal facilities enhances shared used facilities, by adding/removing moveable partitions according to passenger demand. According to ACRP report, Airport Master Plans that provide for single large terminals, or for the various unit terminals to be connected efficiently, greatly enhance flexibility. That is why this parameter is highly relevant to layout generation.

Usually, airport terminal facilities have to follow some predefined order of activities where technological advancements could make significant changes to individual facilities, but do not have much relevance to the connection between various terminal facilities.

Providing enhanced connection between facilities strongly influences the movement of passengers. Passengers are the main driving force behind design flexibility and maintaining appropriate connectivity among various interrelated facilities is considered highly relevant to the volume of passengers.

5. Geometrical simplicity

Layout generation	Technological adaptability	Volume of passenger
■■■	■■	■

Simple geometry in layout design allows more flexibility to the orientation for most of the building types, and hence this parameter given the highest relevance to achieve flexibility in a design process. Architects generally design airport terminals with simple layout for high functionality, and architectural aesthetics are built in to maintain this simplicity. A simple rectangular layout with repetitive structural system is observed in many recently constructed airports such as Heathrow Airport Terminal 5 and Stansted International Airport (Figure 7.6). An expandable linear plan with simple rectangular shape allows creating clear roof spans to form large open areas, it also minimises the need for interior load-bearing walls. It also allows relocating the terminal interior partitions easily and reconfiguring interior operations without any major interruption. Simple layout also facilitates efficient passenger movement. Overall, this parameter is one of the most important criteria to achieve flexibility.

Simple terminal layouts are more easily adaptable with technological advancement. It is assumed that changes in technology will moderately affect the geometry and the shape of a terminal layout.

Volume of passengers plays an important role in determining the area of a terminal, but the basic form of the layout is not affected significantly. For example, larger volumes of passengers would require a simple layout for an efficient circulation pattern. While the number of passengers varies over the life cycle of a terminal, it is not directly affected by the layout pattern.

Heathrow Airport Terminal 5 (Maps)

Stansted Airport (Foster and Partners)

Figure 7.6: Basic rectangular form used for airport terminal design

6. Level change:

Layout generation	Technological adaptability	Volume of passengers
■	■	■

Most international airports are now split between multiple levels to accommodate the complex interactions that take place for departing and arriving passengers. However, level changes within the inbound or outbound levels is suggested to be avoided by the researchers while considering flexibility because ramps and half-level changes tend to coincide with nodal points in the circulation network and will always constrain the optimal use of these areas. However, to accommodate large number of passengers in international airports, level separation is almost unavoidable. Other than the optimal use of areas the level changes do not have much relevance with layout generation, and hence the importance of relevance is considered as relatively low.

Where large volumes of traffic are involved, separation of passengers among multiple levels provides some flexibility in overall functionality. A single level terminal is, however, still preferred for small domestic or regional airports as multiple levels may be too costly for smaller traffic volumes. Total volume of passengers dictates the necessity of level change; available forecasting models are used to predict growth in passenger volumes and the decision on level change is made at the preliminary design level.

According to Edwards (2005) the main function of level changes at terminals is to improve the operational efficiency of passenger and baggage movement. Technological advancement, however, is believed not to affect too heavily on this aspect. Level changes are also very costly to modify.

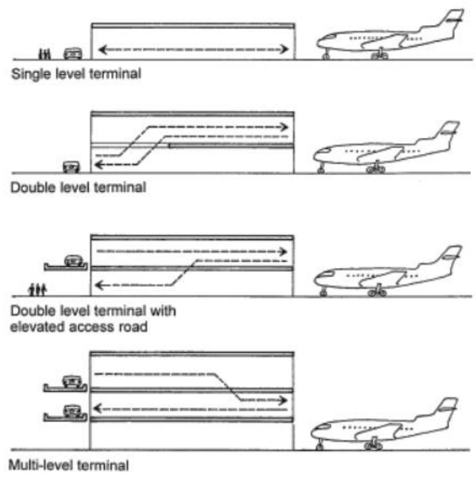


Figure 7.7: Vertical segregation of typical airport terminal (Edwards, 2005)

7. Modularity

Layout generation	Technological adaptability	Volume of passengers
■■■	■■	■■■

Modular design is identified as a key element of flexible design concept as it creates a building that allows for an incremental expansion process. A modular approach also can be achieved with a modular grid system in the structural layout. The importance of modular layout to achieve flexibility has been recognised by various researchers; case studies presented in the literature review (Section 2.4) also show the significance of this design concept.

If the basic layout of a terminal is well adapted to technological advancement, then modularity should not be significantly affected by changes in technology. Additional modules, if required, should simply adopt the same technology that was used in the basic design. Figure 7.8 shows the use of flexible modular structure used in Amman Airport to allow for continued expansion. Innovative, long-term adaptability solutions to a high-quality approach should be tackled with new technologies in mind.

Passenger volume certainly affects the size of a terminal, and so built-in ease of expansion is heavily dependent on passenger volumes. As modules are relatively easy to substitute, remove, or add, they represent options that are built into the design of a new product or system.

Figure 7.8: Amman Airport, modular structure (Building.co.uk, 2013)

8. Building layers

Layout generation	Technological adaptability	Volume of passenger
■■■	■■■	□

The layering concept in achieving flexibility has been identified as one of the core concepts of the current research (Chapter 4). Incorporating a layering approach increases adaptability in a building’s lifespan, and allowing separate layers helps to renew each layer without any significant disruption if needed. The layering concept adopted by other building types, for example, housing and office buildings, have already gained an ability to achieve flexibility throughout the life cycle of a project. The layering concept also influences some other flexible design parameters, such as shared-use facility and furniture arrangement. Hence, the concept of building design as a collection of time-related layers is considered highly relevant to flexible layout generation.

The big risk with not recognising shearing layers is that if the layers are not identified properly and it is not known in which layer a component belongs, it may end up with a building that is extremely difficult to use. For example, an embedded new HVAC system in the structure may end up with tearing down a whole building is air regulations change. At the same time, building layers should allow and give high priority to any changes in technology. Higher adaptation of newer technologies means the building layers are more flexible. With the help of Building Information Modelling (BIM), a dynamic model of components (presented in Figure 7.10) can be produced which evolve and improve over time influenced by shearing layers of change.

The layering concept in terminal design and development basically depends on the hierarchy of changes which have no direct influence with the volume of passengers, and hence it is assumed to have a minimum or no relevance in terms of flexibility.

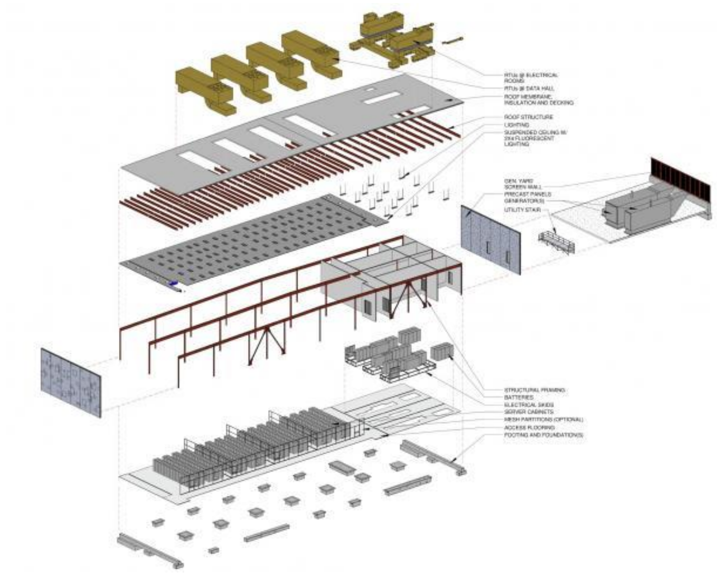


Figure 7.10: Exploded component diagram using BIM (Schultz & Connor, 2014)

9. Circulation area:

Layout generation	Technological adaptability	Volume of passenger
■■	■	■■■

A circulation area is also important to ensure flexibility through straight-forward circulation pattern providing the potential for ‘network circulation’. Safe and comfortable movement of passengers through the terminal building is of particular importance for airports. It is generally preferable to establish clear linear routes and collection points, and they need not be permanent or otherwise constrained by the building plan, structural grid, or other fixed elements. If it is possible to set more than one route between areas, then the layout will be considered more flexible. In the case of unusual traffic situation, circulation areas are used for compromising extra terminal facilities. Schematic diagram at Figure 7.10 shows how the circulation pattern of a building is dictated by the building layout.

Technological advancement, however, is not considered to be a major factor for designing circulation area. It is also considered that circulation area should not be designed only for circulation purpose. The increasing dimension of circulation space accommodates other functions when required in emergency situations.

The volume of passengers determines the orientation and amount of circulation area required. While planning for operational and tactical flexibility the changes in volume of passengers showed direct relevance with it, and hence the relevance should be high. For example, at the time of emergency evacuation, having sufficient circulation areas helps to deal with operational flexibility.

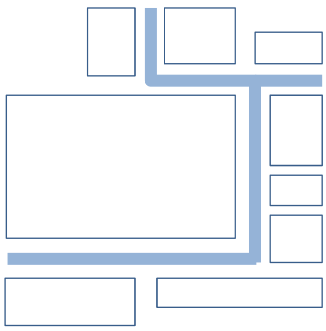


Figure 7.10: Circulation pattern dictates by the layout of building

10. Functionally neutral space:

Layout generation	Technological adaptability	Volume of passengers
■■■	■■■	■■■

The provision of keeping additional spaces while designing a new airport development is already practiced all over the world (examples are available in Chapter 2) although at the planning and design phase flexibility is still not accounted for as a design requirement. In most airports, designers keep some spaces that are functionally neutral for future alteration. In terms of design, this approach means that space is redeployed and can be used later on for other requirements. Functionally neutral spaces serve as great flexible elements in operational, tactical and strategic stages.

Since it is difficult to predict future technologies, there must be enough opportunity for these spaces to be adaptable to any significant technological advances.

These spaces could be used to accommodate sudden increases in passenger volume due to some unforeseen events or during some emergency situation when some service areas require evacuation. If the future planning of an airport terminal has the provision of functionally neutral areas that can accommodate sudden changes in volumes of passengers, the design of that particular airport is considered flexible.

11. Multifunctional/Shared use facilities

Layout generation	Technological adaptability	Volume of passenger
■■	■■	■■■

Shared use facilities are highly recommended by most of the researchers who recognize the need for flexibility in airport terminal design. Shared-used facilities provide operational flexibility in terminal layout due to changes in passenger volume during a day. Appropriately designed shared facilities could also serve very important roles in offering flexibility (more information about shared-use facilities is also presented in Chapter 2). At the same time, without appropriate connection among terminal facilities, achieving shared-use facility is not feasible. It potentially allows more flexibility to the performance of a passenger terminal building. As the need for different functions typically peak at different times, shared and multi-function spaces have the potential to reduce the total space required. For example, a hold room shared by multiple gates typically requires less space than the same number of individual gate hold rooms. Economic efficiency is also a prime motivator for the use of shared-use/ multifunctional facilities in airport terminals.

Within the provision of multifunctional spaces, the introduction of improved software for common-use facilities is an advantage. However, it does not have much relevance in terms of layout generation for technological advancement.

The shared-use wing of the passenger building at Edmonton International Airport in Alberta, Canada, is a prime example of this facility (ACRP-25, 2010). It is designed to serve three different types of traffic (international, domestic and trans-border) for many airlines by using a system of corridors with access points that can be locked or opened to channel passengers when required. This strategy of shared use requires only about half the space that would be required otherwise in a terminal building.

12. Cost benefit:

Layout generation	Technological adaptability	Volume of passengers
■■	■■	

Any proposed modification to an airport terminal will require considerable cost and, hence, it is always important to do a cost-benefit analysis before approving any expansion or modification. This is considered as a critical step at the preliminary stages of a terminal development project as the project has to be affordable given the resources available to the airport. The task of the designer is to maximise the number of requirements that are satisfied by the design and to minimise the cost during the design process. Ongoing maintenance cost also forms an important element of cost-benefit analysis, *i.e.* a low construction cost is not always the best solution if the maintenance cost over the lifetime is significantly more. Maintenance cost means the running, care, repair and replacement of the project elements and systems in order to provide a sustainable operations plan that optimises life cycle costs.

Technological advancement could add value to the existing facilities and, hence, could have a moderate effect on the cost-benefit analysis. The maintenance cost of a flexible service is harder to estimate than a normal design practice.

The volume of passenger will have a direct impact on the cost of running an airport, but at the same time will affect revenue.

13. Furniture/equipment arrangement:

Layout generation	Technological adaptability	Volume of passengers
■■	■	■■

An effective furniture layout supports circulation through the terminal facilities. Furniture arrangement in layout generation is important in providing appropriate flexibility to services. The arrangement of furniture and furnishing has an influence on both operational and strategic changes. Utilising the most modern materials and technologies could provide greater economies of space and terminal efficiencies. Implementation of innovative technologies such as self-check-in solutions, self-boarding gates and 'easy pass' facilities at passport control is rapidly restructuring passenger processes. The volume of passengers will greatly affect the layout chosen for furniture, which could change with time as passenger volumes change. New technologies will also affect furniture orientation, so that stakeholders can make the most use of it.

The furniture arrangement also can use modularity, the seating arrangement presents in Figure 7.11 is enhanced by the connectivity of the Transit system, allowing for two-way or three-way connection with power and data as standard. This means that terminal designers and planners can now offer their clients a seating solution which is both well designed and functional (UFL, 2014).

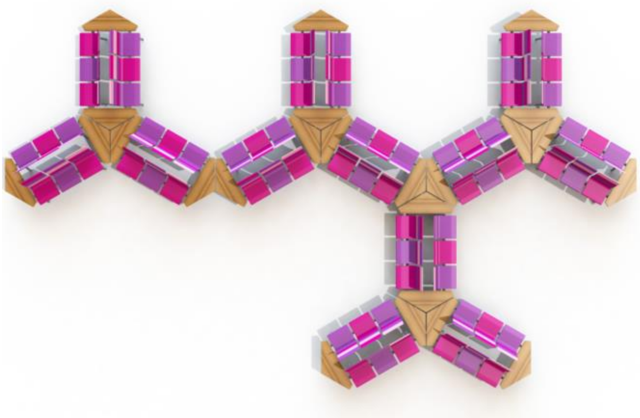


Figure 7.11: A revolutionary new Beam Seat by UFL (UFL, 2014)

This seating can be used as a regular chair, a bench with table, a place to converse with friends or family and a daybed where passengers can lay down for a nap.

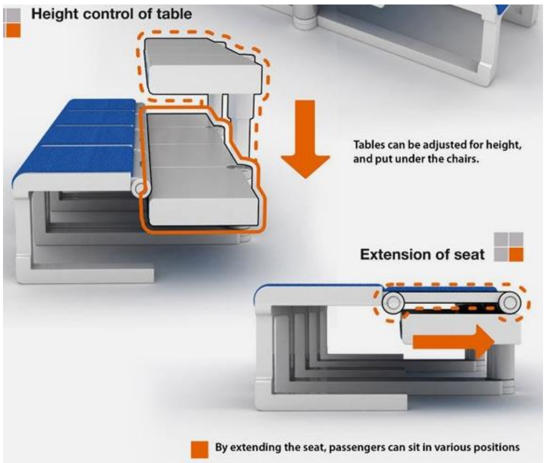


Figure 7.12: Multifunctional seating arrangement at waiting area (Marvel-Building, 2013)

14. Position of service core:

Layout generation	Technological adaptability	Volume of passenger
■■■	■■	

Changes in services may occur throughout the life cycle of a terminal building and are responsible for tackling both tactical and strategic stages of flexibility. The position of the service core is often defined as a permanent element in a layout, and hence it should be carefully designed at the initial stage of an architectural layout. The core position should be placed in such areas which are easier to locate for any necessary changes, irrespective of the size and configuration of an airport. Service core facilities should be updated in every three to five years to keep pace with the consequences of technological advancement and change in passenger volumes. The placement of building services outside of functional areas is suggested in some available research (ACRP-25, 2010; Edwards, 2005). As major building services may limit the terminal's capacity for expansion, the ACRP report also suggests that, if possible, it should be designed for expansion. However, the separation of structure and building services in Stansted Airport, UK provides an example of placing service core inside. Appropriate consideration of the layering concept should also facilitate renewing services when required. In Stansted Airport, the structure and servicing have been integrated into a series of ‘trees’ (Figure 7.13).

Technological innovation is the base of modern service core (Trabucco, 2010). The innovation in service core design is also related to sustainability issues. The efficiency of a service relies on the number and the complexity of services originally involved, the complexity of the relationships between service originals, and the amount of service state information. The potential changes in technology are therefore highly relevant to flexibility.

Passenger movement and changes in number at the various stages, and changes in service core, are not directly relevant.

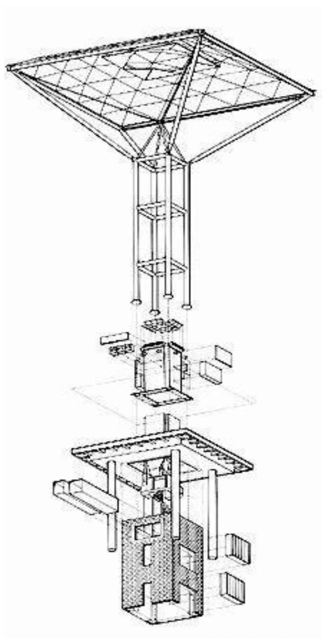


Figure 7.13: Separation of structure and building services within an integrated system (Edwards, 2005)

15. Aesthetics:

Layout generation	Technological adaptability	Volume of passengers
■	■	□

The visual perception of an airport terminal design, however, could play an important role with its acceptability to stakeholders. This perception depends on individual interpretation based on emotional responses and/or comparison with previous experience. According to Edwards (2005) an airport is the first point of contact for a person with a city and, therefore, an aesthetically pleasant airport could play a significant role in consequent experiences. Aesthetic quality of an airport terminal could make passengers feel good about their experiences, but does not directly affect flexibility. However, a soothing experience could make the passengers flexible about any constraints they might experience within the terminal.

Technological advancement could moderately affect aesthetics, for example, innovation of new facade materials may help to improve aesthetics of a terminal at a lower cost, whilst it will not be affected by the change in volume of passengers.

Table 7-5 summarises all proposed design parameters showing their given priority.

Table 7-5: Design parameters for flexible airport terminal design

Level of relevance: ■■■ High ■■ Medium ■ Low

	Design parameters	Design criteria		
		Layout generation	**Technological adaptability**	**Volume of passengers**
1	Ease of expansion	■■■	■■■	■■■
2	Terminal configuration	■■■	■	■■■
3	Moveable/folding partition	■■	■	■■■
4	Connectivity among facilities	■■■	■■	■■■
5	Geometrical simplicity	■■■	■■	■
6	Level change	■	■	■
7	Modularity	■■■	■■	■■■
8	Building layers	■■■	■■■	
9	Circulation area	■■	■	■■■
10	Functionally neutral space	■■■	■■■	■■■
11	Shared use facilities	■■	■■	■■■
12	Cost benefit	■■■	■■	
13	Furniture arrangement	■■	■	■■
14	Position of service core	■■■	■■	
15	Aesthetics	■	■	

7.5 DESIGN EVALUATION

Selecting a suitable layout by evaluating the available options at the conceptual phase of the design process is crucial. Available design alternatives should be checked carefully so that the goals are achieved in an efficient manner. Inevitable uncertainties in airport terminal make is very challenging to choose the appropriate solution. Measurement of flexibility would require both qualitative and quantitative techniques. The current research did not have access to real airport data and hence relied on design hypothesis. However, a number of design alternatives as obtained from the proposed automation technique will be assessed using the proposed set of flexible design parameters. The list of design parameters offers guidance to select the most appropriate terminal layout that will provide flexibility to serve a particular context, although it is almost impossible to satisfy all the proposed parameters for a particular terminal layout. The following points illustrate some tentative application techniques for the proposed hypothesis in obtaining a flexible layout:

- Once the designer investigates all possible options, then a suitable layout should be chosen considering appropriate flexible design parameters that will efficiently serve the most typical passenger flow conditions. Since the designer already knows the spatial requirements to tackle unusual scenarios, it is recommended that flexible design elements should be used to allow transforming the typical orientation into a suitable configuration without causing too much interruption. The final level of evaluation can be adopted using a decision matrix to evaluate the ability of the developed layouts effectively. Within the decision matrix, the design parameters are not compared against each other but to the criteria of evaluation. The decision matrix is used as a tool to guide iterative design processes. It should be made clear that the decision matrix is not a static document, it can change and evolve according to the design problem and the development of each specific terminal layout.

- If a traditional design approach is adopted in the design process, the proposed flexible design parameters should be carefully used to evaluate the design outcome. Each of the design parameters has its own functional merits to facilitate in achieving flexibility. The selection criteria for the decision matrix are based on the functional requirements and/or the objectives of the problem. It should, however, be noted that all proposed parameters may not be applicable to every terminal and, on the hand, additional parameters may be required in some cases to achieve flexibility. The current research does not provide a complete solution, but proposes a hypothesis to evaluate any design for flexibility.

7.6 ELABORATED MAP OF FLEXDFA

In Chapter 4, a conceptual framework for understanding and implementing flexible design for airport terminals was introduced. The detail development process of FlexDFA as explained in the previous chapters presented the road map to achieve flexibility in an initial layout design as well as in a redevelopment process. This section summarises all relevant design aspects and provides a detail design map of FlexDFA.

The first step of the proposed framework presents a conceptual approach that is especially suited for handling typical uncertainties in airport terminal design. A concept of changing layers in airport building was identified in spatial layout as well as in physical structure. Considering the layers of change, the levels of flexibility are identified to develop alternate layouts in step 4 of the framework. Step 2 of the design framework showed that the interaction between the occupants and the processing system is the basis for gathering adjacency information from available BPM of airport terminals. The method proposed in this research presents a fundamentally new concept to exploit BPMs in floor layout design, and paves the way towards recognising the significance of flexible design strategies for an airport terminal design. The activity analysis provides a set of requirements for an airport terminal layout in terms of adjacency. The third step of the FlexDFA developed a custom plug-in for ‘Eclipse’ to map the dual graph with relative weights. The FlowGraph model obtained from Eclipse with relative weights is used to develop spatial layout in Grasshopper. The developed algorithm Floor Plan Generator was used to automate the process of obtaining spatial representation using dual graph.

The final part of the thesis brings the aforementioned concepts together, and extends the focus on identifying design criteria. Alternate layouts are developed under design factors that affect a layout. A set of flexible design parameter is finally proposed that offers guidance on evaluating flexible layouts. If flexibility thresholds are not achieved by the chosen design layout then alternative designs will have to be evaluated. Results obtained from the integration process are assumed to provide the basis for flexibility analysis of a departure terminal layout against possible future scenarios. Overall, adoption of this conceptual framework is believed to offer a new theoretical change during the initial phase of layout design.

Based on the analysis undertaken in the previous chapters, the research has now developed a detail map of the flexible design framework as elaborated in Figure 7.14.

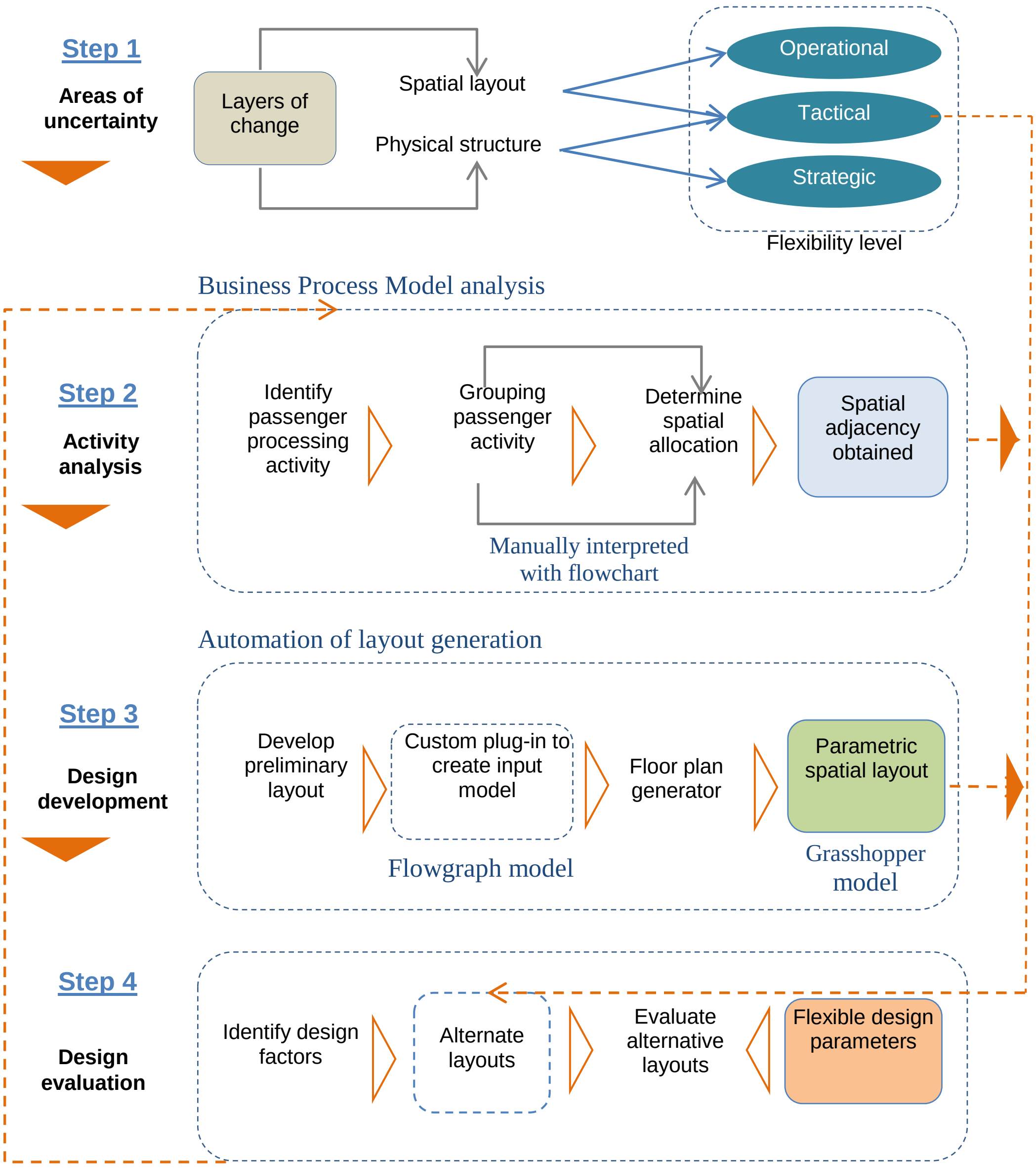


Figure 7.14: Complete map of proposed FlexDFA

7.7 SUMMARY

This chapter presents the determining factors that will affect the evaluation process of an initial layout design to explore process-based amalgamation to assess flexibility in airport terminal design. Both synthesis and evaluation are integrated in a single model for producing alternative design solutions to meet a given set of design criteria. The current research project is an ongoing investigation to explore the potential and the suitability of flexible design concept in airport terminal design.

The list of flexible design parameters presented herein will lead to the development of a complete list to assess the practical implementation of the proposed flexible spatial layout, and hence to optimise the design of airport terminal layout. Quantification of the impact of individual design parameters during the early stages of design is highly dependent on available design information. However, it is important to decide which factors are to be considered during the concept design.

The initial layout of a terminal should be flexible enough to be altered into other generated layouts to ensure efficient operation of the terminal. The proposed conceptual framework is characterised by a number of fields of knowledge. The proposed design framework will provide guidance to the designers to look at key considerations for terminal initial design process such as achieving an optimum balance among varying passenger needs, implementing a flexible solution, and managing the opportunities and risks associated with a terminal design process. The research findings support the development of spatial models for departure facilities to evaluate the relevant parameters qualitatively. Flexible design parameters presented herein would require thorough investigation to come up with appropriate thresholds and allowable tolerance limits using real-life data from various airports.

Chapter 8

Conclusion

8.1 PREAMBLE

A comprehensive review on airport terminal design highlighted the significance of flexibility in this design field and identified considerable research gaps in the area. The current research proposed a conceptual design framework for airports to obtain flexible departure layouts based on passenger activity analysis obtained from business process models for airports. This chapter summarises the major research activities and outcomes of the current research such as contributions made towards the knowledge of flexibility in airport terminal design process highlighting the significance and implications of the proposed concept for airport terminal design. The limitations of the current research and scope for extending the concept through further research are also identified in Section 8.3.

8.2 RESEARCH CONTRIBUTIONS

The primary objective of the current research was to develop a design framework to incorporate flexibility in an airport terminal using passenger processing information obtained through business process models. Considering the time and resource constraints, the current research only considered the departure terminal of a typical airport. Inappropriate understanding and recognition of uncertainties in traditional design process can lead to significant economic losses (Chambers, 2007; de Neufville et al., 2008; de Neufville & Odoni, 2003; Edwards, 2005; Finch, 2009; Magalhaes et al., 2012).

Research questions were developed to answer the gaps identified from relevant literature, and were addressed in a systematic way by analysing passenger processing activities that take place in a departure terminal. The key contribution of the research is the flexible design framework, which is envisaged to assist in developing initial design layout. The proposed conceptual framework is novel in a way that it directly uses business process models in the design process. The following sub-sections briefly outline the steps of this proposed concept.

8.2.1 **Design framework to achieve flexibility**

The development of a Flexible Design Framework for Airports (FlexDFA) (section 4.2) is the fundamental element of the current research. Previous studies (de Neufville, 2008; Lawson, 2005) showed that traditional building design process do not appropriately consider uncertainty in design. This significantly affects operational performance, and hence flexibility should be an integral part of a design process. Butters (2010) suggested four key stages of airport terminal development and identified a number of design components to achieve flexibility in a master planning stage. Magalhaes (2012) proposed a framework but did not provide a comprehensive road map to cope with uncertainties.

The framework proposed (Section 4.2 and Section7.6) in the current research highlights the significance of identifying uncertainties in terminal processing areas, and suggests ways to incorporate those in the design process. Initial step of the framework deals with identification of airport terminal layers and associated uncertainties that could occur in various layers of a terminal building. Following the theory of time-dependent layers, the current research suggested that uncertainty may occur at two main layers in airport terminal design such as spatial layout and physical structure. The following steps include activity analysis, design development and finally design evaluation; all these steps are crafted to provide a detail roadmap to tackle uncertainties.

Overall, FlexDFA provides a rational answer to Research Question 1: "How can the concept of flexibility be incorporated into airport terminal layout development?"

8.2.2 **Novel approach to use BPM in spatial layout**

The business process models (BPMs) developed for airports show the flow and sequence of passenger activities in an airport terminal. BPMs are considered as an integral part to extract useful information for design process; this is a novel concept introduced in the current research.

The interactions between passengers and terminal services/facilities are thoroughly examined (for the case study airports) to get spatial adjacency information in the departure terminals. All passenger activities that take place in international departure area are grouped into seven domains, and are then sub-grouped based on their importance level; mandatory or auxiliary. The selected process models are subsequently transformed into 'modified Business Process Models' (mBPMs) (Section 5.4.2) using a set of proposed logical rules.

Adjacency requirements were represented as an adjacency graph. A generic passenger facilitation process for departure terminal was developed using the modified process models. A range of adjacency networks could be generated to match various options for a new or existing terminal building. Graph theory was used in a simple way to obtain initial space allocation data from the modified process models. In doing all these aforementioned activities, FlexDFA provided an answer to the second research question: "Can business process models be used to determine spatial adjacency for an airport terminal?"

8.2.3 **Automated floor plan generation**

The current research developed an automated technique to generate spatial layout using the spatial adjacency information obtained from BPMs (Section 6.4). A simple demonstration is presented in the thesis considering the departure terminal only, but the concept has much wider practical possibility of exploiting BPMs in complete design of an airport terminal. The automation process involves two stages: at stage 1, a plug-in called 'Flowgraph' was developed (Section 6.5.1) to generate adjacency graph using information on passenger processing from BPMs, and at Stage 2, an algorithm called 'Floor Plan Generator' was developed to generate spatial layout based on the adjacency graph. The 'Flowgraph' has a user-friendly graphical interface and requires very simple techniques to draw graphs involving nodes and links. ‘Flowgraph’ allows an addition of the relative weights to the dual graph links, which refer to the dimensions of a space. The relative weights are based on passenger processing data as easily obtained from BPMs. The Flowgraph model is the input model for Rhino 3D, that is used for generating layouts using the developed algorithm ‘Floor Plan Generator’. This whole process clearly shows that the spatial relationships as obtained from BPM can be used as a design aid for initial terminal layout generation, and answers the third research question: “How can the adjacency information as obtained from BPMs be used to develop spatial layout?”

8.2.4 **Flexible design parameters**

Design principles on flexible design strategy for airport terminals are not currently available in literature. However, there are some scattered guidelines available in literature outlining flexible design elements by de Neufville (2008), flexible design components for space planning by Butters (2010), and a report by Airport Corporate Research (ACRP-25, 2010) also provide options to introduce flexibility. The current research proposed a set of design parameters based on the design principles available in the field of airport terminals as well as those reported in other design fields residential, educational and hospital designs.

A total of fifteen design parameters were proposed in Section 7.4, which could be used as performance indicators by measuring a level of satisfaction in terms of flexibility. The proposed set of design parameter has been evaluated for their influence on design flexibility based on three essential criteria – relative importance in layout generation, technological adaptability, and sensitivity to passenger flow. Each design parameter has been evaluated for its relevance in a scale of high, medium and low. The suggested parameters offer a guideline for the designers to choose the preferable solutions from a number of design options but the level of importance should not be regarded as an absolute measure. Identifying these parameters ultimately answers the final research question: “Is it possible to define a set of design parameters to evaluate flexibility of a departure layout?”

8.2.5 Use in other research field

This proposed design framework creates an integrated and interactive design process that facilitates the sharing of design intelligence across various disciplines. This approach could be considered as a starting point to undertake a deeper understanding of the use of passenger movement in space planning, and can also be applied to other industries where the design of complex buildings is required, for example, hospitals, railway terminals or in similar situations where the design of a structure is guided by the movement of people.

8.3 BENEFITS TO THE AIRPORTS

The proposed framework presents a holistic approach on use of passenger processing information within terminal facilities to identify uncertainties in airport operations. The perceived outcomes that directly benefit airport design process are:

- A new concept showing direct use of passenger processing activities in preliminary layout development.
- Developed research methodology could be used in various design fields to generate flexible layout under a wide range of uncertainties.
- Demonstrated integration of business process models in obtaining space adjacency provides an explicit information flow within an airport terminal design process.
- Presented a design guideline to achieve flexibility in design, operation, maintenance and refurbishment.

8.4 SCOPE FOR FUTURE RESEARCH

The scope of the proposed framework is believed to go beyond airport terminal design process; a generalised flexible design concept could be developed to facilitate building designers as well as all stakeholders involved. Research conducted in articulating this framework also suggests a number of future activities that need to be considered as groundwork for such new concepts to be adopted. Some of the recommendations are explained below.

8.4.1 **Extension of the proposed framework**

The major contribution of this research is the development of a flexible design framework for the departure terminal of airport. The scope of the current research was limited to international departure activities to develop the theoretical framework. Further research in this field is required to incorporate arrival activities so that it could eventually be used as a useful design tool for the whole airport terminal design. Future research activities should also investigate the development of the conceptual framework as a practical tool for other functionally complex buildings where flexible design elements could significantly improve their performance.

As well as including flexible design elements in a design, designers should foster conditions that will help to facilitate the implementation of flexibility as required. Further development, testing, and implementation of such an assessment tool would be a logical next step towards a change in the airport design field producing a paradigm shift. The extension of the current framework should also include the regulatory issues that constrain the ability to implement flexibility.

8.4.2 **Improved algorithms for floor plan generation**

Airports are functionally complex buildings involving significant numbers of stakeholders and their continuing interactions. Developing a theoretical concept considering all activities without using computational algorithms is almost an impossible task. The current research proposes a novel approach for obtaining spatial adjacency from passenger processing information. The proposed approach, at the initial stage, requires appropriate categorisation of activities based on spatial characteristics; the current research demonstrated the concept based on international departure activities. It is obvious that manual grouping for all airport activities is an impossible task, and hence computer algorithms should be developed using the proposed concept to generate modified BPMs.

A simple Floor Plan Generator has been developed as part of the current research to demonstrate the possible automation of the proposed concept. This tool uses adjacency information obtained from modified BPMs, and allows to change relative passenger activity indices to obtain a schematic floor plan showing the required floor spaces for corresponding activities. This tool could be transformed into a practical design tool based on the proposed concept through further research. The evaluation framework proposed in this research presents a crucial starting point for formally understanding creativity in parametric design. Further research should be carried out for the development of full automation techniques.

8.4.3 **Validation using real data**

The flexible design framework proposed in the current research was based on available literature, current practices and traditional passenger activities observed in an airport departure terminal. The time frame of this project did not allow to collect passenger data. This is considered as the main drawback of this evaluation strategy lacking in use of real-life examples. Further research is required to validate as well as to modify the proposed framework to meet practical needs. These efforts will include integration and maximising the use of real life collected from airports. In the changing process of design, adoption of 'FlexDFA' can offer a roadmap leading to a more efficient design process. There is, however, the task of choosing a particular rating system and following its requirements as they constantly evolve.

8.4.4 **Flexible design policy for airport terminal**

For this paradigm shift it is suggested that airport planning and design should include flexible design policy. The National Aviation Policy White Paper, providing a framework for Australia's aviation industry to plan and invest for Airport Master Plan, suggests that flexible design policy should be included in the airport planning initiatives and legislative requirements.

8.5 **FINAL NOTES**

Despite the growing urgency of flexibility in airport terminal design, the aviation industry is not sufficiently aware with responsive activities. The current research proposes a new framework towards a new paradigm of flexible layout design specifically targeted at airport terminals. Direct use of passenger processing activities from business process models in obtaining spatial adjacency is a new concept, which eventually lead to generating preliminary spatial layouts. The holistic approach adopted in the current research provides a more in-depth understanding of adaptability of airport terminal buildings over their life cycle. This will ultimately provide designers with an opportunity to develop alternative layouts to tackle uncertainties of passenger movement.

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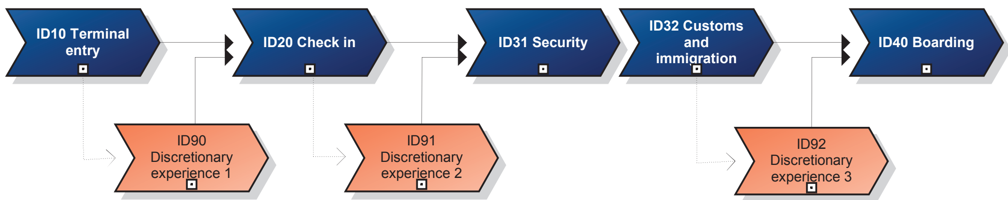
APPENDIX A

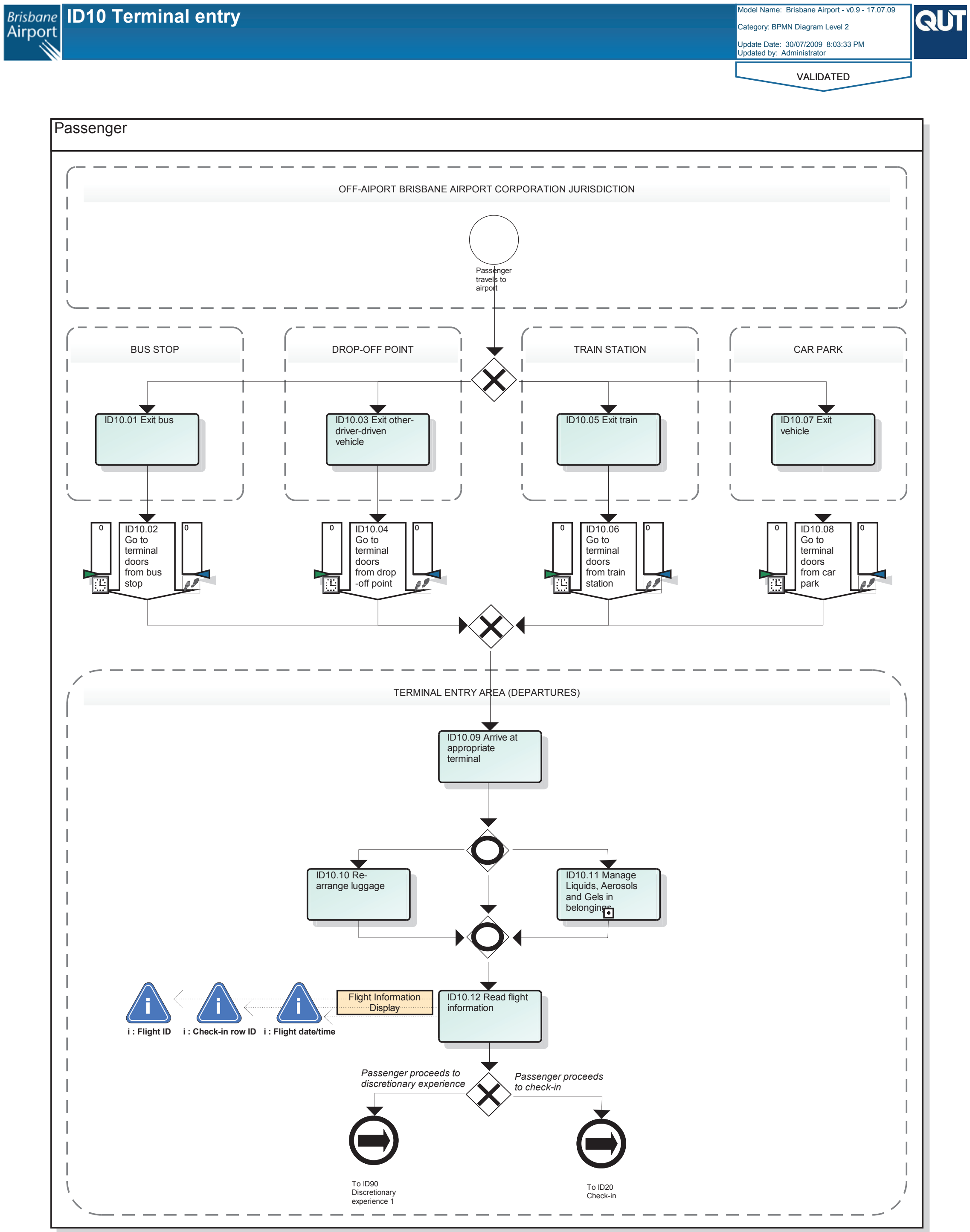
Business Process Models of Brisbane International Airport (BNE)

ID International departure

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: Value Chain Diagram Level 1
Update Date: 30/07/2009 7:59:42 PM
Updated by: Administrator

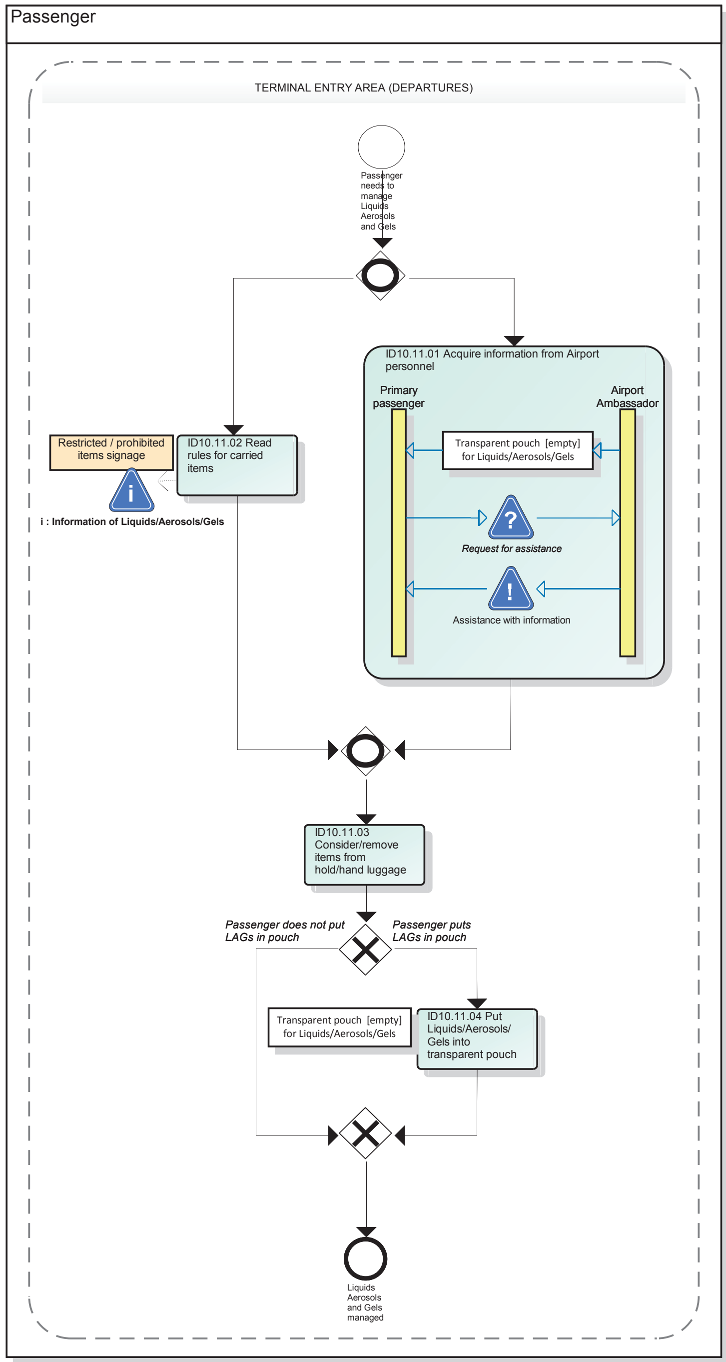
VALIDATED




Brisbane Airport
ID10 Terminal entry
Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 8:03:33 PM
Updated by: Administrator
QUT
VALIDATED
Passenger
OFF-AIPORT BRISBANE AIRPORT CORPORATION JURISDICTION
Passenger travels to airport
BUS STOP
DROP-OFF POINT
TRAIN STATION
CAR PARK
ID10.01 Exit bus
ID10.03 Exit other-driver-driven vehicle
ID10.05 Exit train
ID10.07 Exit vehicle
ID10.02 Go to terminal doors from bus stop
ID10.04 Go to terminal doors from drop -off point
ID10.06 Go to terminal doors from train station
ID10.08 Go to terminal doors from car park
TERMINAL ENTRY AREA (DEPARTURES)
ID10.09 Arrive at appropriate terminal
ID10.10 Re-arrange luggage
ID10.11 Manage Liquids, Aerosols and Gels in belongings
Flight Information Display
ID10.12 Read flight information
i : Flight ID
i : Check-in row ID
i : Flight date/time
Passenger proceeds to discretionary experience
Passenger proceeds to check-in
To ID90 Discretionary experience 1
To ID20 Check-in

ID10.11 Manage Liquids, Aerosols and Gels in belongings

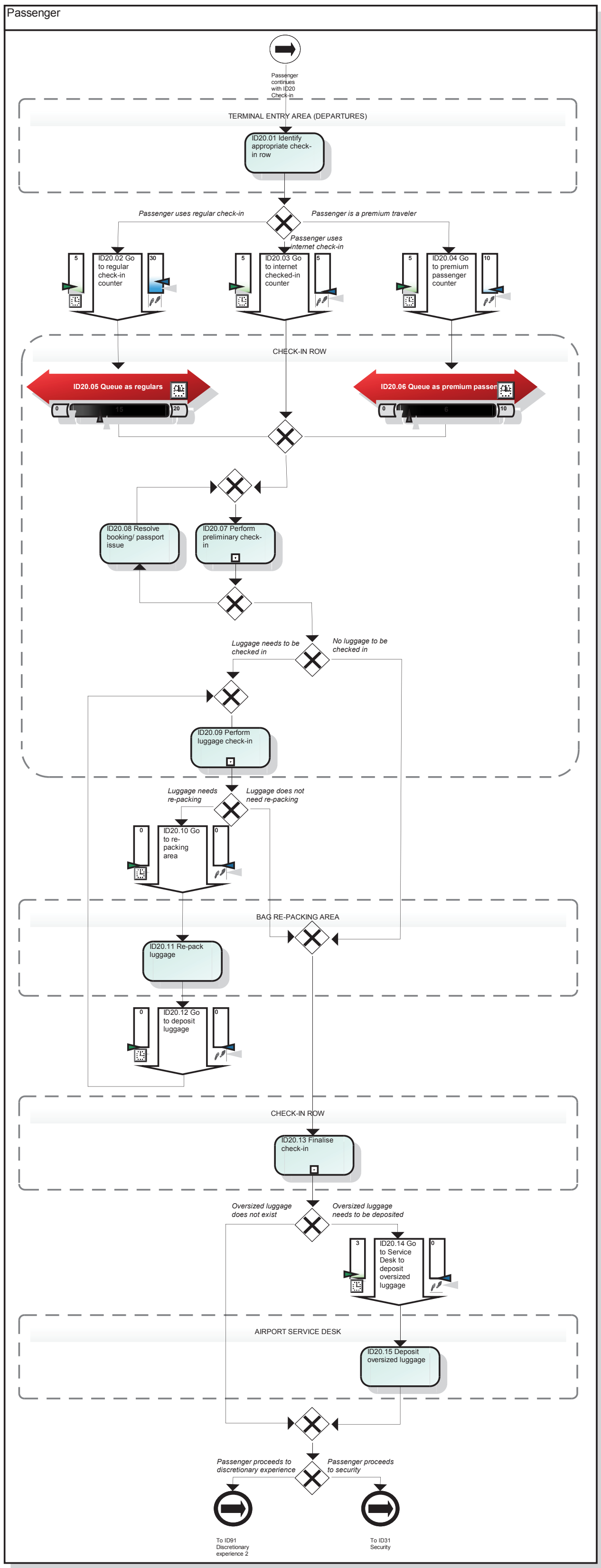
Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:07:05 PM
Updated by: Administrator
VALIDATED



ID20 Check in

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 8:07:54 PM
Updated by: Administrator

VALIDATED



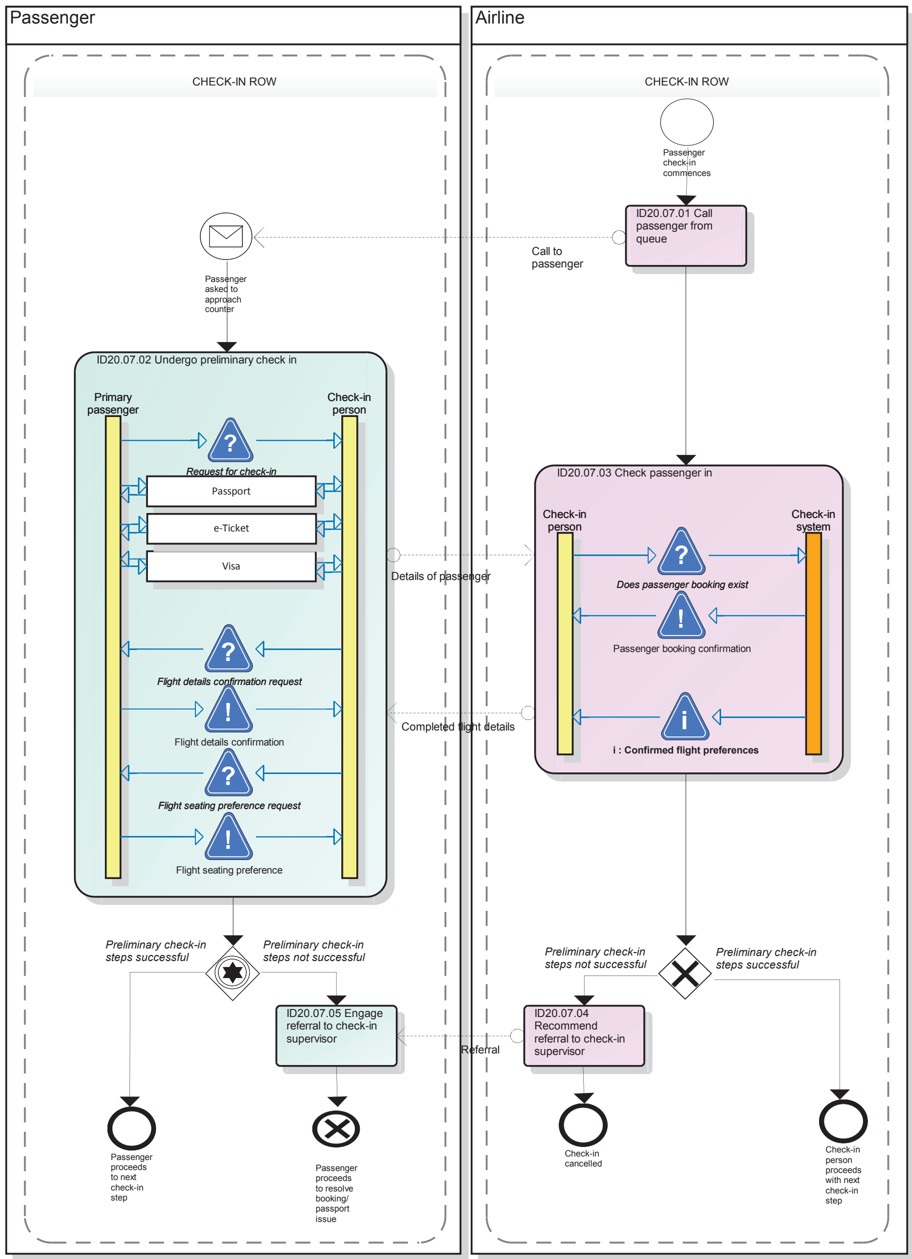
Brisbane Airport

ID20.07 Perform preliminary check-in

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:10:00 PM
Updated by: Administrator

QUT

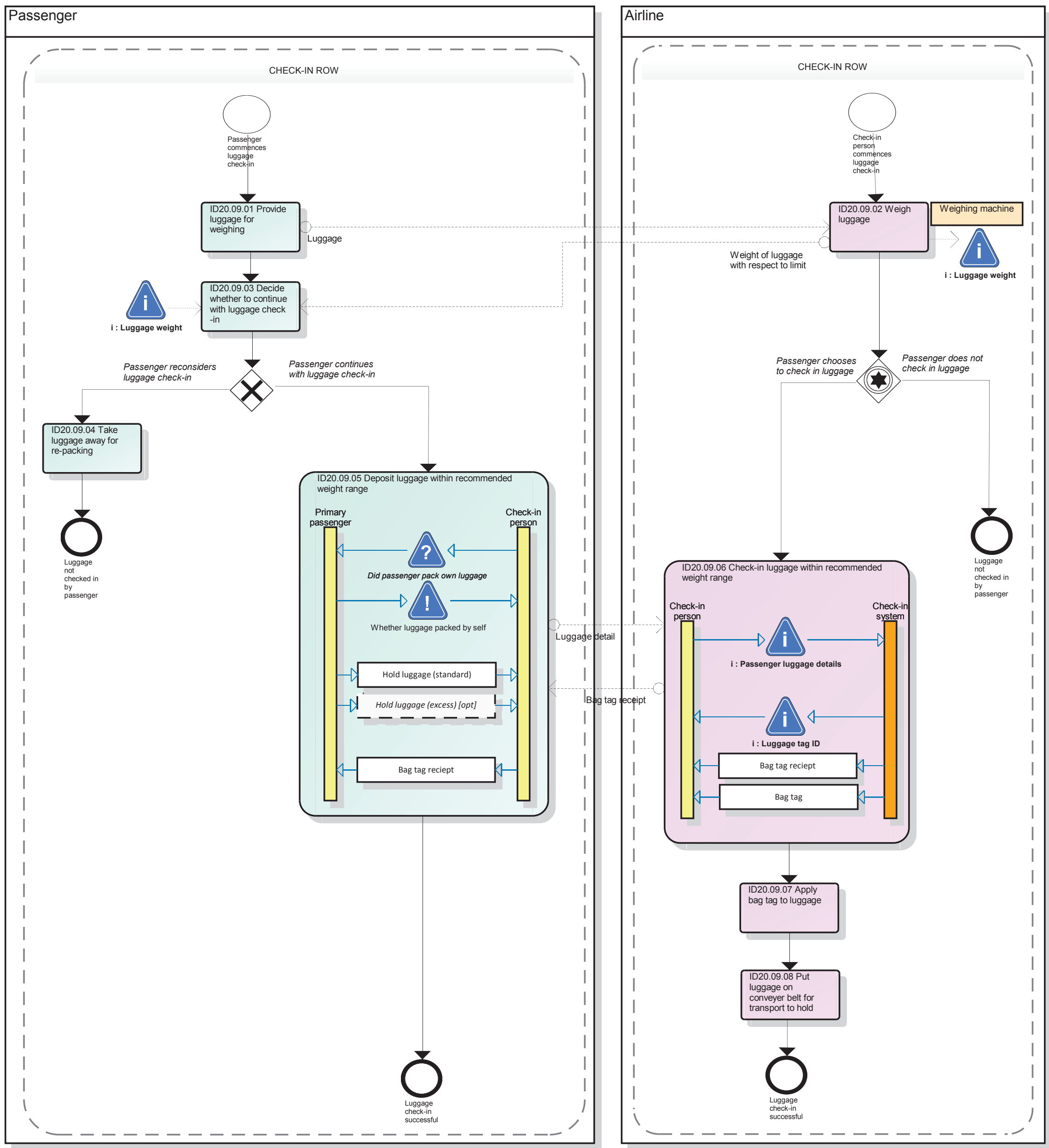
VALIDATED



ID20.09 Perform luggage check-in

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:10:37 PM
Updated by: Administrator

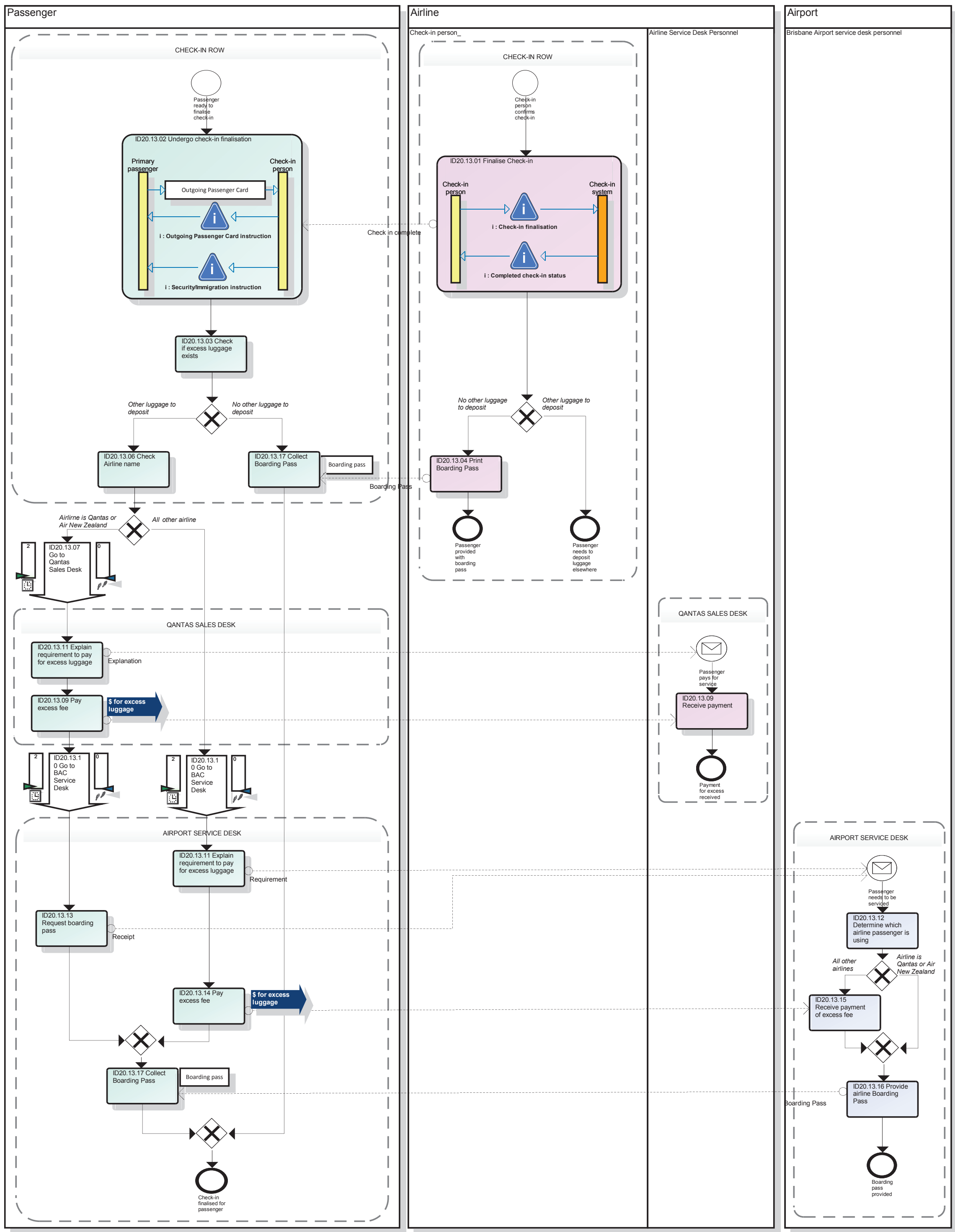
VALIDATED

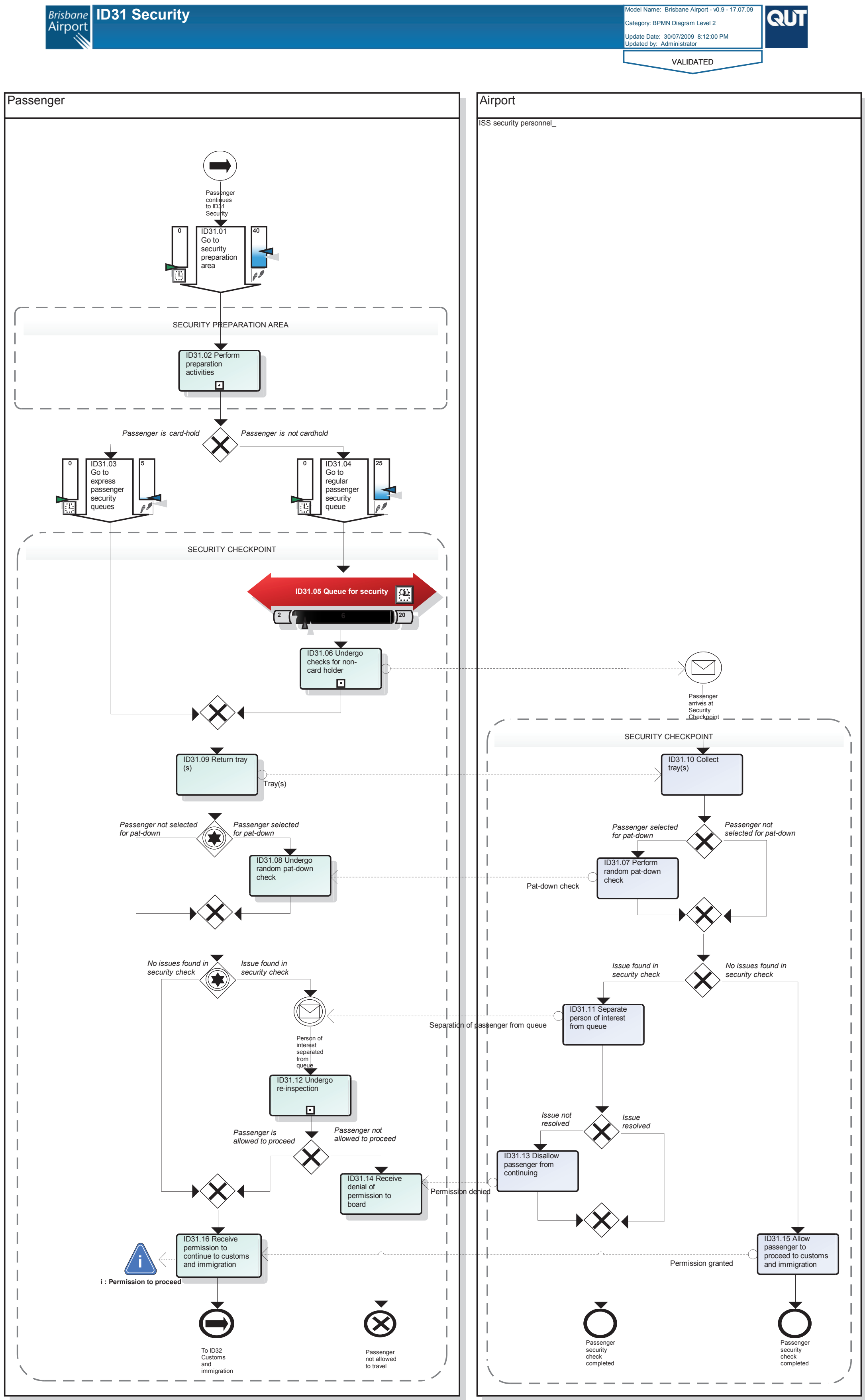


ID20.13 Finalise check-in

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:11:24 PM
Updated by: Administrator

VALIDATED



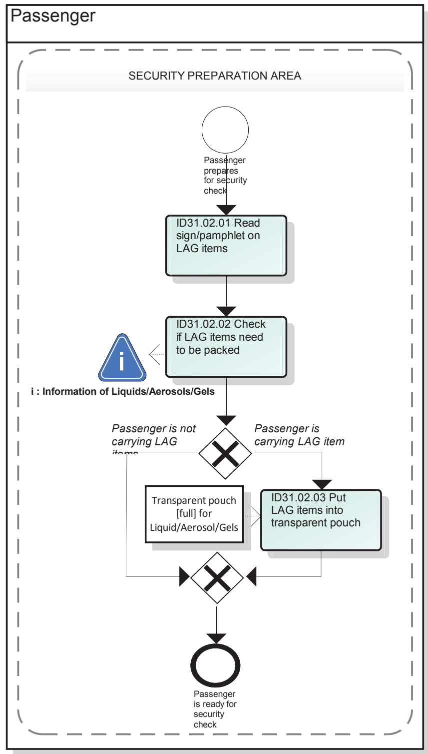

ID31 Security
Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 8:12:00 PM
Updated by: Administrator
VALIDATED
Passenger
Airport
ISS security personnel_
Passenger continues to ID31 Security
ID31.01 Go to security preparation area
SECURITY PREPARATION AREA
ID31.02 Perform preparation activities
Passenger is card-hold
Passenger is not cardhold
ID31.03 Go to express passenger security queues
ID31.04 Go to regular passenger security queue
SECURITY CHECKPOINT
ID31.05 Queue for security
ID31.06 Undergo checks for non-card holder
Passenger arrives at Security Checkpoint
SECURITY CHECKPOINT
ID31.09 Return tray (s)
Tray(s)
ID31.10 Collect tray(s)
Passenger not selected for pat-down
Passenger selected for pat-down
ID31.08 Undergo random pat-down check
Passenger selected for pat-down
Passenger not selected for pat-down
ID31.07 Perform random pat-down check
Pat-down check
No issues found in security check
Issue found in security check
Issue found in security check
No issues found in security check
Person of interest separated from queue
Separation of passenger from queue
ID31.11 Separate person of interest from queue
ID31.12 Undergo re-inspection
Passenger is allowed to proceed
Passenger not allowed to proceed
Issue not resolved
Issue resolved
ID31.13 Disallow passenger from continuing
ID31.14 Receive denial of permission to board
Permission denied
ID31.16 Receive permission to continue to customs and immigration
i : Permission to proceed
Permission granted
ID31.15 Allow passenger to proceed to customs and immigration
To ID32 Customs and immigration
Passenger not allowed to travel
Passenger security check completed
Passenger security check completed

ID31.02 Perform preparation activities

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:12:42 PM
Updated by: Administrator

VALIDATED

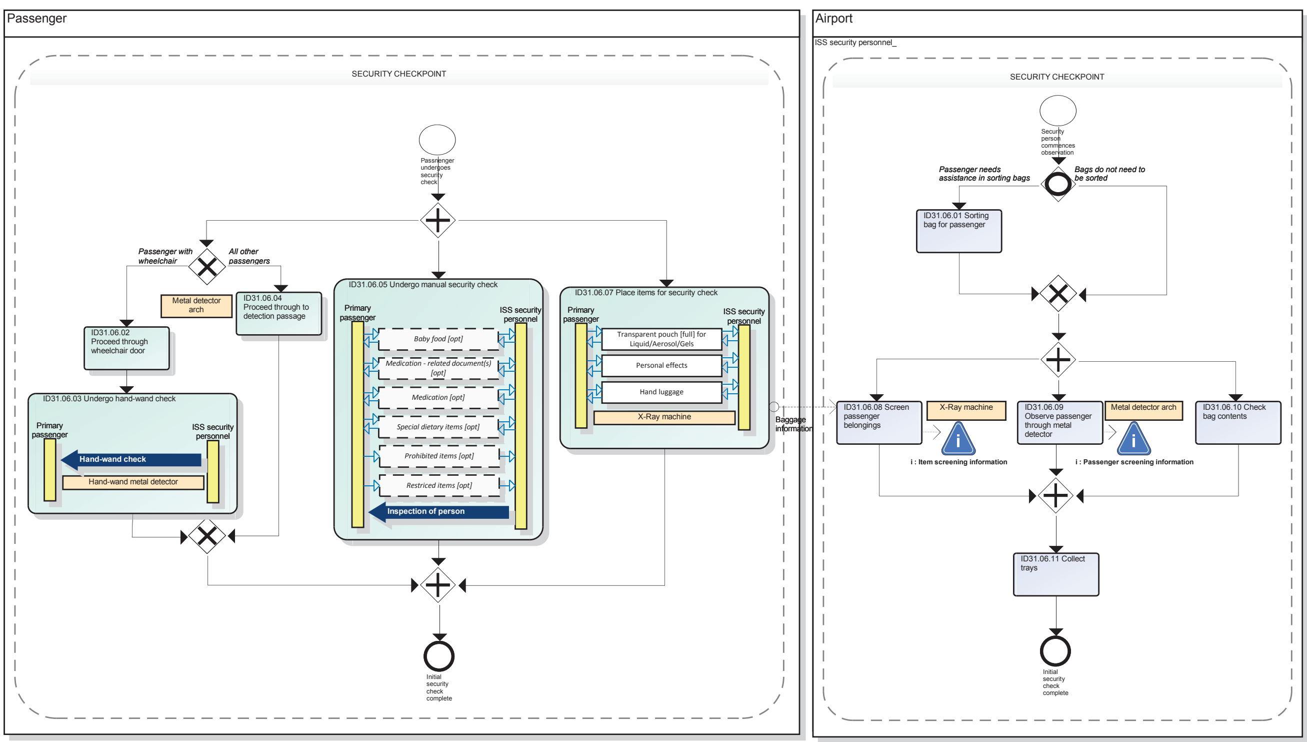


ID31.06 Undergo checks for non-card holder

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:19:19 PM
Updated by: Administrator

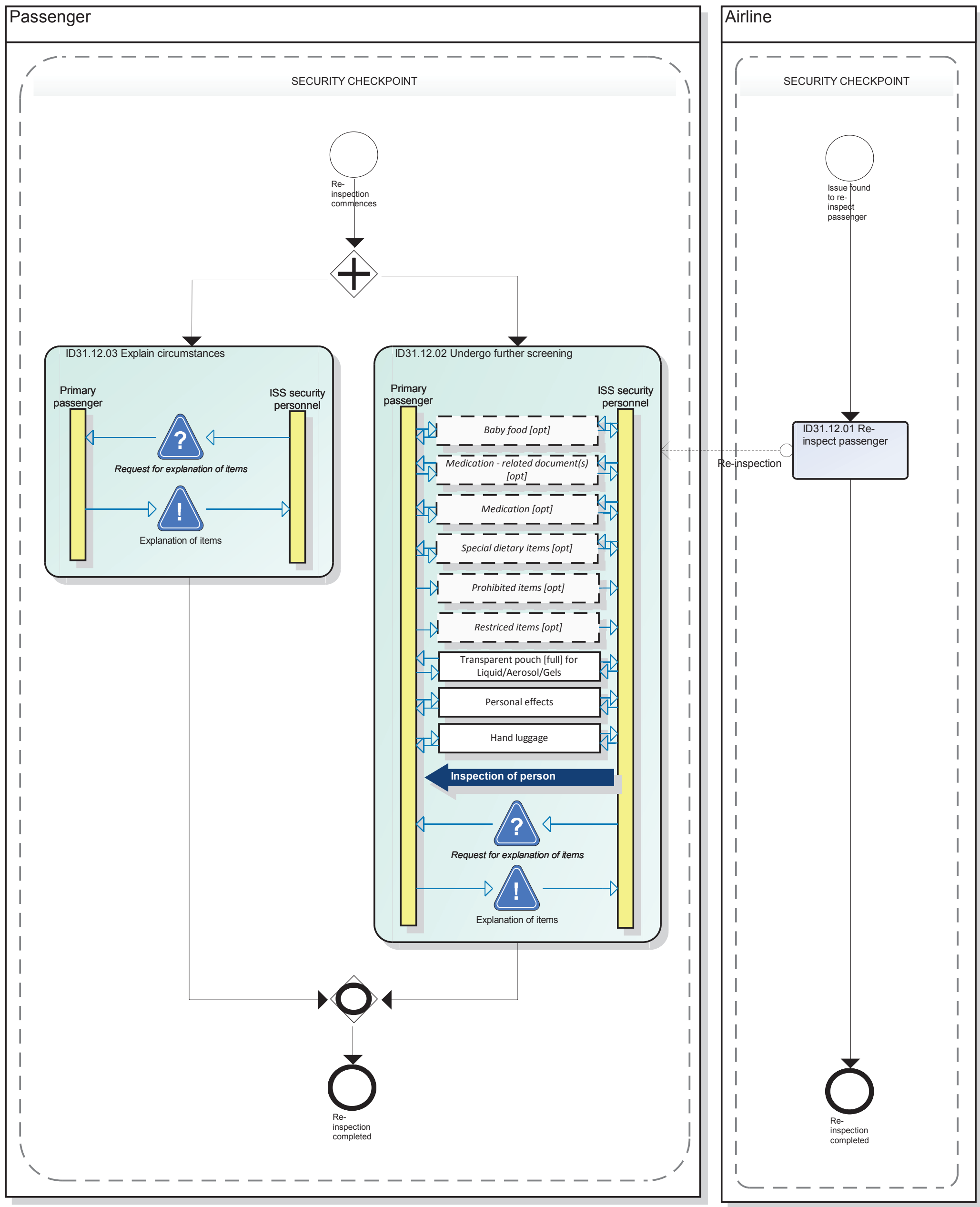
VALIDATED



ID31.12 Undergo re-inspection

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:25:32 PM
Updated by: Administrator

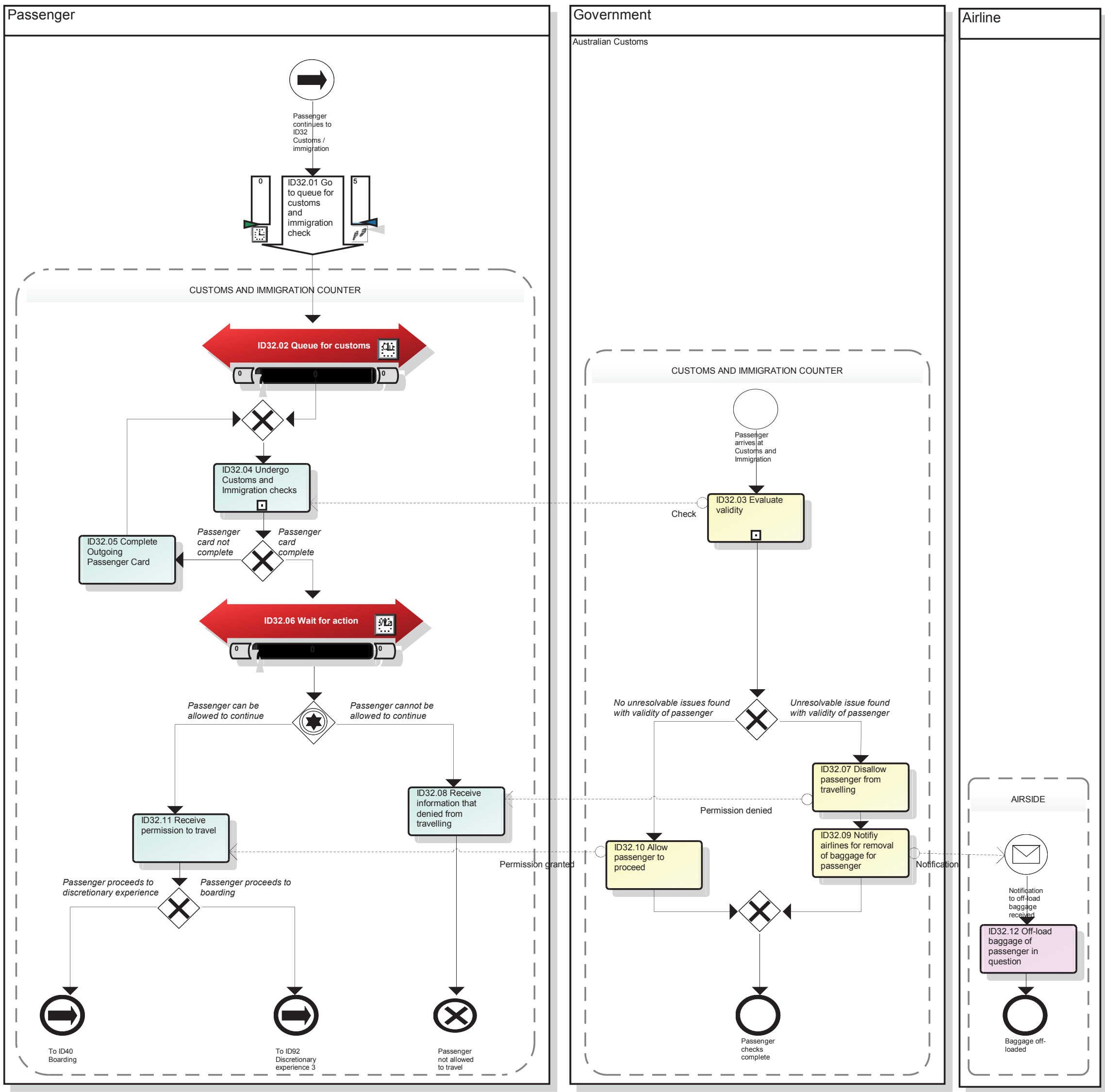
VALIDATED



ID32 Customs and immigration

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 8:26:12 PM
Updated by: Administrator

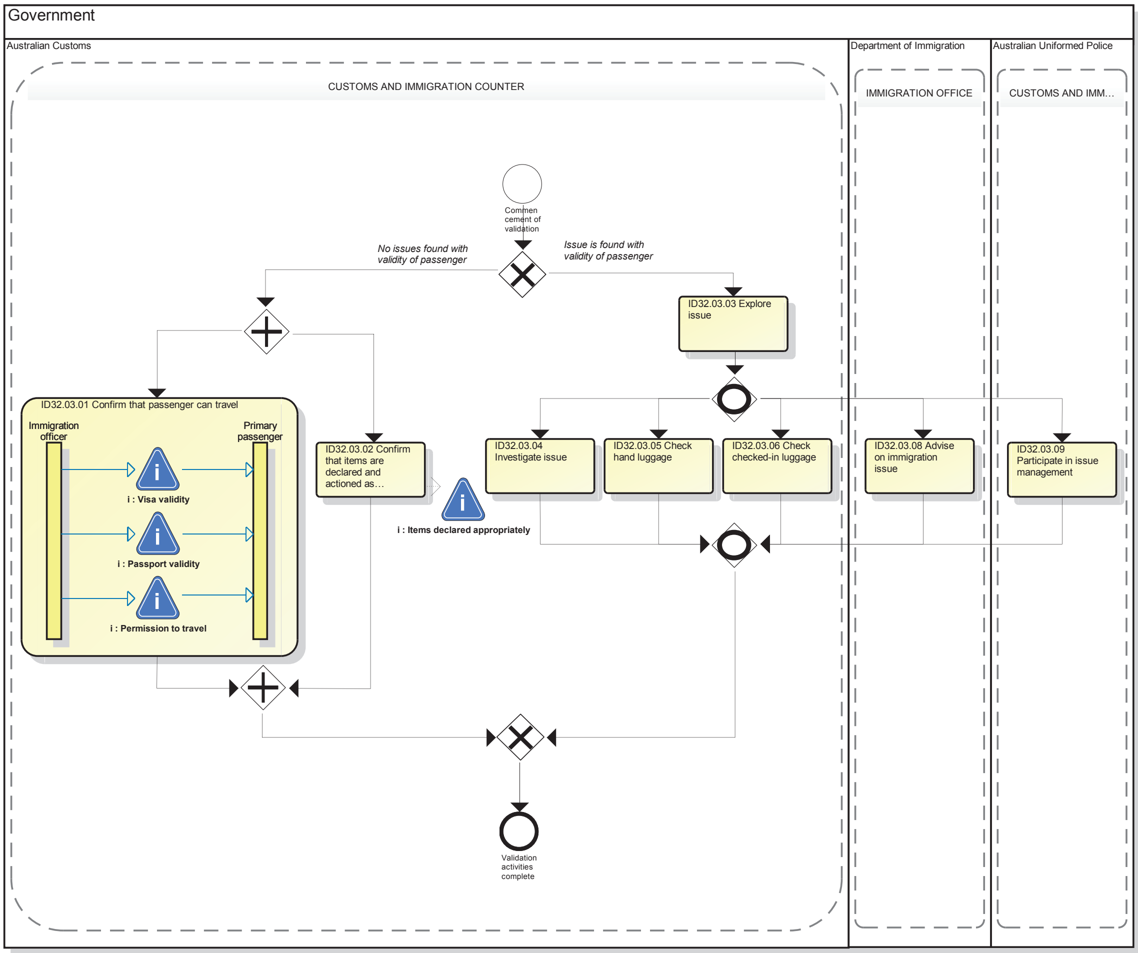
VALIDATED



ID32.03 Evaluate validity

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:38:21 PM
Updated by: Administrator

VALIDATED



ID32.04 Undergo Customs and Immigration checks

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:30:41 PM
Updated by: Administrator

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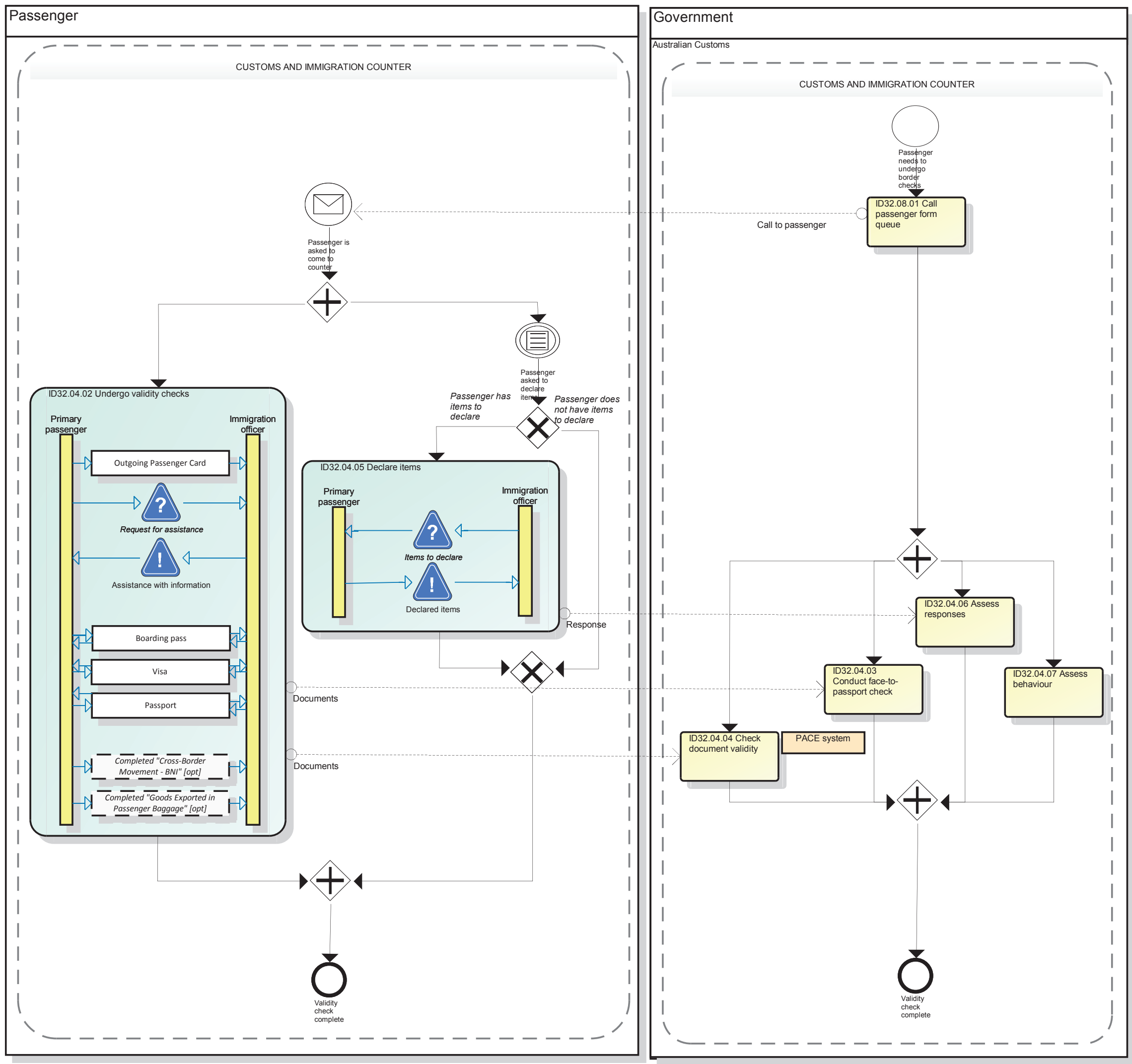
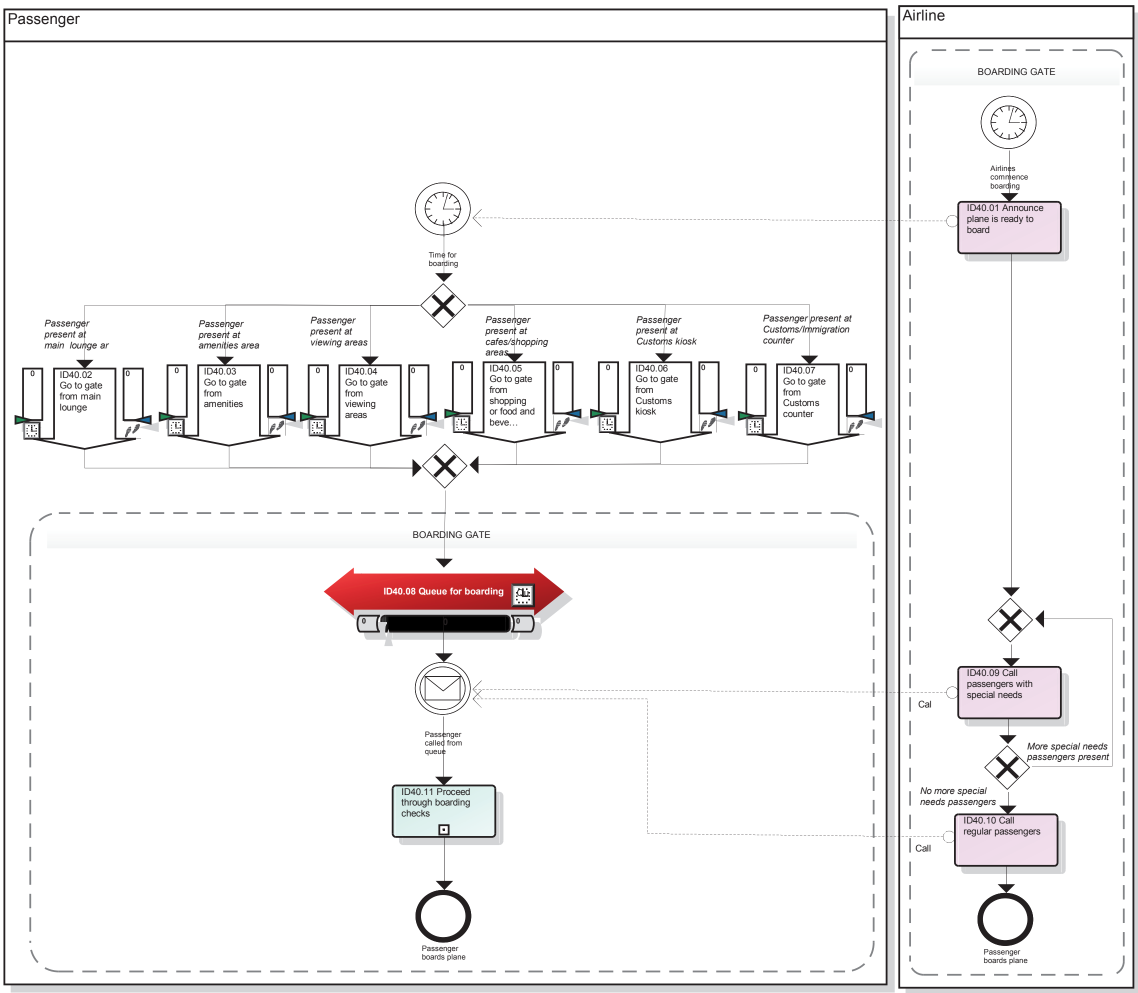


ID40 Boarding

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 8:47:50 PM
Updated by: Administrator

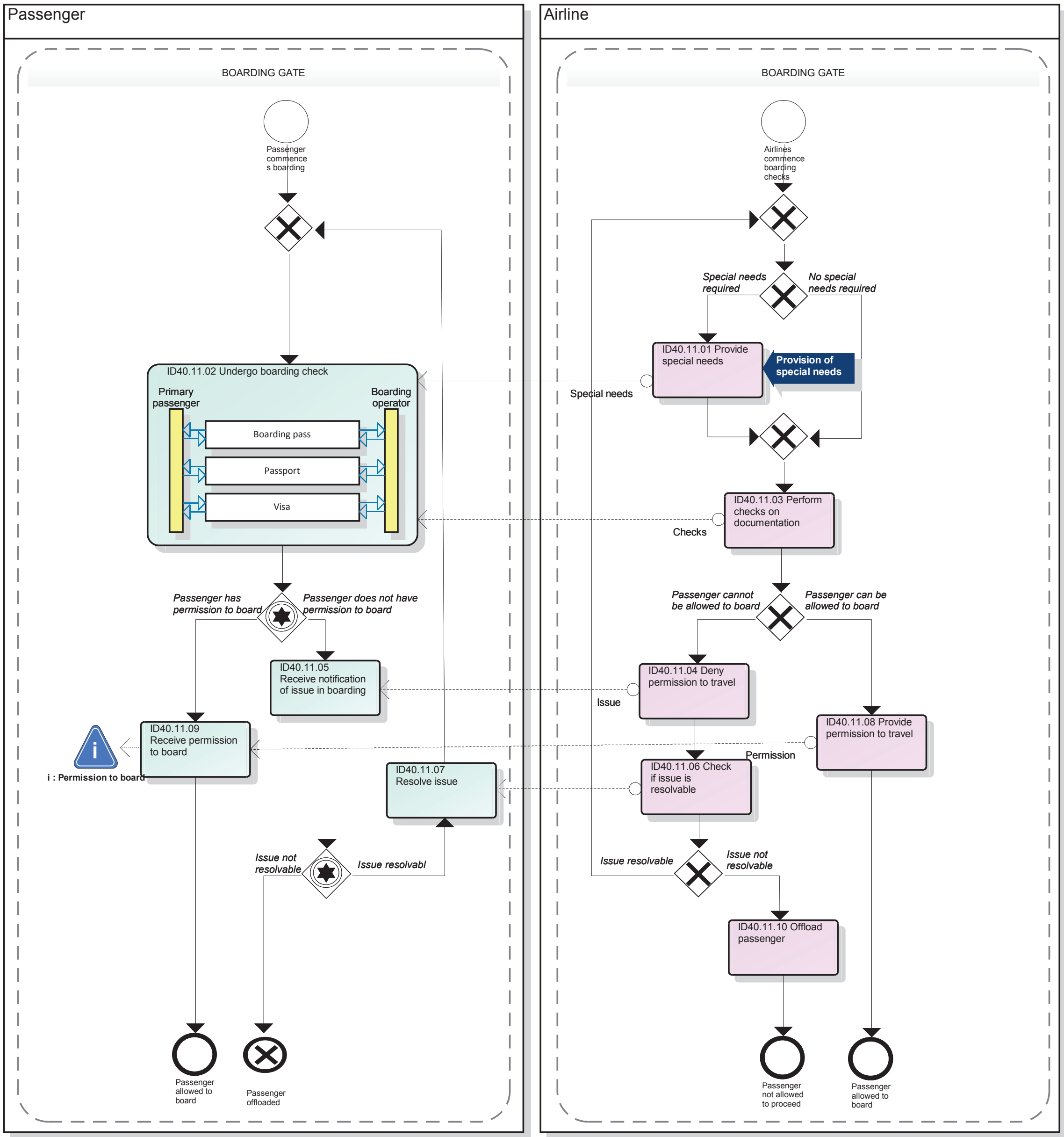
VALIDATED



ID40.11 Proceed through boarding checks

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 8:52:02 PM
Updated by: Administrator

VALIDATED



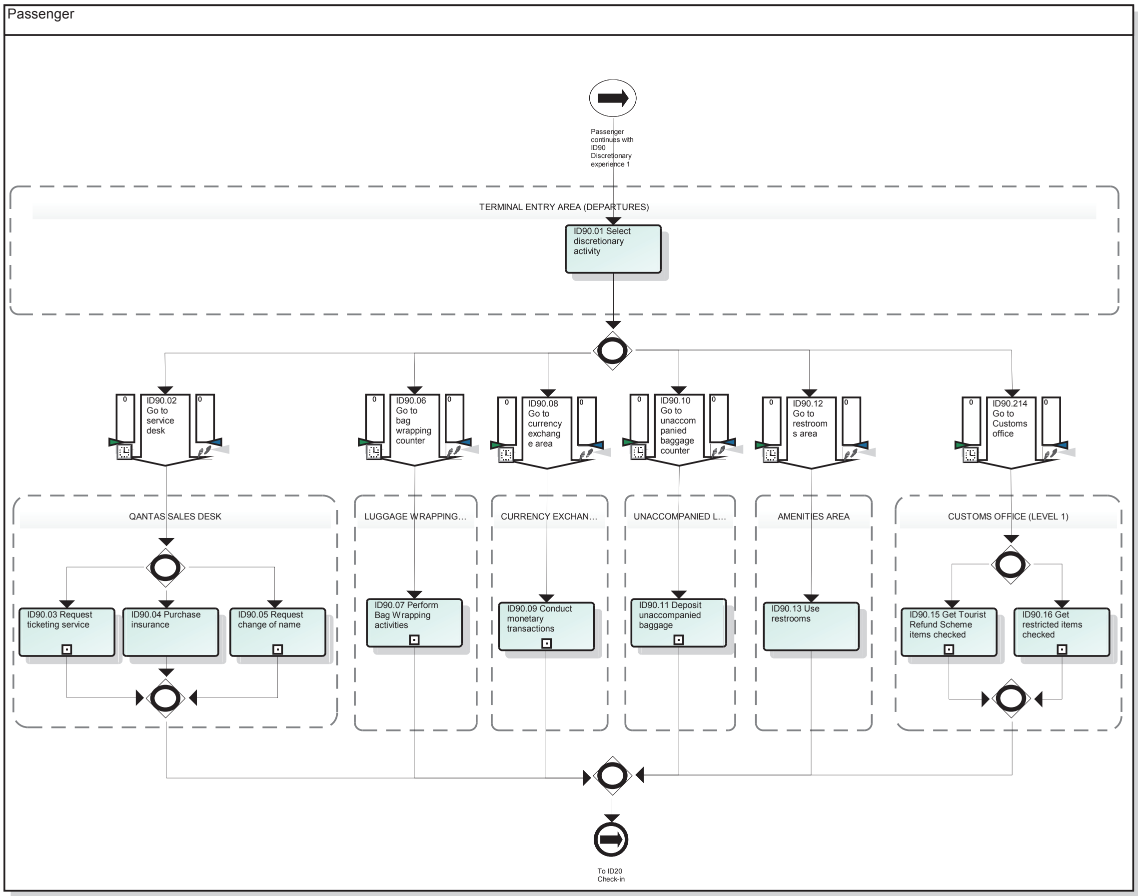
ID90 Discretionary experience 1

Model Name: Brisbane Airport - v0.9 - 17.07.09

Category: BPMN Diagram Level 2

Update Date: 30/07/2009 9:17:18 PM
Updated by: Administrator

VALIDATED



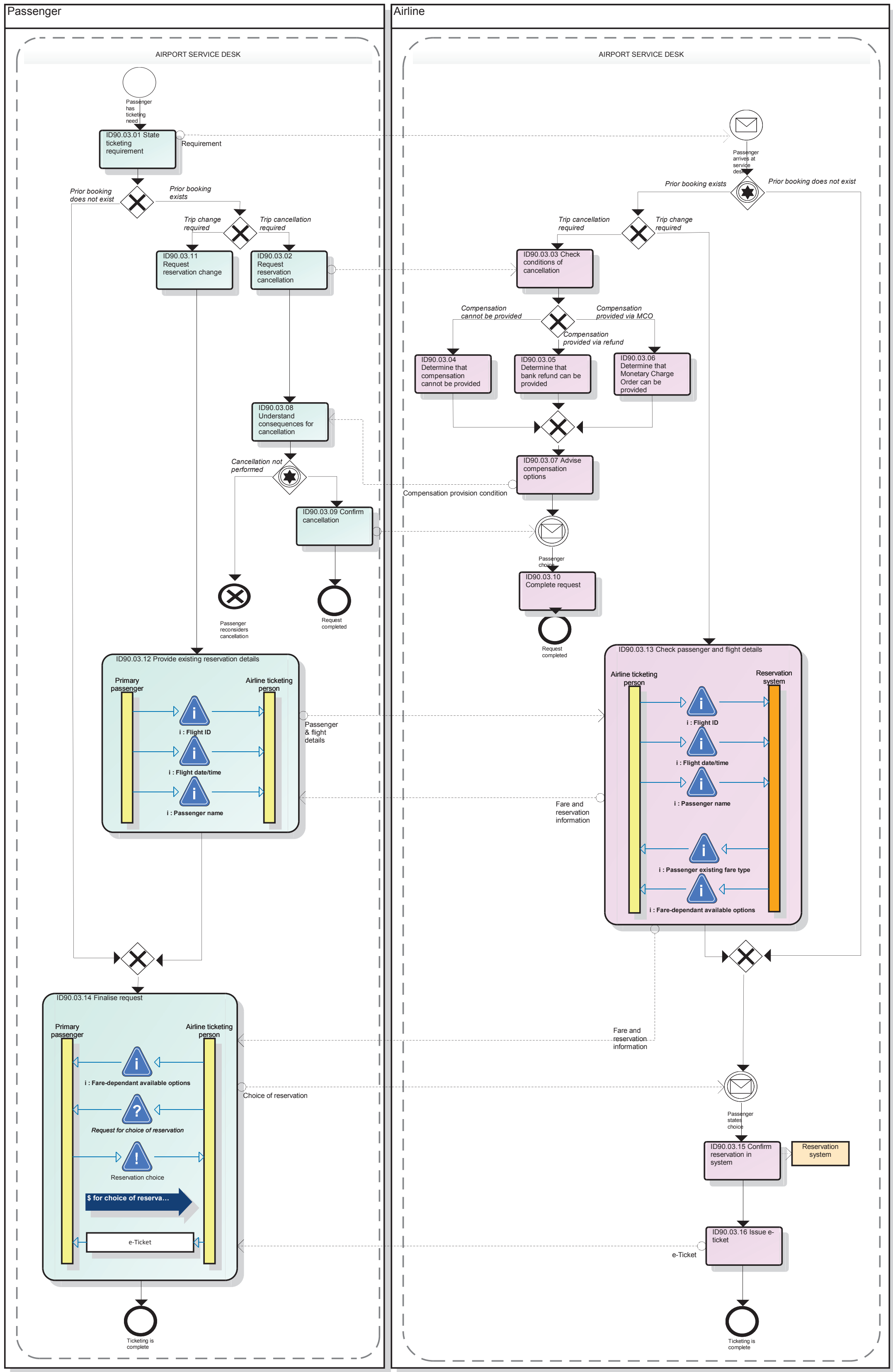
ID90.03 Request ticketing service

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:49:58 PM
Updated by: Administrator

QUT

VALIDATED



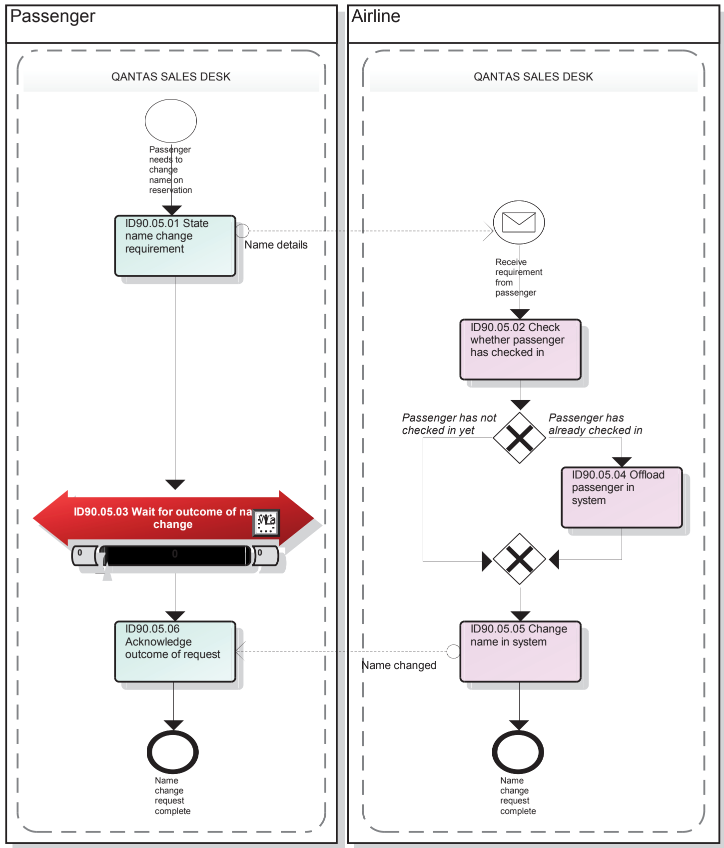
ID90.05 Request change of name

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:43:51 PM
Updated by: Administrator

QUT

VALIDATED



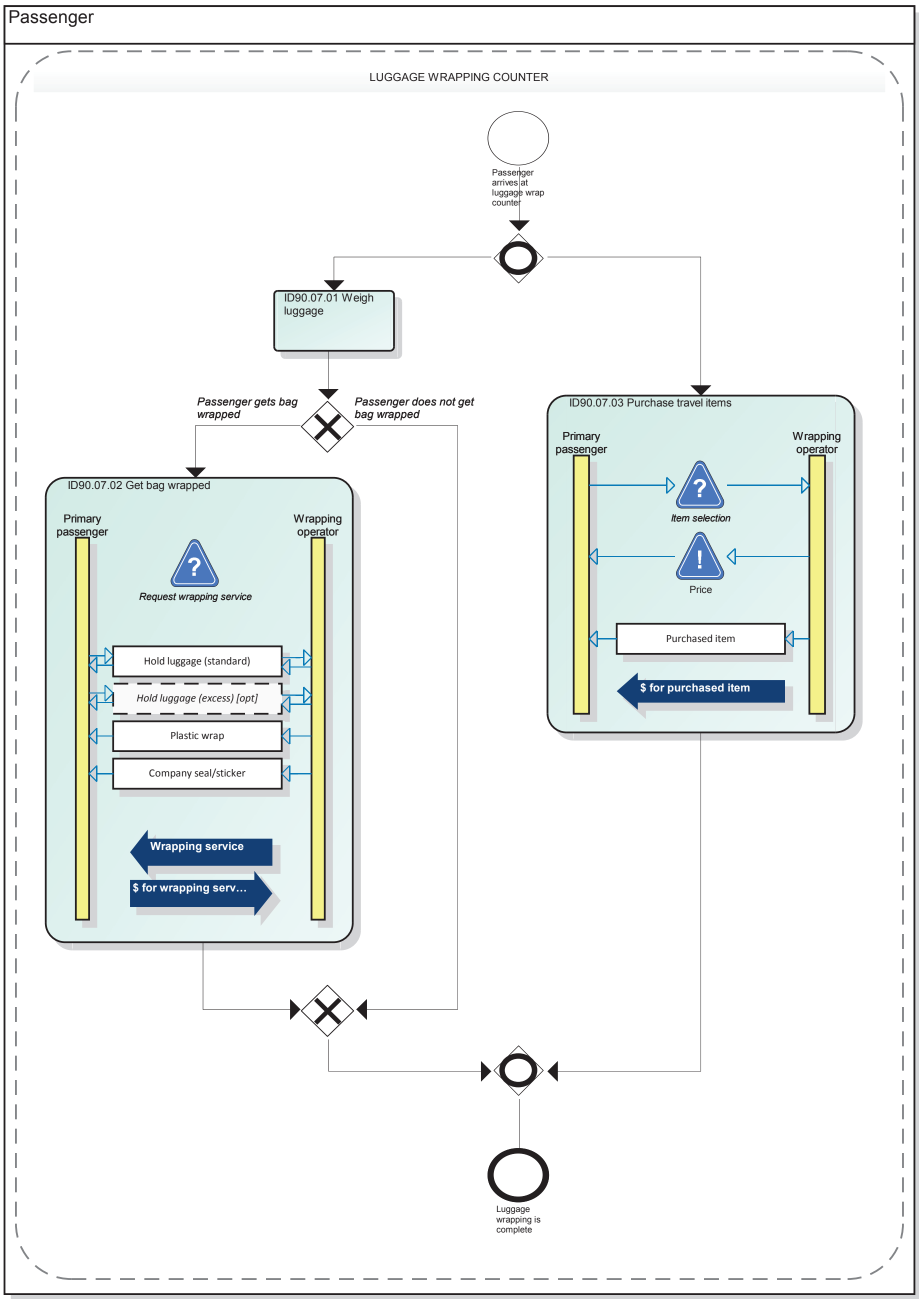
ID90.07 Perform Bag Wrapping activities

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:51:10 PM
Updated by: Administrator

VALIDATED

QUT



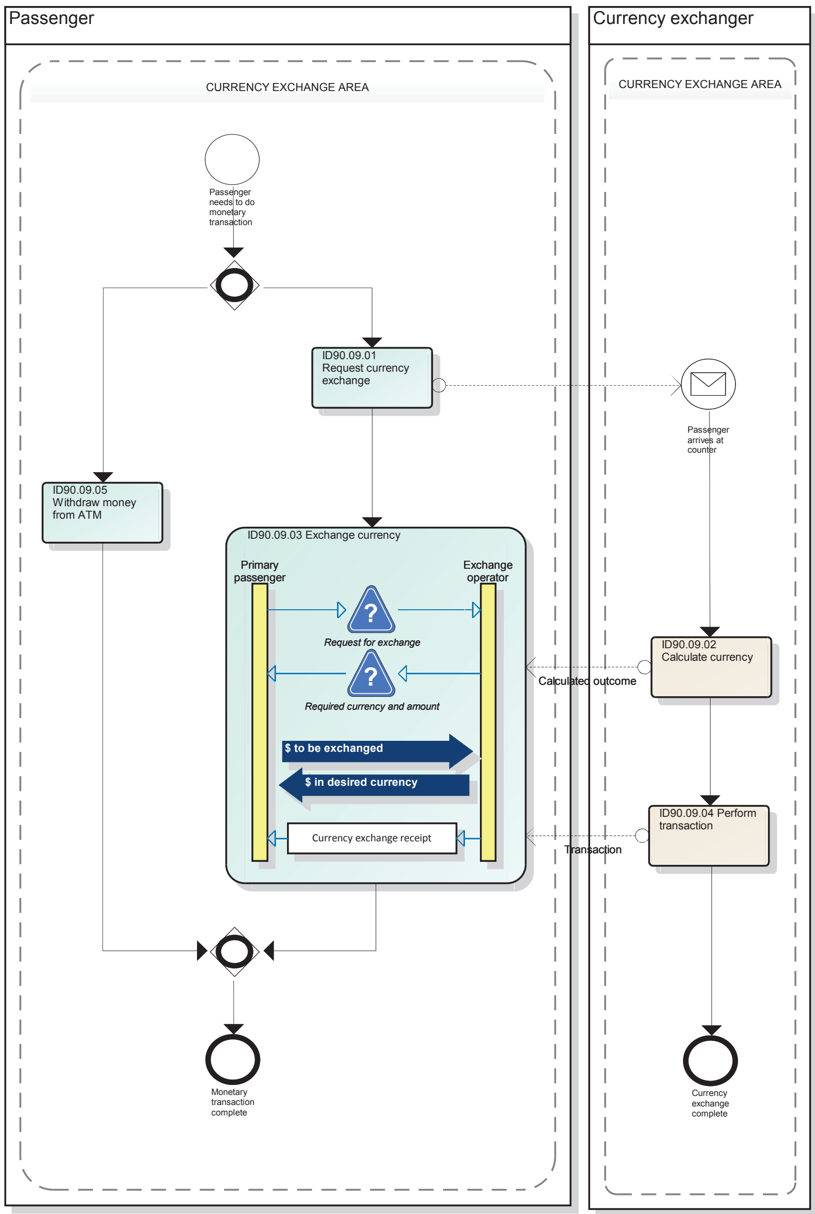
Brisbane Airport

ID90.09 Conduct monetary transactions

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:10:02 PM
Updated by: Administrator

QUT

VALIDATED



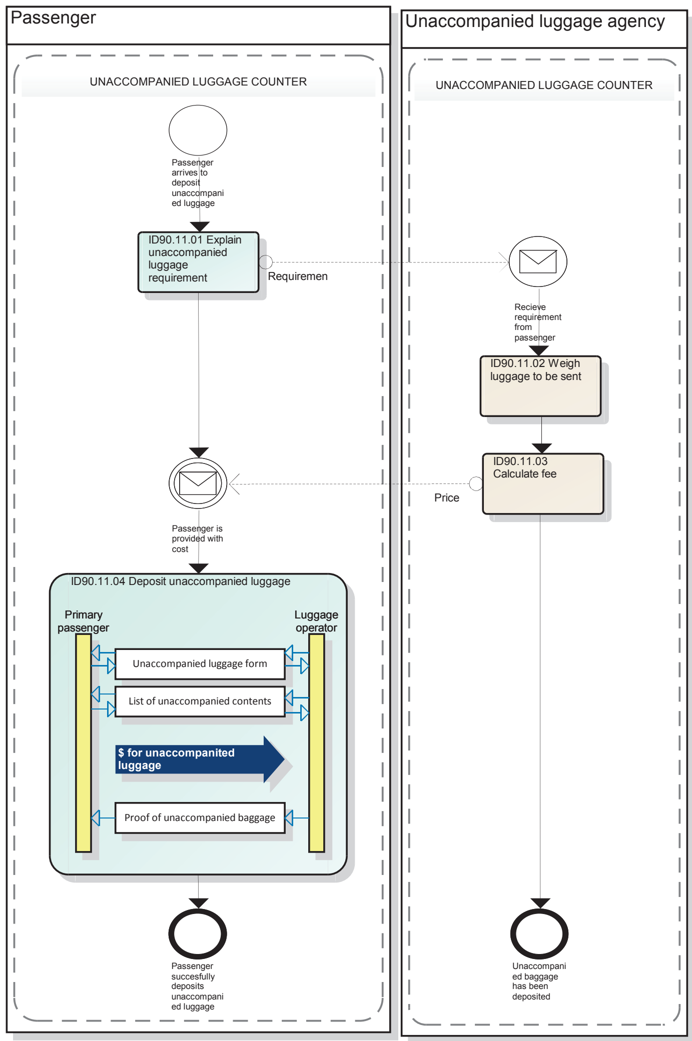
ID90.11 Deposit unaccompanied baggage

Brisbane Airport

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:51:47 PM
Updated by: Administrator

QUT

VALIDATED



ID90.16 Get restricted items checked

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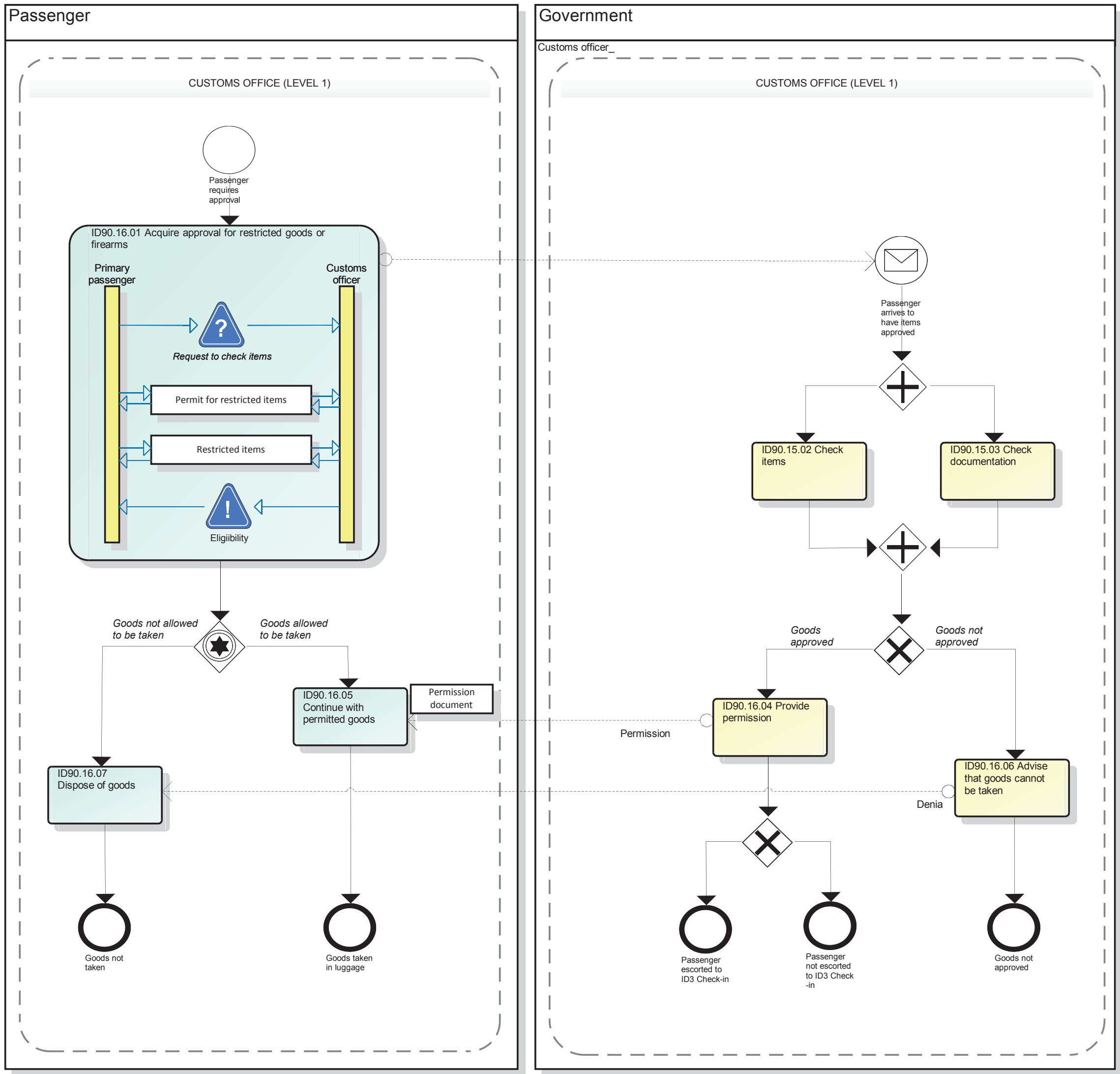
Category: BPMN Diagram Level 3
Update Date: 30/07/2009 9:52:23 PM
Updated by: Administrator

VALIDATED



ID91 Discretionary experience 2

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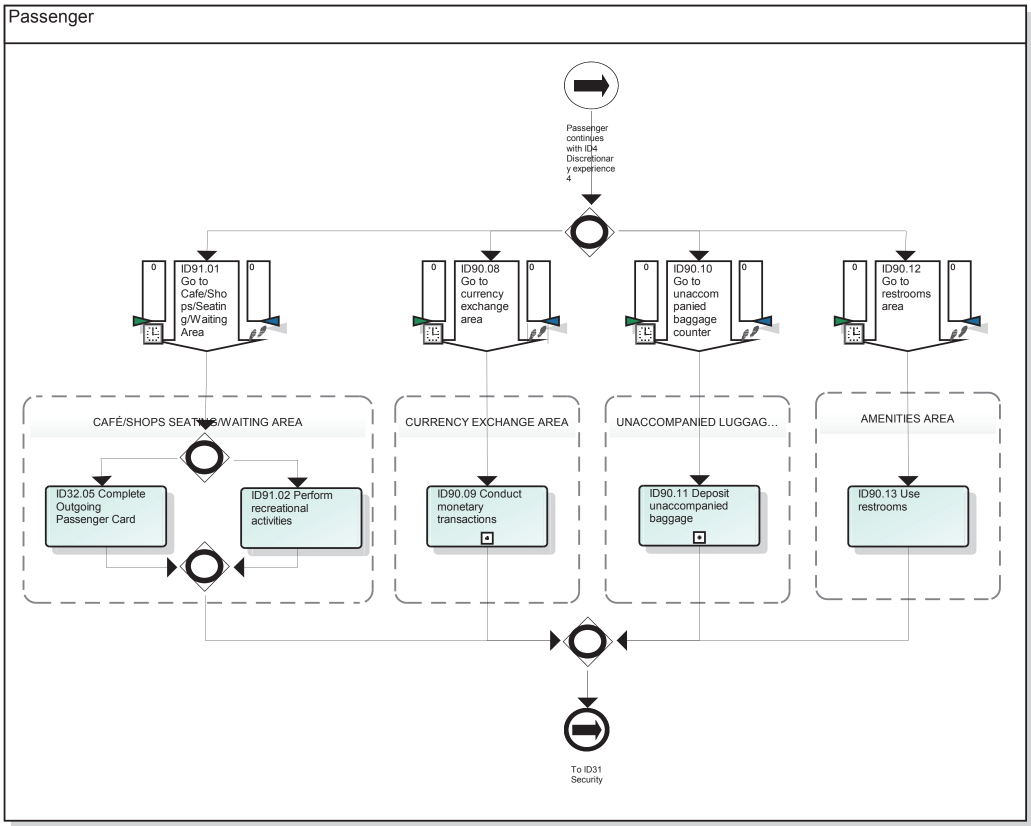
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 9:09:30 PM
Updated by: Administrator

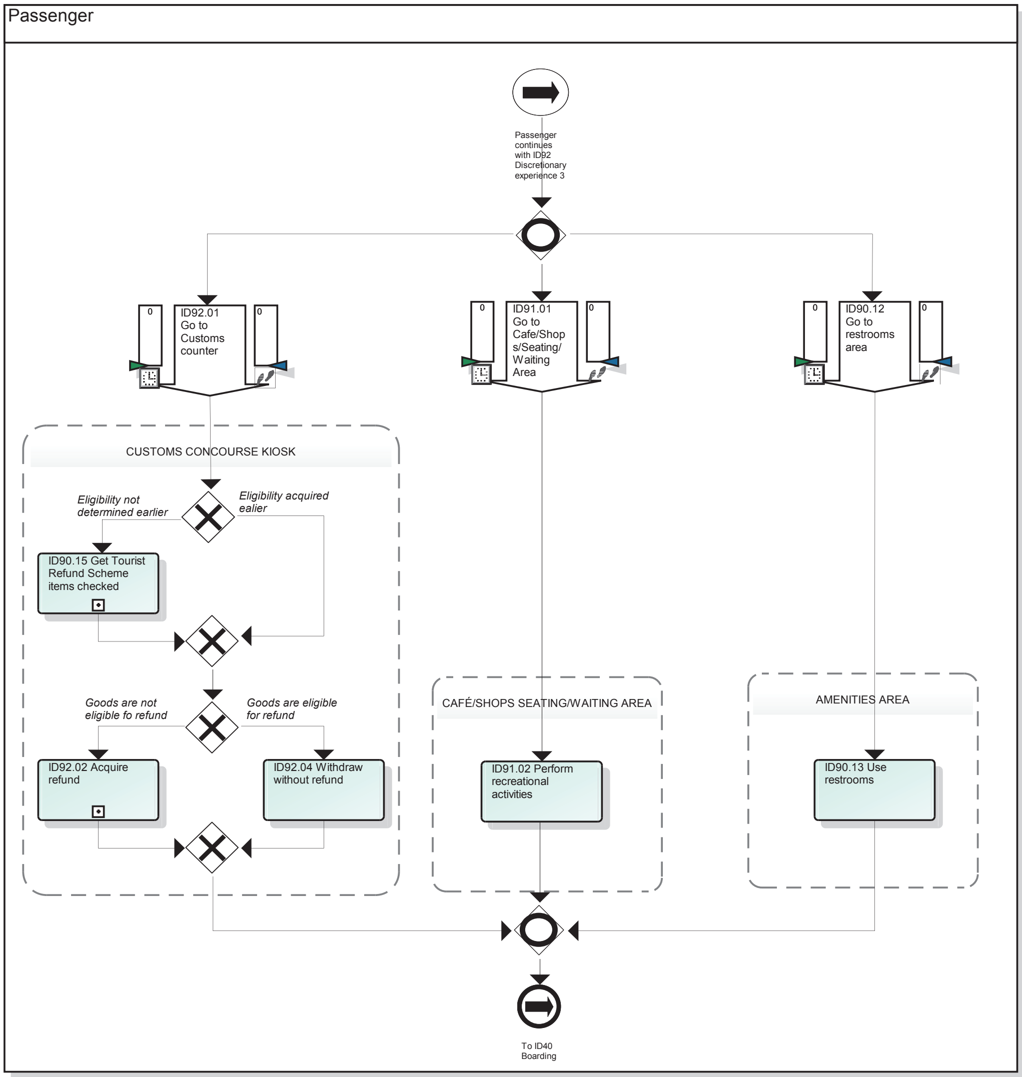
VALIDATED



ID92 Discretionary experience 3

Model Name: Brisbane Airport - v0.9 - 17.07.09
Category: BPMN Diagram Level 2
Update Date: 30/07/2009 9:06:29 PM
Updated by: Administrator

VALIDATED



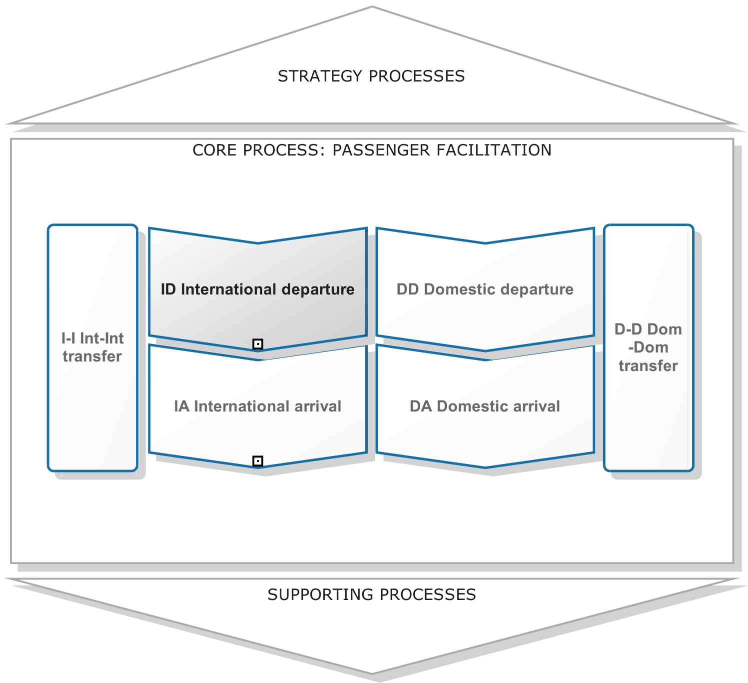
Gold Coast Airport

Airport processes

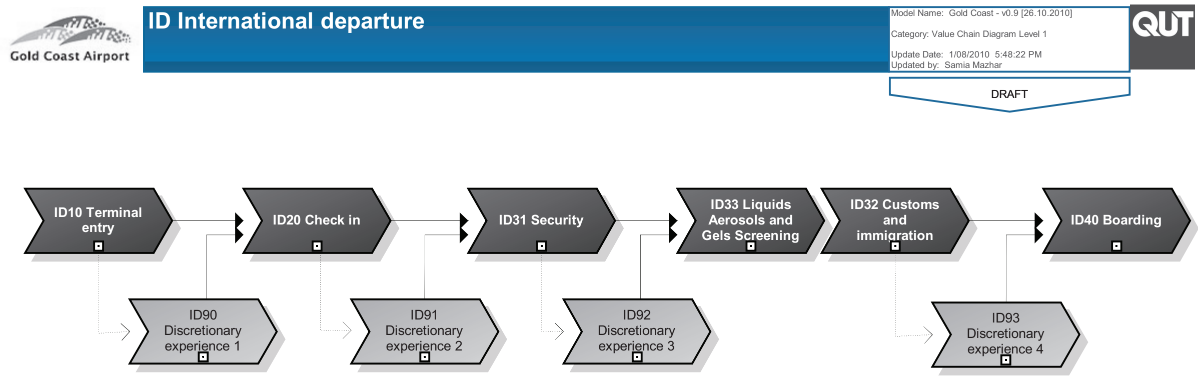
Model Name: Gold Coast - v0.9 [26.10.2010]
Category: Framework Diagram Level 0
Update Date: 1/08/2010 5:45:05 PM
Updated by: Samia Mazhar

QUT

DRAFT



ID International departure



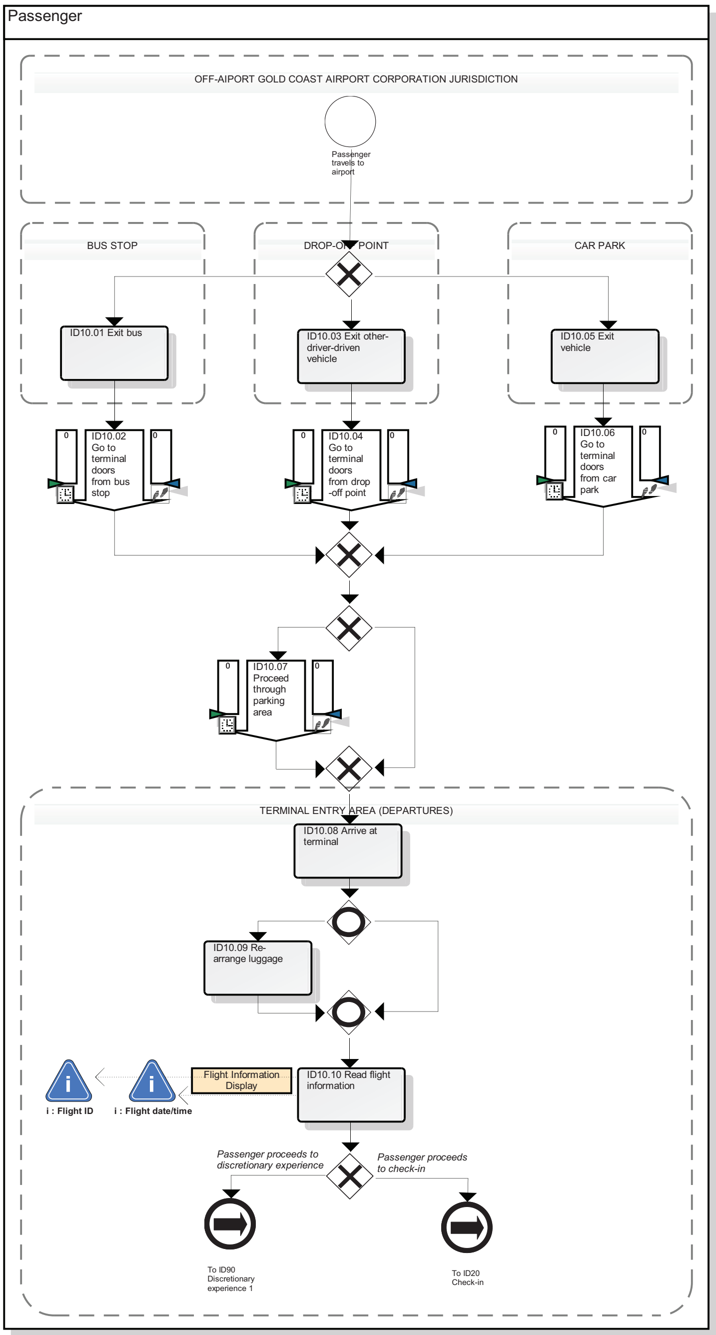
Gold Coast Airport

ID10 Terminal entry

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 1/08/2010 5:49:36 PM
Updated by: Samia Mazhar

QUT

DRAFT



Gold Coast Airport

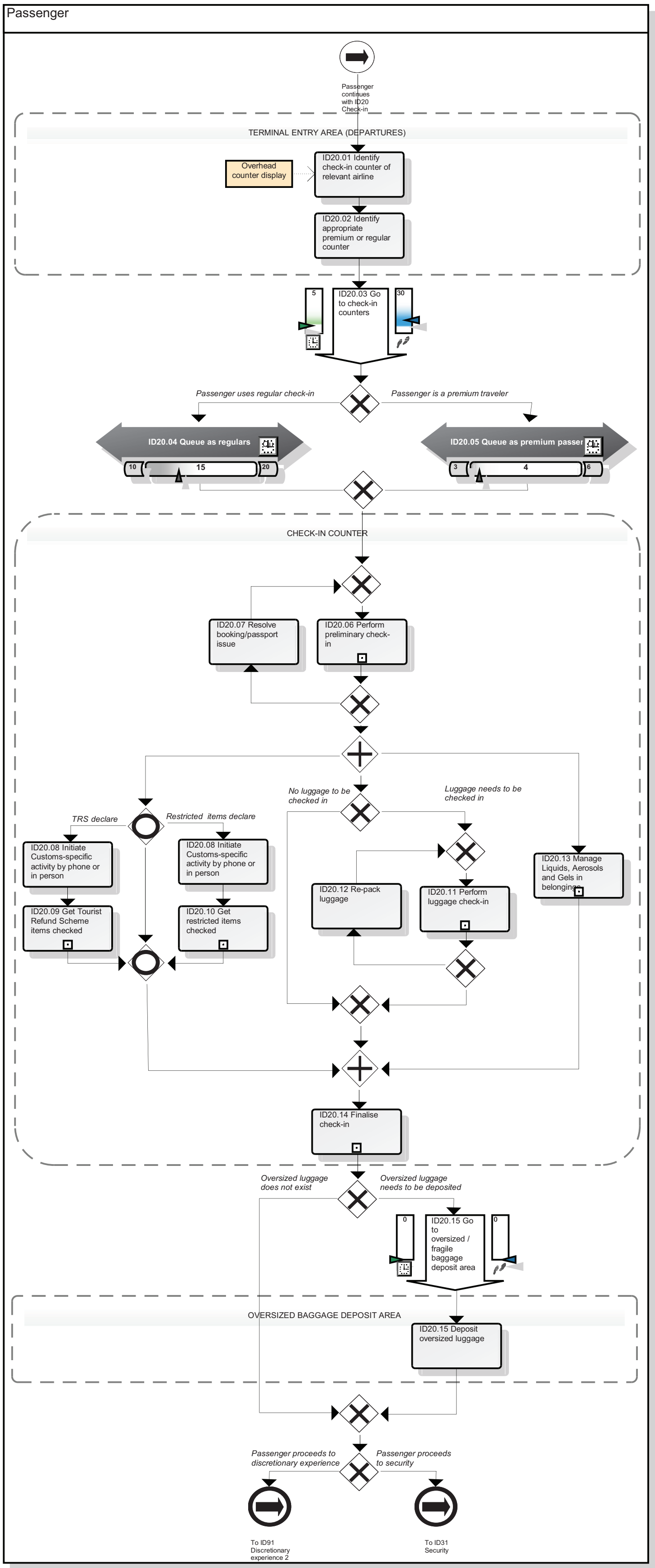
ID20 Check in

Model Name: Gold Coast - v0.9 [26.10.2010]

Category: BPMN Diagram Level 2

Update Date: 1/08/2010 5:50:48 PM
Updated by: Samia Mazhar

DRAFT



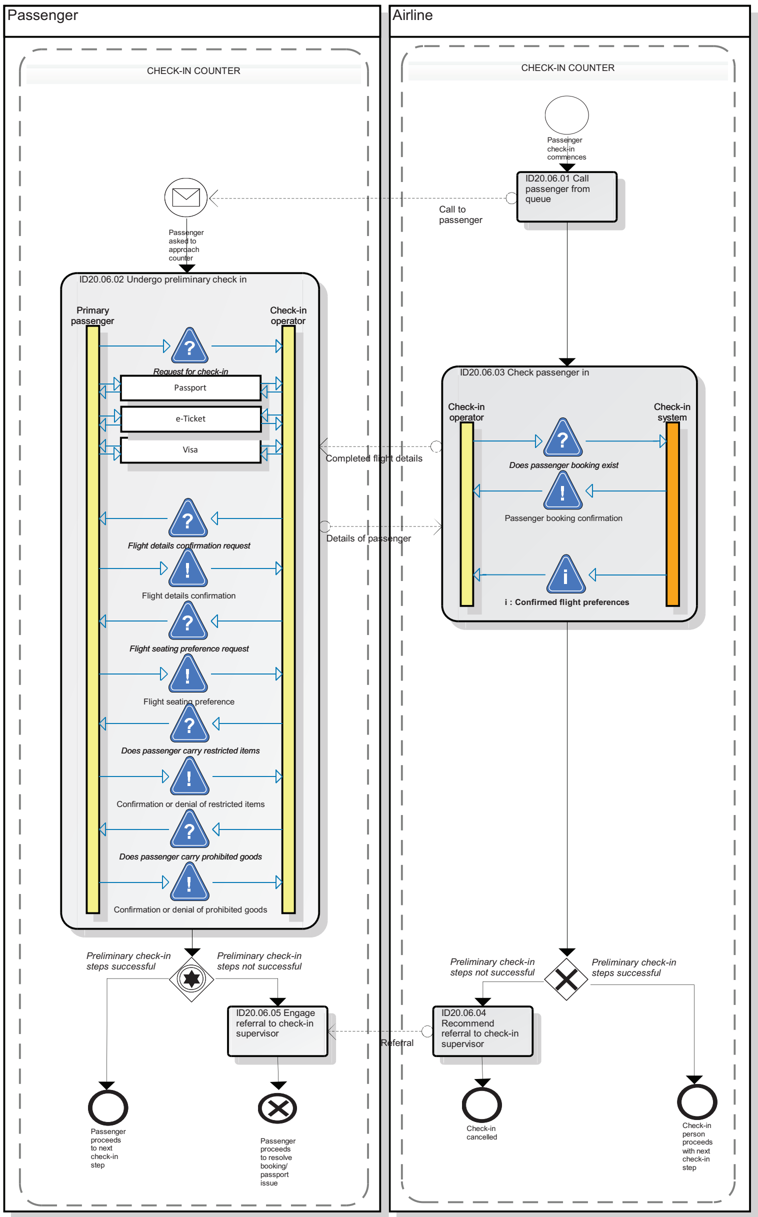
ID20.06 Perform preliminary check-in

Model Name: Gold Coast - v0.9 [26.10.2010]

Category: BPMN Diagram Level 3

Update Date: 1/08/2010 5:56:23 PM
Updated by: Samia Mazhar

DRAFT



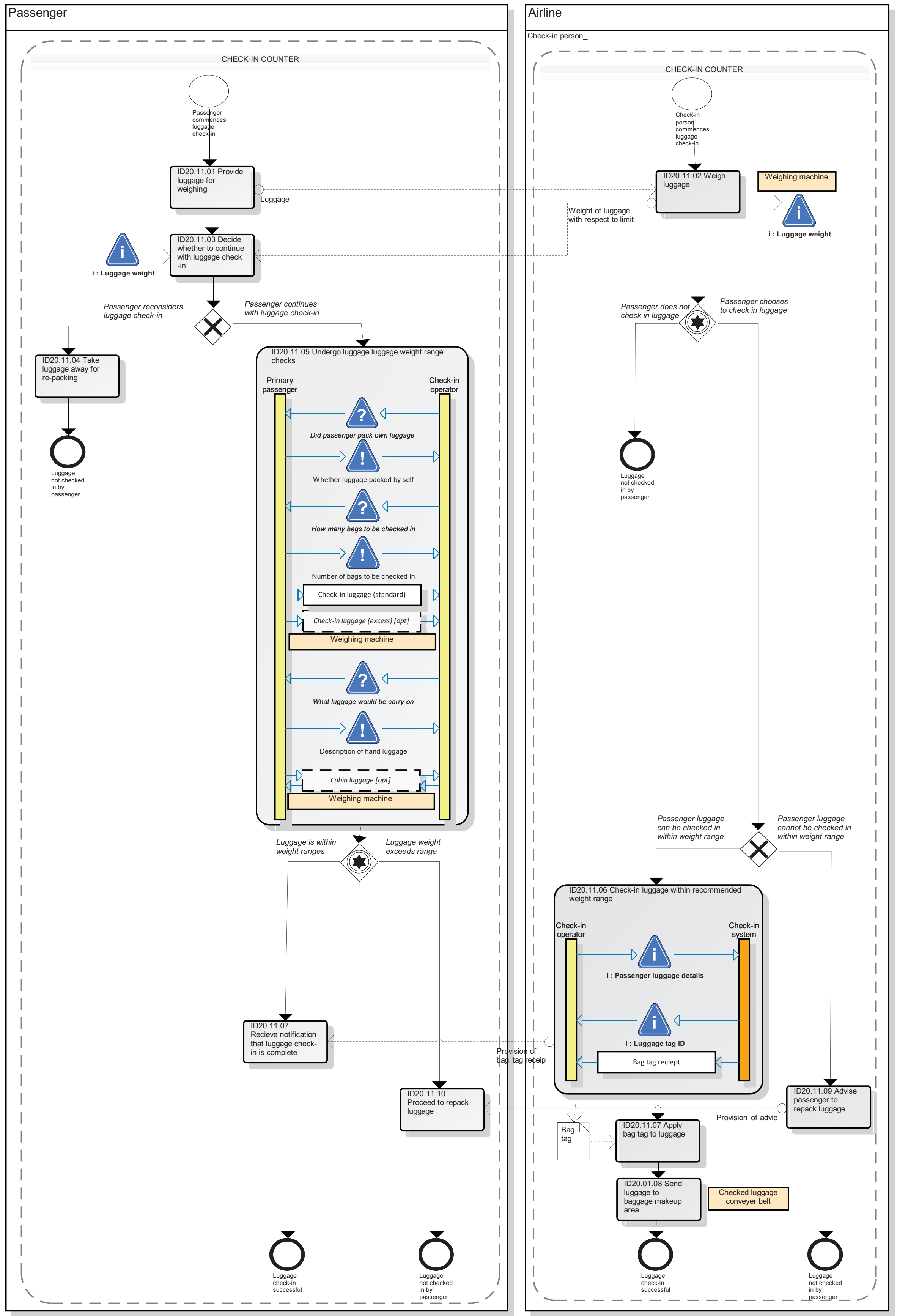
Gold Coast Airport

ID20.11 Perform luggage check-in

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 6:09:26 PM
Updated by: Samia Mazhar

QUT

DRAFT

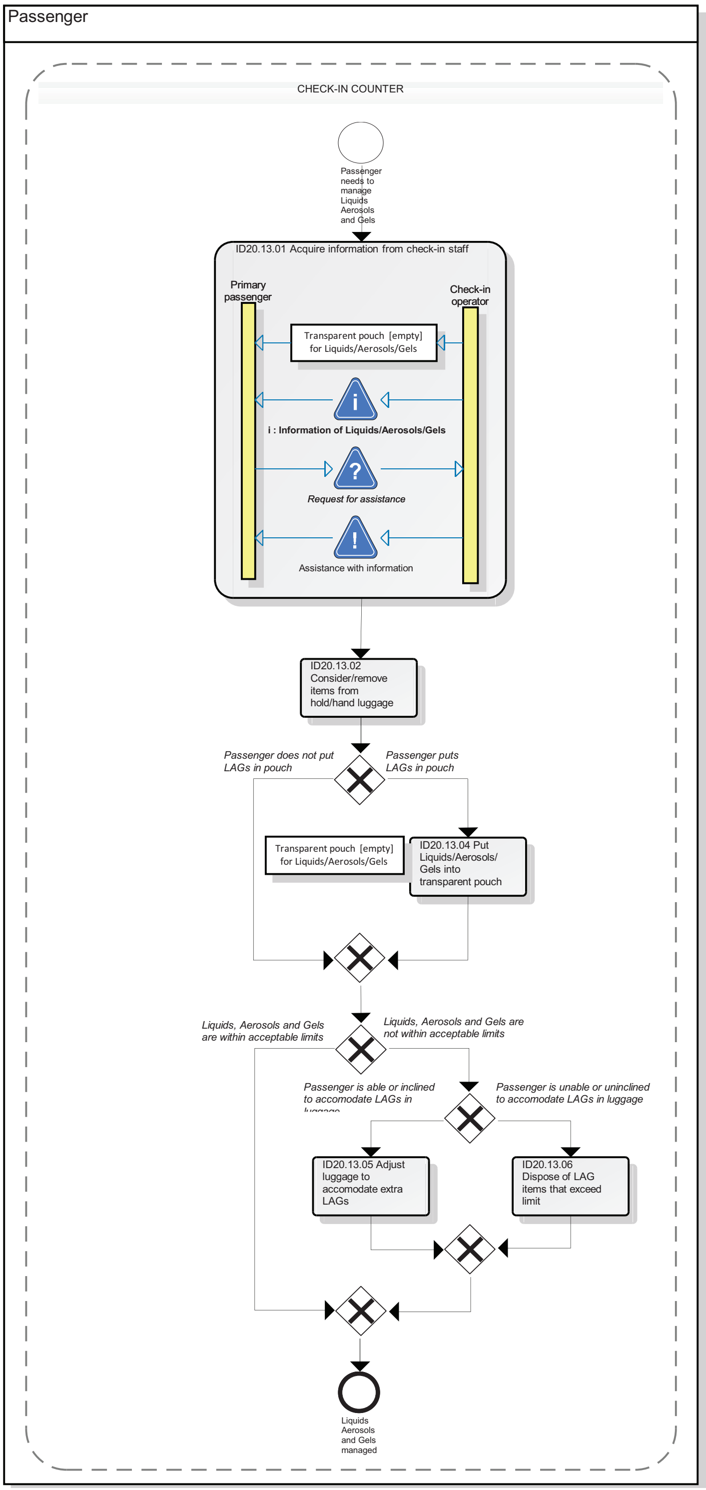


Gold Coast Airport

ID20.13 Manage Liquids, Aerosols and Gels in belongings

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 6:14:15 PM
Updated by: Samia Mazhar

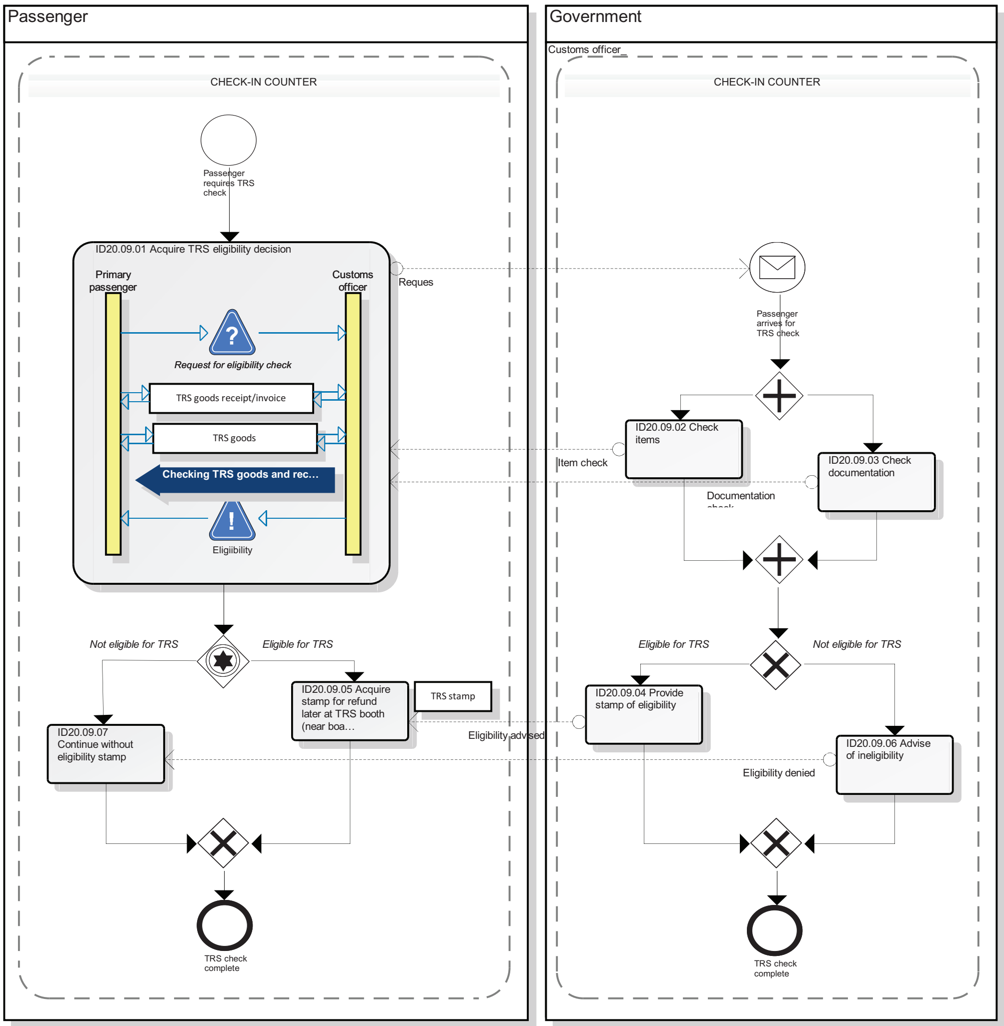
DRAFT



ID20.09 Get Tourist Refund Scheme items checked

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 6:19:40 PM
Updated by: Samia Mazhar

DRAFT



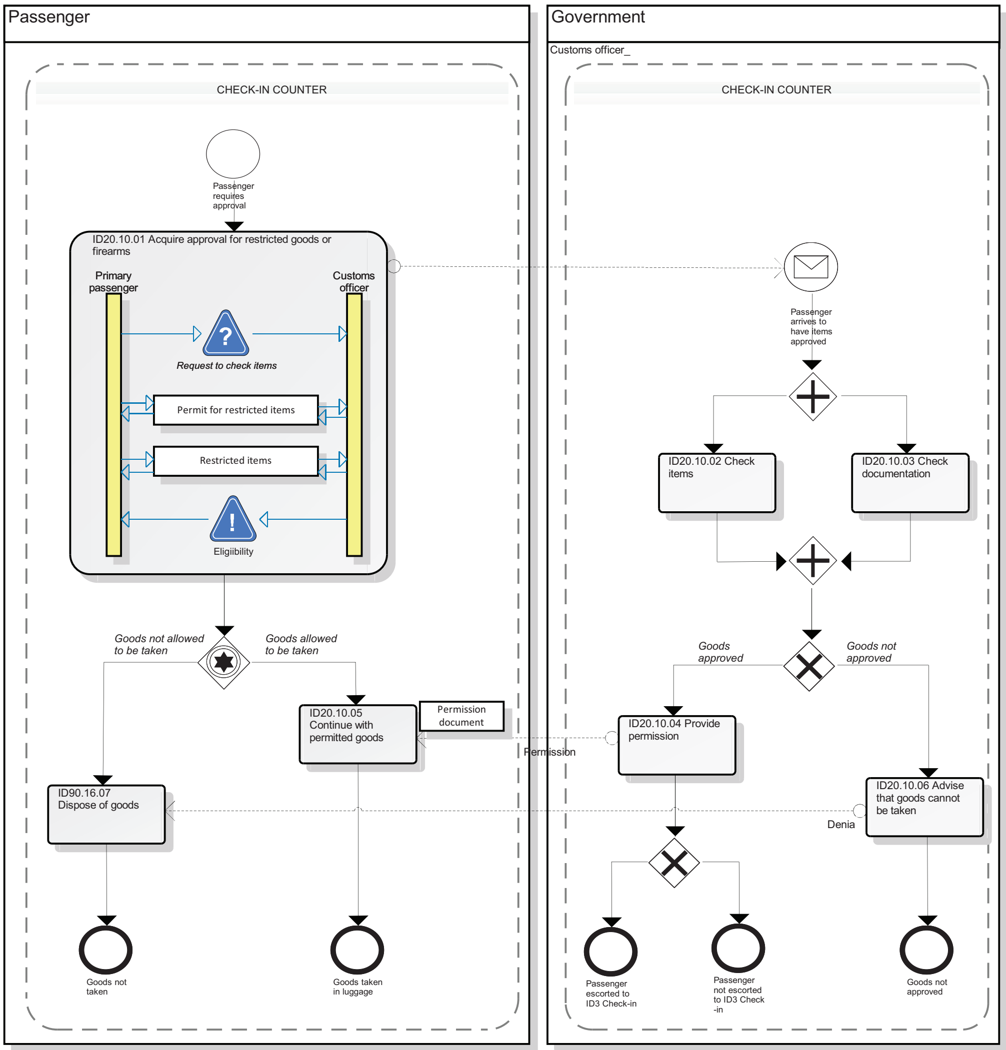
Gold Coast Airport

ID20.10 Get restricted items checked

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 6:23:00 PM
Updated by: Samia Mazhar

QUT

DRAFT



Gold Coast Airport

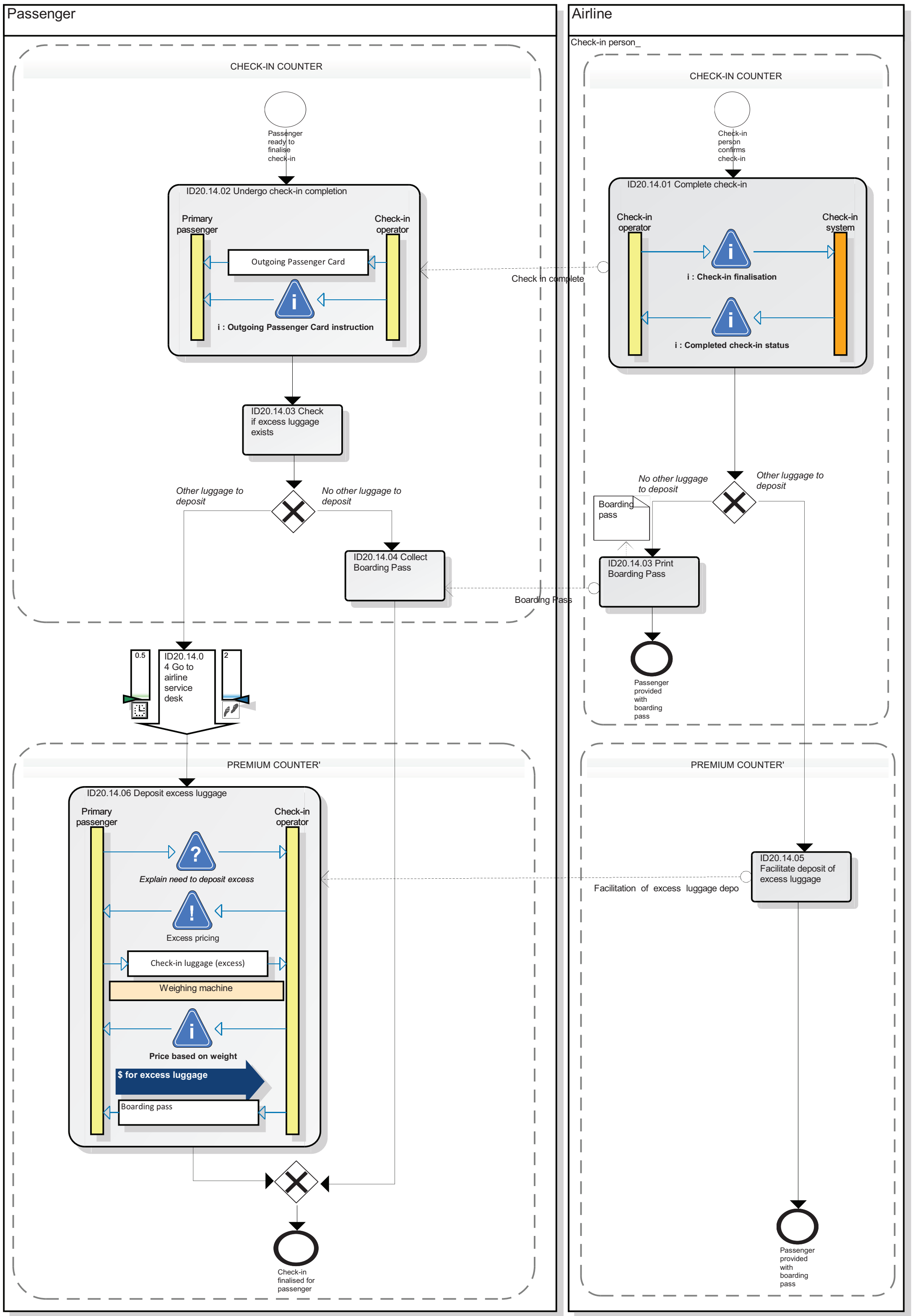
ID20.14 Finalise check-in

Model Name: Gold Coast - v0.9 [26.10.2010]

Category: BPMN Diagram Level 3

Update Date: 1/08/2010 7:02:16 PM
Updated by: Samia Mazhar

DRAFT



Gold Coast Airport

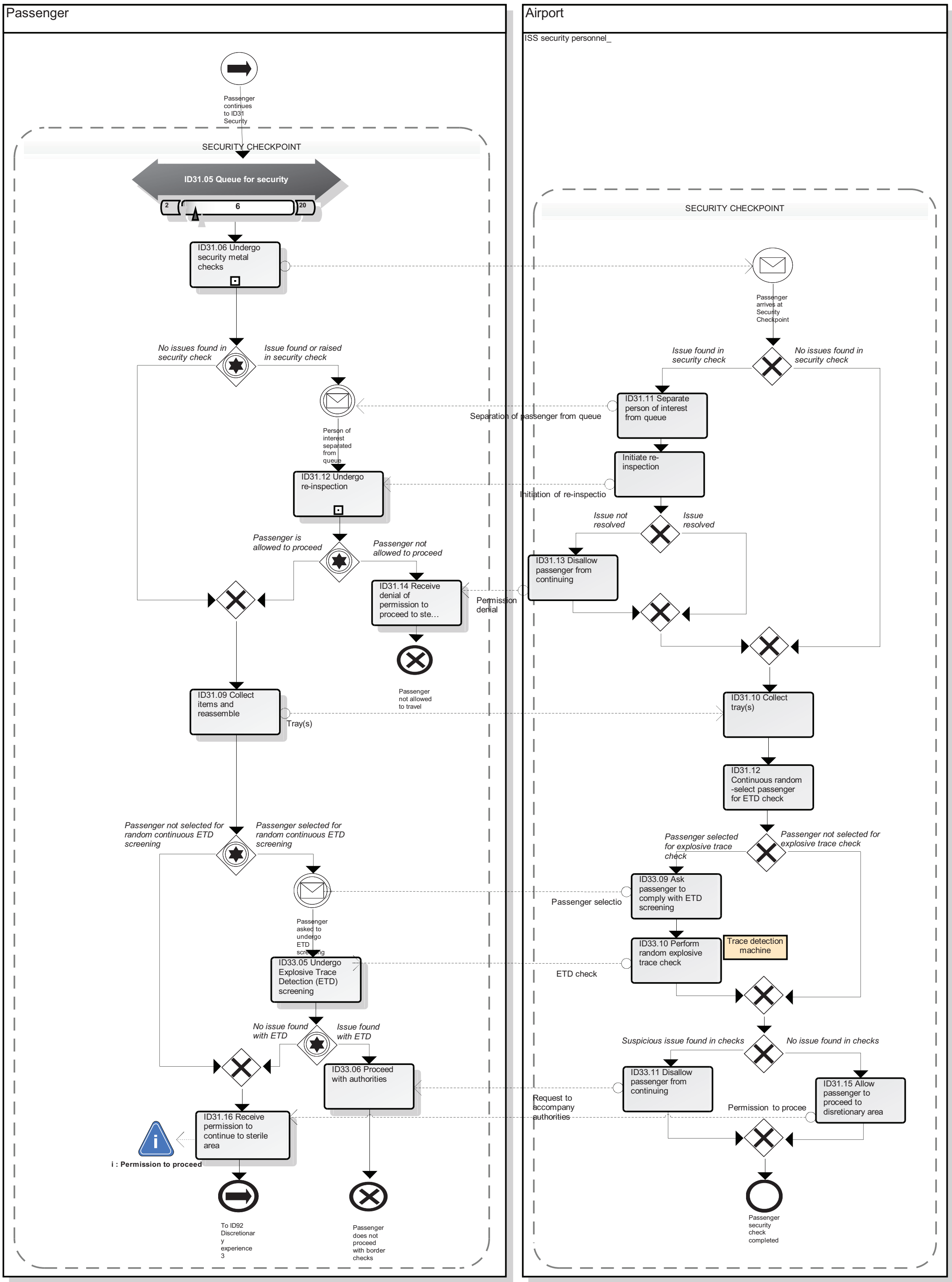
ID31 Security

Model Name: Gold Coast Airport - v0.9 [28.07.2010]

Category: BPMN Diagram Level 2

Update Date: 1/08/2010 8:00:07 PM
Updated by: Samia Mazhar

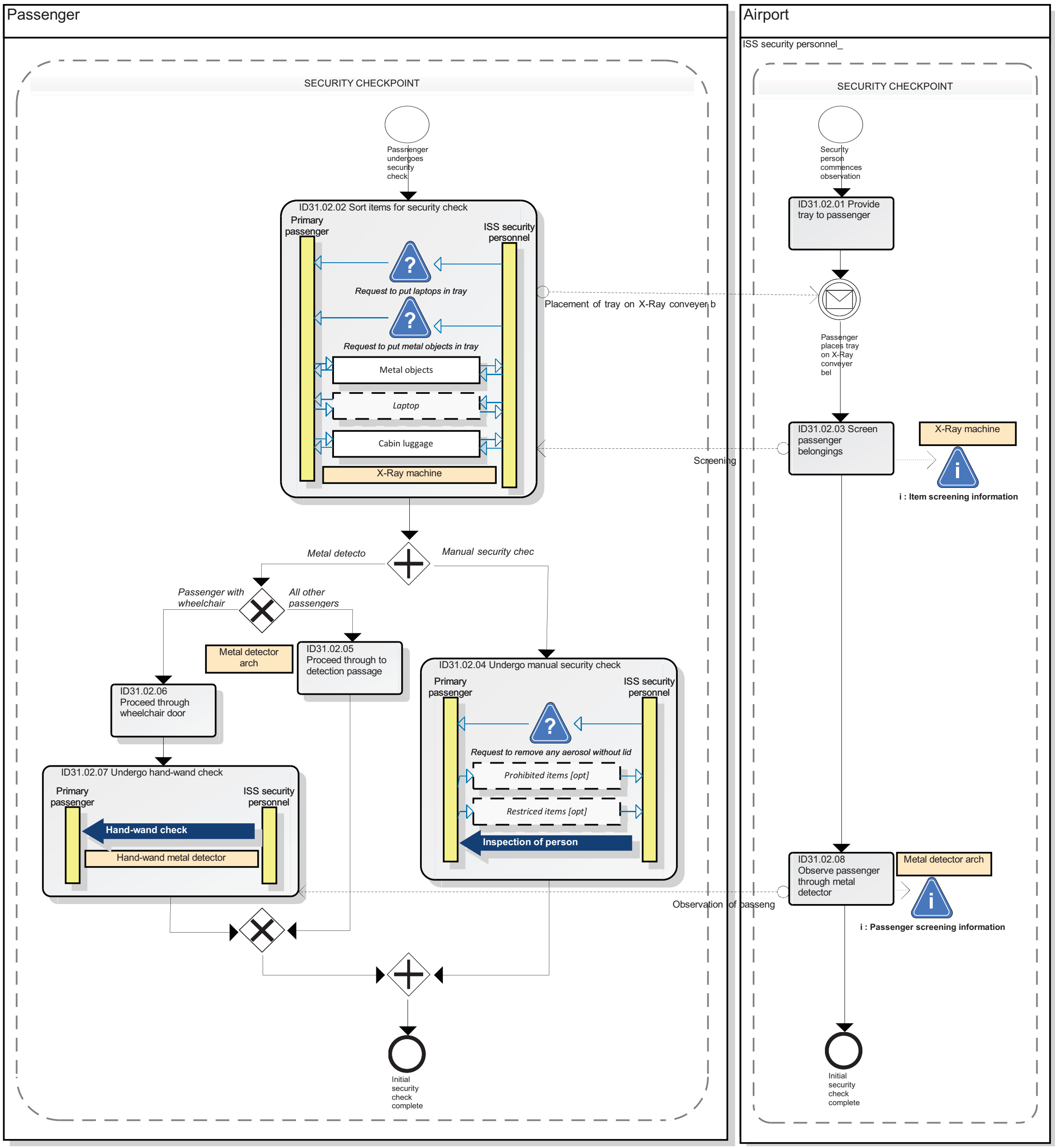
DRAFT



ID31.02 Undergo security metal checks

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 8:05:34 PM
Updated by: Samia Mazhar

DRAFT

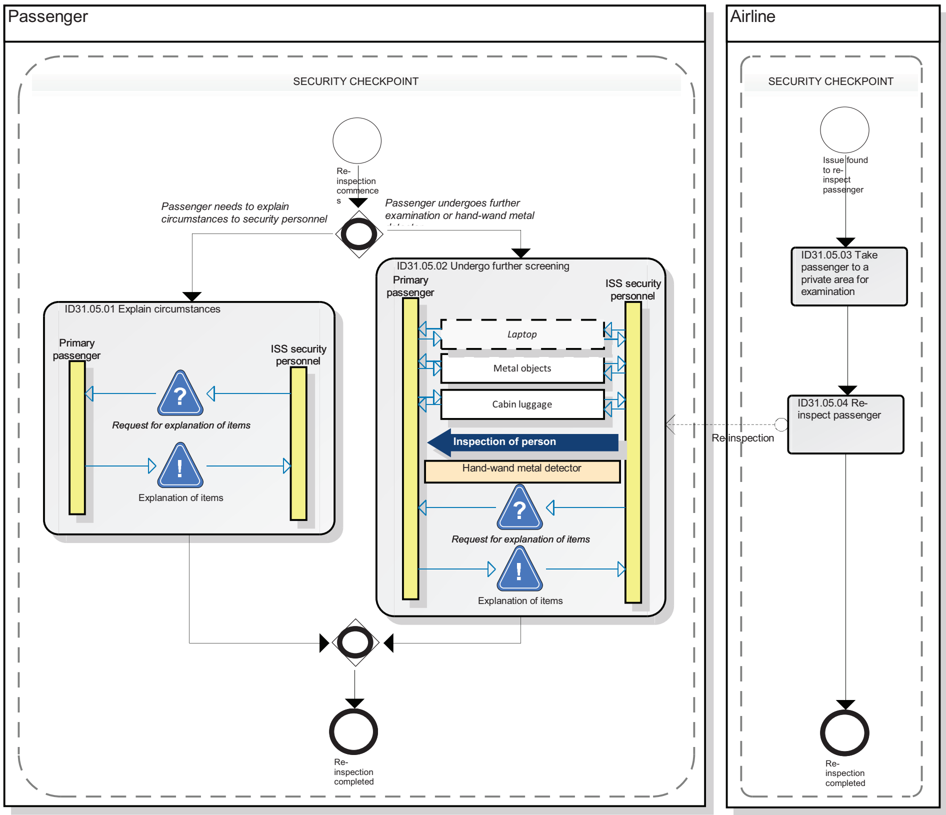


Gold Coast Airport

ID31.05 Undergo re-inspection

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 8:09:44 PM
Updated by: Samia Mazhar

DRAFT



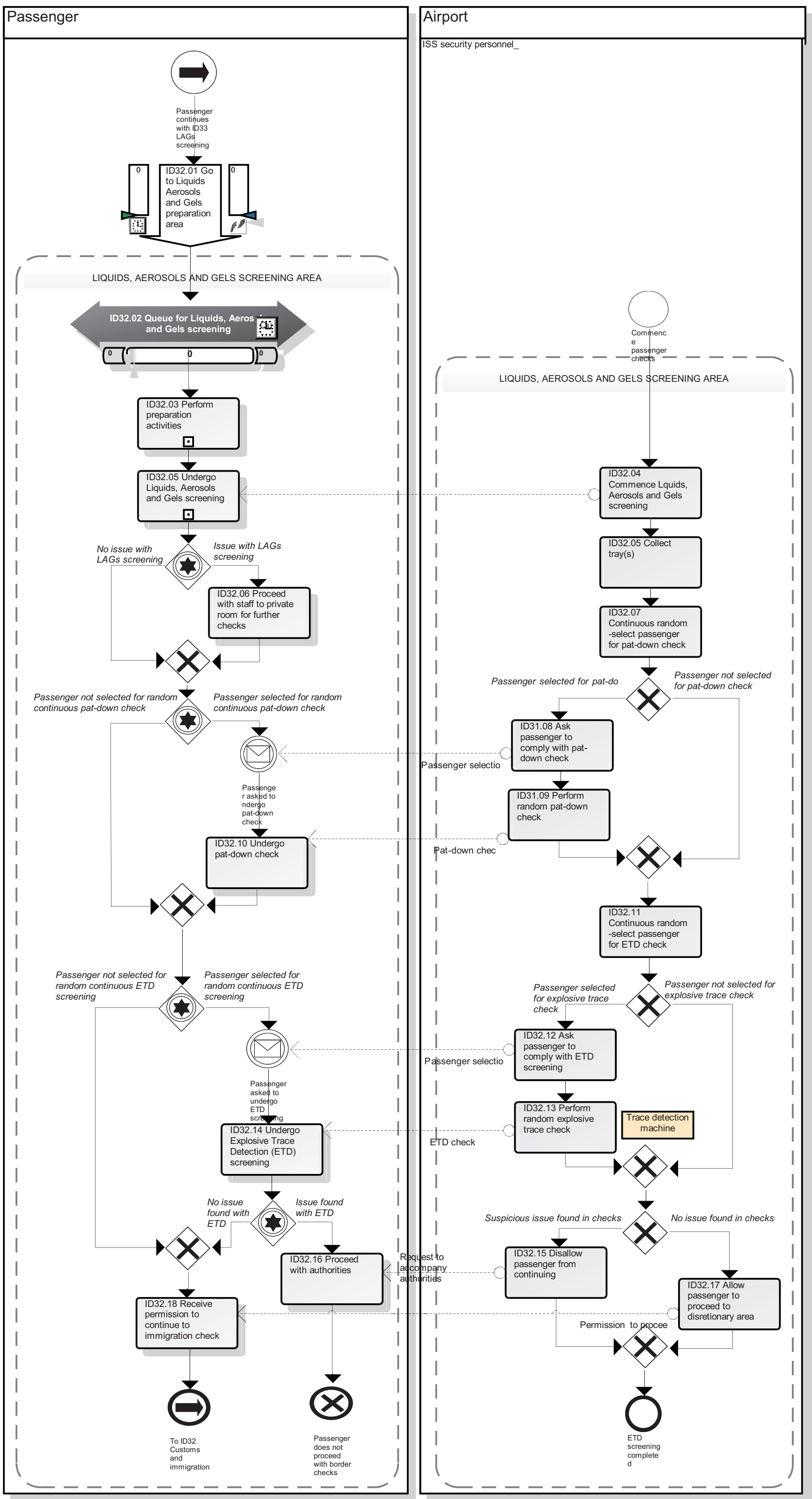
Gold Coast Airport

ID32 Liquids Aerosols and Gels Screening

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 1/08/2010 8:52:38 PM
Updated by: Samia Mazhar

QUT

DRAFT

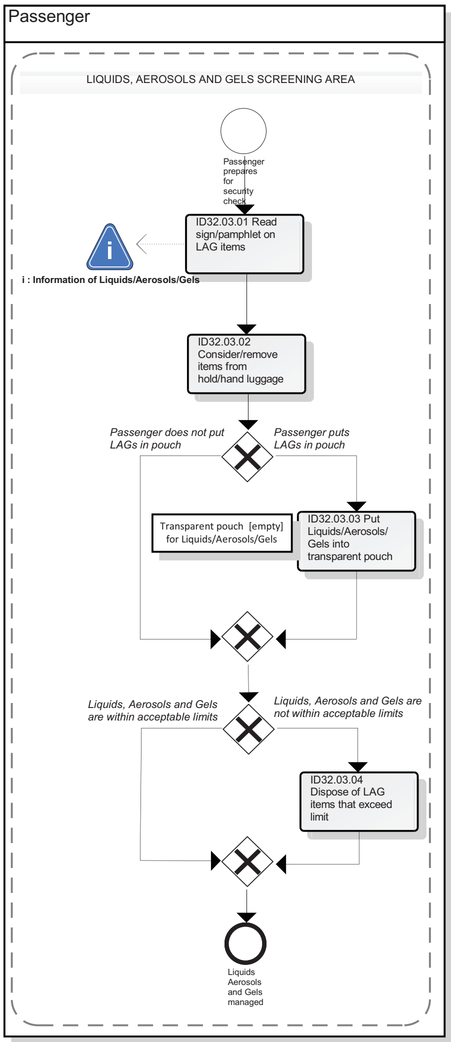


ID32.03 Perform preparation activities

Gold Coast Airport

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 8:54:32 PM
Updated by: Samia Mazhar

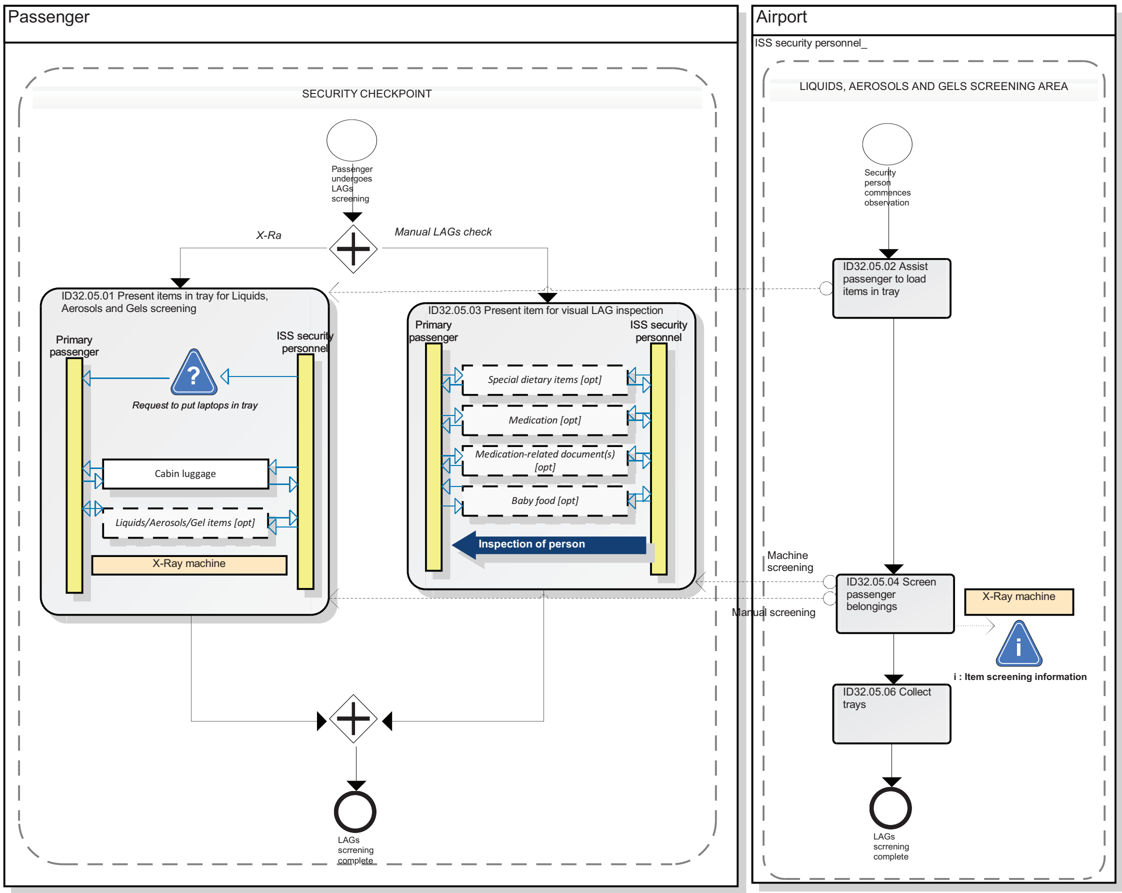
DRAFT



ID32.05 Undergo Liquids, Aerosols and Gels screening

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 8:55:41 PM
Updated by: Samia Mazhar

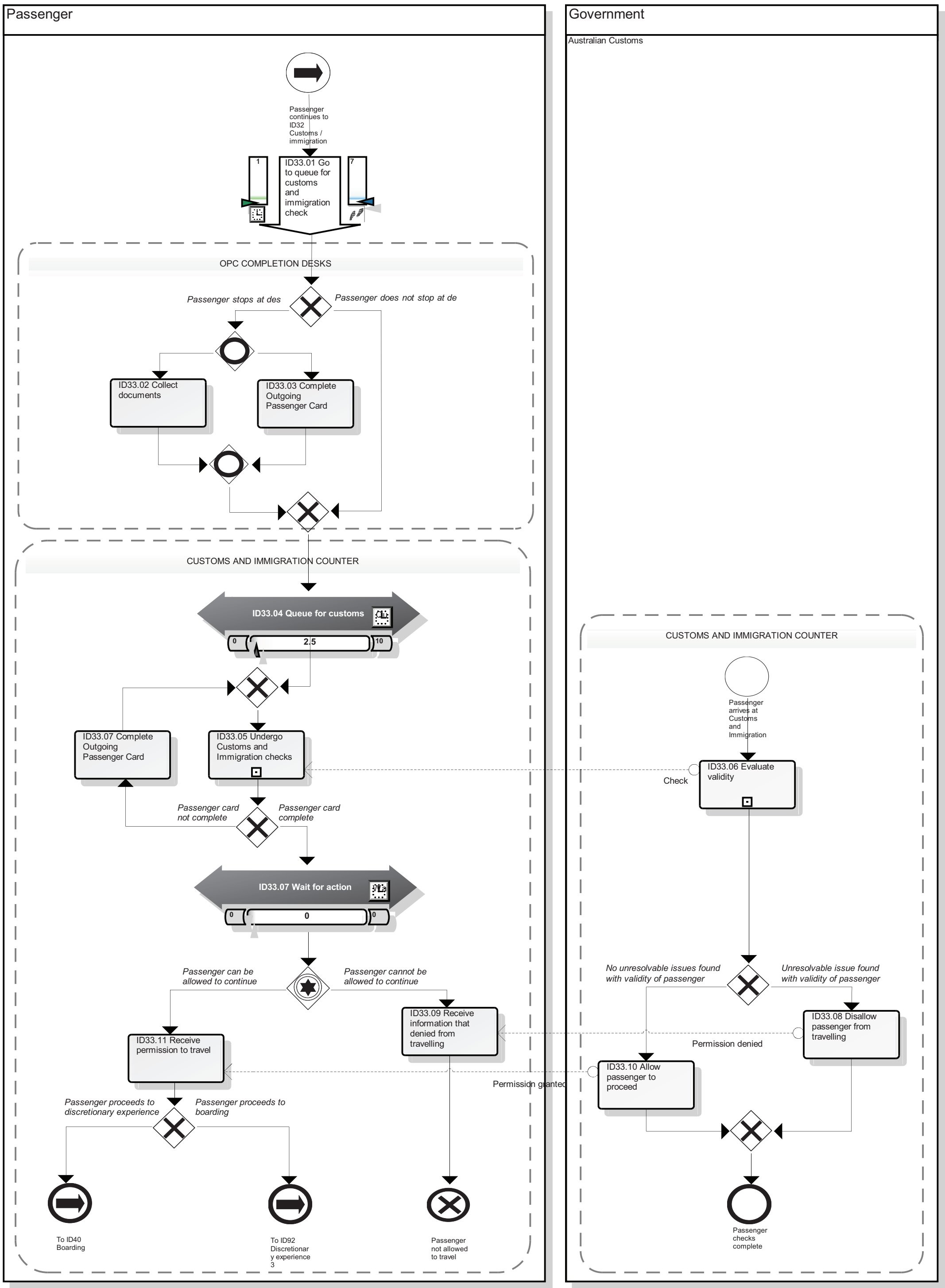
DRAFT



ID33 Customs and immigration

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 1/08/2010 9:34:09 PM
Updated by: Samia Mazhar

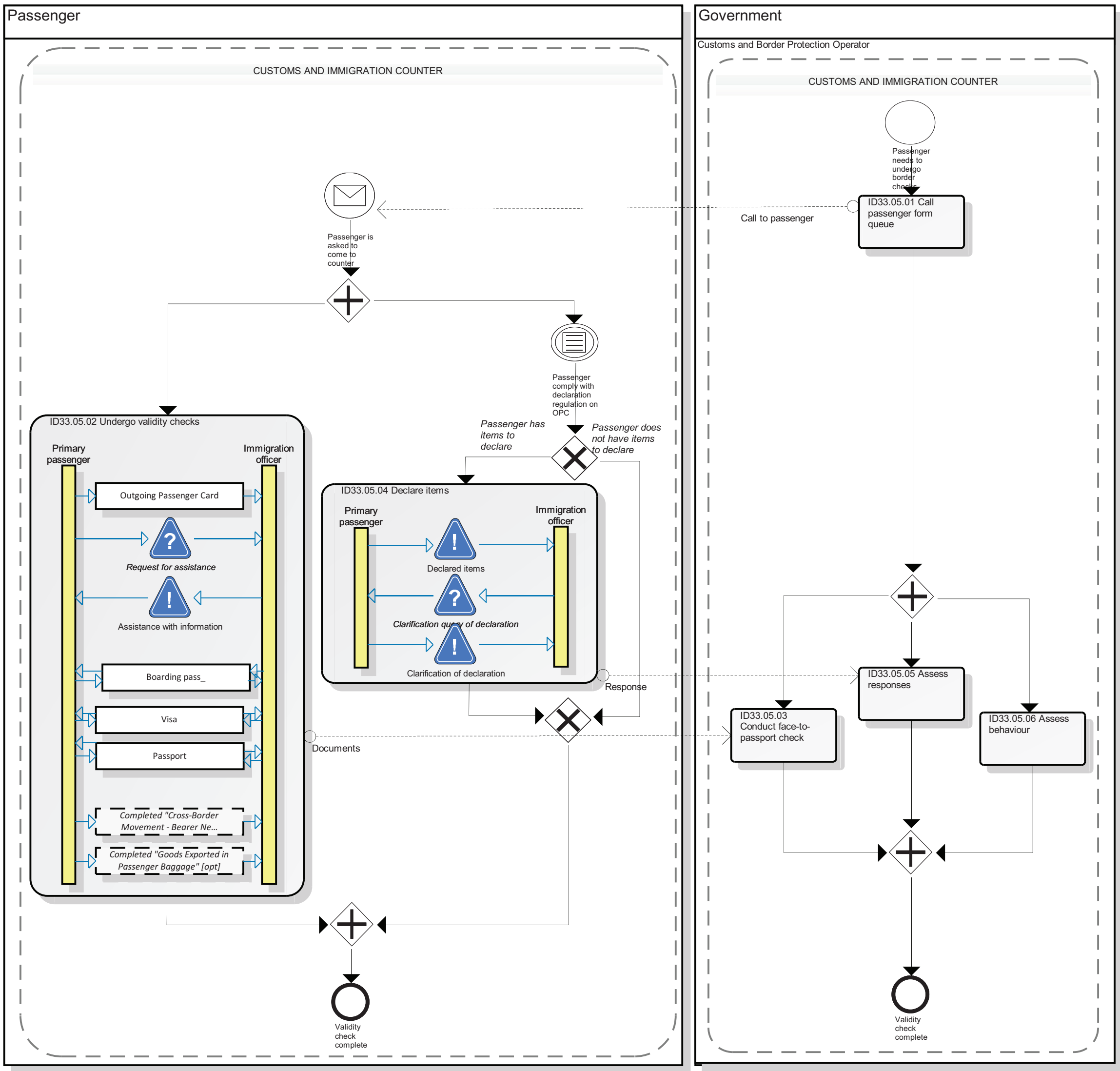
DRAFT



ID33.05 Undergo Customs and Immigration checks

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 9:35:46 PM
Updated by: Samia Mazhar

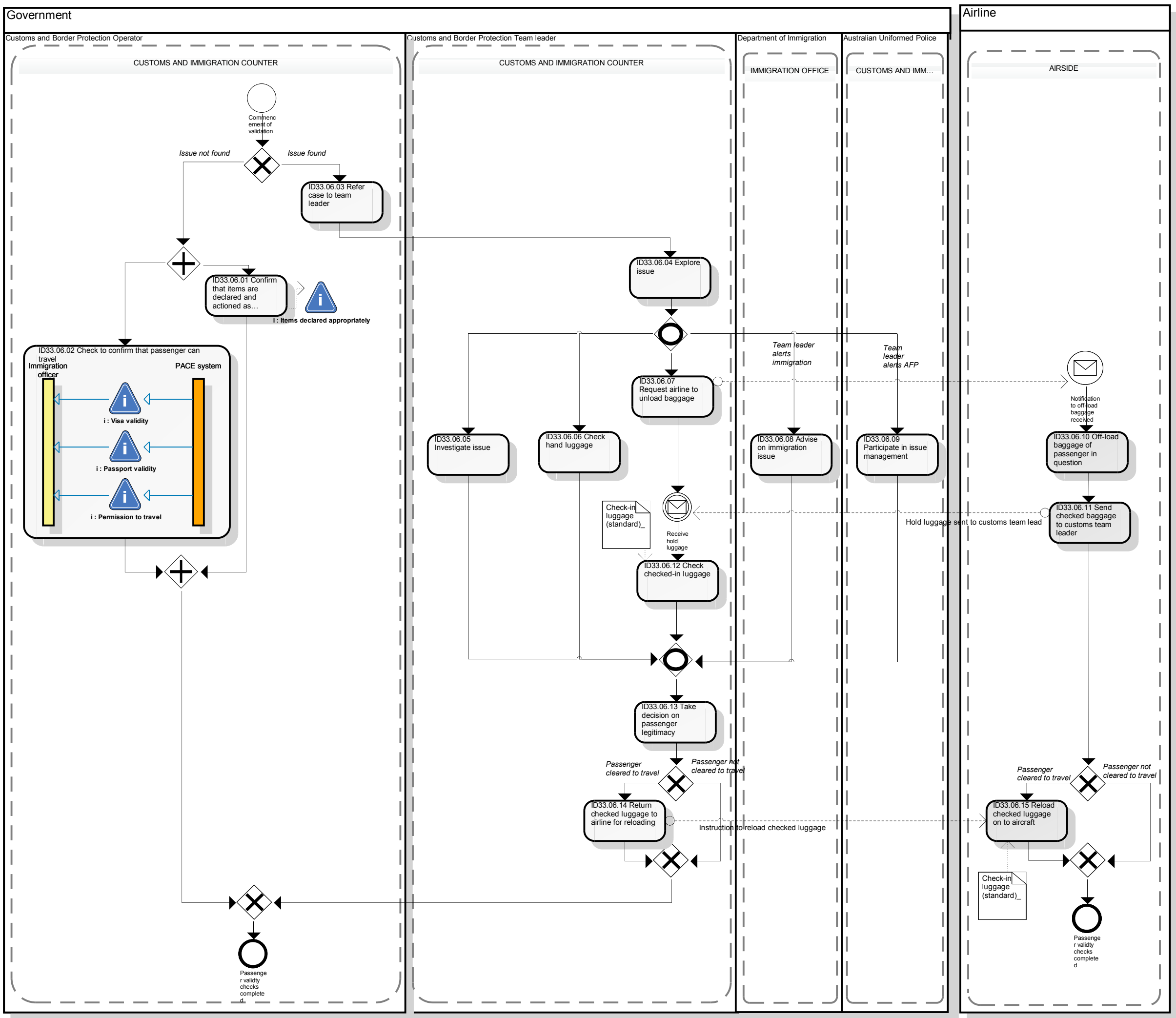
DRAFT



ID33.06 Evaluate validity

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 2/08/2010 6:28:44 PM
Updated by: Samia Mazhar

DRAFT



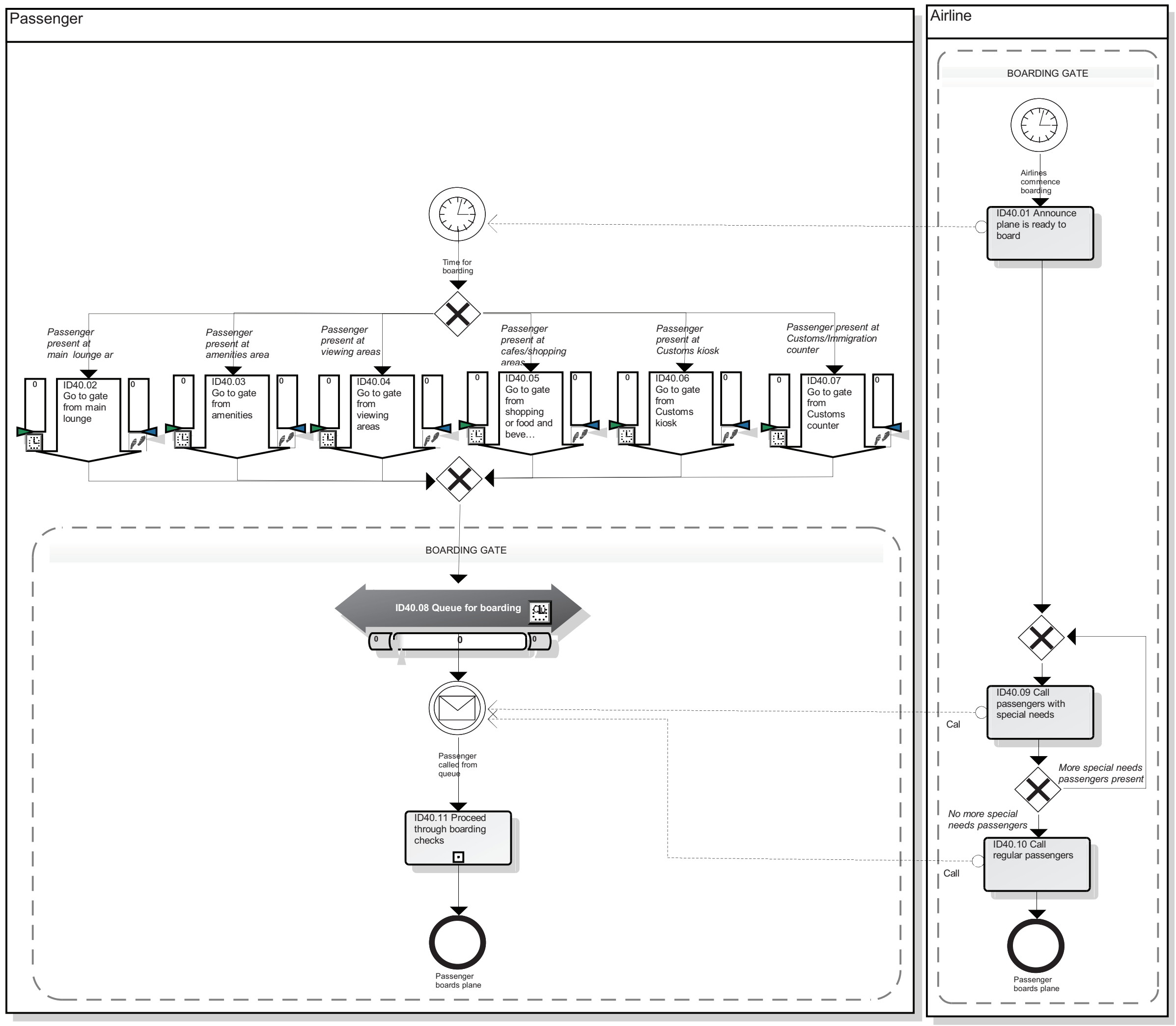
Gold Coast Airport

ID40 Boarding

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 1/08/2010 9:39:41 PM
Updated by: Samia Mazhar

QUT

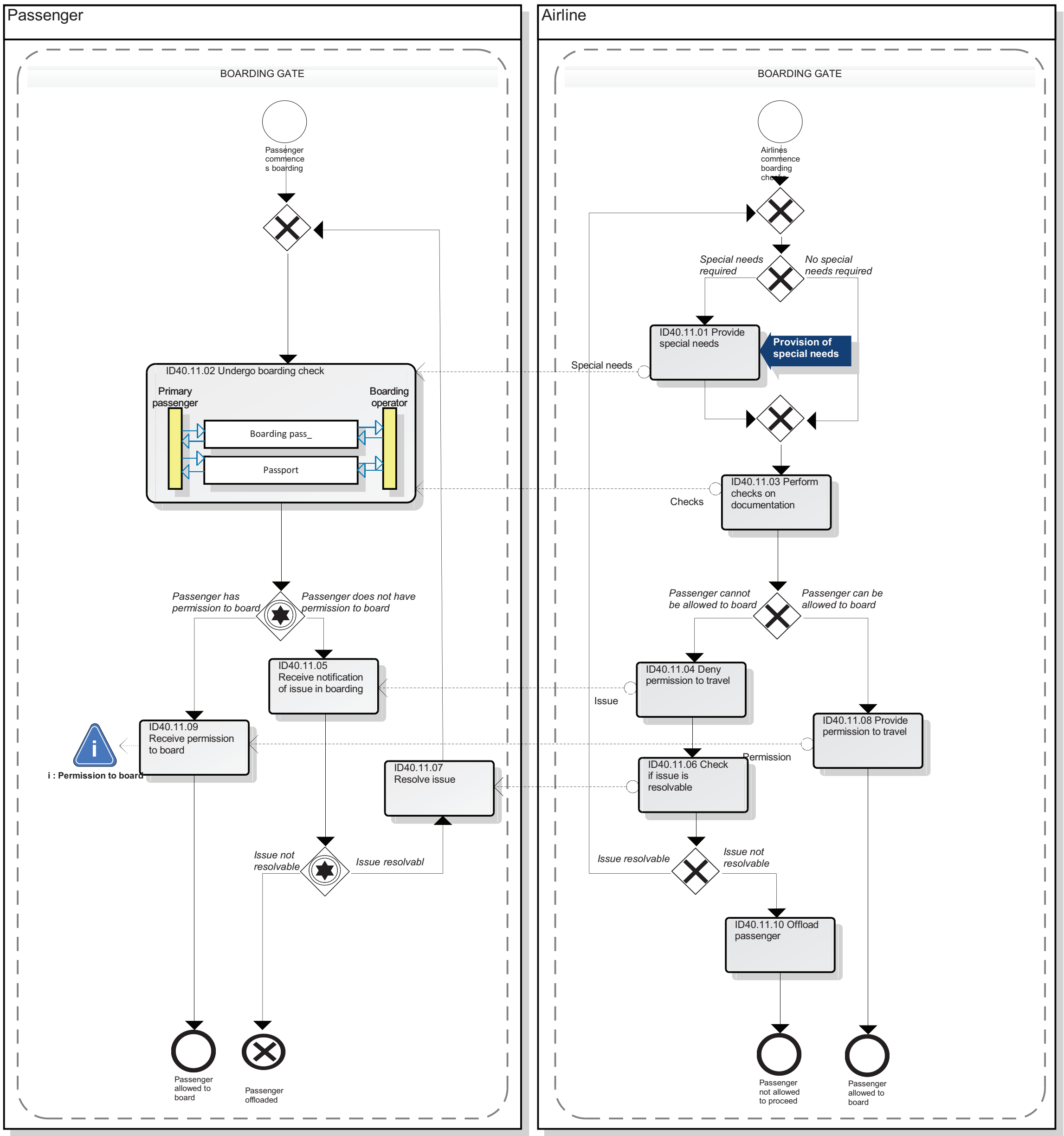
DRAFT



ID40.11 Proceed through boarding checks

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 1/08/2010 9:52:18 PM
Updated by: Samia Mazhar

DRAFT



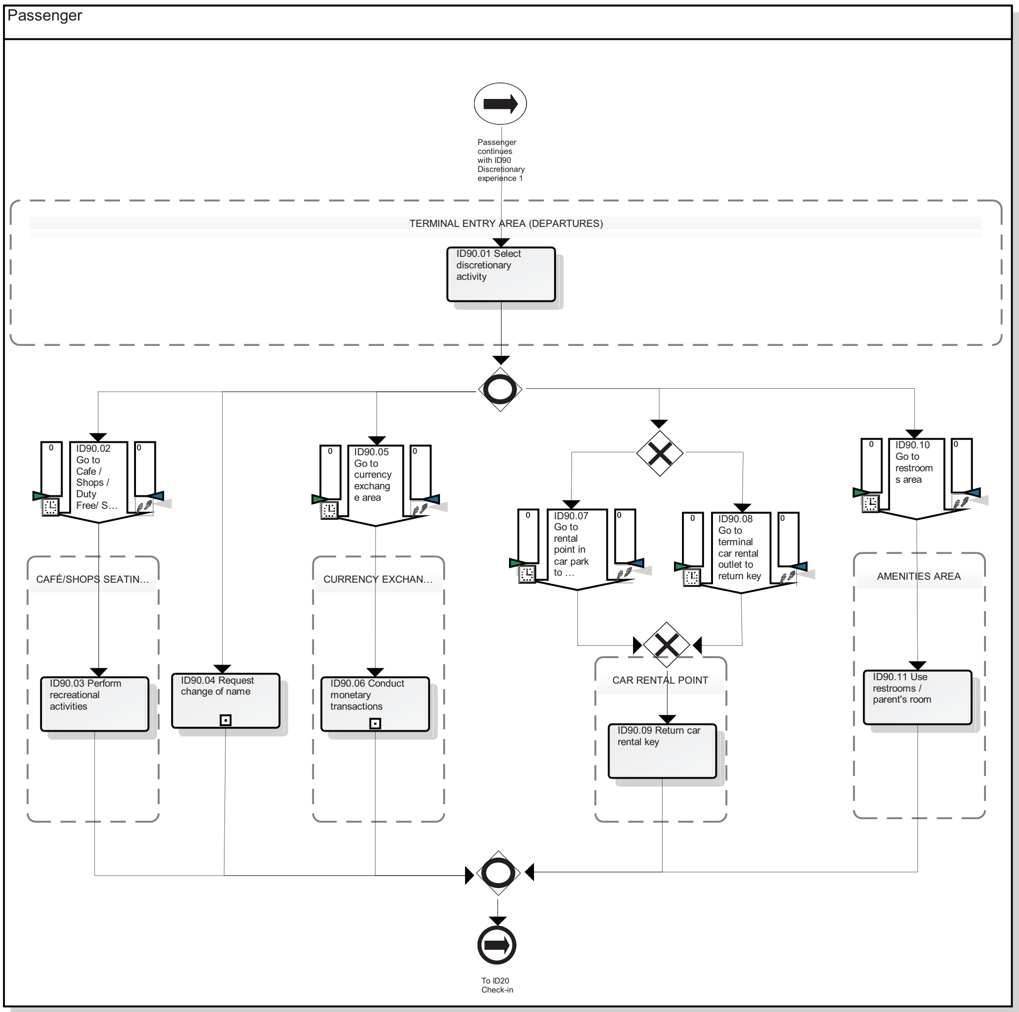
ID90 Discretionary experience 1

Gold Coast Airport

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 2/08/2010 4:44:41 PM
Updated by: Samia Mazhar

QUT

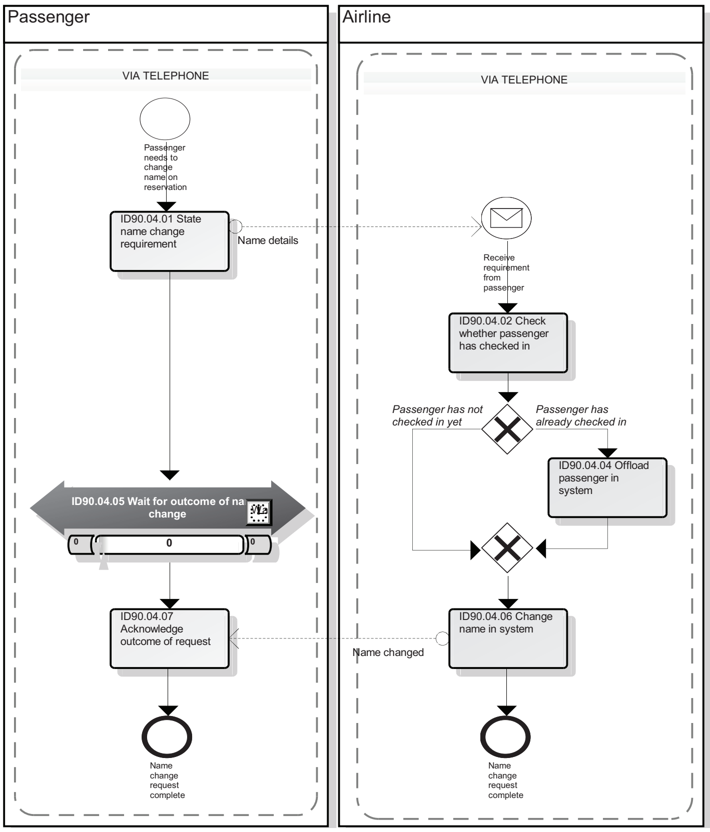
DRAFT



ID90.04 Request change of name

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 2/08/2010 4:49:32 PM
Updated by: Samia Mazhar

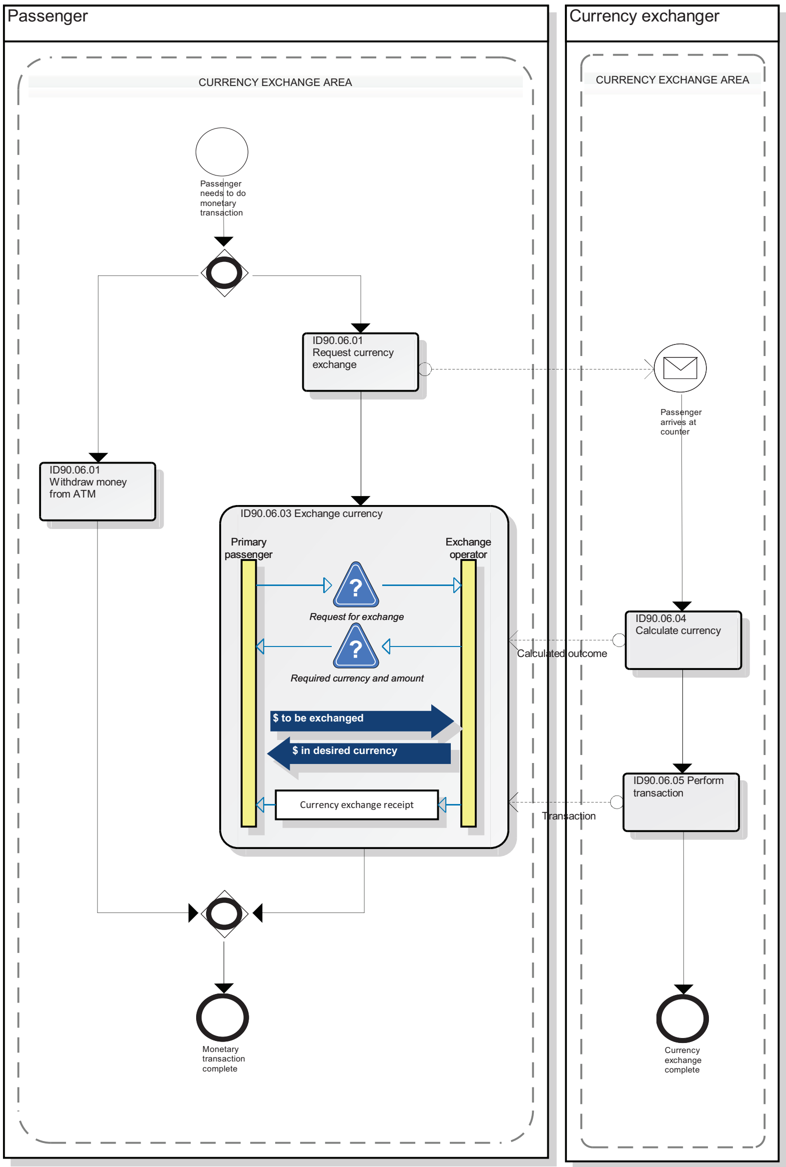
DRAFT



ID90.06 Conduct monetary transactions

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 2/08/2010 4:50:22 PM
Updated by: Samia Mazhar

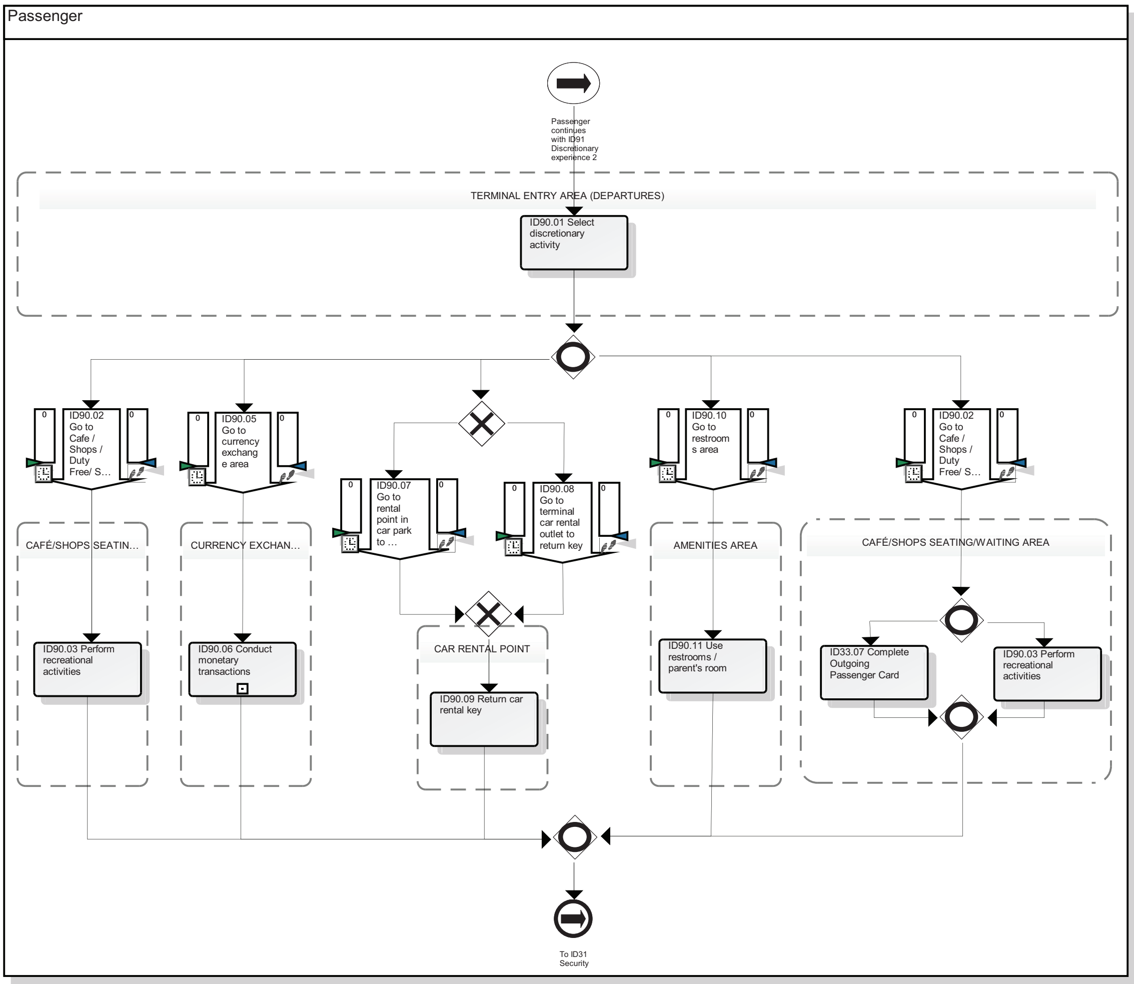
DRAFT



ID91 Discretionary experience 2

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 2/08/2010 5:57:00 PM
Updated by: Samia Mazhar

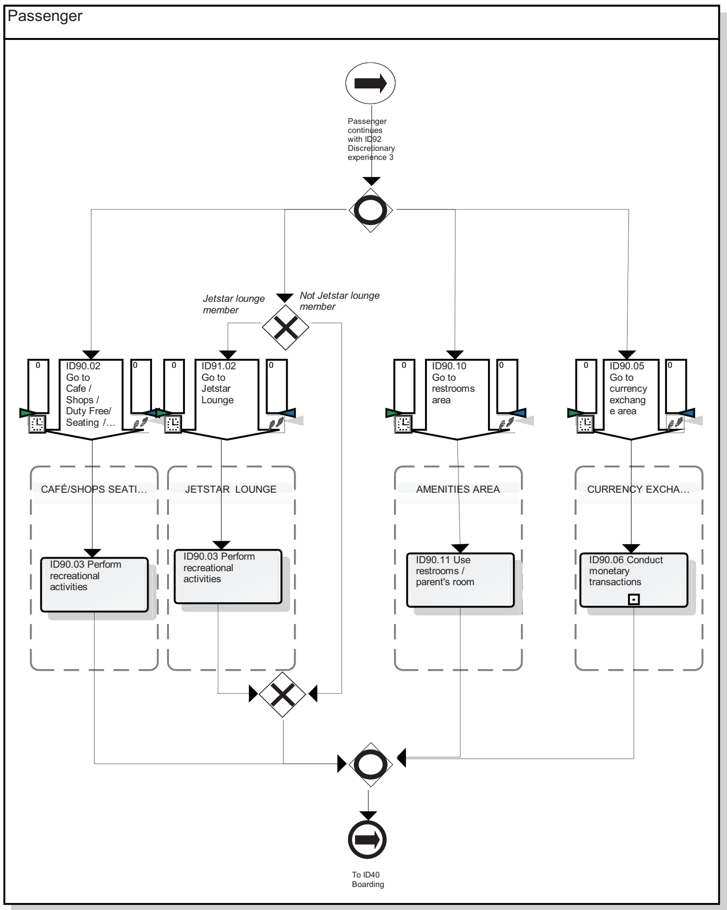
DRAFT



ID92 Discretionary experience 3

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 3
Update Date: 2/08/2010 5:58:28 PM
Updated by: Samia Mazhar

DRAFT



ID93 Discretionary experience 4

Model Name: Gold Coast - v0.9 [26.10.2010]
Category: BPMN Diagram Level 2
Update Date: 2/08/2010 6:47:40 PM
Updated by: Samia Mazhar

DRAFT