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ANALYSIS OF AIRPORT CHECK-IN OPERATION AND ITS RECONFIGURABLE DESIGN AND MANAGMENT

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Key Definitions and Glossary

Air transportation system
According to the definition given by the International Council on Systems Engineering (2006), the air transportation system is "*a combination of interacting elements organized to achieve one or more stated purposes*", i.e. the fast movement of people and goods globally. *The air transportation system is a **large-scale** (i.e. extends geographically worldwide), **complex** (i.e. displays both structural and behavioural complexity), **urged** (needs change dynamics in response to continuous and punctual stimuli), **socio-technical** (i.e. has both social and technical components), **interconnected** (i.e. not isolated from the external environment) **system**. The primary function of the system is to provide domestic and international air transportation services for both passengers and freight. It is linked to the local, national and international economy and by its nature requires a supply of services, of manufacture/technology and employment. The demands for the system originate from passengers and goods. The air transportation stakeholders are airlines, airports, authorities, suppliers and industries. In this thesis, the industrial sector is considered part of the system, because it provides the system with the means, both aircrafts (aerospace industry) and landside technologies, to accomplish the passengers and goods transportation. The main elements of the system can be grouped in:*
***Industrial aviation sector:** aircraft and technologies providers;*
***Aviation transportation sector**:*

- *Infrastructure (Airports);*
- *Airspace;*
- *Operations and services;*
- *Airlines, other companies performing in the system;*
- *Governments and institutions responsible for regulations;*
- *Passengers and freight.*

Configuration
Arrangement of the constituent parts of a system and of all the resources involved in delivering a process, so that the process can be run according to its requirements.

Reconfiguration
Adaptation of the existing configuration, towards a new configuration, within a given time scale, by: modification of the existing system/ process functions; adding/removing system/process functions; modifying system/ process capacity; modifying the way the system/process is run.

Reconfigurability
Property of a configuration assumed by a system and refers to its ability to change time and cost efficiently according to the dynamic external stimuli, i.e.to adapt to the requirements and defines the ease of undertaking reconfiguration actions.

Airport capacity
Airport capacity generally indicates the capacity of the airside, especially in term of number and length of runways. The capacity of runways however determines also the plane traffic in a certain time and therefore it is linked with the number of the passengers flowing in the terminal building. Unlike the runway and gates that have a "hard" capacity definition, the *capacity of terminal processing and queuing areas relates directly to the extent of congestion that passengers will tolerate. The capacity of the terminal depends from the level of service to be offer and expresses the volume of passengers and baggage that can be handled comfortably in the terminal* (IATA, Airport Strategic Business Planning, 2011) *by the planned amount of resources.*

Process
Arrangement of resources that transform inputs in outputs that satisfy internal or external customer needs present in the system (Operations and Process Manager, N.Slack).

Operation
Composition of more processes, operations still transform input into output but on a larger scale. In the airport, the operations are all the processes necessary to achieve the passenger and good transportation. The operation is a set of processes grouped based on a common purpose that they follow.
The term operation usually does not include the resources themselves but refer just to the manner of arrange, operate and manage them.
A more general meaning is assigned to operation in the thesis: operation includes also the resources needed in the processes (i.e. the technology portfolio to the human resources, space,..) as well as the operation policy, organisation and management aspects assisting the processes.

MA	*Manchester Airport*
MAG	Manchester *Airport Group, (owner and manager Group)*
RMS	*Reconfigurable Manufacturing System*
LoS	*Level of Service*
IATA	*International Air Transport Association*
CAA	*Civil Aviation Authority*
DP	*Dynamic Programming*
ILP	*Integer Linear Programming*

Abstract

With the fluctuation in the air transportation demand and the limited ability to increase the capacity and functionality of some key operations at the airport terminals, there are concerns that in the future, given their current designs, the airport terminals will not adapt timely and cost-efficiently to meet the demand. This limited ability causes the generation and propagation of issues in the terminal performances, such as inefficiencies and delays throughout the system, affecting the flow of the air-traffic and the airport's quality perceived by the passengers. According to current research, the check-in is the operation within the terminals that represents its bottleneck and major constraint for the dynamic adjustments of the airport. Therefore, to improve the terminal performance and enable its adaptation to the trends coming from the external environment, this operation needs to be reconfigured.

The evolving and uncertain requirements for the transforming check-in processes and the increasing fluctuations in the passenger air-traffic represent dynamic inputs for the check-in operation, which needs to be adapted instantaneously and at low costs. The ability to respond quickly to the dynamic environment by a rapid and possibly cheap change in the configuration of a process/system is known in manufacturing as reconfigurability. In this thesis, reconfigurability is investigated as a potential strategy to support the adaptation of check-in processes to the dynamic changes in requirements mentioned above. A case study of check-in operations at Manchester Airport in the UK helped to identify the key features of a reconfigurable check-in operation.

This thesis discusses the design of the new check-in configuration at two levels: the hardware, i.e. the technologies adopted in the operation, and the software level, i.e. the way in which the capacity and functionality of check-in technologies should be estimated and allocated. Both the hardware and the software reconfiguration would improve the performance of check-in operation, especially in terms of a more efficient use of the resources. On the hardware side, the present thesis analyses new check-in technologies and proposes a novel methodology to measure the efforts required for moving from one process configuration to another. The methodology is based on the use of a tool called Design Structure Matrix. On the software side, new methods to estimate and allocate check-in resources (particularly check-in counters) were developed. These methods output a capacity plan that dynamically adapts to the demand, thanks to the joint adoption of Dynamic Programming and Integer Linear Programming techniques.

Key words: airport check-in operations, reconfigurability, dynamic programming and integer linear programming.

Sintesi

La tesi che presento, dal titolo "Analysis of Airport Check-In Operation and Its Reconfigurable Design and Managment", si inserisce in un contesto di ricerca piuttosto ampio intrapreso dal gruppo *Distributed Information and Automation Laboratory* (DIAL). Questo gruppo è parte integrante del Dipartimento di Ingegneria dell'Università di Cambridge presso la quale ho svolto un periodo di ricerca ed approfondimento in vista della stesura della mia tesi. Il DIAL, diretto dal Professor Duncan McFarlane, è un attivo gruppo di ricerca specializzato nel controllo di complessi sistemi industriali, con una particolare attenzione al legame che intercorre tra l'aspetto tecnico e quello manageriale. Tra questi, i sistemi manifatturieri, la pianificazione delle risorse, l'asset management di sistemi industriali o di business di varia natura rappresentano alcuni degli interessi principali del DIAL. Il mio lavoro si è dunque inserito in questa panoramica di studi, tra i quali mi sono concentrata su uno dei suoi più recenti argomenti di ricerca che consiste nel trasferire e nell' applicare concetti derivanti dal *manufacturing* ad altri settori, come quello delle infrastrutture o dei servizi. Esempio di questa filosofia è il progetto iniziato nell'Aprile 2009 denominato "*Airport Operations*" a cui hanno preso parte vari *partners* industriali, primo tra tutti l'Aeroporto di Manchester, UK. "*Airport Operations*" comprende più temi di ricerca. Primo tra tutti il tema "*Reconfigurable Airports*" riguarda lo studio dei processi e dei servizi offerti negli aeroporti. L'obiettivo di questo progetto è quello di identificare i limiti delle *operations* per come sono correntemente configurate e migliorarle sia dal punto di vista dei passeggeri che da quello dell'autorità aeroportuale. Il *case-study* principale relativo a questo tema è stato operato sull' Aeroporto di Manchester e ha fornito dei dati molto interessanti nonché utili alla stesura della mia tesi. Fin dalle prime fasi di "*Reconfigurable Airports*" (Tomasella, 2010), è risultato che molte *operations* non sono adeguate al moderno traffico aereo, e a quello atteso per il prossimo futuro. Alcune *operations* in particolare costituiscono il "collo di bottiglia" per il flusso di passeggeri nel terminal e al tempo stesso una complessità di gestione per l'autorità aeroportuale. È dunque in questo ambito che uno studio dettagliato del caso di studio fornito da Manchester Airport Group (la principale autorita' aeroportuale a partecipazione completamente Britannica) ha evidenziato che, fra tutte le *operations* che hanno luogo all'interno dei tre terminal dell'aeroporto di Manchester, l'attività più critica dal punto di vista del bisogno di cambiamento è l'attivita' di check-in.
L'obiettivo di questo mio lavoro di tesi è stato pertanto quello di analizzare questa necessità di riconfigurazione delle aree e dei processi di check-in presso l'aeroporto di Manchester, in modo da migliorarne l'efficacia dei servizi, la qualità della *passenger experince* e l'efficienza nell' utilizzo delle risorse. Oltre

ad adattare la configurazione sulla base dei recenti *trends* di mercato, e di cercare così di incrementare il profitto dell'aeroporto ho lavorato al contempo per fornire strumenti utili per la gestione e di supporto durate la riconfigurazione delle operazioni di check-in. Particolare attenzione e' stata infatti dedicata alla generazione di nuovi *tools* e alla modificazione di techniche gia' esisteni nel *manufacturing* al fine di fornire ai managers aeroportuali un pratico aiuto:

- nel *design* di future configurazioni;
- nella gestione delle risorse;
- nella massimizzazione dell'utilizzo delle stesse.

Il sistema aeroportuale risulta incapace di adattarsi e soddisfare la variabilità della domanda in tempi e costi limitati a seguito dei recenti sviluppi del settore aereo, sia nelle tecnologie adottate, sia nella differenziazione dei servizi offerti (ad esempio la diversità delle compagnie low-cost dalle compagnie di bandiera). Tuttavia, l'importanza del sistema aeroportuale per l'economia e per lo stile di vita moderno rende indispensabile la generazione di nuove alternative. Tali soluzioni sono indispensabili sia nell'infrastruttura ed *equipment* sia nei sistemi di *capacity planning* e gestione delle risorse. L'idea di adattare la struttura esistente a variazioni dei requirements e al contempo di modificare il sistema (idealmente con costi e tempi ridotti) è il medesimo principio su cui si è fondato lo sviluppo dei più recenti sistemi produttivi quali Flexible Manufacturign Systems e soprattutto Reconfigruable Manufactuirng Systems. In questo mio lavoro, infatti, sono stati studiati i concetti derivati dal settore manifatturiero, precisamente quelli di riconfigurabilità dei sistemi di produzione, e sono stati applicati al check-in aeroportuale. La prima fase della ricerca è consistita nell'individuare quali fossero i trends caratterizzanti in generale il traffico aereo e gli aeroporti, in particolare i processi di check-in. Tale analisi ha permesso di generare plausibili scenari futuri per il check-in come *operation*. Un tool, in formato di tabella a molteplici entrate, e' stato disegnato per accoppiare le funzionalita' richieste dai processi di check-in con quelle offerte dalle tecnologie disponibili. Grazie all'analisi contemporanea dei trend e al *tool* qui proposto sono stati investigati le funzionalità, i limiti e la struttura organizzativa di tali operazioni. Parallelamente le numerose visite a Manchester Airport, i diversi meeting e il workshop con i *managers* aeroportuali, hanno contribuito a definire con piu' certezza lo stato attuale dell'operation, le sue caratteristiche e limitazioni. Non solo, tali incontri sono serviti per validare gli *outputs* del *tool* utilizzato, gli scenari designati come probabili per il futuro e confermare le aspettative verso le nuove configurazioni di check-in. Dall'analisi della presente configurazione delle aree e dei processi di check-in a Manchester Airport, sono state poi identificate le due principali problematiche: la prima è legata alla rigidità delle risorse presenti, che consiste essenzialmente nella loro limitata flessibilità, funzionalità e modificabilità. La seconda problematica invece riguarda una sottoutilizzazione delle risorse stesse. Il sottoutilizzo delle risorse infatti è principalmente generato da un planning delle risorse che non tiene sufficientemente in considerazione la variabilità della domanda. Pertanto i due aspetti chiave su cui si è focalizzata questa tesi possono essere riassunti da due concetti: *hardware* e *software*. Il termine *hardware* si riferisce al portafoglio di tecnologie utilizzabili per il check-in, mentre il termine *software* si rivolge al *capacity planning* delle risorse disponibili, cioè le modalità di stimare e allocare le funzionalità e la capacità risorse ai clienti, cioè alle compagnie aeree. L'abilità di adattare le aree ed i processi di check-in, in breve tempo e con costi limitati, è definita riconfigurabilità nella letteratura del *manufacturing* e definirne le caratteristiche e la metodologia da seguire per introdurla nel sistema sono esattamente l'obiettivo finale di questo lavoro. La riconfigurabilità è stata considerata infatti come la potenziale strategia da sviluppare per i processi di check-in, data la dinamicità dei cambiamenti dei requirement e della fluttuazione della domanda. La riconfigurazione che ho proposto per l'aspetto *hardware* del check-in si concretizza nell'introduzione di nuove tecnologie per processare i passeggeri e il rinnovamento del *layout* del terminal. Il *set* di alternative configurazioni descritte e' il risultato di molteplici indagini di mercato e analisi di aeroporti eurpei comparabili con MA. Parte principale dell'aspetto *hardware* e' stato lo sviluppo di una metodologia da applicare da parte dei managers dell'aeroporto qualora si intraprendesse la riconfigurazione dello stesso. Una metodologia di questo tipo è basata, sulla formulazione delle caratterisitiche di riconfigurabilita'dell'hardware, sulla definizione di opportuni indicatori di performance (*KPI*) e sull'uso della cosiddetta *Design Structure Matrix*. Tale tecnica e' stata applicata per la prima volta ad un ambito diverso da quello manufatturiero, ed e' stata pensata come efficace strumento di verifica e misura degli sforzi, in termini di tempi e costi, intrapresi durante il processo di riconfigurazione. Per quanto concerne l'aspetto *software*, ho evidenziato due metodologie per la stima e l'allocazione delle risorse di check-in alle compagnie aeree. Rispettivamente, questi nuovi metodi di *capacity planning* si basano sulle tecniche di Programmazione Dinamica e Programmazione Lineare a Numeri Interi. La riconfigurazione dell'attuale sistema di stima e allocazione delle risorse garantisce un sensibile incremento dell'utlizzo delle risorse e una migliore gestione delle stesse da parte dell'autorità aeroportuale. Non di meno, le nuove variabili intodotte nel *capacity planning* permettono una stima maggiormente adeguata ai *requirements* derivanti sia dai passegeri sia dalle compagnie aeree e al contempo la possibilità di adattarsi dinamicamente al volume di traffico aereo. Con la metodologia proposta l'aeroporto e' in grado di avere maggiore visibilita' sul numero di check-in *counters* richiesto dalle compagnie aeree, predire meglio la domanda delle risorse sia per massimizzarne l'utilizzo sia per definire meglio i termini contrattuali con le compagnie aeree.

1 INTRODUCTION

1.1 Problem Description

One of the greatest challenges for the air transportation system is to increase its scale in order to meet growing demand. Historically, passenger traffic has grown significantly, as recorded by ICAO[1]. Moreover, the current long-term forecasts indicate that the demand for air transportation is likely to re-start its growth after the latest fluctuations due to the economic crisis.

The air transportation system has seen tremendous growth in the last two decades due to liberalisation in developing economies, emergence of low cost airlines, high GDP growth in the BRIC nations (Brazil, Russia, India and China), and airlines' freedom to arrange their operational schedule freely[2].

Future and sustained growth of the traffic assumes that the airport infrastructural capacity is able to accommodate the future demand.

However, the European Commission Aviation and Control (ECAC) forecasted that the capacity of many of the airports around the world will not be able to match the demand, and risks becoming the most constraining factor in air transportation. According to ECAC, given the expected traffic evolution in Europe, an "*ever growing gap between capacity and demand*", referred to as the "*capacity crunch*", will be experienced[3].

The limited capacity at the airports results in congestions and delays. These delays propagate throughout the air transportation network and affect the overall performance of the transportation system.

Therefore, there is a strong necessity to uphold the air transportation system and promote its growth, both in the industrial aviation and aviation transportation sectors. On one hand, the aviation industry is working on providing more aircrafts, with a shorter lead-time, and new types of planes with high passengers' capacity (and less consumption), such as the new Boeing 787. On the other hand, the aviation transportation sector is trying to adapt to the external influences in order to sustain the demand coming from the market.

As departure and arrival points, and as locations where all the operations that enable the movements of passengers, goods and aircrafts take place, airports are the fundamental elements in the aviation transportation sector.

The operations that take place in the airport are the foundations on which all the further air movements are based and therefore influence the success of

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[1] International Civil Aviation Organisation, Statistical Year book,2010

[2] Annual review of Civil Aviation, years 2007-2010, ICAO

[3] ECAC and Eurocontrol: "Study on Airport Capacity",2010, www.eurocontrol.int

passengers and freight transportation. Hence, the operations' design within the terminal's design is particularly important. The aims of the operations' design are to reduce the overall congestion in the terminal, to allow the passengers/goods to easily flow in the terminal, thereby reducing delays, queues and other discomforts.

Moreover, in order to avoid oversized terminal capacity plans, an efficient use of the resources is necessary. To achieve these objectives, airport operations firstly must be designed according to the current requirements and then need to be run as efficiently as possible. The lack of capacity and/or the inefficiency of these operations represent the bottleneck for the whole system. However, the design and management of the operations is a difficult task above all due to:

- the complexity of the airport terminals;
- the evolving external requirements;
- the uncertainty associated with the passenger demand;
- the high influence of the constraints imposed by the aviation sector.

As mentioned, the number of air passengers in the last five years has shown a consistent worldwide growth (up to 16% see Appendix A). However, the recent economic crisis is the key reason for the unpredictable fluctuations in demand and temporary instabilities in passenger flows. In addition to the traffic growth, the aviation transportation is experiencing other trends. The increasing passenger expectations, diversification in the airline business models, technology push and growing attention for environmental sustainability are all generating new challenges for the airport and its operations. While adapting to these evolving requirements, the airport's intent is to arrange the facilities and infrastructure in a way that can guarantee an environment that supports operation efficiency for the airlines, as well as a comfortable and efficient setting for the passengers. Airlines and passengers represent the two main customers' categories for the airport. The passengers' satisfaction is built on the quality perceived in the airport operations, which become thereby the target for the airport to improve its image and with that indirectly its profit.

Airport incomes indeed originate from aeronautical and commercial activities. Aeronautical revenues include aircraft landing fees, aircraft parking and hangar fees, passenger service charges and air traffic control charges (if the service is provided by the airport authority), with landing and parking charges probably being the most important. Concession revenues are those generated from non-aircraft related commercial activities in the terminals and on airport land. Concession operations include running or leasing out shopping concessions of various kinds, car parking and rental, banking and catering, with terminal concessions and rental of shopping being the most significant (Zhang Y., 1997).

In order to maximise the profit, the airport is interested in minimising both the aircraft dwell time, i.e. the time when the aircraft is not flying, and the time spent by the passengers while they go through the terminal operations. The quicker those operations are, the more the terminal is able to host aircrafts and passengers, who are able to spend a longer time in the commercial area, thus making the shopping area more profitable and desirable for commercial activities. To achieve its financial objectives and to cope with the above-mentioned trends, the airports are required to improve operational efficiency at terminal facilities to meet new standards of operational capacity and functionality. More importantly, the airport and its operations should be able to adapt over the time to the changes in the requirements.

1.2 Background

The increasing passenger volume, evolving airlines' requirements and security regulation and the above-mentioned trends influence an airport's ability to adapt to the system with quick adjustments and low financial impacts to those evolving challenges. The University of Cambridge in partnership with Manchester Airport Group (MAG) investigated this ability. The project, named "Airport Operations", operated out of the Distributed Information and Automation Laboratory (DIAL), based within the University's Institute for Manufacturing (IfM). The Airport Operations programme, officially kicked off in April 2009, is an industry-led research programme, which addresses the needs of all partners across a number of areas related to airport operations.

A major research theme in the programme, called "Reconfigurable Airports", aims at providing managers of different airport processes with practical and quantitative guidelines to make their processes (and with that the airport) more reconfigurable. This term refers to the characteristic that provides the airport and its operations with reconfigurability, i.e. the ability to adapt in a short time and with low impacts in the investment to cope with the external changes, so that reconfiguration can alter its behaviour.

Manchester Airport Group (MAG) has been a partner of this project and as a team leader of Manchester Airport (MA) proposed MA a case study to investigate the "Reconfigurable Airports" project. This thesis, developed within the context of the programme, has referred to Manchester Airport as "case study." The first result of the "Reconfigurable Airports" project found that the check-in is a very critical operation in the terminal and is the first one that should be reconfigured (Tomasella, 2010).

In fact, according to MAG, the busiest sections at MA are the check-in area and the security. The delays and queues that passengers might experience during the check-in process are due to constraints in the capacity of service facilities. The check-in operation is a complex set of processes subject to passengers, airlines, the airport authority and technology. Given the strong influences and the uncertain variability coming from passengers (such as increasing volume and service expectations), airlines (such as diversification of business model) and technology (such as technology- push and evolution), future scenarios of the check-in operations are characterised by a high unpredictability, which makes the check-in management and planning difficult tasks for the airport.

The findings of the exploratory case study of MA proved that the estimation and allocation processes are non-optimised and originate the underutilisation of resources in the check-in hall. Simultaneously, , the inefficiency in the estimation and allocation processes causes the inability to adapt to external changes, such as the fluctuations in the traffic in the time and the airlines differentiation of the business model.

In the check-in counter allocation and estimation problem the amount of resources required cannot be predetermined, involving stochastic events such as the passenger arrival rate and service rate.

The process of checking-in passengers is stochastic, and the number of required check-in counters varies with time since the total number of passengers per flight is different. Hence, the passenger show up process and the service time, i.e. the time spent in issuing the boarding pass and controlling the documents, are random processes, whose probability distribution cannot be easily determined.

An additional hindrance to the capacity plan is the time constraint as the time available to meet the present stochastic demand is very limited (from 2 to 3 hours). Other factors such as time of day, day of the week, and destination will all influence the amount of resources allocated. Moreover, the presence of different airlines, with different operational policies and use of check-in counters subjected to contract (between airline and airport) complicate the Airport Check-In Problem (Bruno, 2010). To limit the negative impacts of the check-in operation on the terminal performances, the check-in should be able to follow the demand and its changes. The development of reconfigurability in this operation would allow a better use of the resources. Along with the congestion, delays and time spent by the passenger in the processes would also decrease, while the customers' satisfaction would increase just as the airport income would.

In check-in reconfigurability, two aspects play a crucial role: the technology adopted in the physical configuration of the check-in and the methodology applied in the resource capacity plan. These two aspects can be considered respectively the *hardware* and the *software* of check-in reconfigurability. The technology portfolio and the layout configuration for the check-in represent the physical (hardware) enablers to adapt to the system in a time and cost-efficient manner.

The "software" of the operation configuration relates to the check-in capacity plan. In order to achieve its reconfigurability it is crucial to model the process with all the influential factors and their relationships. Hence, mathematical models help to reproduce properly the physics behind the check-in and provide

solutions for the evolving scenarios and dynamic load of traffic. The reconfigurability refers to the ability of the resource estimation and allocation methodologies to follow the variability in the demand and assign the resources according to the demand fluctuations over time.
Moreover, such a capacity plan needs to consider the contract agreement and the rental policies between the parts involved in the check-in operation. Therefore, the reconfigurability provided by the hardware translates into actual reconfigurability in the system only through the implementation of estimation and allocation approaches able to exploit the reconfigurability potentialities of the resources.
This thesis aims at re-designing the MA check-in hardware and software in order to improve the operation by promoting reconfigurability. Therefore, the design of a new check-in configuration was developed, by investigating the new technologies available in the market and novel mathematical solutions to estimate and allocate check-in counters to airlines.

1.3 Research Questions

Based on the above rationale, the work on this thesis explores the following research questions, in order to support the reconfigurability with reconfigurable technologies and mathematical models to estimate and allocate the available resources.

Research Question 1: *What are the key technological features of a check-in configuration that make it reconfigurable?*

This research question concerns the selection of the technologies and configuration that provide the check-in with reconfigurability. In fact, the technology portfolio and check-in hall layout influence the reconfigurability of the system. The reconfigurability key features, alternative hardware solutions, methodologies to generate configuration options according to the requirements as well as to measure the effort of hardware reconfigurations are all investigated.

Research Question 2: *What are the key features of a check-in resource allocation methodology that allows the check-in process to be considered reconfigurable?*

This research question deals with the mathematical techniques employed in the reconfigurable resource estimation and allocation methodology, so that the result of the application of such methodology is a reconfigurable check-in. A methodology that is able to allocate the resources according to the changing demand and that considers its variability over time is required to support the hardware side of reconfigurability.

Two mathematical techniques have concurred to the reconfigurability development in the software side of the check-in operation: dynamic programming (DP) and integer linear programming (ILP). In the approach proposed in the remainder of the thesis, the former helps in the definition of the number of check-in counters for each flight, whereas the latter supports the allocation of resources according to a new strategy that we propose named "counters pooling". This allocation is based on a desk-sharing practice to be implemented by the airlines across the different operating days in a week. In fact, given the variability in the number of scheduled flights among the days of the week, each airline does not necessarily need the same amount of desks every day. However, contract policies usually assign a fixed number of desks to an airline for the two weeks of the contracts. This restriction forces the airline to rent the amount of resources that are necessary during the peak day(s), and consequently causes an underutilisation of the resources in the other days. Furthermore, peak-demand does not occur on the same day for all airlines. The possibility for airlines to share counters among the days would allow them to rent less desks necessary at peak times, and to borrow counters from the airline that on the same day experiences lower demand.

Simultaneously, this "pooling" strategy would allow the airport to increase the utilisation of the resources, reduce the cost and in the best case save space to be dedicated to other airport businesses.

1.4 Research Methodology

To address the research questions proposed above, this research work followed the methodology reported in Figure 1-I.
First, the research problem was identified by three major contributions, whose time schedule has also been reported in Figure 1-I:

i. The visit to MA;
ii. The workshop carried out at MAG;
iii. The data collected about the current trends.

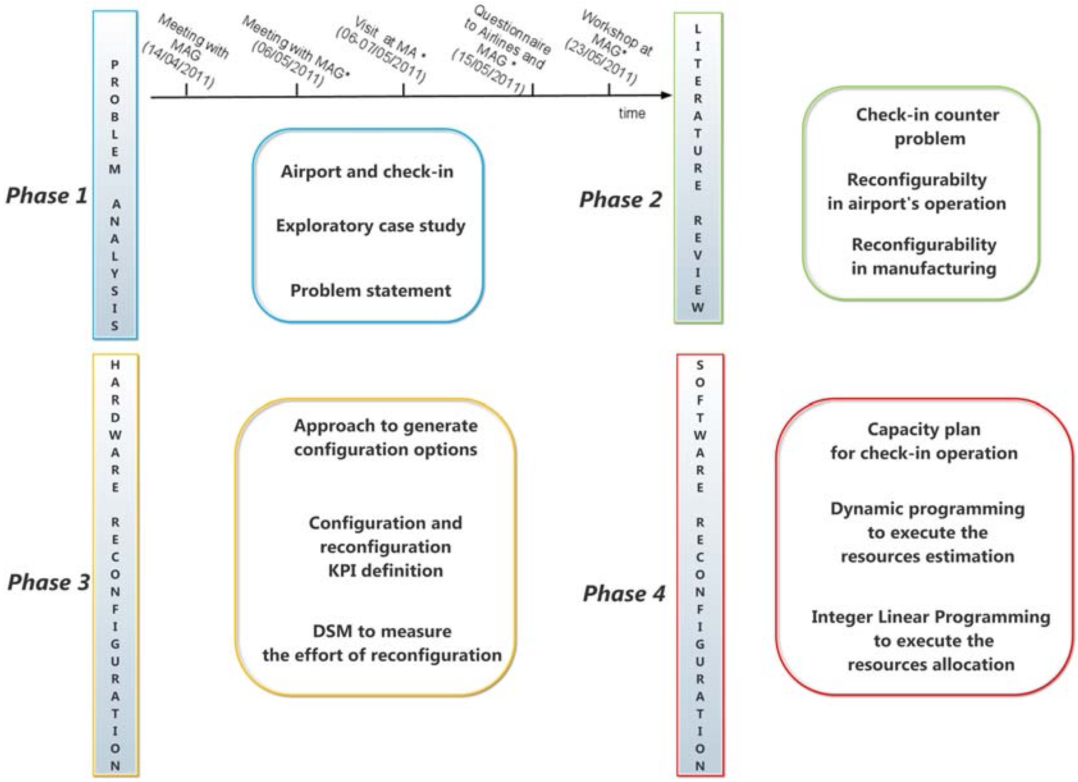

Figure 1-I Research methodology

NOTE. UML: Unified Modelling Language; DSM: Design Structure Matrix; DP: Dynamic Programming; ILP: Integer Linear Programming; MA Manchester Airport; MAG: Manchester Airport Group;*: developed in collaboration with S.Shah, MEng Student at University of Cambridge

In particular, the exploratory case study at MA allowed pointing out the needs of the check-in operation and current configuration existing at MA.
Furthermore, exploring the check-in operation at MA led us to a deeper understanding of the resource management, agreement policy and relationship issues between the airport and the airlines.

In designing the reconfiguration of the check-in operation at MA, the three major problems were addressed:

i. The underutilisation of resources;
ii. The hardware inability to adapt to future requirements;
iii. The software inability to follow the differences in the set of requirements and variability in the traffic load of the flight schedule.

The last two objectives of the hardware and software reconfigurations are related to the capacity of the check-in and motivate the need for reconfigurability in the check-in system. To find alternative reconfiguration solutions able to meet the three mentioned aspects, the existent studies on airports and their operations have been examined, and the reconfigurability knowledge available in the literature has been researched.

This qualitative evaluation is based on three steps: The first step, i.e. the literature review, regards both the software and hardware elements of the operation. The investigation of the alternative technologies available has been developed together with dedicated approaches to generate and compare different configurations (designed from sketch and validated by MAG during the meetings), but also to measure the effort of the reconfiguration process (by the use of the Design Structure Matrix, see chapter 4).

To answer the second research question and support the check-in reconfigurability from the software side, new estimation and allocation methodologies have been studied.

The schedule of collaborations with MAG (the visits at MA, meetings and workshop with MA) as part of the methodology followed has been listed in Figure 1-I. It must be noticed that the setting up of the workshop and the information collection during the meeting have been supported by the collaboration with Sahil Shah, an MEng student at the University of Cambridge. Those activities, the organisation of which involved the contributions of both are indicated with a star*.

1.5 Organisation of the Thesis

This thesis comprises six core chapters, references and appendices. Table 1-I summarizes the short synopsis of the thesis, whose structure is provided in the following.

Chapter 2 is dedicated to understanding airport operations and processes, with a major focus on check-in operations. The work was guided by the exploratory case study carried out at MA.

The analysis of the recent trends will be followed by the definition of the main functional requirements for airport check-in operations. The chapter also defines the check–in reconfiguration problem as will be tackled in the remainder.

Chapter 3 first presents a literature review of previous work on airports and check-in operations, and highlights the existing gaps present in those studies. Particularly, the lack of investigation on reconfigurability-related concepts in the airport literature is underlined. The second part of the chapter brings to attention the concept of reconfigurability in the context of manufacturing systems, and presents and comments on the characteristics and principles of reconfigurability. Throughout a review of the state-of-the-art in the field of reconfigurable manufacturing systems, the unexplored aspects of reconfigurability in the airport operations are identified and discussed.

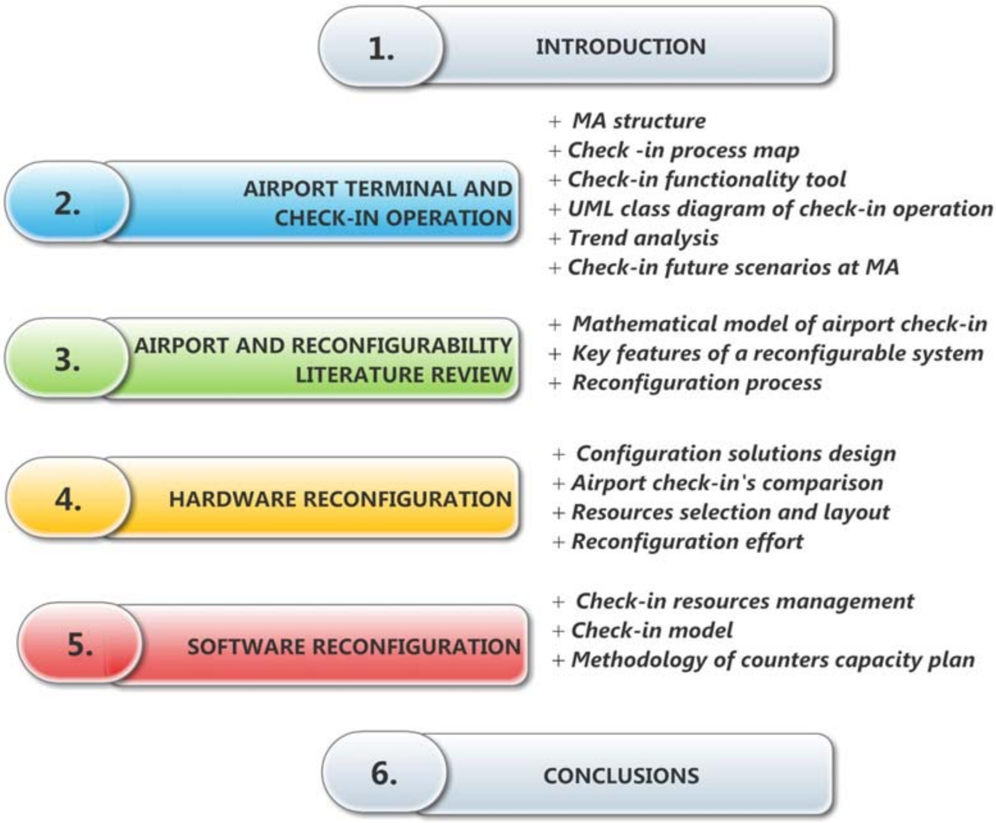

Table 1-I Organisation of the thesis

Chapter 4 deals with the investigation of reconfigurability in the hardware elements of check in operations. The key technological features of the hardware reconfigurability are derived from manufacturing processes and then applied to check-in processes. This chapter illustrates the approach adopted to generate alternative hardware configurations for the check-in at MA, measure them and plan for their implementation and the efforts required.

Chapter 5 is dedicated to the investigation of reconfigurability in the software aspects of the check-in operation. In support to the hardware configuration determined in the previous chapter, an optimal policy for estimating and allocating resources within the check-in operation is presented. DP is applied to estimate the optimal number of desks for each flight from the airport's point of view. Based on these results, an ILP approach is developed to suggest to MAG a novel resource management policy to increase the reconfigurability and efficiency of the system through the "counters pooling" strategy briefly outlined above.

Chapter 6 answers the research questions and concludes this research study by providing a summary of the key results. Limitations of this study are also discussed.

2 AIRPORT TERMINAL AND CHECK-IN OPERATION

Introduction

The airport is a complex network of operations, services and movements of passengers, goods and aircraft. The external environment and the evolving requirements come from the air transportation system (passengers, authorities, industry,..) and affect the airport's infrastructure and organisation. In this chapter all these aspects will be highlighted and investigated in further detail.
This first part of this chapter (sections 2.1, 2.2) describes the airport operations in general, the check-in in particular and the major trends occurring in the air transportation system. The second part (section 2.3, 2.4) is focused on the exploratory case study at MA and summarises the results collected during the meetings and the workshop with MAG. Both the hardware and software sides of its check-in operations are described, together with the current trends affecting the airport, the functional requirements, future scenarios and expectations for the check-in at MA.
The last section (section 2.5) is dedicated to the research problem definition.

2.1 Airports Structure

This paragraph presents an overview on the airport's operations and recaps the result outputted by University of Cambridge in the project "Reconfigurable Airport". The last part of this section illustrates the generic structure of the check-in process.

2.1.1 Landside Operations

The airport structure can be divided into three groups considering the different activities that are carried out: airside, access facilities, and passenger terminals (J. Yen,2009). Airside is directly related to aircraft operations, and includes the infrastructure that supports the flight arrival, turnaround and departure: aprons, taxiways, runways, air traffic control systems.
Access facilities consist of airport access roads, parking lots, or other transportation methods to reach the airport.
Passenger terminals include the area at which passengers enter/leave the airport and incur the necessary processes for departure/arrival such as check-in, security check, and baggage-claim. Terminal halls are traditionally large halls where many activities take place at the same time: commercial business, terminal

operations, passenger movements in the terminal, tickets sellers, ancillary services such as post offices, PRM (Person with Reduced Mobility) assistance, flow of passengers, movements of luggage and carts and so on.
Additionally, a complementary and combined network of actors undertakes these activities: passenger and cargo airlines, airport authorities, handling agents (services providers), in-flight catering firms, general sales agents, car rentals, air brokers, tour operators and travel agents.
Focusing only on the landside, three main classes of landside airport operations can be identified (approaching and leaving operations, terminal operations, baggage operations), as summarised in Figure 2-I.

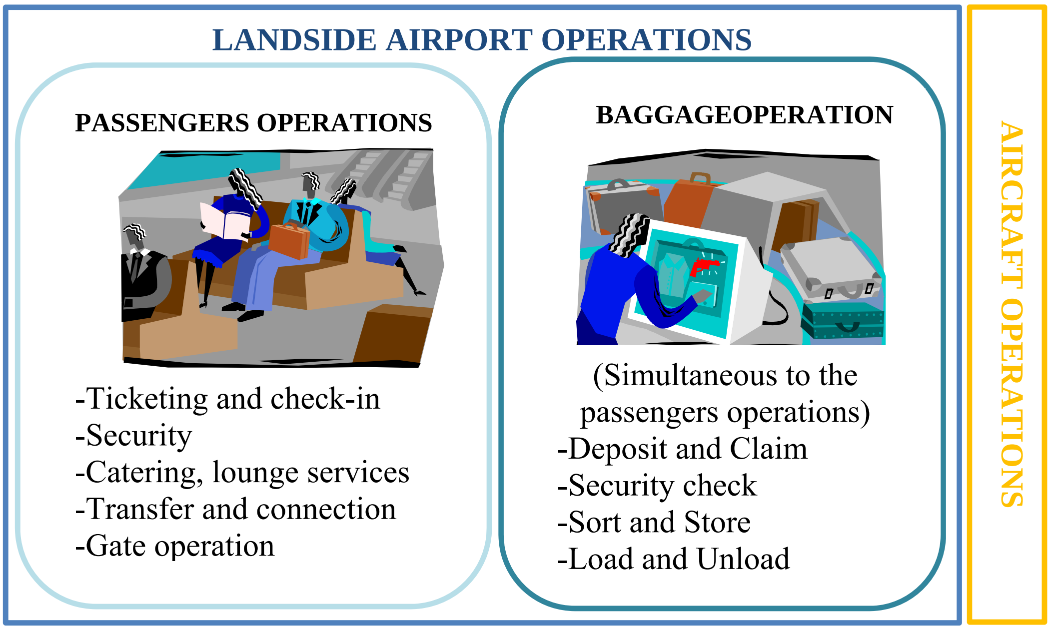

Figure 2-I Areas of Airport Operations

The major inputs of this system of operations and motions are the passengers' arrival rate and the activities that the travellers intent to undertake. These aspects cause a variable load on the system and a high unpredictability of the scenario occurring at the terminals, contributing to the difficulties of tackling the terminals' congestion, crowding and resource use.
The dynamic nature of the air travel demand and its fast expansion do not match with the above-cited rigidity and complexity of air transportation infrastructures and the slow evolution of their operational architectures.
In addition to the increasing traffic, the diverging airline business models, the changing passengers' requirements, the technology push from external stakeholders and the changes in the aircraft industry affect the terminal activities and operations. Consequently, airport authorities are interested in discovering how they can cope with these challenges in order to adapt the capacity and

functionality of their airports to meet the changing requirements and reduce the congestion, crowding and inefficiency of the terminal, while providing high quality of operations.

To simplify the problem, the airport terminal can be treated as a large-scale system with sets of operations and where each set can be designed separately if the interfaces and interactions with the other operations are modelled properly. Cambridge University has adopted this idea of the Airport as a composition of more operations in the project named "Reconfigurable Airports", developed in partnership with MAG. Throughout a workshop with the presence of the airport management team, the business priorities of the airport have been pointed out, together with the key terminal operations, which represent the major criticalities of the system. Among the operations shortlisted, check-in operation was ranked as the top priority one. The check-in area was found to be, along with the security, the busiest sections at MA. The passengers are subjected to queues and delays during the check-in processes, and these delays and queues are due to constraints in the capacity of service facilities. The service facilities for this operation include the amount of floor space that accommodates the check-in desks and passengers in queue, and the equipment assisting the check-in process. Check-in process is a complex operation that can be easily influenced by passengers, airlines, handlers, airport authority and technology.

2.1.2 Check-in Operation

Among the operations mentioned above, check-in and boarding are the sole interfaces between the airlines and their passengers. In the check-in, the decisional control of the airlines can be noticed from the variety of processes and services offered by different airlines. The purpose of this section is to give a general description of the check-in operation; the flowchart in Figure 2-II summarises the stepwise procedure that allows a departing passenger to cross the terminal departure hall end-to-end.

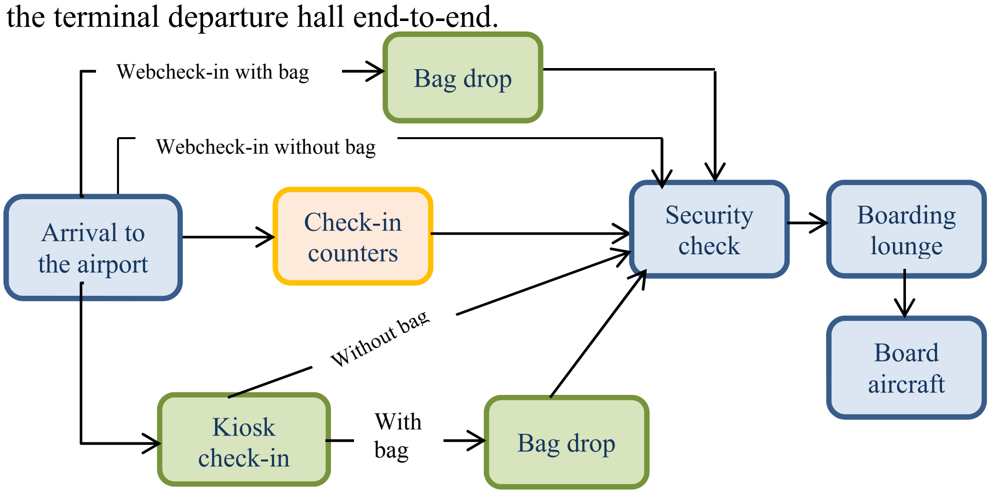

Figure 2-II Passenger Processing Flow

More flowcharts on the check-in processes are reported in Appendix B.
The first step is the arrival at the airport and approach to the check-in counter. After check-in, the passenger proceeds to the security check where the hand baggage and personal belongings are scanned. The check-in baggage in most European airports is scanned in-line unlike the new security requirement at US airports where the bags need to be scanned before taking them to check-in. Passengers once reached the secured area can shop and relax. Prior to boarding the aircraft they queue up in the boarding lounge where the identity of the person is verified once again.
The multitude of routes is a result of various decision points in the process. Passengers can take one of several routes through the check-in processes depending on the combination of their individual choices and the obliged requirements and airlines offers. Hence, as already mentioned, the airlines can decide the services to provide, the processes to check-in the passengers and the resources to rent from the airport.
Indeed, normally the resources available are owned entirely by the airport, which rents check-in equipment to airlines while the airlines often outsource provision of check-in services to companies known as "handlers". Handlers might provide airlines with other services as well, e.g. passenger boarding, and some of them serve more than one airline in an airport and the total number of different handlers may increase with airport size. The general business relationships are summarised in Figure 2-III.

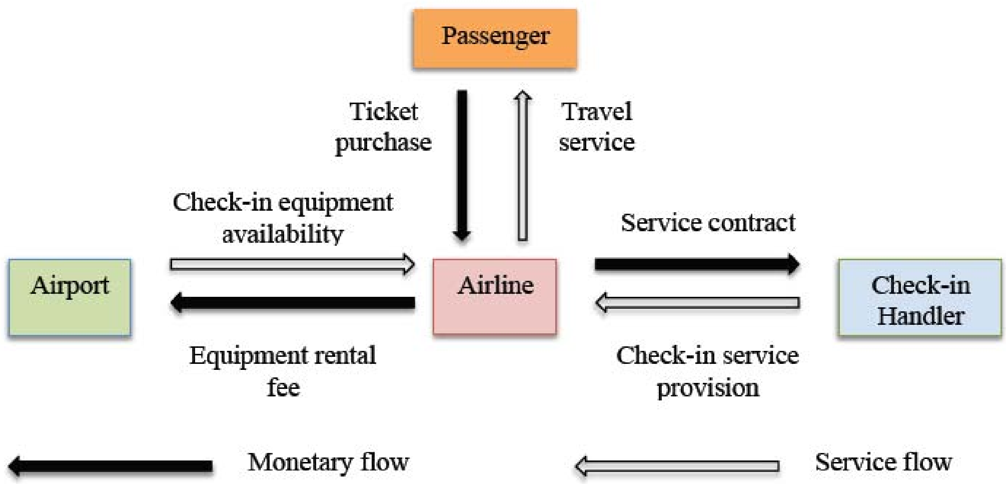

Figure 2-III Business relationships between stakeholders of check-in process.(S.Shah,2011)

2.2 Air Transportation System Key Trends

In this section are discussed the major air transportation influential trends and their consequences on the terminal operations, in particular for the check-in processes.

Due to the complex networks of activities and the strong dependency from the external environment (passenger-, airlines demand, technology involvement, services offer,...) the airports and the operations occurring there are subject to several changing requirements. These requirements concern different aspects of the aviation transportation sector, such as passengers, goods, airlines, authorities, industry and so on. The aviation industry and aviation transportation sectors are presently experiencing a number of trends across several key areas, which however are clearly interrelated.

- Increasing interest in improving passengers' experience at the airport;
- Diversification in the airline business models, i.e. between flag carriers and low cost carriers;
- Increasing number of flights;
- Technology push, either in the aircraft industry (Airbus A380) and in the airport equipment (Iris recognition);
- Growing interest in environment sustainability.

2.2.1 Increasing interest in passenger experience

This section investigates the passengers' perception derived from the level of service experienced at the airport.

Expectations of air passengers have grown considerably in recent years, especially regarding the quality of service offered at the airports (Rendeiromartincejas R., 2006), (Chang H., 2008).

The term "quality" derived from the manufacturing (where quality is defined as conformance to requirements), is mostly used to refer to products and goods, whereas in the service field Level of Service, LoS, expresses the same idea. Since the first research on this topic (Ashford N., 1986), it has been practical common to refer to the airport terminal quality using Level of Service. However, a unique definition of the terminal Level of Service does not yet exist, and many studies (e.g. (Baloun K., 2008) (Manataki I.E., 2009), (Young S.B., 1999)), aviation trade publications and airport press releases provide different definitions to explain the customers' perceptions and judgment paradigms of services and operations at the airports.

Passenger expectations reflect in different factors: easy transportation to and from the terminal, quick check-in process, fast baggage claim, rapid and safe security check, comfortable gate areas, speedy immigration/customs control, etc. Considering for instance the departure, once the check-in and security processes end, passengers move to the boarding area where they can enjoy the leisure offers, do last minute shopping and use other services like restaurants. Time spent by passengers at ticket counters and at other control areas limits their time to appreciate the pleasure offered by airport leisure areas. If passengers spend too much time trapped in the operations, their perception of the airport LoS declines.

Therefore, the following can be assumed as reasonable indicators for the terminal LoS:

i. the time waited by the passenger or spent within operations;
ii. the degree of crowding generated by the presence of passengers in the terminal.

The two aspects are heavily dependent on the characteristics (speed, comfort and services offer,..) of the operations carried out at the terminals.

The increasing attention to meet passengers' expectations has also been motivated by a series of publications from the Civil Aviation Authority (CAA), the UK's independent specialist aviation regulator. CAA has been publishing a set of interviews and investigations carried out from 2009[4] to explore the 'through airport' passenger experience at the largest UK airports by passenger numbers: Heathrow, Gatwick, Stansted and Manchester. The findings of the research revealed that the major expectation for the passengers is to be processed in the shortest time possible.

IATA suggests a set of standards to guarantee passengers high level of service and to encourage the airports to design and adapt the terminals according to passengers' expectations. A new Passenger Experience Management Group (PEMG) has been also created by IATA with the scope of simplifying the global airline network, through training and consulting support to all aviation stakeholders to ensure that people and goods can move around easily. The major objective of the PEMG has been the investigation of check-in operations and the solutions to implement in order to reduce process time and crowding.

2.2.2 Diversification in the airline business models

This section illustrates the evolving differentiation of the airline business models, and their influences on the airport and on check-in operations.

In the last decade the airline scenario changed dramatically. The full European airline deregulation[5] (1998) was the main contribution to the airlines diversification and the emergence of new type of carriers beside the flagship carriers companies. The European airline deregulation offered new opportunities and greater competition in the business paradigms of airlines, whose major contribution was the rise of the low cost carrier (LCC) sector. The LCCs introduced a new business model differing from the traditional strategy of the

[4] www.caa.co.uk/docs/33/Passenger_experience.pdf, published on 9/03/2009

[5] Process of removing entry and price restrictions on airlines affecting, in particular, the carriers permitted to serve specific routes. For more information http://www.econlib.org/library/Enc/AirlineDeregulation.html

flag carriers and forcing the airports all over the world to adapt to their strategies.

Flag-carriers aim at providing a high level of service to their customers, especially on the plane, and encourage a high-level of loyalty from its frequent (business) flyers and most of the time seek high-end infrastructures, located close to main destinations and furnished with a large set of services from their passengers. The business model of the traditional flag-carrier focuses on network and connectivity by a 'hub-and-spoke' network model, mixing long-haul international routes with short haul shuttle services around peak demand slots.

On the other hand, LCCs generally do not offer much product or service-level differentiation, and when offered, strict price discrimination is introduced. Finally, the overall service level takes second place to cost-reduction, provided that the satisfaction of the strictly necessary requirements to flight. This strategy is adopted also in the landside operations policy, offering a very low quality service, e.g. passengers queue longer by opening fewer check-in desks.

The appearance on the market of low cost carriers was largely correlated both with a strong passenger growth and with an increased number of regional airports. It has not been clarified yet how the financial revenue of the airport is influenced by the presence of LCCs.

To investigate if the key benefit for an airport is only a high traffic volume or if the type of airline influences the airport income, (Graham A., 2007) compared the financial performances of airports with varying levels of involvement with LCCs. The study showed, through a case study on UK airports, that the aeronautical revenue to airports does not depend on the nature of airlines, but is related to the money their passengers spend in the retail and catering facilities at the airports and hence will have a net effect of growing the revenues. According to the research, many low cost passengers are not budget travellers and are therefore quite willing, given the opportunity to spend at airports, to do so just as other passengers. In this research has also been argued that low cost passengers make very good shoppers at airports. This is since many LCCs encourage passengers to check-in early because of their first come, first served boarding procedure and because the airline allows for minimum dwell time at the gates. These two factors may increase the time available for shopping. Furthermore, the minimal catering on board encourages the use of airport catering facilities that are also required to have a longer service time due to the longer operating day of the LCCs.

According to the result of this study it seems clear that the airports rather than focusing on selecting the type of airlines to improve their financial performance, need to host a higher number of airlines and flights in order to promote the growth of traffic. In conclusion, the passengers have different expectations and the services offered different fashions according to the airlines, but the solution

for the airport is unique: to transfer the passengers as quickly as possible from the operational area to the commercial area.
To achieve this purpose the airport needs to properly allocate the airlines the amount of resources necessary to carry out the operation in agreement with their strategies in the shortest time possible.
As has been mentioned in section 2.1.2 on the airport landside the check-in is the major operation in which the airlines are able to adopt their own policy. Although the process itself remains the same, there may be variation in the service offering to passengers. Hence, the technology portfolio adopted by the airlines, as well as the space allocation and management of the desk front area is totally up to the airlines, therefore to optimise the infrastructure utilisation it would be useful consider the airline requests. Not all the airlines are interested in the same measure of self-service kiosks, traditional desks, welcoming areas or waiting lounges. Additionally, the service offered to the passenger might vastly differ according to the business model and the passenger expectations.
Another aspect can be included within the airlines trends: the tendency to merge airlines. Alliances help airlines to trim their capacity and restore profits (although rising oil prices pushed them back into loss this year). Concerning this merging tendency, some concrete consequences are noticeable in the check-in hall, more specifically in term of desk assignment and allocation. Even if at first look merging or even sharing routes seems an easy task, it determines the necessity to rearrange the desk layout in order to place the two (or more) new partners together at least for specific period.

2.2.3 Number of flights and passengers

This section discusses the recent evolution of air-passenger volume and its expected future scenario.
The 20 years trend of the air traffic in Europe, between 1980 and the beginning of 2010 reveals a threefold increase in the air traffic. Between 1992 and 2006, the number of intra-EU routes has increased by 150%[6], but unfortunately the economic crisis has slowed down this trend and caused unpredictable fluctuations in the traffic demand during the last 4 years.
Considering the UK, the aviation traffic started to suffer heavily after the crisis from the year 2008. From the "Aviation Trends Publications" of CAA, it has been possible to analyse the variation in the demand registered in the UK[7] in the years 2006-2010. From these publications emerged that between January 2008 and January 2010 the passenger flight numbers have experienced a drastic decrease, which, apart from the a slow recovery undertaken in April-May and June 2010, continued to the end of 2010.

[6] ECAC and Eurocontrol: "Study on Airport Capacity",2010
[7] Monthly report, The Aviation Trends www.caa.co.uk/aviationtrends

The data recently published by IATA[8] confirmed a very volatile month-to-month path since the last quartile of 2010; however, it also registered a renewed expansion in the air passenger traffic, starting from May 2011: since then the year-on-year growth was found to be 6.8%.
Although the increase in demand for air transportation is a promising sign for airlines, civil authorities, terminal operators, ancillary service providers and the aviation industry in general, it also raises a whole range of challenges due to the increased congestion that will result in the terminals.
Such congestion is likely to have a severe impact on airlines' ability to maintain their schedules, especially at hub airports, thereby a less efficient flights departure/arrivals time planning might occur. On the airside, congestion will also result in environmental and safety costs, since the density and complexity of operations will reach an unprecedented level. On the landside, the congestion will reveal in the operations as increasing queuing time, crowding and passenger dissatisfaction. Even though extra capacity will be added to more routes, the terminal handling nonetheless still remains confined to within the terminal. As experienced in many airports in Europe, the attempts to enlarge the terminal capacity whilst changing the airport‘s configuration can be classified into three classes as:

- Expansion plan or adjustments in the existing terminals and constructions to increase the airport capacity;
- Construction of new buildings to increase airport capacity;
- Implementation of new technologies at the airports to increase airport capacity through the improvement of the operational efficiency.

Examples of these reconfigurations are the construction of the new Terminal 5 at London Heathrow (Janic M., 2004), the connection bridge between two terminals at Birmingham International Airport and the trial introduction of ‘Iris recognition’ at Manchester Airport.
Expansion of airport capacity, however, could also lead to a greater congestion on the runways of the airports, and hence the need to ensure timely aircraft takeoffs. Typically, any delay in scheduled flight departures will cascade down to further disturbances in downstream flight itineraries and related increased congestion and upheavals in the terminal halls.
The imperative for a punctual operation schedule would be clear passenger flow through the operations within a specific time window, without having to incur unnecessary extra-waiting times, delays or shortening other terminal activities, especially those from which the airport income is derived, such as time dedicated by the passengers to shopping. To reach the desired pace that allows operating the processes on time, the traffic volume should be balanced by an appropriate capacity plan. The capacity plan has to adapt to the demand and for

[8] IATA, Global air traffic demand, 2011 (see Appendix A)

those operation such as check-in and boarding passengers from the gate includes two stages: the resource terminal estimation itself and allocation to the flight.
The allocation methodology plays a crucial role in the optimal utilisation of the resources, and therefore is fundamental for the airport to seek the best methodology to allocate the resources available and to avoid incurring in congestion or waste of capacity, particularly when the demand is high.
Although the introduction of new technology to check-in the passenger has been reducing the impacts deriving from an incorrect resources capacity plan, the check-in hall still represents a major constrain to the airport growth and the processing of the passengers on time. Beside terminal expansion or construction of new infrastructure, a solution to this problem could be research into new allocation methodologies or novel resources arrangements.
The introduction of new capacity, or new technology could easily help in improving the check-in operation performance, but could represent at the same time an unnecessary investment of extra capacity not needed.
In conclusion the growing air traffic translates into the terminal as an increasing capacity demand. The solution to this problem needs to be investigated both in the allocation methodologies to increase the resource utilisation, i.e. in the software, and in the introduction of new technologies, or other solutions of capacity expansion, i.e. in the hardware side.

2.2.4 New technology on the market and technology push

In this section the trends coming from the industrial aviation sector and their influences in the check-in operation are discussed.
Airport technologies and products of the aerospace industry are not always introduced out of airport choice, but some are effectively pushed into operation by the demands of other stakeholders or external regulations. Airport choices regarding the technology adopted are highly dependent on the security regulation, airlines' choice of aircraft and services to provide in the terminal hall (such as processes offered to check-in passenger or luggage restrictions), image and competition with other airports.
The technology evolution involves the airports on three sides, reflecting the three industrial elements of the air transportation system. The aviation industries, as defined at the beginning of the thesis, comprehend the aerospace, terminal equipment providers for both the technology portfolio applied in the operations and the internal transportation system.
Regarding the airspace industry, the data collected from the International Air Transport Association (IATA) publications[9] can picture the current situation in the aviation industry.
The increasing price of oil had let to forecast the aviation industry's net profits fall from $18 billion in 2010 to $4 billion in 2011[10]. On the contrary, the orders

[9] From the annual meeting, occurred in Singapore last July (2011)

registered between January and July 2011 to Airbus (730 planes) and Boeing (142) amount to a total $90 billion shopping, enough to cover seven years production of these two companies.
The first reason for this contradicting situation can be explored by considering the energy consumption and fuel price. Indeed, oil accounts for a third of operating costs, so the airlines are desperate for more fuel-efficient planes. To this purpose lately Airbus brought out a re-engineered version of its A320 single-aisle family, offering fuel savings of up to 15%, and with that has become the fastest-selling new aircraft in the history with more than 1,000 orders, where the biggest demand is from the Asia-Pacific region. This illustrates the second explanation of the paradox, the tilt of aviation to the East. Despite the economic crisis in the West, the continual growth of the markets in the East is increasing the air traffic and demand of aircrafts as well. The aviation industry is responsible to accomplish airlines requirements and higher levels of security on the planes with lower environmental impacts, such as noise and gas emission.
Regarding the landside technology providers, advances and novelties derive from the new equipment and resources applied in the terminal operations, mainly to improve their performance and to make the airport gain a better image in the market while providing the passengers with an innovative and modern offer. IATA is taking various initiatives to promote the innovative and modern offer in the terminal and to improve the passenger experience, while taking into consideration the industry outcomes and looking to collaboration between airlines and airports. From 2004 IATA win the airlines backing to improve efficiency and reduce costs[11].
The role of IATA is to educate and bring awareness to the industry about the common vision for simplified business models. It will also encourage adaptation of common standards and provide support and necessary market intelligence to all the stakeholders.
Any of the above-mentioned changes in the technical equipment used in either the land or airside of the airport, coming from the manufacturing/technology and aerospace industry respectively, affects the airport infrastructure and its operations. The introduction of new aircrafts models, such as Airbus A380 or the upcoming Boeing 787 and Airbus A350, of new security technology, biometric identification and baggage drops are some examples of the latest innovations. Construction works and apron adjustments to host the re-sized planes, new security gate or mobile baggage conveyance systems are the reflections in the terminal of the technology-introduction. The market launch of new models of aircraft influence the airport terminal both in the airside (expansion plan of the taxiways and runways, modifications in the turnaround

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[10] Source “The Economist”, July 2011
[11] IATA, Annual General Meeting”, 2004

operations,..) and landside (higher number of passenger per plane influence all the check-in security and boarding operations).

The introduction of the Airbus A380 is having significant impacts on many airports. There are high costs in accommodating it, by widening the runway and by building specialised gates at terminals—in some cases (Melbourne) these costs are modest (less than US $50 m), though in other cases (London Heathrow and Los Angeles) the costs will be considerable (several hundred US $m)[12]. Even once the costs are sunk, the extra costs of handling the A380 tend not to be any higher than those for any other type of aircraft. However, the terminal capability to host an A380 represents an attractive and prestige issue for many airports and regions. The effect of new models of aircraft and the consequent occurrence of revolutionary change in the passenger capacity as is the case for the A380, generate evident impacts also in the terminal operations. Considering the check-in operation, for example, the time and the effort to process the maximum number of passengers per flight up to 400 are very different from the ones required to check-in up to 850 per single departure[13]. Manchester Airport has been one of the first airports in England to introduce the A380 and is expecting a higher traffic load of this airplane. If so, the Airport would need substantial changes to accommodate the amount of passengers and to allocate the right amount of resources to support the operations.

The introduction of new technology can represent a solution to this issue; however, the increasing volume of passengers and growing size of aircraft have not always been accompanied by a renovation of equipment.

Regarding the check-in operation for instance, even though airlines and airports seem to agree and collaborate in the effort of introducing novel technologies in the terminal, it is worth highlighting two aspects of the uncertain opinion of passengers limiting the innovations to spread into the system.

Passenger position on the new technologies is not very clear, and especially in some airports around the world customers have shown little interest in modern alternatives such as the self-service options.

To manage this last aspect, in recent years many studies and surveys have been conducted to understand the passengers' inclination and preferences in terms of check-in technologies.

According to the previous survey done by SITA[14], passengers are reluctant to use self-service check-in because they prefer an interaction with employees provided by the traditional service. Also the results of a study headed by J. Lu (Lu J., 2011) confirm those of the SITA survey. The Author investigated factors that influence whether air travellers' choose conventional counter or self-service check-in, including kiosk and web check-in. This study uses American,

[12] IATA "Landside impacts of the new A380",2010

[13] The A380 capacity is equal to 525pax (3 classes), 644pax (2 classes), 853pax (single class).

[14] Airport IT Trends Survey, Airports Council International and SITA

Australian, Korean, and Taiwanese airline passengers to explore the factors that influence their choice among different check-in services. The findings suggested that a strong relationship exists between passengers' selection and their nationalities. Western passengers' use self-check-in services more frequently than Eastern passengers do; however, more than one third of Korean respondents choose web check-in service. Hence, passenger nationalities should be taken into account when implementing self-service check-in systems. The results also indicated that business travellers, online ticketing users, people travelling with fewer than three people, frequent flyers, travellers with little baggage, and younger passengers are more willing to use self-check-in services.

Other studies analysed the satisfying and dissatisfying elements of kiosk usage to better understand the passenger behaviour relative to the new kind of technology such as the kiosk. H. Chang and C. Yang (Chang H., 2008)collected data to aid identification and exploration of the importance and performance of service attributes. This study concluded that potential kiosk users expect to have a highly controllable environment during kiosk usage. Airlines might be able to mitigate frequent flyers' resistance to kiosks by providing extra benefits or seat-selecting privileges (normally not available at the desks).

2.2.5 Environmental sustainability and disruptions

In this section is illustrated the airport concerns about the environmental sustainability and the consequences derived by the occurrence of disruptions. These aspects are only briefly discussed due to their low influence on the check-in operation.

In the last decades, the construction or expansion of airports has been subjected to severe controls and regulations. The attention on the environmental implications has been driving optimisation in the use of existing infrastructure, promoting the use of technological developments and at the same time to improve safety and efficiency and only the planning framework of new infrastructure is essentially needed (Upham P., 2003).

The environmental considerations, given the small environmental impact of check-in operations, are not relevant in the development of this thesis and therefore are left to other studies for further research.

Although this cannot be consider as proper trend, the occurrence of any disruption has high implications for the airport system and related business such as airlines. Over the past decade airlines have been buffeted by one external shock after another, from the terrorist attacks of September 11th 2001 and the SARS health scare to recession in Western economies, volcanic eruptions (last year in Iceland, this year in Chile), the Japanese earthquake and tsunami, and the rise in oil prices. The effect of this succession of troubles can be observed in the unpredictable congestion at airports.

2.3 The Exploratory Case Study: MA

In the previous sections the generic structure of the airport, its operations and trends have been discussed in order to highlight the needs of reconfigurability of the airport operations, in general, and check-in in particular in order to follow to the evolving requirements.

Four parts compose this first section dedicated to MA case study.

The first of them describes briefly MA layout and structure, the second one focuses in detail on the configuration of the check-in operation at MA. Through the use of Unified Modeling Language (UML) Class Diagram, section 2.3.2, a visual definition of the check-in elements, their interactions and relationships is presented.

The following two sections (2.3.3 and 2.3.4) add more detail to the operation and in particular discuss the software and hardware sites of the operation.

The investigation about the hardware of the check-in operation has been supported by the use of a tool that identifies the check-in functional requirements given the inputs to the system: passengers and luggage information.

This tool, developed during the thesis work, has been presented during the workshop with MAG and validated from the managers in the same occasion.

2.3.1 Manchester Airport

This section offers a brief description of Manchester Airport.

MA is the biggest airport in the north of UK and handled 17.8 million domestic and international passengers in 2010[15]. In the same year, it was the 4th busiest airport in the United Kingdom in terms of passenger numbers, and the busiest airport in the UK outside the London region. It was also the 3rd busiest UK airport in terms of total aircraft movements and the 24th busiest airport in Europe[16].

Even during the recent crisis, Manchester Airport continues to invest in its infrastructure. These investments aim at improving passenger experience through better security facilities, an enhanced retail environment and new executive lounges. Investments during the years have also included security body scanners and new lounges for customers travelling on top airlines such as Emirates at Manchester.

The Airport, officially opened on 25 June 1938, is owned and managed by MAG. The airport has won awards including World's Best Airport 1995 and Travel Weekly Globe Awards' UK Best Airport 2008[17].

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[15] Manchester Annual Report, 2010, http://www.manchesterairport.data.co.uk

[16] UK Civil Aviation Authority, http://www.CAA.uk

[17] "Manchester Airport Awards", http://www.manchesterairport.co.uk

MA provides regular direct flights to 190 destinations worldwide by over 60 airlines, including:

- Flag carriers (as American Airlines, Continental Airlines, Delta Air Lines, Emirates, Etihad Airways);
- Scheduled airlines (as Bmibaby, EasyJet, Flybe, Jet2, Virgin Atlantic);
- Charter airlines (Thomas Cook Airlines,Thomson Airways)

This multiplicity of airlines and relative business models forces MAG to meet different airline needs and adapt its offer to their own requests. Thereby, MA has tried to group the airlines and distributed them among the terminals according to their business models.

The disposition of the three terminals (Terminals 1, 2 and 3) at MA shown in Figure 2-IV.

Figure 2-IV MA map, source http://www.manchesterairport.co.uk

Terminal 1 handles international traffic, Star Alliance members[18], scheduled airlines and charter operators as Thomas Cook Airlines. In summer 2009, a £50 million redevelopment programme, including a new £14 million 14-lane security and additional catering and retail facilities was implemented. A new boarding area was also added to the existing pier (Pier B) to accommodate the capacity of the Airbus A380, with which Emirates operates daily flights to Dubai. The current capacity of the terminal is around 11 million passengers a year.

Terminal 2 handles SkyTeam airline members[19], long haul and charter airlines flying to international destinations. Terminal 2 opened in 1993, and connected with T1 through the "sky link", a bridge long 10-15 minutes walking time.

T2's current capacity is around 8 million passengers a year, but MAG is planning its expansion to handle ultimately 25 million passengers a year and also to withstand the demands of the Airbus A380. In 2007, an £11 million project commenced to redevelop Terminal 3 handles British Airways, Air France, Bmi, Easyjet and other airlines including those operating seasonal flights. Terminal 3 opened in May 1989, for many years British Airways has been the principle airline operating from this terminal, making T3 the de facto British Airway terminal. Recently the growing influence of the other airlines operating in T3 such as Easyjet and Bmi have pushed MAG to re-allocate and rearrange the terminal area in order to host more airlines in an appropriate manner.

A project for the future development of the Airport, according to what emerged from the first meeting with MAG, consists of merging the check-ins at T1 with those at T3. As will be highlighted in the last section of this chapter, three terminals for a 20 million (passengers/year) airport such as MA generate a high resource redundancy and turn out to be a costly and inefficient solution. The alternative configuration mentioned by MAG to solve the inefficiency given by the surplus of facilities at T1/T3 could be the construction of a new and separate building dedicated to check-in services for the two terminals, replacing for example the car park between the train station and the current locations of T1 and T3.

2.3.2 Configuration of the check-in operation at MA

This section presents the structure of the check-in operation and highlights the hardware and software configuration of the operation. The aim is to identify, by the Unified Modeling Language (UML), the connections and associations among the elements of the operations, in order to support the re-configuration process in section 4.3.4.

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[18] http://www.staralliance.com/en/about/airlines/

[19] http://www.skyteam.com/

The UML Class Diagram in Figure 2-V visually combines the software and hardware sides of the operation and represents check-in operation from a broader perspective.

The formal representation of all the fundamental elements of the check-in is important for two reasons:

i. It highlights the software and hardware sides of the operation and their correlations;
ii. It facilitates MAG in the identification of the links and connections and with the reconfiguration process steps of de-coupling, arrangement and re-coupling of the resources configuration section 3.8 (et al McFarlane D., 2008a).Moreover, on the base of this UML Class Diagram is built the Design Structure Matrix, the key methodology applied to measure the check-in reconfiguration efforts.

The purpose of this diagram is to summarise the software and hardware connections in the check-in operation. Further details on UML can be found in the Appendix C or in (Fowler M., 2004), used as a reference in this work.

The boxes in the diagram represent the classes, i.e. the entities of the system (first arrow of the box). Each class contains information about its attribute (second arrow) and the operation in which is involved (third arrow). A class is linked to others according to the relationships existing, which mainly consist of data and information exchange, passengers/goods movements and other interactions among the resources. The nature of the relationship occurring can be association (pointed out by a solid line between the two classes), aggregation (pointed out by a solid line and empty diamond shape at one end) or composition (pointed out by a solid line and filled diamond shape at one end).

Association is a linkage between two classes, and the nature of the relationship can be specified on the line with a verb. At either end of the line, the name of the objectives of the relationship can also be tagged.

Aggregation expresses a collection of entities part of a specific class. The class that contains the other classes does not have a strong life cycle dependency on the contained classes (if the container is destroyed, its contents are not).

More specific than aggregation is the composition. Composition has a strong life cycle dependency between instances of the container class and instances of the contained class/es.

Figure 2-V shows all the classes that form the check-in operation and their relationships.

A dashed blue line has been used to tag the classes that directly correlate with the software side of the operation, whereas an orange full line has been used to visualise the classes part of the hardware. The *Check-in Reconfiguration problem* and the use of a queue model for the estimation of resources represent the interface between the hardware and software. Indeed, beside the *Flight Time Table, Aircraft Size* and *Stakeholder*, the hardware asset installed also highly influences the capacity plan and the resources managing activities.

To identify the hardware configuration of the check-in operation, the classes to look at are the *check-in hall layout and utilities*, *check-in hall equipment*, *stakeholders* and *check-in modules.*
The classes associated with the *Check-in Hall* have not been described in detail since this would be out of scope; a rigorous description of the modules in use at MA is reported in Appendix E.
Other classes in the system, such as *Handlers and Check-in Operator* are not directly involved in the solution of the check-in problem, but support the success of the operation once the configuration is settled.
In the diagram also emerges the structure of the stakeholders involved in the operation: the check-in resources are owned and leased by MAG, through a two week contract agreements with the airlines.
The high number of relationships between the *Queue Model* and *Check-in Hall Reconfiguration Problem* classes highlights the complexity of the capacity plan and resource management that the airport authority has to face.

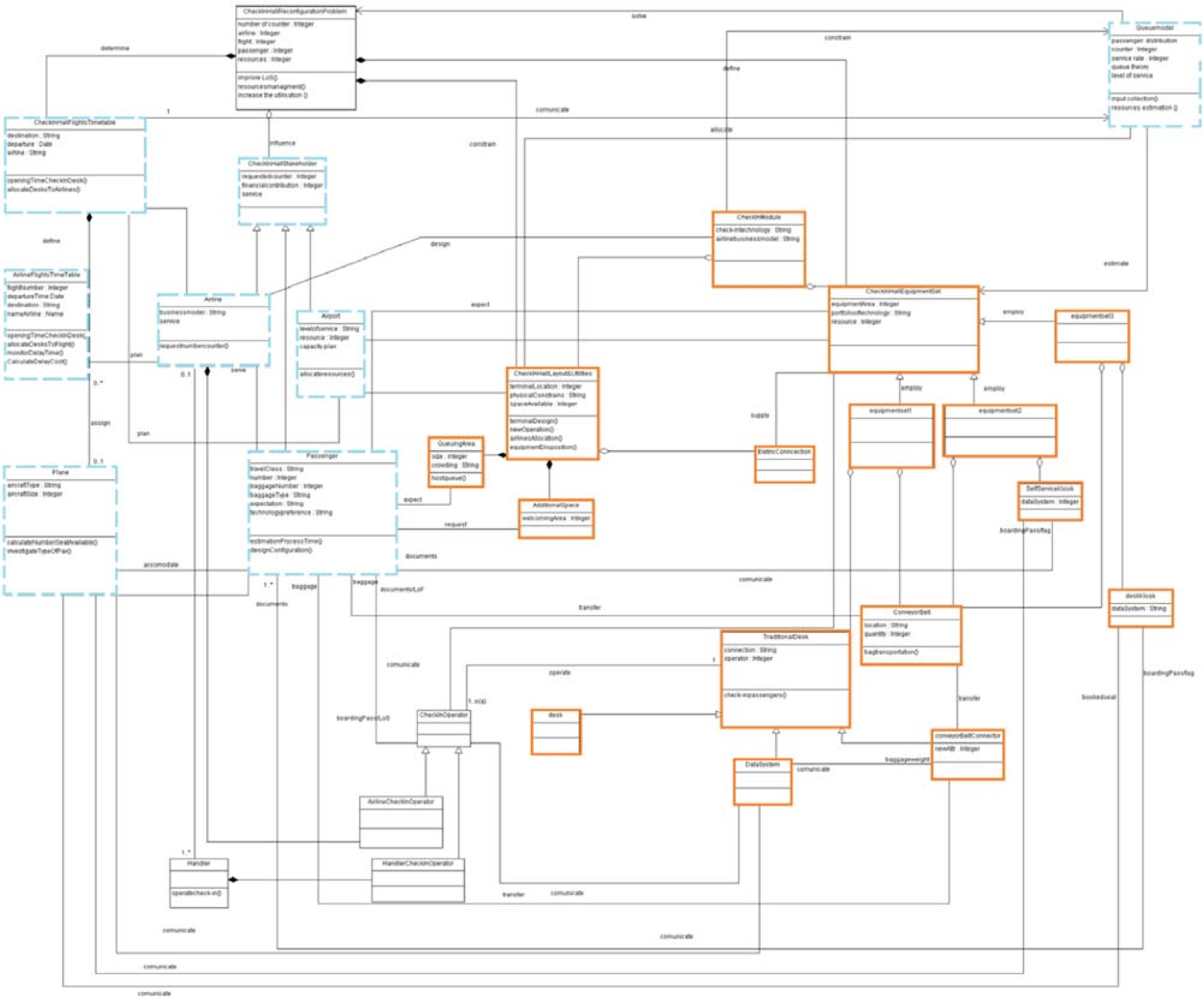

Figure 2-V UML Check-in class diagram

2.3.3 Software configuration of the check-in operation at MA

This section highlights some aspects related to the resource management at MA as they have been observed during visits at MA and perceived from discussions with MAG.

The resource estimation calculates the number of check-in counters that an airline needs during a day, starting from the estimation of the resources needed by a single flight. The scope of the estimation process is the decision of the optimal number of check-in counters to open for departing flights, in such a way so as to balance the operative costs of the service and the passenger waiting time at the terminal, reducing the occurrence of delays. MAG applies a simulation model to estimate the number of counters necessary for each airline. The resource planning is carried out two times a month: at the beginning of the month, to form a general idea of the monthly check-in counters request, and after two weeks to define the demand in more detail.

Despite the existence of this simulation model, the effective number of counters agreed on in the contract between airline and airport is defined manually. Hence, traditionally the airlines request to the airport authority the amount of resources desired.

The final intention of the airport is to meet the airlines' requests, even if discrepancies occur between the airline demands and MAG's calculations. Thus, the risk of violating the optimal counters allocation increases, with possible consequences in the underutilisation of the resources and/or a low performance of the operation.

The allocation process at MA is done manually: based on prior experience and simple heuristics. The reason for such an allocation policy is the evaluation of additional parameters to the ones considered in the resource estimation. According to the information collect during the first meeting with MAG, the rule-based and physical circumstances play a crucial role in the allocation process at MA:

i. All counters assigned to a company must lie adjacent to each other;
ii. Some of the counters in the check-in halls in T3 and T1 are split by a staircase, making it undesirable to allocate a counter for the same company on either side;
iii. Each area in the hall is governed by restrictions on the amount of people waiting, due to the presence of other businesses or facilities, different sizes of the front areas, presence of corridors or other facilities.
iv. The check-in for a flight has to occur in the same terminal as the flight departure, therefore the balance of the airside facilities should match the one of the landside facilities, to avoid extra congestion in the terminal;
v. Some airlines, especially the more influential ones in the airport, might express particular interest to be allocated to a particular terminal, or even in one specific area.

2.3.4 Hardware configuration of the check-in operation at MA

This section describes how the analysis on the check-in equipment at MA has been developed during this project.

Firstly, a stepwise description of the check-in has been carried out and then the key functional requirements of each step of the check–in process have been identified together with the resources able to meet them.

The generic passenger check-in passenger flow presented in Figure 2-II has been analysed in greater detail just as it occurs at MA.

The flow has been broken up in four modular stages, in order to better identify the functional requirements. The stages, described in Figure 2-V, are de-coupled from each other in that certain passengers may completely bypass a stage if they do not require it, and this would not affect the steps within another stage.

Each stage consists of several decision points. The high-level flowchart in Figure 2-IX shows routes and decision points. A "swim-lane" arrangement is displayed for which stakeholder is responsible for executing each step. The passenger's individual requirements determine their choice at the decision points and thus determine which of the two branches of the process to follow as shown in the flowchart of passenger route Figure 2-IX.

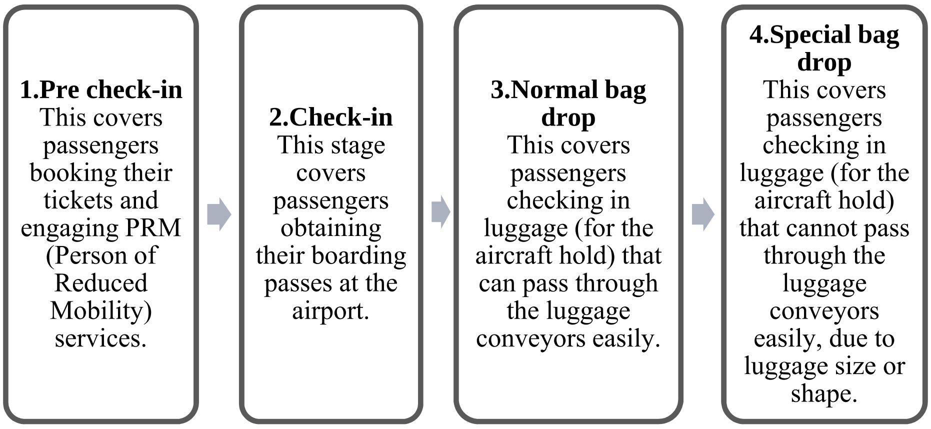

Figure 2-V Breakdown of check-in process

The flowchart has been developed to highlight the decisions and actions undertaken in the check-in processes.

The basic representation of the passenger flows can also be applied to observe the differences occurring in the process due to a change, such as the introduction of a new technology. For example, it can be noticed that the new concept of self-service kiosks, if compared with the traditional one, splits the process in two parts: receiving the boarding pass and leaving the baggage at bag drop-off. The passenger arrives at the airport and proceeds to the counter, which issues the boarding pass based on the information provided by the passenger. The passenger then proceeds to the fast baggage drop-off if he/she has any baggage otherwise the passenger can move to the security check. Although the instructions at the kiosks are normally very direct, the speed of checking in depends on the familiarity of the passenger with the automated machine itself.

Flow charts with more details on the traditional check-in, self-served and bag drop processes are reported in Figure 2-IX.
The fundamental step of the hardware configuration is to select the hardware based on the functional requirements, therefore a methodology has been proposed to identify the functional requirements, from the flowchart, and to match them with appropriate hardware configuration options.
The tool developed in collaboration with S.Shah is applicable to each of the four check-in stages and enables a systematic analysis of what is required for checking-in passengers. The method matches the different resources to the current requirements that satisfy them.
The tool's application can serve different purposes, based on the type of inputs selected:

purpose I. If the current hardware configuration and the current scenarios are used as inputs, it is possible to notice the redundancy in the resource utilisation and the effective tasks assigned to each equipment;

purpose II. If the current hardware configuration and the future scenarios are used as inputs, it is possible identify where the overload in the system is likely to happen;

purpose III. If the alternative hardware configuration and the current or future scenarios are taken as inputs, it is possible verify that all the requirements are satisfy.

Four essential parts make up the tool, as shown in Figure 2-VI.

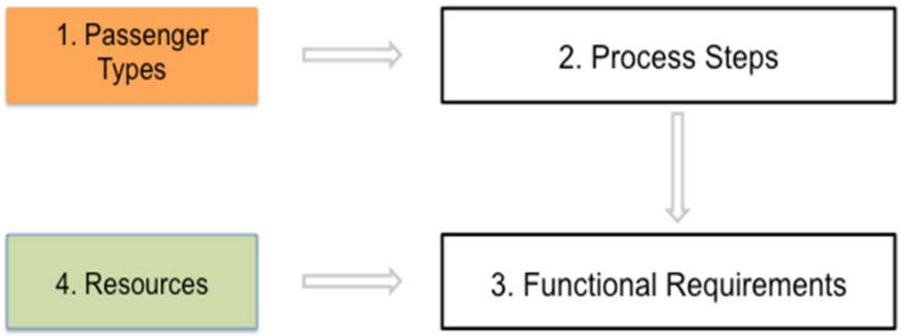

Figure 2-VI Concept for tool that extracts functional requirements to determine system

The initial step is the selection of the type of passenger to check-in among all the possible passenger types, which for each stage of a process are identified. In this case, passenger types are listed based on the combination of choices that specify their route at each decision point in the stage, as illustrated in the check-in process mapping. Then, for each passenger type listed, the necessary process steps they pass through are mapped (step 2). From each process step, the functional requirement is identified (step 3). This part of the tool remains "solution neutral", emphasizing what is required from the process rather than how it is currently satisfied. Its importance becomes more significant when considering the potential of alternative resources and technologies as discussed further on.
The last step (step 4) lists the resources available, the current equipment in the check-in hall or the technologies that might be installed in the

future. Where functional requirements are met by a particular resource or piece of equipment, the relationship is recorded by an “X” in the matrix. This procedure is followed for each of the four steps that build up the check-in process. The tool’s appearance as applied to any stage of check-in, as shown in Figure 2-VII.

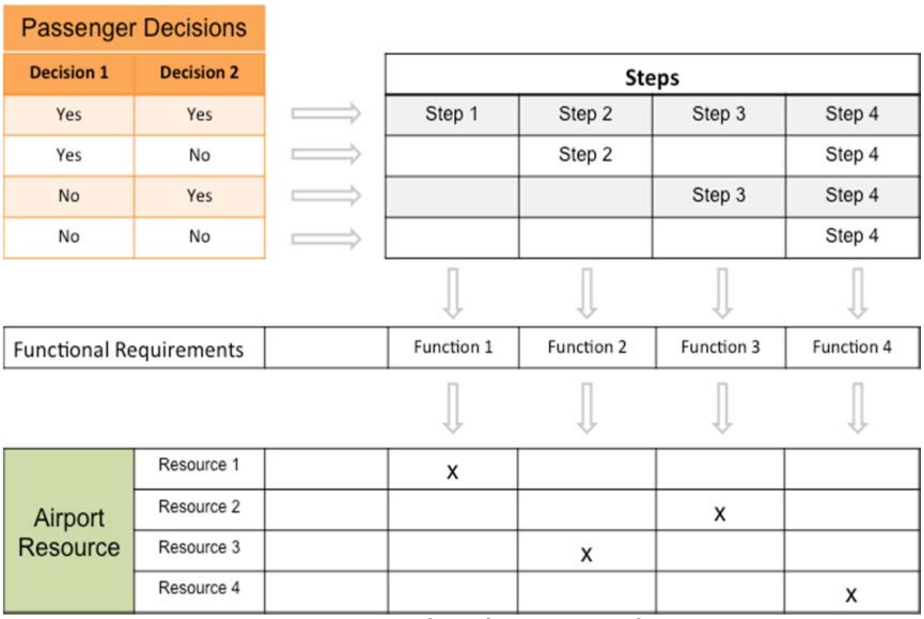

Figure 2-VII Layout of tool for any stage of check-in

Figure 2-IX shows how the tool, regarding purpose I, is used to display stage 3 of check-in (normal bag drop), and its application to the other stages for their current configurations are shown in Appendix D.
Through the application of this tool to all the check in stages, it emerged that the current hardware configuration is able to satisfy all the requirements, as obvious was expected; however, the configuration of the bag conveyor and the organisation of the bag drop process seems not to optimise the use of resources, causing redundancy in the system. Hence, if the passengers have already received the boarding pass, printed either at home or at the self-service kiosk, but they still need to drop off their luggage, they are still required to stand in line at the traditional desks, show their documents, have the bags tagged and finally leave them on the conveyor. Overall, if the passengers travel with luggage, and decide to print their boarding pass by themselves, they are nevertheless consequently subjected to a double check-in processes.

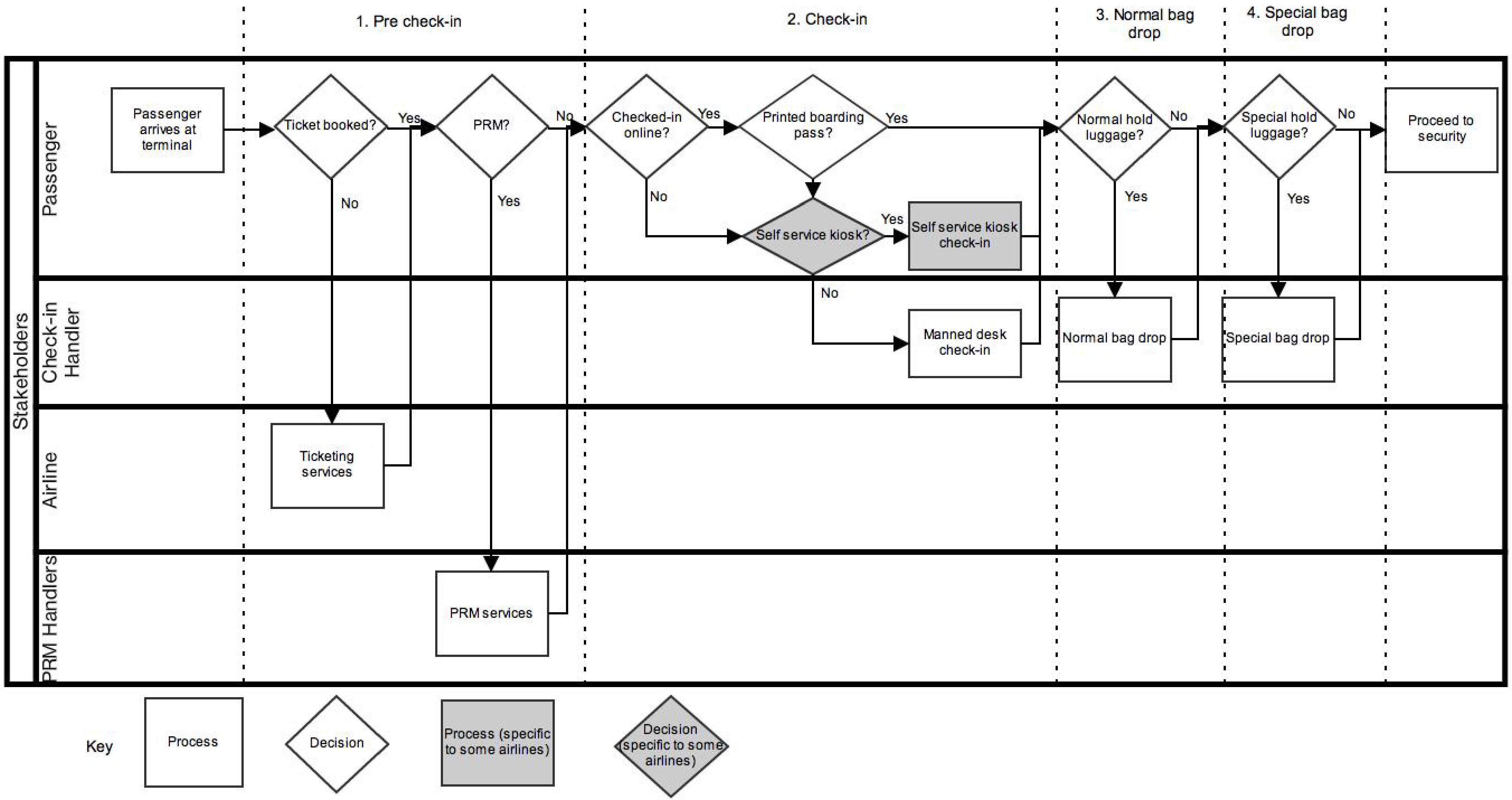

Figure 2-VIII High level flowchart of passenger route through check-in. Note: PRM = Person of Reduced Mobility

Luggage?	Luggage exceeds ticket limit?	Pay extra fee?												
N	N/A	N/A												Exit bag drop process
Y	N	N/A		Queue at desk	Show flight information	Show ID	Weigh luggage				Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	Y		Queue at desk	Show flight information	Show ID	Weigh luggage		Request baggage fee	Register payment	Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	N		Queue at desk	Show flight information	Show ID	Weigh luggage	Reduce baggage weight			Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Functional Requirements				Waiting for check-in desk	Communicate information	ID verification	Weight measurement	Space for opening luggage	Communicate information	Payment registration and receipt generation	Generate unique luggage identifier	Attach identifier to luggage	Path for luggage transfer	Path for passenger flow to security
System resources	**Subsystem resources**													
Self service kiosks	Graphical user interface GUI													
	Kiosk printer													
	Passport scanner													
	Area around check-in kiosks													
Check-in desks	Handler				x	x			x			x		
	Graphical user interface GUI				x				x					
	Luggage tag printer										x			
	Boarding pass printer													
	Passport scanner					x								
	Feeding luggage conveyor						x						x	
	Area around check-in desks			x				x						x
Customer service desk	Agent									x				
	Debit/credit card reader									x				
	Area around customer service desk													

Figure 2-IX High level flowchart of passenger route through check-in. Note: PRM = Person of Reduced Mobility.Figure 2-X Tool used to display functional requirements for stage of check-in (normal bag drop)

2.4 Future Scenarios of the Check-In Operation at MA

This section explores the future of the check-in operation at MA, by understanding the nature and impact of the trends (illustrated in section 2.4.1) on the check-in system (described in sections 2.3.2, 2.3.3 and 2.3.4).
The final aim is to define, through the information collected during the meetings and the workshop with MAG, the future scenarios that MAG is likely to face given the recent trends.
The first section (2.4.1) describes the trends affecting the check-in at MA, following the same classification of the key areas of influence used in section 2.2.
The second section (2.4.2) illustrates the future scenarios likely to occur in MA, according to the information collected from MAG and airlines' questionnaires (distributed to four airlines: Emirates, British Airways, Easyjet and Thomas Cook (see Appendix F)). These questionnaires have been drafted in collaboration with S. Shah.
Once the expected scenarios are defined, by the use of the tool presented in section 2.3.4 (purpose II) they can be translated into future functional requirements and the overload in the system can be identified.

2.4.1 Trends at MA

The influences deriving from the trends relating to the aviation transportation system have been investigated in the context of MA during the meetings with MAG.

Increasing interest in passenger experience

The importance of meeting passenger expectations and with that providing a higher LoS has been confirmed by MAG as one of the major drivers for the check-in process reconfiguration.
Two aspects motivate the recent increasing attention on passenger expectations. The former is the increased sensibility and awareness of passengers in terms of service provided. The second is the diversification occurring among the check-in processes undertaken by the passengers. The spread of a multiplicity of airlines with different business models and services offered, and the introduction of new ways to operate the check-in have generated a wider range of passenger types and requirements. The Airport's offer needs to be adapted to these evolving and enlarged set of requirements and expectations coming from the passengers. This need implores the Airport to introduce new technologies as well as arrange dedicated areas and facilities for specific groups of passengers, e.g. the lounge built for Emirates.
Moreover, providing a high LoS at the check-in operation guarantees to MA a privileged position, for both airlines and passengers, among competitors, such as Liverpool Airport and East Midlands Airport.

Diversification in the airline business models

The presence of airlines with different business models makes it difficult for MAG to accomplish the multiplicity of the requirements and deliver ad hoc resources and facilities to the airlines that help process the passenger flow smoothly, quickly and in accordance with their business strategy. Moreover, the standardised and common use equipment existing at MA limits the differentiations in the offer.
During the first meeting with MAG the lack of involvement of the Airport Authority in the check-in operation has also been confirmed, as well as the freedom of the airlines to decide the operational policy.
In order to note similarities and differences between the different airline's check-in processes, MAG organised a two-day visit at MA terminal halls. The visit has enlarged the knowledge of the check-in processes available at MA and the business relationships occurring within the check-in operation. In particular, for the airlines observed it has been possible to identify the differences in the check-in policy drawing the "check-in modules" (Appendix E).
Given increasing differentiation of the airlines and the intention of MA to accomplish the requirements coming from its clients, the airlines, MAG's latest objective is to reach a diversification in the offer to the airline through the ad hoc allocation of area, lounge and facilities. The investment in the construction of the lounge for Emirates is a perfect example of that. To meet the airline requirements, the Group's primary aim is to understand the basic needs and business paradigms of each airline.

Number of flights and passengers

During the meetings with MAG it emerged that MA is expecting a growth in the number of passengers of up to 150% within the next 10-15 years. In this future scenario according to the estimation calculated by MAG, the number of resources required to operate the check-in in the traditional way, i.e. counters with operators and the same allocation methodology applied nowadays, would explode if any action on the system were not undertaken.

New technology on the market and technology push

According to MAG, the reluctance of passengers to use the self-service technology has constrained the radical change in the check-in configuration at MA. Because of that, the introduction of new technologies has not yet contributed drastically to a reduction in check-in time. From the experience during the check-in visit and the information obtained from MAG it emerged that technology development has helped achieving some improvements in the last 10 years, but the process itself at the end has not be renewed significantly, even with the introduction of equipment such as self-check-in kiosks.

The appearance and layout of check-in areas have evolved only in a minor way, small arrangements have been done to position the kiosk (on the hall wall opposite to the traditional desks) and the location of the conveyor belt and the counters (elements that define the general layout of the check-in hall) have always been in the same configuration. Despite the uncertainty about the passenger reaction in front of a more "automated" check-in operation, the positive results deriving from the introduction of highly self-serviced check-in processes in other airports is stimulating MAG to embrace the new era of technology.
A considerable potential change that MAG is considering is the introduction of iris-scanning technology: Passengers will have their eyes scanned as soon as they check-in by high-tech machines, which can recognise an individual's iris while they walk around.

External disruptions

The unpredictability of the terminal congestion caused by disruptions, as underlined by MAG is quite simple to manage thanks to the short time extension. Hence, although the consequences in the delays and terminal congestion will massively affect the performance, the limitation on the time of these negative impacts makes them affordable and tolerable from both the airport management and business side.
With respect to check-in processes specifically, the consequences of adverse weather or other kind of disruptions are mainly related to the baggage sorting and their re-distribution back to the passengers if they are forced by these external events to overnight nearby or within the airport.

2.4.2 Future scenario expected at MA

This section discusses the expected check-in scenarios at MA, given the trends forecasted in section 2.4.1. In the dimension related to requirements influenced by passengers, the future scenarios that MA is likely to face have been outlined during the meetings with MAG, Terminal check-in visit and questionnaires sent to airlines (Appendices F) and MAG (Appendices G).
From the information collected from MAG, the possible future scenarios arising at MA consist of four basic dimensions relating to requirements influenced by:

i. Passengers
ii. Luggage
iii. Airlines
iv. External stakeholders

During the workshop, these dimensions have been discussed and examples of the expected evolution in the requirements have been questioned to the airport managers in that occasion. The trend affecting the air transportation system has been applied as drivers to forecast the check-in evolutions. Several managers suggested the same scenario examples independently; this duplication of examples is taken to show

how pertinent that scenario is when considering the collective opinion of the MA managers.
The main possible scenarios expected at MA were discussed in the workshop with MAG, and are summarised below; where the passenger influenced scenarios were the most frequent suggestion.

2.4.2.1 Passenger Influences

Due to the abovementioned trends, the influences on the check-in dependent from the passengers can be grouped into 7 major classes:

1. Increasing number of passengers
2. Increasing number of low-cost passengers
3. Increasing use of self-service processes
4. Increasing use of remote check-in
5. Increasing diversity of check-in products
6. Increasing diversity of check-in products
7. Increase in passenger expectations

The first scenario, the increasing volume of passengers, is the one that attracts the most concern from MAG. The growth in the passenger traffic, both due to an increasing size of the aircraft or number of flights, results in an extra need for check-in resources. If a lack in the capacity or an efficient resource allocation and use occur, the terminal will incur an excessive congestion, which finally can translate into disturbances in the check-in processes and in the downstream operation. Thereby, a late response to this scenario must be avoided.
The increasing penetration of low-cost carriers in the airline industry is likely to increase the number of passengers using check-in services that are typical of this type of airline. Low cost carriers have established an alternative business model having expanded from their original niche markets (Franke M.,2004).
If the passenger preference for self-service check in technologies grows, it could stimulate new check-in methods in the future: remote locations via digital devices such as computers and mobile phones connected to the internet and other telecommunications networks. Alternatively, there may be an increased use of check-in at remote locations such as train stations and bus stations.
An increasing number of passengers may reuse the same routes and become familiar with the check-in processes of their chosen airlines. These passengers seek a 'minimum touch' approach with uninterrupted flow at the airport, as opposed to first time travelers who require more 'hand holding' through check-in (Motte A., 2010).
Passengers' expectations of the check-in process may increase in the future with regard to speed and ease of processing, at the same time also the diversity in the products of check-in increases

2.4.2.2 Luggage Influences

Related to the abovementioned trends and the passenger influences, the luggage issues are also evolving and their impacts on the check-in can be illustrated as follows: The volume of overweight luggage can increase seasonally. For example during holiday seasons the proportion of group travelers and families with heavier luggage increases due to longer average trip durations. Certain airlines, which maintain routes to holiday destinations, are more likely to have passengers arriving with overweight luggage. Passengers without hold luggage could increase in particular seasons. Business travelers, typically making shorter trips, increase in proportion noticeably in September after UK school holidays finish. Moreover, some airlines are aligning with this trend by increasing the capacity for hand luggage inside their aircraft cabins by enlarging overhead locker sizes.

2.4.2.3 Airline Influences

In the previous paragraph, the airline's business model has been illustrated as one of the major trends affecting the aviation market in the last years. Nevertheless, the differentiation in the operation policy has been pointed out as an objective for the airport through which to improve the offer to airlines.

Competition amongst airlines may result in increasing service level differentiation at check-in. This may be in the form of providing different numbers and type of check-in desks per flight with variations in staff treatment of passengers as described in the previous section. MA is also experiencing the introduction of new routes from the airlines already present in the terminal. This aspect imposes a change in the flight time schedule and a higher request for resources during the day.

The number of acquisitions or alliances forming between airlines may increase. These airlines would demand desks that are adjacent to their partner airlines creating larger check-in "blocks" of desks. These blocks of desks would be harder to divide, potentially making desk allocation more complex.

Airlines may choose to use common-use bag drop facilities, making luggage acceptance the responsibility of the airport instead of the airlines or the handlers. The centralised facilities might enable cost efficiencies if current bag drop facilities are underutilised.

2.4.2.4 External Influences

The external influences are those related to the pressure coming from the current market environment in which the airport acts, and can be considered the pressures on using less space, reducing the operation cost and competing against nearby airports. The increasing pressure on using less land and space may come from environmental regulation or simply from a business drive to use land more effectively.

In conclusion, the future scenarios likely to occur in MA demonstrate the need to focus on two aspects of the check-in operation: functionality and capacity. The resources functionality expansion should be developed to accomplish the passenger, luggage and airline diversification. On the other hand, the increasing demand must be followed by an adequate capacity plan, which does not necessarily translate into a capacity upgrade (acquisition of new equipment), but could also refer to a more efficient resource management policy.

2.5 The Check-In Counter Problem at MA

This section states the research problem, underlines the expectations of MAG for the future check-in configuration and thereby describes the objectives of the reconfiguration process.

The presence of three terminals, according to MAG, is the main cause of the infrastructural inefficiency. Summing together the resources spread in the T1, T2, T3 the total amount turns out to be much higher compared to what it would be in a single-terminal arrangement. T1 and T3 have 5 separate check-in halls, in different buildings, on different floors and with different queuing capacities (i.e. "free" space available in front of the check-in booths). In contrast to this is T2, with one block of check-in desks and more space to be used to organise queues and carry out check-in processes in a more efficient way than in T1 and in T3,whose configuration has three major consequences:

i. The terminal congestion increases due to a more complicated passenger flow and the route finding in the halls;
ii. The capacity available, due to the dislocation of capacity, is not easy to allocate to the airlines.
iii. The presence of spare desks hither and thither in the terminal leads to a resource inefficiency that can reach the 80%.

This situation is balanced by a high flexibility of the facilities: check-in desks at MA have a short "change over"(i.e. they do not need a long setting time) and are common-use among airlines. All the check-in counters have the same functionality. Any airline has access to its own database from any computer installed on the desks and thereby can potentially operate the check-in at any counter.

Overhead flexible screens can be reconfigured quickly at each new allocation of the desk to a different flight/airline: flight info and branding aspects (e.g. airline logo and colors) can be changed in real time based on the diverging needs coming from the airlines.

Although the intent of MAG to distribute the existing multiplicity of airlines of a different nature (flag carrier, low cost, charter,..) on different terminals by business models, the scheduling of the flight timetable and the building constrains imposes limits on the airport in terms of systematic organisation of the spaces and resources.

Delays and queues are consequences of a non-optimal utilisation of space and resources. A more efficient use of the resources if combined with a more efficient resource allocation policy and management, can improve the operational performance. Moreover, if the delays, queues and congestion were reduced, the LoS offered would improve. All these considerations support the decision of MA to reconfigure the check-in operation.

The need for more efficient allocation methodology of the resources is also motivated by their underutilisation, indeed, most of the time the resources allocated to the airline are used solely in certain hours of the day or in some case in only some days in the month. The fixed number of counters established by the two-week contract (that normally extends to longer periods) does not allow the airport to follow the variability in

demand and optimise the use of resources on a daily basis. Hence, the majority of the flights are not scheduled every day in a week, and not even every week in the month, characterised by the same departure timetable.
Moreover, it has been found that lately airlines tend to request too many counters compared to the ones needed to process their passengers. Hence, to prevent possible occurrences of long passengers waiting time or flight delays (if the resources are not enough to process the passenger in the planned window of time to check-in) and supported by the cheap cost of the counter's rent (£4.60 for half hour), many airlines prefer to oversize the resources needed. According to MAG, these over-requests could reach 30% compared with the amount estimated by MAG's simulation. The soft and conciliatory policy adopted by MAG pushes the airport to accomplish the airlines requirements. During the off-peak time, this does not represent a problem for MA because of the high availability of counters in the terminal, but during the peak times an over demand could be unaffordable for the airport. This tendency has been generating two major consequences:

- The underutilisation of the resources in the terminal;
- The mistaken assumption that is driving MAG to plan for expansion projects, instead of a reconsideration of the allocation policy.

Give the ability to the current configuration to adapt to change in the demand on a daily basis, following the peaks would allow the airport to make better use of its capacity. The ability to follow the daily demand of the airlines furthermore would provide the airlines with the amount of resources effectively needed according with their daily departures.
A better use of the resources would represent for MA the key to reach also those targets of its strategic plan that are related to the improvement of the check-in operation. A reconfiguration of the check-in halls, indeed is motivated also by intentions of MAG of:

1. Meeting the requirements coming from the expected future scenarios, especially concerning the fluctuation and growth of demand;
2. Meeting the customer LoS expectations, i.e. the reduction of congestion and delays;
3. Accommodating new upcoming technologies;
4. Differentiating the offers to the airlines.

The current capacity plan and the resource management at MA do not seem to consider any of the abovementioned factors and therefore a reconfiguration of the check-in hall is necessary.
The new configuration is designed to be able to adapt to the current changing requirements, but also to keep the ability to adapt to future evolutions. Hence, the motivations stimulating MAG to reconfigure the check-in operation are related to aspects continuously evolving over time.

2.6 Conclusion

This section summarizes the problems of the current check-in configuration at MA that limit the optimal performance of the operation. The major issues of the check-in operation at MA can be classified into four classes: two related with the hardware (the presence of three terminals and use of traditional resources), two related to the software configuration (the type of contract agreements and resource estimation methodology).

In Table 2-I, for each of these four issues are highlighted the consequent sub-problems experienced at MA.

These sub-problems in turn can be grouped into two classes, according to their origins:

i. Rigidity of Configuration;
ii. Underutilization of resources.

Hardware configuration	**Presence of three terminals**	**<u>UNDERUTILISATION</u>** • Complicated passenger flow • Difficult allocation • Spare desks hither and thither • Duplication of resources
Hardware configuration	**Use of traditional resources**	**<u>RIGIDITY</u> HW Not adaptable to evolving requirements** • Impossible differentiation in the offer to the airlines • Impossible differentiation in the offer to the passenger and difficulty in meet passenger expectations • Fixed layout
Software configuration	**Contract agreement and allocation method**	**<u>RIGIDITY</u> SW Not able to follow the dynamic demand** • The fixed number of counters established by the two weeks contract does not allow the airport to follow the variability in the demand • Variability of the passenger load is not considered
Software configuration	**Counters estimation (Oversized)**	**<u>UNDERUTILISATION</u>** • Counters not used for many periods; • Lack of capacity during the peaks

Table 2-I Problem definition

The rigidity represents the lack of reconfigurability in the operation, and indicates the inability of the system to follow the changing requirements every time they occur.

The underutilization of resources leads to the need for additional capacity although it is not really necessary, and is due to the current hardware and software configuration design, e.g. the terminal layout and the estimation-allocation methodologies.
Configuration rigidity and resource underutilisation are the limitations for the optimal performance of the check-in operation and therefore the alternative reconfiguring solutions need to be investigated.
The objectives of the reconfigured solutions revolve around a better use of the resources, and the implementation of reconfigurability into the system, in order to remove all the "rigidities" that would not allow to adapt to future evolving requirements.
Overall, to achieve feasible and appropriate solutions to the reconfiguration problem at MA, three aspects have been addressed in the problem solving:

i. The underutilisation of resources;
ii. The hardware inability to adapt to future requirements (hosting technologies or growing passenger volume);
iii. The software inability to follow the dynamic demand and variability in the traffic load of the flight schedule.

The last two objectives of the hardware and software configurations represent the rigidity of the operation and motivate the reconfiguration of the check-in system.
To find alternative configurations able to meet the three abovementioned aspects, the existing airport and operational research has been investigated, together with the reconfigurability knowledge available in the literature.

3 AIRPORT AND RECONFIGURABILITY LITERATURE REVIEW

Introduction

This chapter presents a literature review about the check-in operation and the reconfigurability paradigms. Two main sections form this chapter. The former outlines the existing approaches applicable to the check-in resources capacity plan and explores the reconfigurability background within the airport operations design.

On the one hand, many studies have been found on the check-in operation. The majority of them investigated the reduction of terminal congestion, delays and customers' dissatisfaction (Chun H., 1999), (Yan S., 2004), (Takakuwa S., 2003). Given the nature of the check-in system, queuing theory and simulation models have normally been applied. These techniques have been mainly to compare the performances of alternative technologies and layouts exploited in the check-in operation.

On the other hand, the review of publications about airport or generally services' reconfigurability did not conduce to any result. The novelty of reconfigurability in this field and the consequent lack of previous research on this topic has motivated the investigation of reconfigurability in literatures of other sectors, such as manufacturing.

Indeed, reconfigurability in manufacturing has been researched for the last 20 years and some findings already applied in the manufacturing systems. The idea of introducing reconfigurability in a production asset was proposed for the first time in 1999 by Koren at the University of Michigan in order to design a production asset "*able to modify behaviour, strategy and technologies adopted in the business framework*". Reconfigurable Manufacturing Systems (RMSs), according to the definition given by Koren and Ulsoy (Koren et al., 1999) are constructed "*for rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of its components*" cost and time efficiently. In the manufacturing literature about reconfigurability, some key principles of reconfigurability have been discerned.. Firstly, key features of reconfigurability and the steps of a reconfiguration process have been detected, secondly the general approach to a reconfigurable system has been adapted from the production systems to the services delivery assets.

The second part of the chapter highlights the basic aspects of reconfigurability, the reconfiguration features and other key notions derived from the manufacturing literature are the core of the second part (3.2) of this literature review.

3.1 Airport Check-In Literature Review

As shown in chapter 2 the airport is a complex system. With particular attention to its landside, some researchers have focused on the airport facilities layout problems, some others on the optimum design of airport terminals and its operation and some on the check-in resource estimation and allocation (referred as "check-in counters problem").
The publications on the last topic mainly apply the queue theory or simulation approach and focus on the flow of passengers, the comparison among the operation performances given different technologies and service times. The publications in this field turn out to be the most interesting for this thesis and this section is entirely dedicated to the literature review on check-in counter problem.
The aim of this section is to investigate the approaches adopted to solve the check-in counters problem. Particular attention has been dedicated to investigate and recognize how the variables of the system have been modelled. The mathematical models develop in the context of airport check-in have been studied. Moreover, this literature review is to look for studies on airport reconfigurability and their findings.
It should be noted that the following review is more focused on the software side of the traditional check-in counter problem, less attention has been dedicated to the investigation of the hardware alternatives and comparison of technologies in the academic research. Hence, the investigation of new technologies and novel solutions for the future at MA has been rather explored in other types of publications, such as airport reports, market research and information gathered directly from MAG.
The earliest research on the design and optimization of check-in, as an operation and as capacity involved, go back to 50 years ago. During the '60aviation started its growth, and many airports expanded or built from the sketch to satisfy the demand. At that time, the first concerns arose about operational issues, such as queue waiting time, terminal layout, check-in counter functionality and allocation policy. The interest for a better understanding of the check-in system but the lack of simulation techniques obligated the researchers to adopt the queue theory to model it.
The first paper published in this area is by (Lee A.M., 1966) who provides a model for the check-in counter system using a Poisson passenger arrival stream and an M/M/s queue and constant service rate.
A single-server system and state-dependent service rate with "*a potentially infinite capacity system*" was modelled by (Hadidi N., 1969a). (Hadidi N., 1969b) commented further on the analogy of the state dependent single-server system and found an interesting result: even though the single server (check-in operator) increases his rate of service when an arrival occurs, the problem of waiting time is still relevant. The queuing theory can be used for passenger flow analysis; however, must be notice that the steady state assumption is not valid for airport terminals due to the high variability in the number of arrivals and

departures during the day. Hence, the well-known steady state results for queuing systems are inapplicable.
Thus, when the simulations techniques were introduced to model this random and complex flow process, the reliability of the operation model and the results derived from it, such as capacity plan, were highly improved. In particular, the development of sophisticated simulator made possible the application of the results in the real case, supporting the resource estimation carried out by the airports authorities. An example of this is (Chun H., 1999). The Authors introduced an intelligent resource simulation model to assign on a daily basis the number of check-in counters to allocate to each departure flight. One of the performances controlled by the model is the level of service offered offering to passengers, which consists in the waiting time and queue length.
In the Intelligent Resource Simulation System (IRSS) they proposed, many factors have been included in the model, such as:

- Different service rates for different destinations;
- Different passenger arrival rates for different times of the day or days of the week;

The so-predicted amount of resources needed is then used by a constraint-based resource allocation system responsible for allocating the actual check-in counters available in the terminal. The arrival process has been modelled using passengers' arrival statistics collected for different categories of flights (grouped by type of airlines, destination, departure time and so on). These statistics show that the inter-arrival times of passengers are IID random variables and follow non-stationary Poisson process, i.e., the arrival rate of passengers is a function of time.
The simulator proposed by these Authors have been employed at the Kai Tak International Airport, guaranteeing a more accurate means of predicting resource requirement than the manual approach used at that time, based upon the individual experience of each human scheduler.
To assist airport authorities in the assignment of common check-in counters (Yan S., 2004) developed an Integer Programming model with the objective of minimizing passengers walking distances between entrance, check-in counters and gate associated to a flight. The Author referred to the common use check-in counter assignment problems as CUCCA and aim at a monthly basis assignment plan.
This research differs from Chun's on several points:

i. Chun modelled the assignments are done daily, and the model itself is solved one day before operations, while in Yan's are for a whole month, solved a month before operations;
ii. Chun's model evaluated only the queue length, whether Yun's model indirectly considered also the airlines or the airport authorities viewpoints, while reducing the passenger movements, seen as enablers of congestion and chaos in the terminal;
iii. Chun's model considers the possibility of varying the number of counters assigned to a flight within its time window, in daily

operations, while in Yan's research the number of counters assigned to a flight is fixed during the month.

These changes in Yan's formulation enlarged the size of the model too much and to solve it, a heuristic method has been developed by decomposing the original model into three heuristic models, each of them formulated as a single-day CUCCAP. The simplex method with the branch-and bound technique was employed to solve single-day CUCCAPs. Therefore, although the valid and realistic definition of the problem, and the useful results might be carried out from it, the applicability of this research in the real world is very limited and even the heuristic model does not provide results quickly and easily.

The later studies thus have tried to simplify the assumptions and the parameters.

Two further studies have investigated the changes in the operation's performance (throughput and level of service) while introducing some changes in the operation.

(Joustra P., 2001) simulated the condition of congestion based on check-in operations of a regular working day, using the International Kansai airport in Japan as exploratory case study. The simulation aimed at investigating alternative solutions to improve the service at check-in and reduce the number of passengers that are not processed in time, i.e. before the counters close. The results of the simulation suggested that the number of passengers losing their flights due to delays in the check-in operation can be drastically reduced by the addition of a staff supporting the standard working group. Moreover, the use of different check-in desks for different passengers' classes, such as tourists, business and first would also reduce the number of delays.

The departing flow of passengers at the Buffalo International Airport (Niagara) has been the case study for (Takakuwa S., 2003) in order to compare the performance resulting from different scenarios consisting of alternative check-in technologies.

Besides the "indoor" check-in desks (which represent the classical solution) at Buffalo terminals there is the option of the "outdoor" curbside check-in (i.e. on the sidewalk outside the terminal), where a number of agents accept passengers and their baggage, coming directly from parking lot or bus and taxi. It has been found by the Authors that the replacement of the inside check-in desks with the outside curbside asset, would improve the whole process and the waiting time would be adjusted on a lower value.

A very interesting attempt of this study is the evaluation of the possibility to choose the best type of check-in depending on the weekly day. For example, the express kiosk can be an optimal mode for on Monday's travelers, consisting in large part by executive class usually without baggage to be loaded, whereas it is not suitable on Friday and Saturday days, whose passengers are mostly for pleasure trip having a great number of bags to check. This solution, which seems support the reconfigurability of the check-in hall, has not been investigated further or implemented elsewhere.

A simplified assumption that ignores variability of service time adopts the time block concept related to counting periods has been implemented by (Ahyudanari E., 2005). The Authors developed a model to investigate the influence of the type of queue and operator service time on the check-in process at airports. The proposed model is based on queuing theory concepts and computes the optimum number of check-in counters. A time block is equal in length to the average service time. Thus, the passenger service capacity during a time block is equal to the number of servers.

Data on passengers flow are collected in time intervals divided into blocks, which are time dependent on the size of the average service time. In particular, periods of 10 minutes are considered the most convenient choice, since the earliness distribution of passenger arrivals documented also by (IATA, 2004) is based on ten-minute intervals.

A graphical output indicates delays and passenger waiting times over the period of analysis. Based on these results, the congestion levels have been estimated and compared for variable number of counters in service. This analysis allowed computing the optimum number and the configuration of check-in counters, where the variables involved in calculating the number of resources, such:

• Service time;
• Arrival curves;
• Configuration and typology of check-in;
• Costs

The model optimization is indeed based on system total cost minimization. The costs considered include the cost of space, the operating cost and the cost of uneasiness endured by passengers when the waiting time exceeded the tolerable limit. The evaluation of the cost of space allows also estimating the optimum size of the check-in area.

This work highlighted two significant problems that represent a source of uncertainty also for the development of the model presented in this work.

The first problem is the lack of consistent data related to cost of various components, the second is the difficulty to obtain passenger arrival distributions.

Without considering the costs, given the difficulty to estimate them, (VandijkN., 2006) proposed a combined approach where: the simulation is utilised to determine the minimal numbers of desks in order to meet a service level for each separate flight and integer Programming to minimize the total number of desks and the total number of desk hours among more airlines.

Van Dijk et al. proposed introduced a novel assumption in the simulation approach, which will be very helpful for the definition of the dynamic programming in chapter 5: finite calling population size. They highlight the fact that one of the important features of this problem for any single flight is the finite calling population size. Hence, they resort to “terminating simulation” to identify the number of counters to open, unlike almost all the other works, which use non-terminating simulation.

A different cost minimisation has been developed by (Bruno, 2010). The paper analysed the pure deterministic scheduling problem, by proposing a new model for the check-in allocation. The objective function includes the costs associated with maintaining a queue and the costs associated with opening a desk, both of them as they are perceived by the airlines. The optimization problem consists in the determination of the minimum number of check-in desks to be opened in a time interval to ensure a certain service level.
Naples (Italy) International Airport has been used as case study by the Authors and the results obtained seemed to confirm the suitability of the model to solve real case studies. However, variants of the model to describe practical operating constraints and physical, i.e. layout of the desks, and queue parameters and queue model are needed to develop a more complete solution of the problem.
(Parlar M., 2008) aimed at gaining an analytical insight in the check-in counters allocation to the airlines. They examined the problem of optimal dynamic assignment of check-in counters for a flight with a N a priori known number of booked passengers. The transient probabilities of the queuing process has been computed in the time window when the counter are open and using these probabilities the system has been defined in terms of expected number of passengers in system and waiting time. Focusing on a single flight, the Authors did not take in account the daily dependency of the arrival rate, but a different procedure has been adopted to estimate the arrival rates over different subintervals. The cost function over these subintervals has been minimized in order to provide a dynamic assignment of the counters to open from the airlines viewpoint. The operating costs of the service provider are here minimised through the combined use of queuing theory and dynamic programming.
The thrust of such a research is to assign valuable resources efficiently to meet business demand without compromising service standards. The model presented by these Authors has represented basics of the estimation methodology proposed in chapter 4.

3.2 Gaps in the Literature

Some common aspects among the publications reviewed can be highlighted, together with some gaps existing in the literature. This section summarises the main aspects on which the existing studies have focused on and discuss their limitations.
Three aspects have found in common among the publications reviewed:

1. It has been recognised by all the research the need of reducing the congestion and selecting the configuration technologies that increase the operation efficiency and the passenger satisfaction;
2. The "hardware side" of the check-in configuration has been the major objective of the studies. Thus, normally the researchers have compared the performances of different technologies portfolio in terms of queuing time and throughput of passengers (in some case also the cost of the check-in equipment has been considered),

without considering the differences in the software models. The objective of their research was indeed the selection of the best technology;
3. The Airport point of view and its costs related with the check-in have not been considered [except from (Ahyudanari E., 2005)].

Other common aspects of the mentioned publications are listed below and can be considered as their major limitations:

1. The first limitation in these models are consequences of the approach applied, i.e. simulation vs. analytical models. One hand the analytical models have used specific distributions (or combinations of distributions) for their variables, or simplifications of many assumptions, failing to capture the complexity, variability and stochasticity of airport terminal operations and flows. On the other hand, the simulation models have been either models of specific airports, or general simulation platforms that require substantial modelling effort and knowledge to represent a given airport terminal. Most of the time the high complexity imposed the support of a heuristic solution (Manataki E., 2009).
2. The lack of investigation on the real agreement issues and assignment policy between airlines and airport is not taken in account;
3. The lack of reconfigurability in the approaches proposed, although all the papers have highlighted the variability of the check-in load and the changing trend. The resource estimation is "static", i.e. based on a single day (exception for (Yan S., 2004)), air traffic, without considering the flights distribution over a longer period of time. The common solution adopted to overcome this limitation has been design the terminal capacity for the peak hour or day. However, the overestimation of the resource capacity does not imply that the system is able to dynamically adapt to the external fluctuations.
4. Related with the previous limitation, is the lack of investigation on the paradigms that provide the check-in operations with the ability of adapt to the changes.

Other works have also been investigated in the literature of queuing theory, capacity plan and resource allocation. It has been found that the management of call centres and supermarket check-out counters are close to the capacity plan of the check-in counters. However, in the supermarkets and call-centres, the population is not a finite number and the steady state might be reach. Queuing models with finite population are more in use, for example in the context of machine repair, in manufacturing system or in the stochastic population models.

The key aspects of the literature reviewed are summarised in Table 3-I

	(Chun H., 1999)	(VanDik, 2001)	(Takakuwa S., 2003)	(Yan S., 2004)	(Ahyudanari E., 2005)	(VandijkN., 2006)	(Parlar M., 2008)	(Bruno, 2010)
Targets	Tolerable waiting time and queue length	Reduce the n. of pax that are not processed in time	Waiting time	Walking distances between entrance, check-in desks and gate	Minimisation of costs: cost of space, operation and excessive waiting time	Minimal numbers of desks in order to meet a service level	Minimise the cost of check in counters to open	The costs associated with maintaining a queue and the with opening a desk
Service rate	Beta distributed different service rates for different destinations	Constant	Technology dependent	Constant	Ignores variability of service time: time block	Constant	Constant	1.5minute for all the passenger
Arrival rate	Poisson arrival, different arrival rates for passenger, times or days of the week	Poisson	Poisson	Poisson	Statistical data from IATA	Finite calling population size, Poisson arrival rate	Finite calling population, Poisson, time dependent	Statistical data from IATA
Plan-length	Daily allocation	Daily	Week (type of check-in choose on the weekly day)	Monthly	Day	Day	Single-flight	Daily
Viewpoint	Passengers	Passenger	Passenger	Passenger, indirectly airport &airlines	Airport, passenger	Airlines	Airline	Airlines
Approach	(Simulation	Simulation	Simulation	Simulation	Simulation and optimisation	Simulation, heuristic	Queuing theory, DP	Combinatory optimisation

Table 3-I Key aspects of the literature review on airport check-in

3.3 Manufacturing Reconfigurability

This section summarises the essence of reconfigurability as meant in the manufacturing literature, where the of reconfigurability has been widely discussed. Hence, the recent developments in manufacturing machine design have been based on the idea of having a machine that can quickly be setup to produce different product types in a short amount of time. Since the airport check-ins are largely dynamic systems and require rapid response to changes in the operating environment, exists a high potential for such concept to be implied on the check-in.

In manufacturing, the term reconfigurability has been defined in different ways, nevertheless, there is no doubt that the reconfigurability refers to the ability of production systems of meeting the changes and uncertainties of manufacturing environment. In a dictionary sense, the term reconfigurability of a system can be defined as its ability to adapt to a new task by altering its configuration (Oxford English Dictionary (2005)).

Proposed for the first time in 1999 by Koren at the University of Michigan during a seminar, reconfigurability in the manufacturing assets is the feature that ensures "*no more, no less, and at the right moment the required functionality and capacity within the manufacturing process*" (Koren Y., et al., 1999). According to this definition Reconfigurable Manufacturing Systems (RMSs) can "*rapidly adjust the production capacity and functionality, in response to new circumstances, by rearrangement or change of its components cost and time efficiently*". The need of changeable functionality and scalable capacity in a manufacturing system is due to the importance for the production system to react to the demand, to the recent growing interest in reduce the lead-time and waste, and increase the customisation and product variety.

The reconfigurable manufacturing systems are thought to have machine components, machines, cells, or material handling units that can be added, removed, modified, or interchanged as needed to respond quickly to changing requirements. A fully reconfigurable system does not exist yet; however, is the subject of major research efforts around the world. Hardware reconfiguration also requires major changes in the software used to control individual machines, cells, and systems as well as to plan and control the individual processes and production.

The key feature of RMS, which distinguishes an RMS from other production assets like Dedicated Manufacturing Systems and Flexible Manufacturing Systems (see section 3.4.3.) is an adjustable capacity and functionality (Koren Y. et al., 2000).

Reconfigurable manufacturing systems aim at:

i. Reducing lead time for launching new systems and reconfiguring existing systems;
ii. Achieving rapid manufacturing modification and quick integration of new technologies and/or new functions into

existing systems using basic process modules (hardware and software) that would be rearranged quickly and reliably.

The components to reconfigure may be machines and conveyors for entire production systems, mechanisms for individual machines, new sensors, and new controller algorithms.

The key enabling technologies to obtain such a production system are open-architecture control of the software and modular machines of the hardware (ElMaraghy H., 2006).

A reconfigurable hardware and software would generate a manufacturing system readily reconfigurable, and provide it with certain key characteristics (Koren et al., 1999,) such as: modularity of component design, integrability (for both ready integration and future introduction of new technology), convertibility (to allow quick changeover between products and quick system adaptability for future products), diagnosability (to identify quickly the sources of quality and reliability problems), customization (to match designed system capability and flexibility to applications), and scalability (to incrementally change capacity rapidly and economically).

The concept of using basic process modules, i.e. developing the system 'modularity', has been investigated since the beginning of the '90, and seems the most developed characteristic of reconfigurability. The increase of modularity in the system has been though by (Liles D.H., 1990) as the key to organise intelligent, complex, individual machines and information processing equipment into a flexible manufacturing system to follow the demand of customers. Other investigations on modular product system and concurrent engineering method have been carried out by Rogers et al. (Rogers G., 1997). The authors proposed a new manufacturing paradigm based on building Modular Production Systems (MPS): a production system made up from standardized modular machines.

(Tsukune H., 1993) was the first to highlight how the modularity in the devices needs to be accomplished by a modular control system. A modular control system consists of different programming languages and software that run independently in the system in order to achieve an accurate overall control of the hardware. With the modularisation of the software, it is possible re-use and sharing programs due to the introduction of a database that collects and controls programs as software modules and that at the same time guarantees the correct execution of the tasks.

The same concept of two different levels of modularity in the system has been adopted by (Bi Z.M ., 2008) to distinguish two levels of reconfigurability. According to the Authors changing hardware resource mainly addresses reconfigurability at lower levels, i.e. at the job-shop level, where changing software resources and/or by choosing alternatives methods or organization structures addresses reconfigurability at the higher levels, i.e. organisational, enterprise level, see Figure 3-I.

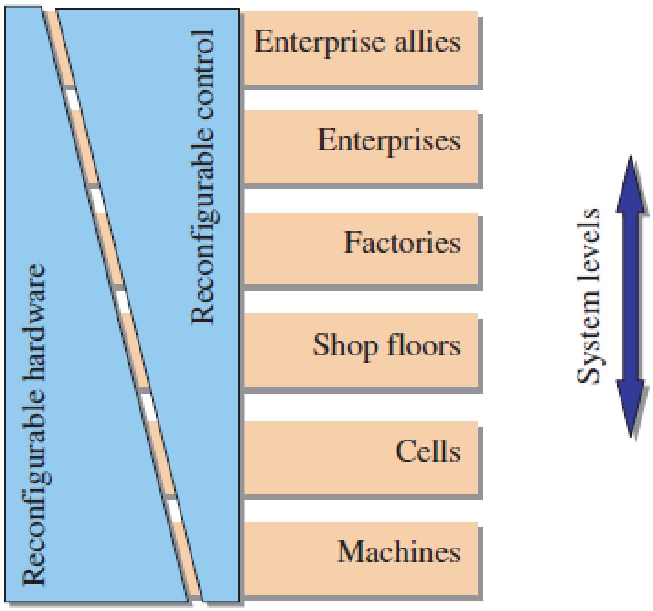

Figure 3-I Reconfigurable levels in the system [source (Bi et al., 2008)]

All the recent works on reconfigurability (ElMaraghy H., 2006; Reza M., 2011; Valente A., 2011) have underlined how to achieve a greater degree of system reconfigurability the two aspects to work on are:

i. Distributing control autonomy to the system components;
ii. Designing and building modular hardware structure, where elements can be easily decouple and re-couple together.

3.4 Reconfigurability at Different Levels of the System

This section is organised in three parts. The former defines the above-mentioned level of reconfigurability hardware and software and summarises the importance of their implementation in a manufacturing system. The second and the third sections respectively discuss the reconfigurable hardware and software evolutions within the manufacturing systems.

3.4.1 Needs for Hard- and Software reconfigurability

The problem of reconfigurability in the manufacturing systems can be broken up in different sub-problems of reconfigurability: hardware and software. Hence, an RMS should be designed at the outset for feasible rapid changes in structure, both in hardware and software components to quickly adjust the production capacity and functionality within a part family.

The hardware and software distinction in the manufacturing assets, have been applied by (ElMaraghy H., 2006) to classify the manufacturing system re-configuration methods physical (hard) and logical (soft). The "hard" reconfiguration regards machines, operations, processes, product mixes, material handling, production control, routing, production

planning, as well as increase in the production volume, capacity, and capability scalability (expansion/reduction).
The “soft” or “logical” re-configuration refers to reconfiguration of the system that is employed with today’s technology, with or without physical reconfiguration, and allows achieving a quicker and cheaper adaptability of the system. Figure 3-II illustrates the manufacturing system reconfiguration as described in (ElMaraghy H., 2006).

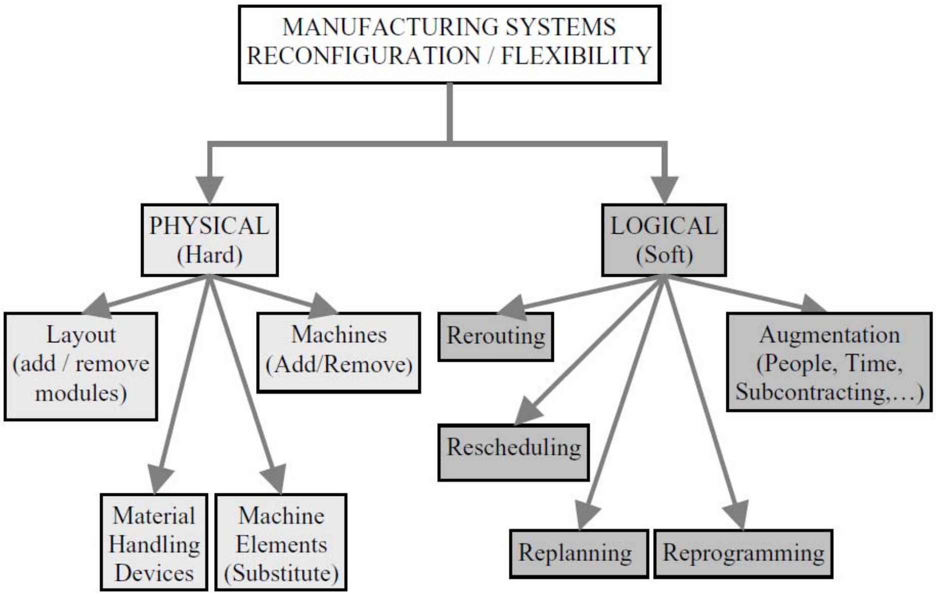

Figure 3-II Manufacturing systems reconfiguration (ElMaraghy, 2006)

The motivation of introducing hardware and software reconfigurability to support reconfigurable manufacturing systems is based on the belief that some economic benefits can be obtained by increasing reusability and reducing the excess capacity and/or excess functionality present in other types of manufacturing systems.
The motivation of building reconfigurable manufacturing systems is due to the rapid changes in product- demand, life cycle, volume and feature, which generate at the same time markets more competitive, turbulent and uncertain.
The phenomena that have a great impact upon the performance of a manufacturing system have been summarised by (Ishii K. et al., 1995) and are briefly reviewed as follows:

i. Quick production: The more quickly a product is introduced, the better its prospect is for achieving and maintaining a large part of the market; a new product brings a higher profit margin;
ii. Mass customization: Products become versatile and customized;
iii. Fluctuating volumes;
iv. Low price: The competitive environment of a globalized market is motivating to reduce the price of many products, with the same quality and service levels;
v. Quality and durability: Since the customers are becoming more and more aware of product feature and value, tend to regard quality and durability as essential features of items;

vi. Sustainable production: The recent increased awareness of environmental issues and sustainable aspects require new and sudden proceedings and solutions for the production processes.

To respond to these evolving requirements, throughout the years the manufacturing systems have evolved and concentrated all the effort to create a high adaptable manufacturing system. Positive results, illustrated in the sections 3.4.2 and 3.4.3 have been achieved by the implementation of both software and hardware reconfigurability.

3.4.2 Development of Reconfigurable Software

This section highlights the importance of an adaptable, i.e. reconfigurable, control system, meant as the core of the software reconfigurability. Its evolution in the manufacturing is also described.

An adaptable control system allows a better control of the system's hardware elements and provide the best support to the reconfigurability in the production operations.

The evolution of industrial control system has been running parallel with the evolution of reconfigurable manufacturing systems. Industrial control system has gradually progress from centralized, hierarchical control architecture to loosely coupled "heterarchical" control architecture. Control tasks traditionally managed by a large and expensive centralised control unit, typically a PLC, have been divided into sub-tasks handled by smaller controllers.

Indeed, the hierarchically-based industrial control systems does not have the ability to follow the changing conditions, therefore is necessary a fundamental architectural change to the way in which the control is organised, i.e. move from a centralised to a distributed control.

Distributed autonomous units can operate as a set of cooperating entities able to provide high operational flexibility and change capability to the system. It seems therefore fundamental to implement these cooperating entities in manufacturing systems such as distributed, self-organizing and well-operative organizational structures in order to cope with the dynamic system changes.

Among the methodologies for control design proposed for the next-generation manufacturing systems there are Holonic Manufacturing System (HMS). In an HMS, key elements such as machines, work centres, plants, parts, products, persons, departments, or divisions have autonomous and cooperative properties. These elements are called holons. In an HMS, each holon's activities are determined through the cooperation with other holons, as opposed to being determined by a centralized mechanism. An HMS could therefore enjoy high agility, which is an important characteristic for future manufacturing systems.

In conclusion some manufacturing support functions and intelligent control will represent the software side be necessary to achieve effective reconfiguration in the system. The software reconfigurability includes several aspects(ElMaraghy H., 2006), among them, a software that can help select the best equipment (machine tools) based on their capabilities, and future CAD/CAM to generate CNC part programs that will include appropriate speeds, feed rates, tools and fixtures selections.

3.4.3 Development of Reconfigurable Hardware

This section discusses the evolution of the manufacturing systems that drove to the RMSs and highlights the operative differences among the previous paradigms of production systems, as DMSs and FMSs.

Throughout the centuries, several different manufacturing paradigms have been introduced to meet the market's requirements defined by the historical frameworks. However, none of the previous manufacturing concepts seemed able to satisfy the current critical requirements for a manufacturing system.

The manufacturing responsiveness is the novel economic objective for the manufacturing, i.e. the production system must acquire the ability to respond to disturbances and to adapt to external changing conditions. The reconfigurable manufacturing systems would enable a very quickly development of new products and sudden adjustments of the manufacturing system capacity to client demands.

Unlike the other types of systems, the RMS aims to be installed with the exact production capacity and functionality required, eliminating the capital investment waste characteristic of the Dedicated Manufacturing Systems (DMS) and of the Flexible Manufacturing Systems (FMS).

The logic behind the DMSs and the FMSs, is to provide the production systems with an overestimated capacity and functionality, in order to meet feasible future needs.

Therefore, most of the time what happens is that the dedicated lines do not operate at their full capacity and the flexible manufacturing systems never use some of the functionalities available. Both cases create a loss that RMS technology attempts to eliminate.

An RMS is designed to allow the addition of the extra capacity only when required, and to add the supplementary functionality when needed.

The FMSs have constituted a good starting point to develop RMSs, although the challenges generated by the above-mentioned evolutions make such manufacturing systems reaching their limits both from technical and economic points of view. Flexible manufacturing systems are planned for a well-defined spectrum of parts, a production volume with relatively low fluctuations, and precise manufacturing standards in order to diminish technical risks and increase return on investment. For this reason the FMSs developed in the last two decades are generally expensive, due to the numerous and not always necessary functions, the inadequate system software (since developing user-specified software is extremely expensive) and due to the low reliability, and high obsolescence caused by the advances in technology and their fixed system software/hardware.

3.6 Flexibility, Changeability and Reconfigurability

The concept of having flexible or reconfigurable machines to support the re-deployment of machines and reconfiguration of systems discussed above resonate strongly with the notion of flexibility, changeability and reconfigurability. This paragraph presents one of the many classifications that have been proposed for these three concepts.
Although all flexibility, reconfigurability and changeability (Elmaraghy H., 2007) deal with modifications of manufacturing systems, differences exist among them: timing, cost and number of steps necessary to implement changes.
(Terkaj, W., 2009) proposed a classification and a structured framework for the definition of the three different forms of flexibility. The Authors start from defining as a Compound Flexibility Form the different forms of flexibility in a system, e.g. Mix Flexibility, Routing Flexibility, etc..
Each Basic Flexibility Form is thereby defined as the aggregation of two key concepts: Dimensions and Levels.
Figure 3-III represents the conceptual classification and definitions of the basic flexibility levels, but the aspect to focus on is the definition of Basic Flexibility Levels. These levels are related to real implementation of various forms of flexibility in the manufacturing system, see Table 3-II.

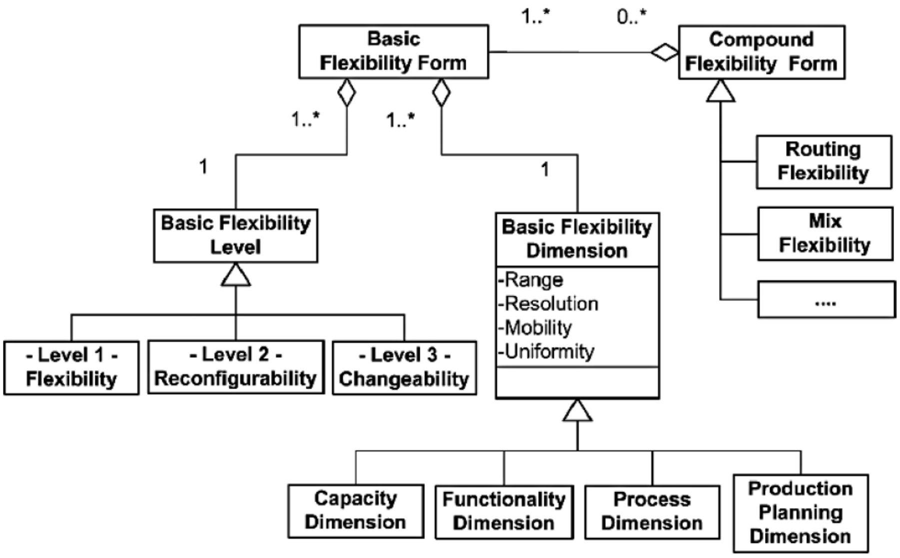

Figure 3-III Classification of the basic flexibility levels (source [Terkaj W. et al, 2009)])

A basic flexibility dimension characterized by its attributes might be available in a given system or it can be acquired if not. In the first case, the system is one-step ahead compared to the second case. The system is in the second level, i.e. it is characterised by flexibility. In the systems of the second level, some actions need to be taken to obtain the same capability, i.e. arrangement of element called enablers, already present in the system. However, the system has a disposition to be modified and adapted and this ability is called reconfigurability. The Authors referred to the predisposition of acquire a new ability through the acquisition or introduction of novel enablers as changeability.

Basic flexibility	Level	Definition
Flexibility	Level 1	The system has the ability
Reconfigurability	Level 2	The system can acquire the ability already having the enablers
Changeability	Level 3	The system can acquire the enablers

Table 3-II Definition of the basic flexibility levels (source [Terkaj W. et al., 2009)])

Related to the definition given, can be assumed that the software reconfigurability is more close to the system flexibility, assuming that the machines tool and components are already present in the system and the system control's reconfiguration requires the run of new code or connection in the network without involving acquisition of new mechanical parts.
On the other hand, hardware reconfiguration is more close to the concepts of reconfigurability and changeability, requiring either rearrangement or acquisition of physical components of the system.
Given these considerations, can also be noticed that software reconfiguration generally involves minor investments and shorter term compared with the hardware reconfiguration.
However, in this thesis is employed the same terminology to refer to system's level of flexibility according to the presence or not of enablers in its asset.

3.7 Key Characteristics of an RMS

This section summarizes the key features of a manufacturing system that allows it to be readily reconfigurable, as derived from the literature.
Both the hardware and software reconfigurability participate in the construction of an RMS, whose design is address to implement a set of the key characteristics in order to reach a high level of reconfigurability (Koren Y., 1999). Initially five key features of reconfigurability have been proposed by (Koren Y., 1999): modularity, integrability, customization, convertibility, diagnosability.
All these key characteristics determine the ease and the cost of reconfigurability of manufacturing system, but can be assumed that modularity, integrability, and diagnosability decrease the reconfiguration time and effort; customization and convertibility reduce cost related with the hardware of the RMS.
More recently, these initial five key features have been reformulated in four key features in (McFarlane D., 2008a) as diversity, modifiability, responsiveness and fault-tolerance, as given in Table 3-III. The table defines each of the key aspects and describes the trend that requires the implementation of the feature itself in the system.

Those key characteristics, defined by the Authors, should be taken in account from the beginning design phase of an RMS, in order to design and allocate all the system's components in an appropriate manner.

KEY FEATURE	Definition	Trend
Diversity	The ability to manage multiple product streams.	Wider range of tasks
Modifiability	The ability to support ready integration of new processes or the reorganization of existing processes.	Process changes
Responsiveness	The ability to provide a timely response to changes in product demand.	Uncertainties and variations in demand
Fault-tolerance	The ability to tolerate failures or disturbances and when necessary provide graceful degradation of performance.	External disturbances and delays

Table 3-III The four key aspects of reconfigurability (source [McFarlaneD. et al , 2008a])

3.8 Reconfiguration Process

This paragraph summarise the conceptualization of the reconfiguration process as suggested by (McFarlane D. et al., 2008b).
According to the Authors the reconfiguration process is comprised of 7 steps, as shown in Figure 3-IV, and represent a methodology that can be followed once the reconfiguration of a system needs to be undertaken.

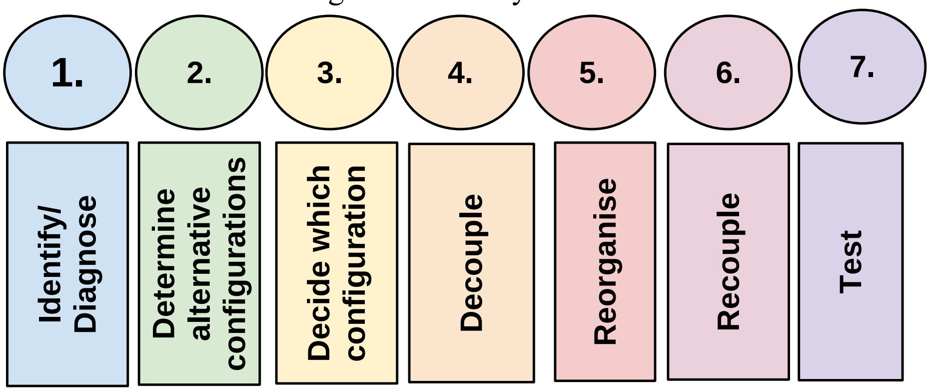

Figure 3-IV Reconfiguration process conceptualization proposed by [McFarlane D. et al.,2008b]

The first step (***Identify / Diagnose***) consists in the definition of the requirements for reconfiguring the manufacturing system. The requirements are based on the expected characteristics of the manufacturing system, such as for example the throughput and types of products to be manufactured, after the manufacturing system has been reconfigured.

In the second step, (***Determine alternative configurations***) the configuration of the manufacturing system is chosen among the alternatives listed.
In the third step (***Decide which configuration***) the selection criteria are chosen, for example cost, time, effort required to reconfigure the system. Based on the configurations defined in previous step the best configuration is chosen.
Some modules in the initial configuration of the manufacturing system must be de-coupled if the existing modules are to be removed from the original manufacturing system. Physical modules such as machines and logical modules such as software components are considered in this activity. In step four (***Decouple***) these decoupling activities are analyzed. The rearrangements of the modules that need to be setup and re-coupled to the other modules in the manufacturing system are faced in step 5 (***Reorganize***). The setup process may include, programming, configuring internal parameters of these elements. In step 6 (***Re-couple***) all the modules are re-coupled together and finally in step 7 (***Test***) the system is tested and commissioned to make sure that the configuration meets all the requirements and operates reliably.
The reconfiguration process not only requires the definition of the system design, as described in the previous chapter, but also necessitates the definition of a reconfiguration policy, i.e. the set of decision to take during the time to adapt the system to the external changing requirements.
Moreover, as it will better described in section 4.2.4 an approach to address the reconfiguration process has been investigated by (McFarlane D., 2008b). More in details, this method supports the de-coupling/ rearrangement/ re-coupling steps and evaluate the ease of reconfiguration by using the Design Structure Matrix (DSM).

3.9 Conclusion

The literature review about the check-in operations has presented a brief overview on the *state of the art* about the check-in and it has been highlighted the lack of investigations on reconfigurability.
On the other hand, the concepts of reconfigurability have been largely developed in the manufacturing literature. Therefore, it might be helpful to reformulate some of the reconfigurability concepts derived from this sector and transfer it to the airport operation. Hence, the framework matured to design a reconfigurable manufacturing system has been used as guideline to develop reconfigurability in the check-in.
Thereby, the results of the studies reviewed have been applied to the check-in operation with the appropriate modifications.
The foundations on which built the reconfigurability of the check-in and its reconfiguration have been: the separated implementation of reconfigurability in the hardware and software, the definition of the reconfigurability key features and the approach to measure the effort of reconfiguration.

4 HARDWARE RECONFIGURATION

Introduction

The contribution of this chapter is to guide the reconfiguration decision makers in generating and evaluating alternative configurations. Particular attention has been dedicated to the reconfigurability features needed in a check-in configuration, as well as to the efforts required in the reconfiguration process.
The design of a new configuration called the "Hardware Reconfiguration Problem" (HRP) is detailed in section 4.1. A solution approach is then elaborated and proposed to MA as a possible path towards renovating the hardware configuration.
The ultimate objectives of the check-in's technologies and layout reconfiguration are to ensure higher capacity and functionality of operation. While choosing among alternative configurations, two fundamental issues need to be considered:

i. The evaluation of the configuration reconfigurability as a metric, so as to allow comparison among alternatives and measurement of the configuration efficiency.
ii. The planning for a reconfiguration approach as a stepwise decisions process, to enable decisions to be made for both immediate actions and future adjustments.

Indeed, as suggested by (Matta A., 2008) the reconfiguration problem can be treated as a Markov Decision Problem in order to optimize the entire sequence of reconfigurations that might occur. This approach however, is not applicable in this thesis given the limited information available on the airport financial situation and strategic plan for the future.
Thus, the methodology proposed to MA to address the hardware reconfiguration of the check-in is focused on "one step" reconfiguration, without defining the entire sequence of the reconfiguration to be undertaken.

4.1 Problem Description

The problem addressed in this chapter is the methodology development to apply at the initial steps (step 1 and step 2) of the reconfiguration process by (McFarlane D., 2008b) presented in section 3.8.
The HRP is divided into three classes corresponding to the three stages faced during the configuration design:

1. The importance to highlight the reconfigurability within the system.
2. The need to consider the requirements that must be satisfied in the present as well as in the future.
3. The importance of measuring the reconfigurability efforts as part of the reconfiguration strategy and actions planning.

4.2 Solution Approach

The approach exploited in solving the airport HRP is summarized in the flowchart shown in Figure 4-I. The chapter is composed of three sections: problem description, solution approach and results obtained. The problem has been defined in section 4.1. In this section the solution approach is elaborated and discussed.

The three sub-problems of HRP identified in section 4.1 have been tackled respectively as follows:

1. The reconfigurability features have been investigated in order to apply them in the configuration they. A set of performance indicators has also been proposed to characterise both the reconfiguration and configuration;
2. A tool that enables the tracking of requirements imposed by the forthcoming external causes and functionality has been designed;
3. A methodology to measure the efforts needed for the reconfiguration process has been developed.

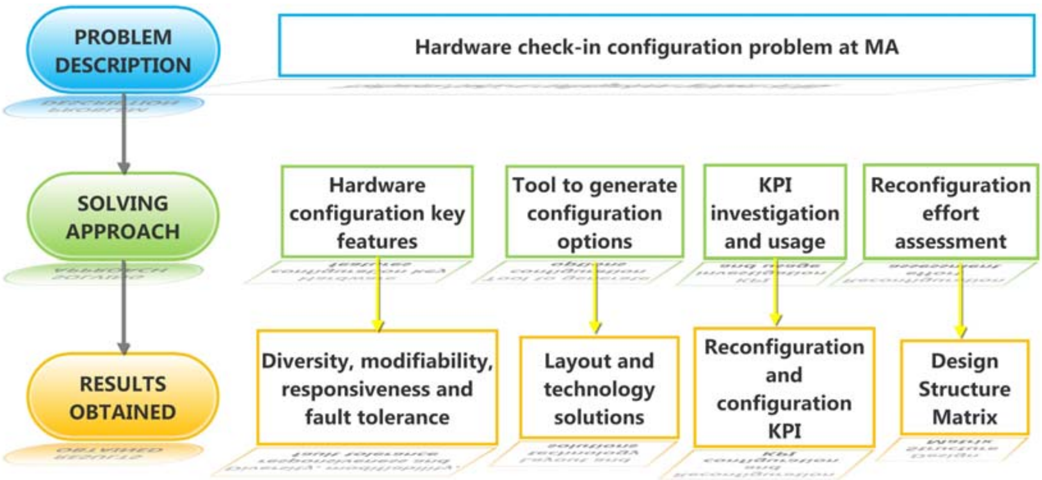

Figure 4-I Chapter IV structure

In the first part of this chapter the approach steps to design a new check-in configuration are discussed. These steps are shown in the green boxes of Figure 4-I. The second part of this chapter illustrates the results obtained by applying the techniques suggested. Some of these results have a generic validity, such as the KPI definition or the reconfiguration efforts, some others relate directly to MA case study, such as the terminal layout configuration.

4.2.1 Identification of Hardware Configuration Variables

This section illustrates the importance of defining configuration variables especially in addressing the solution of the airport HRP.

Two classes of variables mainly affect the check-in hardware configuration:

i. Those represented by the resources responsible for the delivery of the check-in processes;

ii. Those related to the resource arrangements, so that the operation can perform according to the airport targets.

The former of these classes includes the technology portfolio that can be installed at the airport; the second one refers to the layout and disposition of the technology portfolio available.

The final outcome of the hardware configuration design is completely dependent on these variables.

4.2.2 Generation of configuration options

This section illustrates a generating method for different check-in configurations at MA.

The alternative configuration options investigated for the check-in have been grouped -according to the variables' nature (arrangement and technology §4.2.1)- in:

i. Layout options – relating to physical positioning and orientation of resources e.g. number of check-in desks per unit area.
ii. Resource options – relating to what resources are needed in check-in services e.g. self-service kiosks, luggage conveyors etc.

Three different contributions have been exploited to generate configuration portfolios:

- The investigation of other European airports layouts;
- The research of alternative equipment available in the market;
- The design of a tool proposed at MAG and used during the workshop, to generate alternative configurations able to meet the functional requirements of the check-in operation.

4.2.2.1 Configuration design

In order to generate new configuration options for MA layout, seven European airports have been selected and their layout configurations investigated. These 7 airports were selected based on the similarity of their annual traffic of passengers with MA (18 Million/year), as shown in Table 4-I.

Appendix H includes all the details collected about these airports, information gathered from the airport official websites and the annual reports published on-line.

This comparison of airports is meant to:

1. Seek existent alternative configurations which might be installed at MA in the future;
2. Highlight possible correlation between the check-in hall layout, the technology installed and the consequent check-in operation performances.

To achieve the last purpose a simplified approach has been adopted: the number of check-in counters installed in the terminal has been associated with the resources' layout. Moreover, some data on the annual air-traffic, number of airlines operating at the airport, number of runways, number of check-in counter has been collected. This data has been matched with the amount of resources in the check-in hall and their layout.

Airport	Location	Passengers/year
Vienna International Airport	Vienna	19691206
Sheremetyevo International Airport	Moscow	19123007
Oslo Airport Gardermoen	Oslo	19091113
Düsseldorf International Airport	Düsseldorf	18988149
Malpensa Airport	Milan	18947808
London Stansted Airport	London	18573803
Dublin Airport	Dublin	18431625
Manchester Airport	Manchester	17759015
Brussels Airport	Brussels	17181000
Stockholm-Arlanda Airport	Stockholm	16962416
Athens International Airport	Athens	15411099

Table 4-I Airport comparable with MA in term of passengers' traffic a year

While looking for numerical information on the check-in counters, their layout and on other infrastructural characteristics, the investigation for new technologies and layouts has also been undertaken. For this purpose, other airports around the world have been studied.

4.2.2.2 Technology Portfolio Design

This section illustrates the tool proposed to MAG to generate new configurations and to ensure their ability to meet the operation's functional requirements.
The tool proposed in section 2.3.4 can be exploited following two different methods.

4.2.2.3 Use of Tool (I)

Method (I) takes future scenarios as inputs and outputs the required changes for the existing resources in the process. Use of the tool with method (I) is a five-step procedure summarised in Figure 4-II.

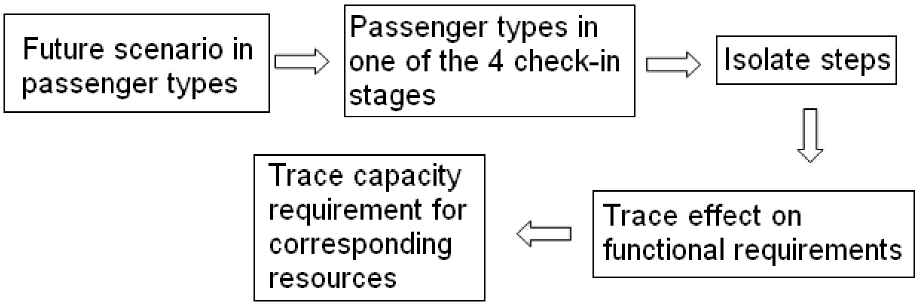

Figure 4-II General procedure for use of tool (I)

The steps to follow for the correct use of the tool are the following:

1. Translate future scenarios into effects on the proportion of certain passenger types.
2. Identify the relevant passenger types in one of the four stages of check-in.
3. Trace the steps they take through the stages and isolate steps unique to those passenger types.
4. Trace the change in demand on the functional requirements derived from the steps.
5. Trace the effect on capacity requirements for the corresponding resources.

An example is given to show the usage of the tool. The future scenario assumed in step one is the impact of an increase in the volume of overweight luggage (as described in 2.4.2.2). As a result, the proportion of one or more defined passenger type(s) will increase in a particular stage. The identification of the characteristics relevant for the upcoming scenario is part 1 of the five-step procedure. Parts 2-5 of the method (I) are easy to identify directly from the tool interface shown, with the data set for this example, in Figure 4-V where the impact of the scenario is traced in grey shading.

4.2.2.4 Use of Tool (II)

Method (II) takes alternative process resources as inputs and outputs the combination of these resources that forms a complete resource configuration option.

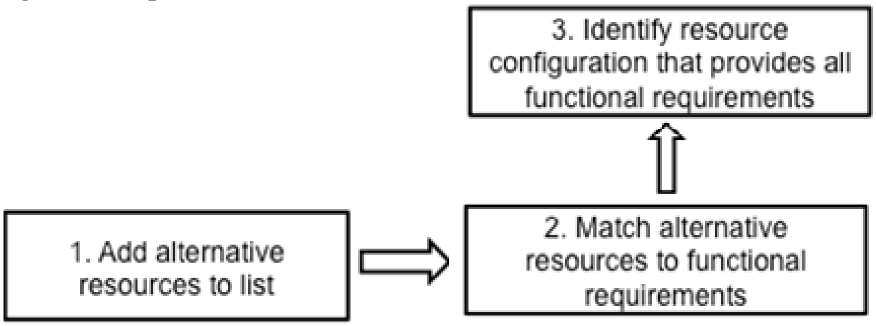

Figure 4-III general procedure for use of tool (II)

Figure 4-III summarizes the steps to follow the correct use of the tool. Use of the tool with method 2 is a three-part procedure:

1. Add alternative resources to the existing resource list.
2. Match these new resources with the functional requirements they cater for.
3. Identify a resource configuration that provides the whole range of functional requirements.

Figure 4-IV summarises the two different outputs obtained using the two methods (I) (II).

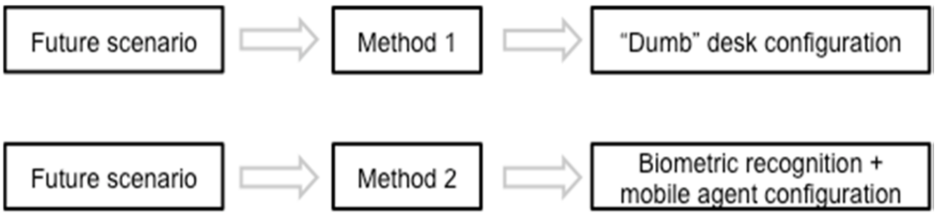

Figure 4-IV Comparison of two methods of using the tool

Part 2

Part 3

Luggage?	Luggage exceeds ticket limit?	Pay extra fee?												
N	N/A	N/A												Exit bag drop process
Y	N	N/A		Queue at desk	Show flight information	Show ID	Weigh luggage				Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	Y		Queue at desk	Show flight information	Show ID	Weigh luggage		Request baggage fee	Register payment	Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	N		Queue at desk	Show flight information	Show ID	Weigh luggage	Reduce baggage weight			Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Functional Requirements				Waiting for check-in desk	Communicate information	ID verification	Weight measurement	Space for opening luggage	Communicate information	Payment registration and receipt generation	Generate unique luggage identifier	Attach identifier to luggage	Path for luggage transfer	Path for passenger flow to security
System resources	**Subsystem resources**													
Check-in desks	Handler				x	x			x			x		
	Graphical user interface GUI				x									
	Luggage tag printer										x			
	Boarding pass printer													
	Passport scanner					x								
	Feeding luggage conveyor						x						x	
	Area around check-in desks			x				x						x
Customer service desk	Agent									x				
	Debit/credit card reader									x				
	Area around customer service desk													

Part 5

Part 4

Figure 4-V Impact on stage 3 of increasing number of passengers without hold luggage

Luggage?	Luggage exceeds ticket limit?	Pay extra fee?												
N	N/A	N/A												Exit bag drop process
Y	N	N/A		Queue at desk	Show flight information	Show ID	Weigh luggage				Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	Y		Queue at desk	Show flight information	Show ID	Weigh luggage		Request baggage fee	Register payment	Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Y	Y	N		Queue at desk	Show flight information	Show ID	Weigh luggage	Reduce baggage weight			Print luggage tag	Tag luggage	Check-in luggage	Exit bag drop process
Functional Requirements				Waiting for check-in desk	Communicate information	ID verification	Weight measurement	Space for opening luggage	Communicate information	Payment registration and receipt generation	Generate unique luggage identifier	Attach identifier to luggage	Path for luggage transfer	Path for passenger flow to security
System resources	**Subsystem resources**													
Check-in desks	Handler	*			x	x			x			x		
	Graphical user interface GUI	*			x									
	Luggage tag printer										x			
	Boarding pass printer													
	Passport scanner	*				x								
	Feeding luggage conveyor						x						x	
	Area around check-in desks			x				x						x
Customer service desk	Agent									x				
	Debit/credit card reader									x				
	Area around customer service desk													

Figure 4-VI Impact on stage 3 of increasing number of passengers without hold luggage

Checked-in online?	Printed boarding pass?	Prefers self service kiosk?	International flight?											
Y	Y	N/A	Y											Proceed to bag drop
Y	N	Y	Y		Queue for kiosk		Enter booking details		Scan passport				Print boarding pass	Proceed to bag drop
Y	N	N	Y			Queue for desk		Show booking details	Scan passport				Print boarding pass	Proceed to bag drop
N	N/A	Y	Y		Queue for kiosk		Enter booking details		Scan passport		Select seat		Print boarding pass	Proceed to bag drop
N	N/A	N	Y			Queue for desk		Show booking details	Scan passport			Seat allocated	Print boarding pass	Proceed to bag drop
Y	Y	N/A	N											Proceed to bag drop
Y	N	Y	N		Queue for kiosk		Enter booking details						Print boarding pass	Proceed to bag drop
Y	N	N	N			Queue for desk		Show booking details		Show photo ID			Print boarding pass	Proceed to bag drop
N	N/A	Y	N		Queue for kiosk		Enter booking details				Select seat		Print boarding pass	Proceed to bag drop
N	N/A	N	N			Queue for desk		Show booking details		Show photo ID		Seat allocated	Print boarding pass	Proceed to bag drop
Functional Requirements							Communicate information	Communicate information	ID verification	ID verification	Communicate information	Communicate information	Issue boarding pass	
System resources	Subsystem resources													
Check-in desks	Handler	*								x	x	x		
	Graphical user interface GUI	*						x						
	Luggage tag printer													
	Boarding pass printer												x	
	Passport scanner	*							x					
	Feeding luggage conveyor													
	Area around check-in desks													
Alternative systems	Alternative subsystems													
Retina/Iris imaging	Eye scanner								x	x				
Mobile agent	Handler									x	x		x	
	Mobile check-in device (eg. tablet pc)						x	x			x	x	x	

Part 1

Part 2

Part 3

Figure 4-VII Alternative resource configuration to replace existing resource configuration at stage 2

4.2.3 Definition of Key Performance Indicators

This section discusses the need for Key Performance Indicators KPIs and the technique used to define them for the check-in operation.

The definition of KPIs is fundamental to compare different configuration options and to select the one to implement for the check-in operation. Hence, using the tool many configurations can satisfy the same requirements, but one (or some) guarantees better performance. Therefore, a selection among the alternative portfolios of technologies has to be done. The different performances that can be obtained by the configuration implementations are the drivers of this choice.

Performance is the ability to carry out a task or fulfil some requirements or claims. The check-in operation's performance is related to moving travellers and their bags through the check-in hall. Comfort, convenience, costs, and atmosphere can be some indicators of the performance, but there is no general acceptance of what constitutes adequate terminal building performance.

Indicators had to be designed due to the lack of universal definitions for KPIs that became apparent from the literature and discussions with MAG. During the workshop with MAG managers the proposed KPIs have been commented, emended and finally re-defined and confirmed as KPIs for the check-in systems. An inspiration for the formulation of check-in KPIs has been the framework for KPIs, reported in the Appendix I, presented by C. Lemer (Lemer, 1992), who classified the check-in performances in three classes considering the passengers, airlines, and the airport operators points of view. The initial definition of KPIs proposed to MAG was composed of two separate categories, as shown in Figure 4-VIII:

i. Configuration KPIs – criteria measured when a configuration is set up and operating.
ii. Reconfiguration KPIs – criteria measured when transitioning between configurations.

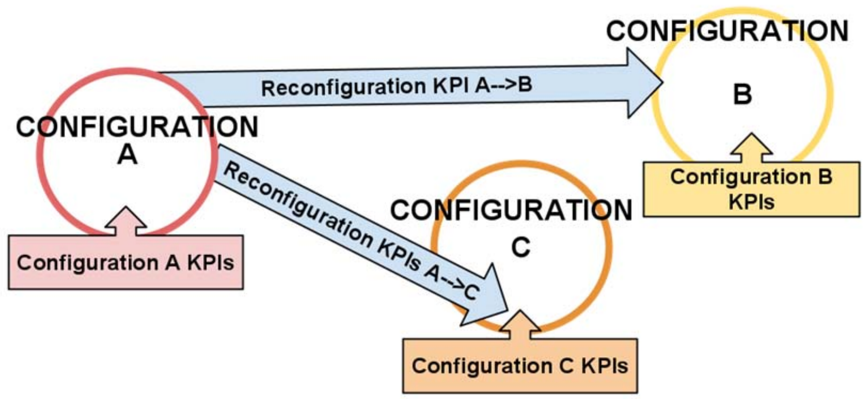

Figure 4-VIII Configuration and Reconfiguration KPI

The reason for two separate categories is that both the "state" and the "transition" are important selection criteria. The changes occurring while moving from the current configuration are show in Figure 4-VIII as the arrows emanating from configuration A.

The comparison and consequent selection of the next configuration for the check-in hall can be carried out through a "KPI table" containing the alternative configurations as the columns and the configuration and reconfiguration KPIs as the rows.

	Configuration1		Configuration2		Configuration3		Best configuration
Configuration KPI 1	..£	..%	..£	..%	..£	..%	1
Configuration KPI 2	..£	..%	..£	..%	..£	..%	3
Reconfiguration KPI1	..£	..%	..£	..%	..£	..%	1
....	..£	..%	..£	..%	..£	..%	..
	Tot £		Tot £		Tot £		1

Table 4-II Configurations Comparison by the use of KPIs

Table 4-II can be used in two different ways. The first way gives an absolute value for each configuration through the assignment of unique metrics, for example cost [£]. This can be used to estimate the performance of the configuration in relation to the indicator under consideration. This procedure requires the definition of a unique measurement standard to associate to all the indicators.

The second method is a "relative evaluation" of the configurations' performances. Since each KPI for the configurations are compared among themselves by a relative value, expressed either as a percentage or by ranking, the choice of the configuration to implement in the system could be the one recorded as the best most frequently.

Once the optimised configuration is selected, the changes and efforts required to reconfigure the system need to be identified. Hence for a detailed reconfiguration process planning must be expressed: the amount of the investment, construction works, time and resources needed.

4.2.4 Reconfiguration efforts assessment

This section illustrates a method to assess the effort of the move from one configuration to the next one selected through KPI measurement.

The objective of this section is to examine a methodology to support the de-coupling/ rearrangement/ re-coupling steps of the reconfiguration process, illustrated in section 3.8 (McFarlane D., 2008a). These three steps of the reconfiguration process require the identification of the configuration components interactions and relationships. Hence, before undertaking a reconfiguration it is necessary to gain a clear knowledge about the component to replace/remove/add and the connections to remove/modify/introduce among them. A first attempt to identify the relationships occurring among the system's components has been done in section 2.4, by the UML Class Diagram, which also allows distinguishing the nature of the interactions in association, aggregation or composition. Although a Class Diagram contains all the basic information about the classes and their interaction, it cannot be used to assess the necessary modifications or measure the ease of reconfiguration. A method to address the reconfiguration process and evaluate the ease of reconfiguration has been proposed in (McFarlane D., 2008b) and is based on the use of the Design Structure Matrix (DSM). A DSM displays the relationships between components of a system in a compact, visual, and analytically advantageous format.

A DSM is a square matrix with identical row and column labels and provides insights into how to manage complex systems or projects, highlighting information flows, task sequences and interactions. The first step to design a DSM is to map onto matrix the system boundaries and the components (facilities, machines,…). The UML Class Diagram has been used to identify the classes, i.e. the components, considered important to insert in the DSM for this purpose. The matrix structure can be described by the following:

- The rows and columns are the elements of the system;
- An off-diagonal mark signifies the dependency of one element on another. Reading across a row reveals what other elements the element in that row leads to;
- Scanning down a column reveals what other elements the element in that column depends on (dependency relationship), while reading across a row indicates the output influenced (causal relationship).
- Elements along the diagonal are represented by the shaded elements;

The interactions between the elements can be of different natures, and it is important to specify the interaction type to measure the effort required in the reconfiguration when two elements are de-coupled or re-coupled. Pimmler et al. (Pimmler T. U., 1994) suggested four types of interactions, as shown in Table 4-III.

Type of interaction	Meaning
Spatial	Associations of physical space and alignment, needs for adjacency or orientation between two space elements
Energy	Needs for energy transfer/ exchange between two elements
Information	Needs for data or signal exchange between two elements
Material	Needs for material exchange between two elements

Table 4-III Type of interaction in a DSM

Referring to the configuration process (McFarlane D.,2008a) in
Figure 4-IX only steps 4 to 7 are considered through the DSM to evaluate the effort of reconfiguration. On the other hand, the effort required in Step 5 can be evaluated by calculating the complexity, which together with the DSM results is proportional to the effort required to perform Step 7.

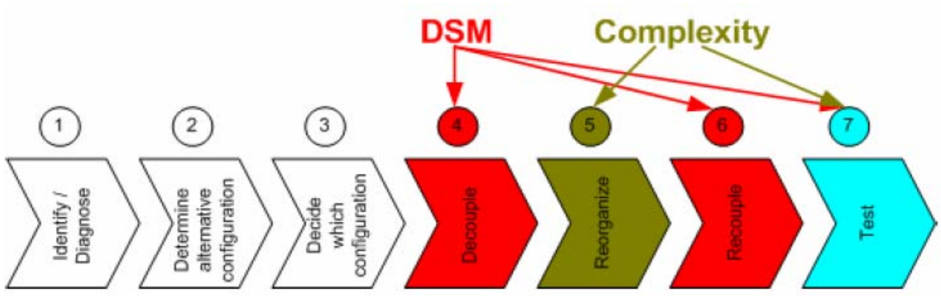

Figure 4-IX Reconfiguration process, DSM and Complexity measurements

In the decoupling step, step 4, some modules are disconnected from the system and either removed or moved to other parts of the system. To disconnect the interfaces the manufacturing system must be decoupled. Since this phase mainly relates to the interfaces, the DSM can be used to capture the effort required to perform decoupling. However, when the new interfaces between the disconnected or the newly added modules and the other modules in the system are to be created, the DSM structure changes and can hence be used to capture the effort required to perform re-coupling.

If two DSMs one for the current configuration and one for the future selected configuration are designed and compared among them, the consequences from the changes within the configuration elements can be highlighted.

The differences between the two matrixes, in terms of interactions existing with other elements, correspond to the changes that will occur in the check-in operation due to its reconfiguration. Some of these elements are the same for the two configurations, old and new, and represents those system parts that are not replaced, however, due to other modifications; their interactions can be affected as well.

4.3 Result of the reconfiguration design

This section reports the results obtained by following the approach presented in the section 4.2.

4.3.1 Hardware configuration variables

In this section, the configuration variables that had to be taken into account while designing the check-in configurations are discussed.

The variables to consider in the technology are more precisely represented by the:

i. Type of service to be accomplished from the technology asset, e.g. full service, self-service, online/off-site check-in, single or split process of bag dropping;
ii. Process parameters such as service-time length, familiarity of the passengers, reconfigurability, cost, reliability of the asset ...;
iii. Operational benefits such as staff reduction, flexible layout, and simpler infrastructure;

iv. Reconfigurability in order to enable the configuration adjustment to external and future changes.

The variables to consider in the layout design are:

i. Level of integration of the technology equipment with the infrastructure;
ii. Accessibility for the passengers;
iii. Interferences and connections with other operations;
iv. Reconfigurability in the arrangements in order to organize the resources into different layouts.

Given the importance of reconfigurability as a variable in the check-in configuration design, for the reasons given above, particular attention has been dedicated to identifying the reconfigurability key features.

To ensure the accomplishment of reconfigurability in the system the key features to include in the configuration design have been investigated.

These key features have been identified by applying the concepts offered by the manufacturing reconfigurability literature. In particular this section analyses the four key features (diversity, modifiability, responsiveness and fault tolerance) proposed by (McFarlane D., 2008a).

Table 4-IV summarizes the reconfigurability key features meanings. For each feature the major trend that motivates its presence in the configuration is identified. This table also proposes a conceptual configuration solution of that specific feature.

To be known as reconfigurable, a configuration should be provided with all those four key features. To clarify the meanings of these features a configuration example stressed on each feature is proposed (different level of check-in reconfigurability corresponds to different ways to implement these features.) Moreover, a measure of time and cost to implement the solution are estimated.

The cost-indications are meant to identify the main type of investment needed to implement the solution proposed. Arrangement cost refers to cost incurred in the (re) arrangement of the current resources given the current infrastructure configuration, infrastructural cost refers to the cost due to modification in the infrastructure and technological cost to the cost acquisition of new equipment.

	Definition	Trend	Configuration solution		
			Concept	Time	Cost
Diversity	The ability to manage multiple type of passengers streams.	Wider range of airlines and differentiation in the traveller expectations.	Customisation of the terminal areas, equipment arrangement in order to differentiate the offer and provide *ad hoc* services	$\propto months$	Arrangement
Modifiability	The ability to support ready integration or reorganization of the process itself or of the other occurring in the terminal.	Technology push, passenger requirements, changing in the external rules.	Reduction of the interferences technologies/infrastructure, weak connection among the elements, deletion of technologies dependencies among each other.	$\propto years$	Technological and infrastructural
Responsiveness	The ability to provide a timely response to changes in passenger volume.	Variations in demand, due to increasing number of flights/routes or of the aircraft size.	Portable devices to issue the boarding pass, sharing desks policy among airlines, common use desks and distributed locations to check-in.	$\propto months - year$	Arrangement, infrastructural and technological
Fault-tolerance	The ability to tolerate disruptions or disturbances	External disturbances and departure delays not caused by check-in but that carries to extra congestion in the operation.	Introduction of "emergency/last minute" check-in desks or portable devices to issue the boarding pass.	$\propto month$	Technological and arrangement

Table 4-IV Reconfigurability features for the check-in system

4.3.2 Configuration design solutions

In this section the results obtained from the investigation about the airports layouts and check-in technology, as well as the results arose from applying the tool described in section 4.3.1 are discussed.

The section is organised in two parts. The former of them contains the conclusions derived from the airport comparison and the configuration options proposed for MA layout, both for the traditional check-in counters and the self-service kiosks. The second section summarises the options arose by the use of the tool.

4.3.2.1 Layout solutions

Some general conclusions originated from the comparison of the airport layouts; however, the difficulty of gathering accurate information about the terminals, particularly on the halls meter square extensions and amount of resources available, has blocked the research.

The conclusions derived from this comparison are the followings:

i. Two alternative layout options detected for the current check-in counters exist, the so-called "frontal" and "island". "Frontal" type counters are usually placed along the wall. The arrangements of these counters could be uninterrupted or separated. The uninterrupted arrangement is called linear type, and the counters are placed side by side. The separated arrangement, "pass through" type, allow passengers to walk through after check in due to the presence of space between the counters. The "island" type consists of a number of counters in one location. This type of counters usually consists of 10 – 15 individual counters. If the installed baggage conveyor belts are doubled, i.e. two conveyor belts are placed close to one another, the total number of counters can be doubled as well.
ii. A variety of options in allocating the operations within the terminal area is available. The terminals where the operations are positioned in rows seem to facilitate the flow of passengers and are assumed to be better performing configurations.

This last consideration motivated the design of a new configuration for MA check-in hall even keeping in use the traditional check-in counters. The layout modification has been developed for MA T1, where a critical blockage in the passenger flow has been noticed during the visits at MA and confirmed by MAG.

In the current layout of check-in at MA Terminal 1, the main luggage conveyor belt behind the check-in desks is a physical constraint to letting passengers pass through the check-in area to the security. Hence, the presence of the conveyor behind the desks forbids the straight flow of passenger after the check-in. This forces the passenger flow to move around the check-in area to move from check-in to security, as shown in Figure 4-X.

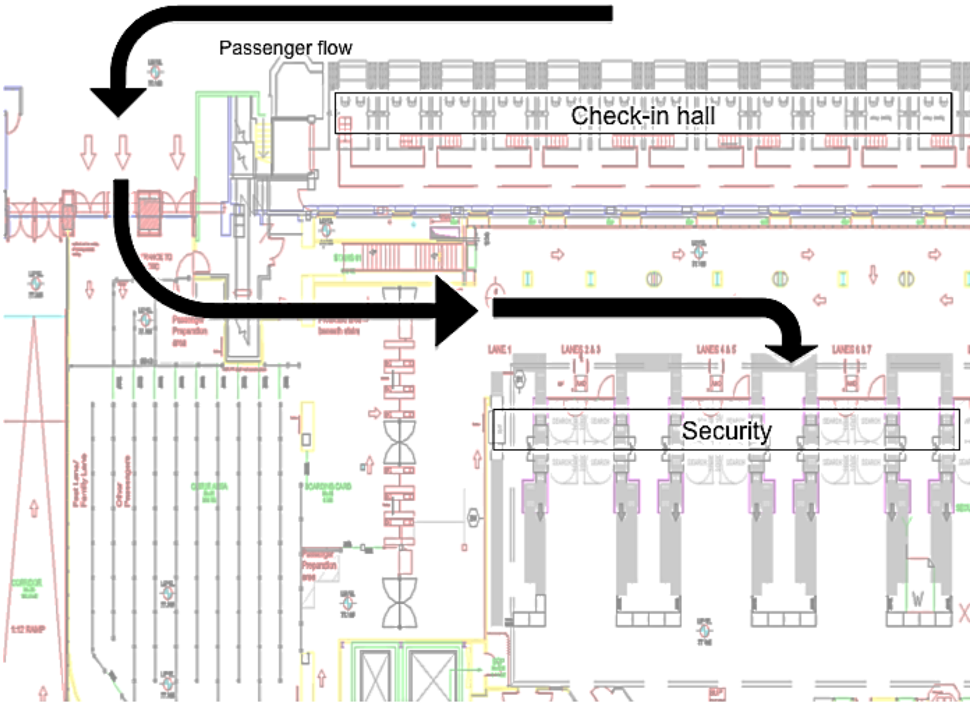

Figure 4-X Part of current floor plan for Manchester Airport terminal 1. Origin: Tim Ward, MAG. Adapted to show current passenger flow

To increase the throughput and facilitate the flow of passengers allowing them to and move directly to security the check-in counters should be re-arranged. According to ICAO Airport Planning Manual (1987), an alternative configuration that would make easier the passengers flow is the counters disposition called “pass through” and showed in Figure 4-XI.

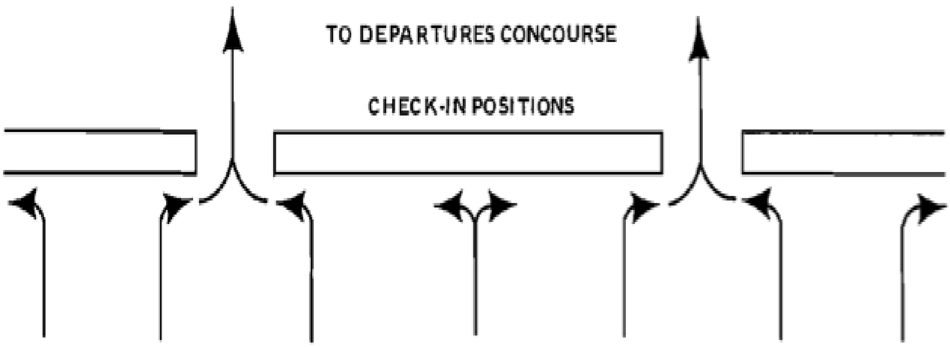

Figure 4-XI Pass-through Check-in Configuration

To modify the check-in configuration, the check-in counters should offer to passengers a way of getting past the main luggage conveyor belt behind the check-in desks. The new layout can be achieved by building the main luggage conveyor belt below the check-in floor and using the feeding luggage conveyor belts to transfer luggage downwards.

This alternative configuration would offer a shorter walking distance for passengers and greater surface area for transfer between the two processes, as shown in Figure 4-XII. The throughput might be increased and passengers' average dwell time in the free duty shopping area of the terminal could increase. The feasibility of such a reconfiguration would need further investigation since it requires a significant infrastructural change to the check-in process.

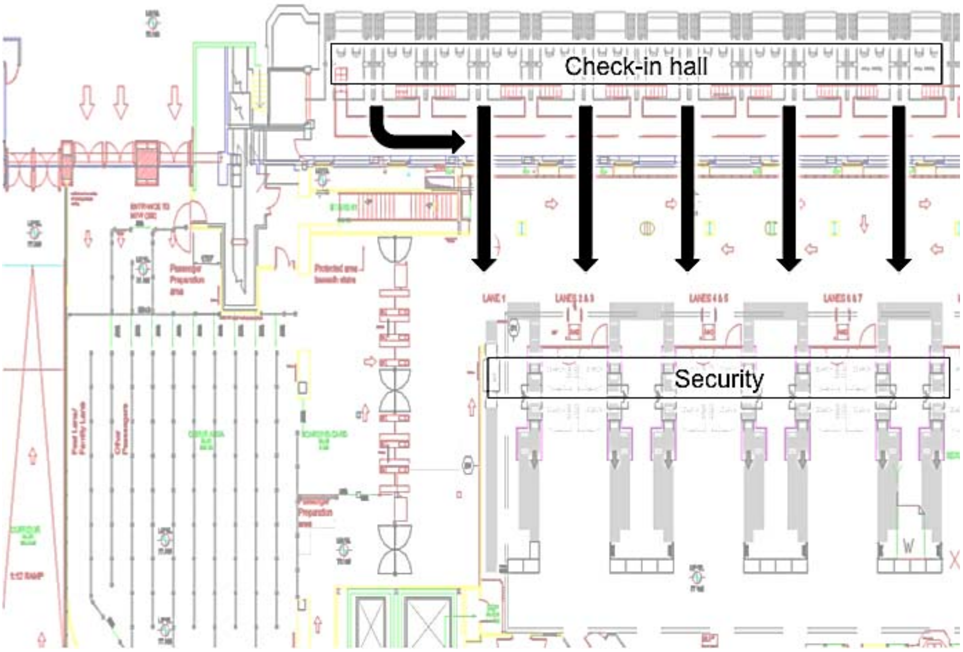

Figure 4-XII Part of current floor plan for Manchester Airport terminal 1. Origin: Tim Ward, MAG. Adapted to show potential passenger flow

The replacement of the traditional check-in counters with self-service kiosks does not require the implementation of the previous layout configuration proposed. Kiosks would change the entire configuration of the check-in hall.
Self-service kiosks seem to guarantee a more flexible configuration, compared to the traditional counters rigidly connected with the bag conveyor. Self-service kiosks are more compact and require less space in comparison to the same number of check-in desks, because they are not physically connected with the bag conveyor that leaves more flexibility in the resource allocation.
Since the connection with the conveyor belt could be removed, the future configurations derived from the use of self-service kiosks would probably all become "pass through" type.
Other arrangements of the self-service kiosk and bag-drop have been observed in Munich Airport, Marseille Airport and London Heathrow.
Those resource dispositions are illustrated in Figure 4-XIII, Figure 4-XIV and Figure 4-XV, are considered adaptable at MA terminals for the future.

Check-in and Bag Drop I (Installed at Munich Airport)

Single stage process:

- *Full service counters replaced with kiosks.*
- *Boarding Card and Bag Tag Printing. Scale and Payment.*
- *Bag Collector Belts retained*
- *Sit within footprint of traditional check-in desk*
- *Same queuing areas provided as for traditional check-in*
- *No staff required for bag drop security*
- *One bag belt island currently equipped this way.*
- *Approx 25% of all check-in is kiosk based.*

Figure 4-XIII Example of Check-in and Bag Drop configuration

Check-in and Bag Drop II (Installed at Marseilles Airport)

Two-stage process:

(1) Check-in:

Traditional manned 'dumb' check-in desks
Weigh scales and payment function. No bag belt attached to the coutners.
Single line queuing for check-in
Flow: Passengers proceed thru desks to bag drop

(2) Bag drop:

Bag drop forms part of security queue.
Short queue to two fast bag drop "holes in wall"
2 bag drop positions for 12 check-in counters.
Very short processing times

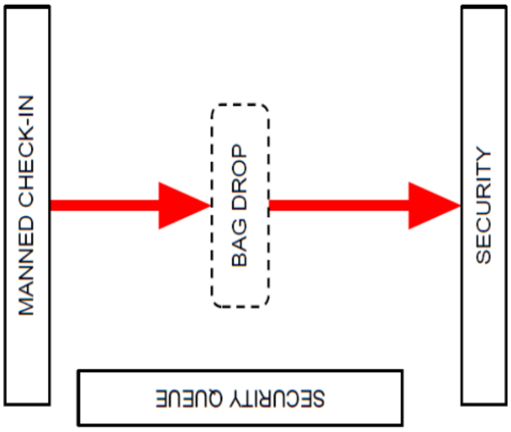

Figure 4-XIV Example of Check-in and Bag Drop

Check-in and bag drop III (Installed at London Heathrow)

Two-stage process

Passengers sorted at entrance by welcoming staff:
Traditional with agent (increasingly premium passengers only)
Kiosk and bag weigh
Fast bag drop only

<u>Check-in:</u>

About 15sqm per kiosk provided

<u>Bag drop:</u>

Traditional counters used for both premium check-in & bag drop.
Staff confirm bag weight and tag bag.
Overweight bags returned to kiosk or ticket counter.

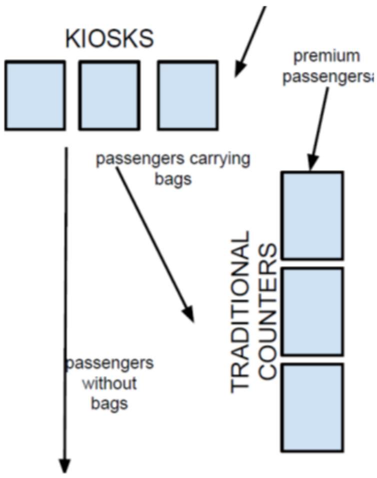

Figure 4-XV Example of Check-in and Bag Drop configuration

4.3.2.2 Solutions arose through the use of the tool

As summary of all the information collected from ideas discussed at the workshop with MAG and from use of the tool presented in section 4.2.2.2, this section presents the configuration alternatives likely to be implemented at MA.

Suggestions for reconfiguration, arising from the workshop with MAG, were found to have three basic approaches:

i. Decoupling of processes – separating process elements that currently occur at the same location.
ii. Coupling of processes – joining process elements that currently occur at different locations.
iii. Modification of the process – changing elements of the existing process.

Decoupling of Process Elements:

Check-in prior to airport

Check-in could be performed prior to reaching the airport. No particular method of check-in was specified, so this option could include any method as long as it takes place off the airport premises removing the need for any check-in halls.

Separate check-in from bag drop

The bag drop process could be physically separated from the check-in process. Bag drop could be performed elsewhere within the airport or even at remote locations such as train and bus stations. This concept could be extended to remote bag collection where airlines or handlers collect passenger's luggage from their accommodation (e.g. from hotels for premium service passengers).

Separate airline touch point from bag drop

Airlines could have a separate location in the airport where they register the presence of their passengers somewhere other than at bag drop. It was suggested that the touch point be prior to bag drop so that passengers can be directed within airport at the earliest instance after their arrival.

Self-bag tagging

Passengers would generate their own luggage tags at self-service kiosks in the airport and attach them to their luggage themselves. Passengers would then proceed to deposit their luggage at a self-service bag drop facility where the luggage tags are scanned and reconciled with boarding passes. Luggage is then weighed, measured and dispatched to the relevant flight without any agent intervention.

Coupling of Process Elements

Merge security and check-in

Merging the check-in process with the security process could improve operational efficiency by taking advantage of current non-value adding time at the check-in desk. The possibility of performing security scans on the passenger and their hand luggage while they wait at a check-in desk during the check-in process would convert the waiting time into value added time. However, the details of this solution need deeper consideration of whether the time needed to perform both check-in and security scan can be balanced, such that neither of the processes deters the speed of passenger flow. Further to this, the technology and equipment to perform a security scan would need reviewing to assess whether it can be physically implemented adjacent to a check-in desk.

Flexible check-in desks

Flexible check-in desks would allow any passenger to check-in at any desk for any flight. This solution is coupling in the sense that all airlines' needs (with regard to check-in services) would be consolidated into a single check-in area and the service is likely to be provided by a single handler on behalf of all airlines. A homogenous check-in service would reduce the opportunity for airlines to differentiate themselves at check-in.

Modification of Process Elements

Paperless check-in

Paperless check-in would transform documentation into an electronic form. This is already done in some airports (e.g. La Guardia, New York[20]) where boarding passes are sent to a passenger's mobile phone in the form of a Multimedia Messaging Service (MMS) containing flight and passenger details together with a machine readable barcode image. This can also provide paperless boarding where passengers scan their boarding pass image to board an aircraft with minimal handler involvement.

Mobile Ticketing Technology

Many airlines already offer check-in and boarding information to be sent directly to mobile phones, and use barcodes on home-printed boarding passes. It is also possible to send a unique two-dimensional (2D) barcode to a mobile phone, and read it directly from the screen using imaging technology. The code can be scanned from any direction and no space is required around the code. The code has built-in error correction, which makes it a good choice for paper tickets as well.

Reusable personal bag tags (RFID)

Current paper luggage tags with thermal barcodes could be replaced with reusable RFID luggage tags containing the same information in an electronic form. The potential of RFID tagging removes the need for paper documentation and may enable improvements in baggage handling systems downstream since scanning no longer relies on line of sight with paper barcodes.

Mobile agents

Check-in agents equipped with wireless electronic devices[21] could check-in passengers without being constrained to a specific physical location within the airport. This would allow flexibility of positioning check-in services in the airport and may eliminate the need for fixed

[20] Waddell, G. (August 2008) http://businesstravel.com

[21] These types of handheld device are being developed by ARINC, http://www.arinc.com.

check-in desks. Boarding passes would be printed or issued electronically by the device wherever it is located.

Biometric identification

Biometric identification technologies could be used to replace current identity verification. Passengers currently verify their identity by scanning passports or showing other photographic identification documents. Biometric identification makes use offingerprinting, iris recognition or facial recognition technologies in the future.

4.3.3 Defined KPIs defined for the check-in operation at MA

This section reports the KPIs defined for the check-in operation at MA. Through the workshop with MAG these KPIs have been discussed and emended in order to generate a different classification of the KPIs. The distinction between configuration and reconfiguration KPIs is still valid, but new indicators have been selected.

In the first set of KPIs proposed, for each configuration and reconfiguration KPIs subset, four classes have been proposed: time, space, human resources and equipment. Some physical indicators thought to be representative of the performance of the check-in configuration and reconfiguration have been listed for each class during the workshop. This was in terms of time, space, human and equipment resources. The physical indicators were then translated into financial indicators. Consequently, it is possible to refer to all the indicators with a unique measurement unit and thereby facilitate the comparison of configurations. For example, a physical KPI for the reconfiguration for the time-class is the time spent in implementing the new configuration, and its financial translation is the cost due to system stop. A physical configuration KPI always belonging to the time-class is the average time spent by a passenger to reach the shopping area, and its financial translation is an opportunity cost of time spent in the shopping area. Appendix L reports the KPI tables initially proposed at MAG. Through the discussion with the airport managers, those KPIs have been modified and a new set of indicators has been defined. The new set of KPIs, as illustrated in 4.3.3.1and 4.3.3.2, keeps the distinction between configuration and reconfiguration KPIs.

4.3.3.1 Configuration KPIs

This section reports the list of configuration KPIs as derived from the workshop with MAG through the discussion and interviewing of MA managers.

Configuration KPIs are further divided into two groups:

i. Indicators relating to resources enabling the check-in process, classified as: Overall Equipment Effectiveness (OEE), Airport Management Time, Operator Performance, Duplication of Operation and Redundancy;
ii. Indicators relating to output of the check-in process, classified as: Throughput, Passenger Experience and Luggage Handling.

The meaning of the resource KPIs is summarized in Table 4-V.

KPI	MEANING
OEE	• Resources 'availability • Speed of process passengers • Quality, i.e. number of passengers processed correctly
Airport Management Time	The time required from airport management staff to: • Maintain the system's hardware and software • Manage relationships with the airlines
Operator Performance	The ability of operators to run the process in the particular configuration
Duplication of Operation	The duplication of operations that may be required by a particular configuration may increase the time taken to process passengers, e.g. passengers having to show their passport once to obtain a boarding pass at a self-service kiosk and once again at a check-in desk to generate luggage tags.
Redundancy	The ability of the system to maintain operation when parts of it breakdown.

Table 4-V Configuration Resource KPIs

The output KPIs required a more detailed explanation, given as follows:
Throughput: The number of passengers and luggage items processed per unit time by the check-in process. For the airport, increased throughput is likely to be reflected in passengers spending more time airside rather than landside of the terminal which results in increased monetary spend per passenger in the retail, catering and lounges area of the terminal (Zhang Y., 1997).
Passenger Experience. The passenger experience through the check-in process is often an opportunity for airline's to differentiate themselves from each other, especially in the case of network carriers whose product offering to passengers is not homogenous. For example, Emirates have 1st class, business class and economy class passengers and specific desks to service each passenger class. The 1st class check-in desk does not service economy class passengers even if a queue forms at economy desks while the 1st class desk is available. Further to this, the check-in handler may deliberately take more time to check-in 1st class passengers, such that are given more attention and friendlier customer service.[22]
Luggage experience, which can also be considered as extension of the passenger experience. Reconfiguration of check-in services may impact how carefully luggage is handled, the check-in process and in processes further downstream. Luggage, like passengers, is also not necessarily homogenous as it could vary in size, weight and shape. This requires varying methods of handling at check-in e.g. luggage containing fragile items or luggage likely to jam the conveyor belts must be checked-in at baggage inspection desks. Luggage processing capability would need

[22] This method of service was confirmed by Swiss Port Handlers at Manchester Airport.

consideration in any configuration with regard to loss or damage of luggage items.

4.3.3.2 Reconfiguration KPIs

This section reports the list of reconfiguration KPIs as derived from the workshop with MAG through the discussion and interviewing of MA managers. Reconfiguration KPIs can be classified as:

Acquisition Cost. The cost of acquiring new equipment and resources for reconfiguring the process could consume a significant proportion of a budget for reconfiguration work. The importance of acquisition cost varies slightly with economic conditions. It is even more important during a recession eg. in 2008 when MAG were being capital rationed, which limited the available capital and made long term investments harder to justify. After the recession, it is possible to shift away from the pressure of limited capital and justify acquisition based on whole life costing which accounts for the cost of owning and maintaining the equipment spread over the entire useful life of the equipment.

Disposal Cost. Old equipment no longer needed by a new configuration might incur significant disposal costs if it is obsolete and cannot be sold again. Accounting treatment may or may not choose to ignore the residual value of equipment being disposed making it a sunk cost. In either case, there will still be some cost in removing this equipment from the airport.

Reconfiguration Process Cost. The process of reconfiguration itself will have some real costs and some opportunity costs. Real costs consist of the temporary extra labour and equipment needed for carrying out the reconfiguration at infrastructural level, e.g. the time taken for training operators and other stakeholders to adapt to the new configuration.

Opportunity costs consist of the time during which the airport cannot use the area being reconfigured and temporary disruptions to adjacent facilities or processes.

4.3.4 Check-in reconfiguration efforts

This section shows the results derived by using the approach suggested in section 4.2.4 to measure the reconfiguration efforts.

The elements of the check-in operation included in the DSMs have been grouped into 5 major classes: equipment set E.S, (which is subject to reconfiguration, and therefore is defined as equipment 1,2,3), layout & utilities, passengers (pax), aircraft and timetable. Table 4-VI shows the elements used in the designing of the DSMs. It is noted that some of the elements stay the same in both matrices.

The interactions among these elements can be of different nature. Based on the classification proposed by (Pimmler T. U., 1994) the types of interaction used in this work are illustrated in Table 4-VII.

E.S. 1	desk
	data system
	conveyor belt connection
	staff
E.S. 2	desks
	conveyor belt connection
E.S. 3	desk kiosk
	data system
	security gate
Layout & Utilities	conveyor belt
	queuing area
	electricity network
	equipment area
	additional space
Pax	passenger
Aircraft	aircraft type
	aircraft dimension
Timetable	number of flights

Table 4-VI Element of the check-in operation used in the DSM

The nature of the interaction influences the modifications needed during the reconfiguration. The comparison between the current and future configuration DSMs allows the identification of construction works and changes needed to achieve success in the reconfiguration. Indeed, comparing the two matrices cell by cell an easily identify the changes occurring between the systems. The higher the number of differences between the two, the higher the effort of reconfiguration.

To give an example, it has been assumed that the current configuration **E.S.1** will be replaced alternatively by two of the solutions proposed in section 4.3.2:

1. **E.S. 2**, which represents the configuration of the new pass-through layout proposed in section 4.3.2.1;
2. **E.S. 3**, which represents the combination of traditional desks with security gates (the security and check-in operations merged).

The first DSM presented is the one of the current configuration, in Figure 4-XVI.

Symbol	Type of interaction	Meaning
a	**Algorithm**	An algorithm is traditionally in defining the relationship
t	**Type Of Service**	The dependency is based on the type of service offer, i.e. the business model applied
n	**Dimension & Number**	The interaction is perceptible through a numerical value linking the elements
i	**Information/Data Shared**	Needs for data or signal exchange between two elements
m	**Material Flow**	Needs for material exchange between two elements
c	**Physical Connection**	Associations of physical space and alignment, needs for adjacency or orientation between two space elements
e	**Energy**	Needs for energy transfer/ exchange between two elements

Table 4-VII Nature of Interaction among DSM elements

The information to address the reconfiguration process that can derived are the following:

i. By scanning down the columns corresponding to the equipment replacement, in this case E.S.1, it is possible to identify the dependence relationships between E.S 1 and the other configuration elements. When E.S.1 is removed those dependent configuration elements will not be needed anymore (from E.S.1). Therefore, those elements can be deleted from the system, if not needed for any other purpose (this control is done by scanning the other columns).

ii. By reading across the rows corresponding to the equipment to replace, E.S.1, the causal relationships with the other elements can be identified, and with that the consequences of the removal of the E.S. 1 can be pictured.

		desk	data system	conveyor belt connection	staff	conveyor	queuing area	Electricity network	equipment area	additional space	passenger	aircraft type	Aircraft dimension	number of flights
E.S. 1	Desk		c	C	c		n		c					
	data system	c			i		n				i			
	conveyor belt connection		i			m	n		c		m			
	Staff		i				n				i			
layout&utilities	conveyor belt			m /c					c		m			
	queuing area										c			
	electricity network	e	e	e		e								
	equipment area	c		c	c	c	c			c				
	Additional space				t									
pax	Passenger	t	i	m	i/n /t		t			c /t		t	n	
aircraft	Aircraft type		i							t	t			
	aircraft dimension	n	i	n	n		n			n	n			n
Timetable	number of flights	n	n	n	n	n	n	n	n	n	n			

Figure 4-XVI Current Configuration DSM

On the other hand, focusing on the DSMs of the future configurations considered, Figure 4-XVI, Figure 4-XVII and Figure 4-XVIII the information that can be derived are the following:

i. By scanning down the columns corresponding to the new equipment to introduce, in this case E.S.2-E.S.3, it is possible to identify the dependence of relationships with the other configuration elements.

ii. To organise and re-couple the system, once E.S.2-E.S. 3 are introduced, the dependency-elements need to be arranged and settled in order to integrate and host the new equipment.

iii. By reading across the rows corresponding to the equipment to introduce, E.S.2-E.S. 3, the causal relationships with the other elements can be identified and with that the consequences of the reconfiguration can be pictured.

		conveyor belt	queuing area	electricity network	equipment area	additional space	passenger	aircraft type	aircraft dimension	number of flights	desk	data system	staff	conveyor belt connection
layout&utilities	conveyor belt				c		m							m/c
	queuing area						c							
	Electricity network	e									e	e		e
	equipment area	c	c			c					c	c	C	c
	Additional space												t	
pax	passenger		t			c/t		t	n		t	t	i/n/t	t
aircraft	aircraft type					t	t							
	aircraft dimension		n			n	n			n	n	n	n	n
Time table	number of flights	n	n		n	n	n				n	n	n	n
E.S. 2	desk		n		c							c	c	c
	data system	c			i		n				i			i
	staff		n				i				i	i		
	Conveyor-belt connection	m	n		c							i		

Figure 4-XVII Future Configuration DSM for E.S. 2

		conveyor	queuing area	electricity network	equipment area	additional space	passenger	aircraft type	aircraft dimension	number of flights	desk kiosk	data system	security gate
Layout & utilities	conveyor belt				c		m						
	Queuing area						c						
	Electricity network	e									e	e	e
	equipment area	c	c			c					c		c
	Additional space												
pax	passenger		t			c/ t		t	n		t	i	t
aircraft	aircraft type					t	t					i	
	aircraft dimension		n			n	n			N	n	i	n
Time table	number of flights	n	n		n	n	n				n	n	n
E.S. 3	desk kiosk		n		c							c	c
	Data system		n								c		i
	Security gate		n		c	n					c		

Figure 4-XVIII Future Configuration DSM for E.S. 3

All the mentioned changes that occur among elements of the system are labelled by the nature of the interactions. In this way it is possible to:

- Identify the modification and changes needed to move from one configuration to the other;
- Estimate the efforts of the reconfiguration, by counting the number, the number of changes that occurs in the cells that are the same between the DSMs of the future and current configuration. A more accurate estimation of the reconfiguration effort can be carried out if the relationship between the elements could be defined through cost and time values needed to de-couple, organise and re-couple them.

The use of DSM for measuring the reconfigurability of a service operation, such as the check-in, has never been explored before and the approach proposed is a first attempt to use the DSM to assess the reconfiguration process of a generic system. Further research can be developed especially to assign a quantitative meaning to the interactions and relationship identified, both in terms of time and cost involved in their reconfigurations.

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5 SOFTWARE RECONFIGURATION

Introduction

This chapter focuses on the check-in "software", which helps manage the capacity plan and management of resources exploited in the check in operation. The software configuration is the methodology by which the resources estimation and allocation is done. Figure 5-I summarises the structure of this chapter. Firstly, the persisting flaw in current software configuration in allocating resources is introduced. This is followed by developing a new methodology, which is applied in the MA case study to increase the capacity planning efficiency.

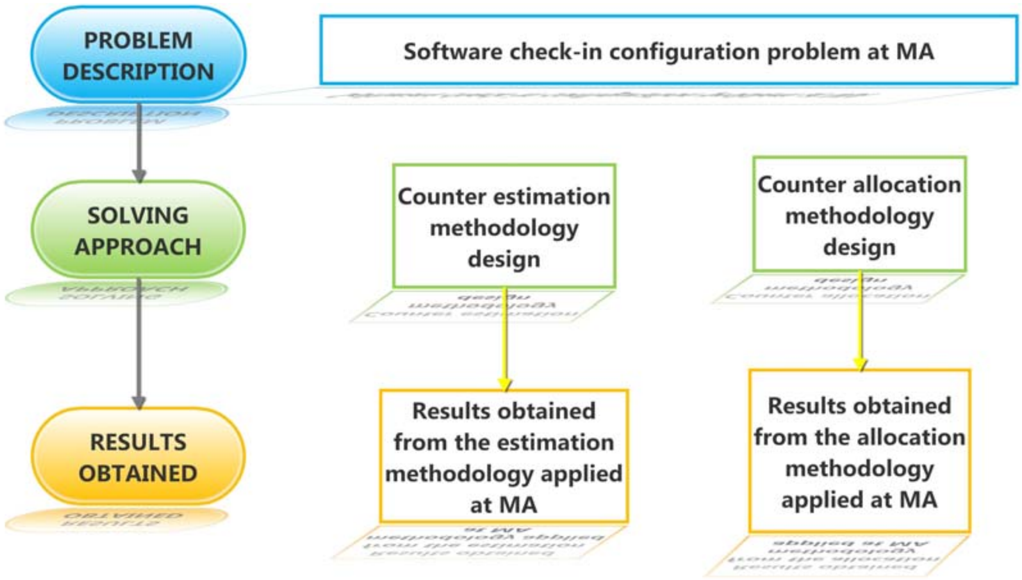

Figure 5-I Structure of chapter 5

5.1 Software Configuration Problem Definition

The problem observed at MA and discussed in this chapter is the lack of re-configurability of the check-in resource management, which leaves a high proportion of check-in desks underutilized.

The purpose of this chapter is to highlight this and propose solutions to increase the utilisation of the check-in counters without compromising customer satisfaction.

Two major limitations of the current applied software configuration at MA (already fully discussed in paragraph 2.5) are summarized below:

i. The current software configuration does not consider the variability in requirements of their customers that may be driven by evolving business models or changing passenger needs (for example the acceptable queuing time);

ii. The current software configuration does not deal with the dynamic aspects of traffic and the consequent variation in the resources required meeting the changing demand; this leads to either underutilisation or overloading of resources during peaks and troughs in demand.

In the proposed reconfiguration, optimization of the check-in financial performance, i.e. the cost, from the airport's point of view has been included in addition to the two limitations listed above. To our knowledge none of the software configurations applied by the airports have included all the three parameters listed above, which make this study distinguishable and novel in its approach.

5.2 Solution Approach

The problem is solved in two steps: estimation of the resources required and their allocation. This approach is summarised in Figure 5-II.

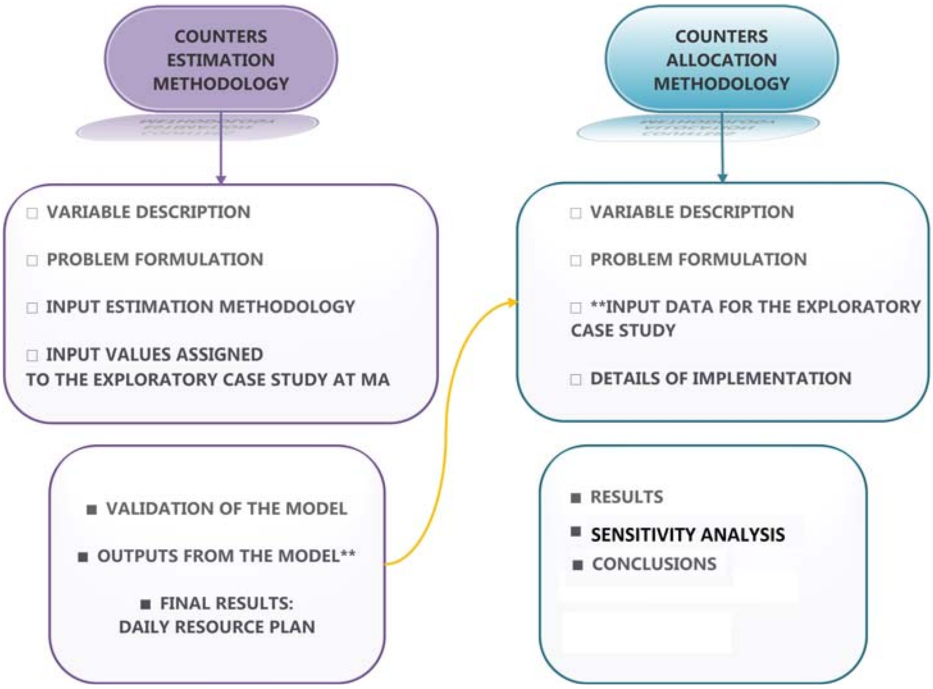

Figure 5-II Solution Approach

Following this approach, the objective of the first part of the software configuration design has been the development of a new resource estimation methodology. This methodology quantifies resources necessary for the airlines to operate the check-in processes by minimizing the financial requirements i.e. cost of the check-in operation for the airport.

In addition, this method includes external requirements imposed on the airports such as those coming from the airlines and passengers, and the operational parameters like arrival and service rates. Following this, the input data and variables to apply in the model have been identified and defined for the exploratory case study at MA.

Having calculated the resources required for a flight, the daily resource estimation and allocation is the next core objective of this chapter, which can finally provide information for longer time plans such as weekly and monthly schedules.

5.2.1 Variables description

The resource estimation consists of evaluating the amount of check-in counters needed by the airlines to process the passengers of a departing flight within a defined time period (generally 2-3 hours).

On one hand, the number of counters assigned to each flight should allow the airline to clear the passengers checking into the dedicated counters within a specific time period without having to incur a long queue or flight delay due to exceeding the time required to process check in for all passengers. On the other hand the decision about the number of desks to assign to each flight should consider the costs incurred to provide a minimum level of service. Given these aspects, the resource estimation problem provides the number of check-in desks while taking into account several parameters related to the passengers, airlines and airport. The parameters considered important to include in the resource estimation are reported below, together with their descriptions.

Stochastic passengers' arrivals

The passenger arrival's time is one of the most influential parameter, since it determines the load for the check-in system. The passengers' arrivals are unpredictable and depend on the personal choice of the travellers and on many other circumstances, such as unexpected traffic on the way to the airport and so. Some statistics throughout the years have been conducted to model the passengers' behaviour.

As showed by (Chun H.W. et al., 1999) for some flights, passengers tend to arrive very early, and for some others, especially for very early morning flights, they tend to arrive late. Despite these observations, it is not possible to forecast the passenger arrival rate. The length of the time interval that separates the arrival of two passengers is random.

The distribution more appropriate to model this arrival rate, also the most common in the literature as discussed in chapter 3, is the Poisson.

Service rate μ

The variability of the service time, and ~~so~~ of the service rate, is due to several aspects: human factors involved in the check-in operation, different types of processes (e.g. check in of passengers with bags, single or group, first class, responsiveness/age of the passengers) and nature of the services offered by the airline. The service time can be defined by an average value; however, it is stochastic. For the service rate no distribution will be used in this work, whereas a wild set of values will be exploited to model the service time variability.

Space available to each passenger standing in queue, Crowding of the area, Time spent in queue

According to IATA the definition of the airport LoS (Level of Service) is based on different parameters such as space available to each passenger standing in the queue, crowding of the area and time spent in queue. Therefore, airports need to consider and fulfil the requirements for these parameters in order to meet IATA standards as well as standards set by local regulatory authorities.

Cost of the check in operation

The cost of the check-in is represented by the check in rental and operational cost (incurred by the airlines), cost of usage of the terminal area by the passengers and the counters and the cost resulted by a low level of service (all incurred by the airport). For a detailed definition and comprehensive discussion about the level of service LoS see section 2.2.1.

The literature review of chapter 2 helped in identifying the importance of each of these four sets of parameters and their numerical estimations. Table 5-I summarizes the corresponding publications and their proposed aspects that have been included in the model. Generally, the proposed aspects have not been implemented directly in the model in the same way they were proposed by the authors. Modifications have been applied to the aspects based on our requirements, whilst the conceptual meanings have been preserved throughout their application. The third column of Table 5-I illustrates how each parameter has been introduced in the model. The estimation methodology proposed is based on the combination of QT (Queueing Thoery) and DP (Dynamic Programming). This enables the method to match the operational performance with an optimisation model that minimises a certain cost function over more intervals of time.

	ASPECT RE-VISITED	MODEL PARAMETER
(H. W. Chun et al., 1999)	Service time depending on different flight destination, stochastic arrival rate	Variation of service rate μ within a range of vale, Poisson arrival rate
(Joustra, P., and Van Dijk, 2001)	Stochastic arrival rate	Poisson arrival rate
(Takakuwa S., 2003)	Servicetime depending on the process, stochastic arrival rate	Variation of service rate μ within a range of vale, Poisson arrival rate
(E. Ahyudanari, 2005)	IATA earliness distribution, cost of lost-opportunity for the airport due to the resource space occupancy	Poisson arrival rate changing within the time window, cost of space in the check-in hall
(Yan, 2004)	Stochastic arrival rate	Poisson arrival rate
(Vandjk & Vandeluis, 2006)	Finite calling population size of the passenger to process, stochastic arrival rate	Death process from finite calling population of N passenger booked
(M. Parlar, 2008)	Estimation of resources for a single flight, queuing analytical model and DP, stochastic arrival rate	Multi-counter queuing model and minimization of cost function through DP, Poisson arrival rate
(Bruno, 2010)	Penalty for queue too long	Penalty for queue too long

Table 5-IElements modelling the check-in operation re-exploit from the existing literature

5.2.2 Estimation problem formulation

In this section, the mathematical model used to estimate the resources is presented. The description of the model is divided in three sections, the first of which refers to the QT, th0e second one to the DP and the third illustrates the cost function minimisation.

5.2.2.1 Multi-counter check-in system

The queuing model used is a multi-counter (more than one counter per flight) model with a single queue, with the arrival process occurring according to a "passenger show-up" from the finite population of passengers who booked the flight. The passengers' showing-up can be modelled as a continuous time Markov death process, where the states of the system represents the current size of the population modelled and the transition is limited to the death, i.e. a removal from the population.

The passengers' arrivals, which occur at a random time, correspond to a transition of the state, i.e. a removal from the total population of travellers N of a single flight. The calling population size will decrease with time and will never reach the steady state. Therefore, a transient solution is needed to effectively describe and manage the queue.

The state of the system,(m, n), is represented by the number of passenger arrived m and served n at a certain time t within the total time interval T available to process the passengers, $t \in [0, T]$. The time T is a fixed time-window, i.e. the check-in counters are open only for a defined period before the departure.

The number of counters to open, c, is the decision variable of this problem and its value results from the balance of the operative conditions of the check-in system during the time interval T with the cost. The operative conditions include the number of passengers in the system, the space they occupy and the average waiting time to be processed.

The decision about the number of counters is a consequence of the state of the system, i.e. combination of passengers arrived not served and served.

The variable c depends on the number of passengers, m, who have already reached the check-in area and the number of passengers already served, n. Therefore each of the system states can correspond to a different number of counters.

Some assumptions have been made on the stochastic parameters μ and λ, to simplify their modelling.

The service rate μ with which the passengers are processed is considered constant during the time. However, to model its variability, a set of different values of service rate μ have been applied and their influence on the number of counters compared.

The passenger show-up rate can be modelled as a Poisson distribution with the λ parameter depending on the time. To model the time dependency of λ, the total time interval T has been divided in K subintervals $[t_k, t_{k+1}]_K$over which the show-up rate is stationary.

At the beginning of each of these subintervals the decision about the number of counters to open for each state of the system in the interval

considered is taken based on the operational conditions of the system in each of the occurring system states.
At the beginning of each sub-interval, t_k, the value of (m, n) varies in the ranges $0 < m < N$ and $0 < n < m$ and describes the system in terms of passengers load. At the end of the interval, t_{k+1}, the new state, named (i, j) to be distinguished from the initial, is reached. (i, j) defines the state at time t_{k+1}; i, j respectively indicates the number of passenger arrived and served at time t_{k+1} and their values vary from i, j are $m < i < N$ and $n < j < i$.
Both the show-up of passengers event $\mathrm{A}(t_{k+1})$, i.e. the removals of passengers from N, and the service of passenger event $\mathrm{S}(t_{k+1})$ are stochastic; the stochastic process $\{\mathrm{A}(t_{k+1}), \mathrm{S}(t_{k+1})\}$ is a Markov process, i.e. in the series of random events $\mathrm{A}(t_{k+1}), \mathrm{S}(t_{k+1})$ the probability of ~~an~~ occurrence of each event depends only on the immediately preceding outcome $\mathrm{A}(t_k), \mathrm{S}(t_k)$.
For each subinterval $[t_k, t_{k+1}]$, the transient probability that at time t_{k+1}, *i* have arrived and *j* have been served given that at time t_k, *m* had already arrived and *n* had been served, and $\mathrm{c_k}$ counters had been opened is defined as:

$$P^{c}_{m,n,t_k}(i, j, t_{k+1}) = Pr\{A(t_{k+1}) = i, S(t_{k+1}) = j \mid A(t_k) = m, S(t_k) = n\} \quad 1)$$

To calculate the conditional probabilities a set of Partial Differential Equations (PDE) in terms of the unknown function $\mathrm{P^{c}_{m,n,t_k}(i, j, t_{k+1})}$ for given values of $\mathrm{m, n}$ at time $\mathrm{t_k}$ must be developed. In (M. Parlar, 2008) the partial differential equation in term of the probability generating function (p.g.f.) of $\mathrm{P^{c_k}_{m,n,t_k}(i, j, t_{k+1})}$ and through appropriate calculations (see Appendix of (M. Parlar, 2008)), the exact solution of the PDEs for the unknown p.g.f is found and the exact close form of the distribution $\{\mathrm{A(t), S(t)}\}$ of the process is given as follow, for $\mathrm{c_k} \geq 1$, $\mathrm{m} \leq \mathrm{i} \leq \mathrm{N}$,$\mathrm{n} \leq \mathrm{j} \leq \mathrm{i}$, $0 < t < t_{\mathrm{k+1}}$:

$$\alpha(\mathrm{c_k}, t) = \frac{\lambda_k}{\lambda_k - \mathrm{c_k}\mu}\left(e^{-\mathrm{c_k}\mu t} - e^{-\lambda_k t}\right) \text{ with } \lim_{\lambda_k \to c\mu} \alpha(\mathrm{c_k}, t) = \mathrm{c_k}\mu t e^{-\mathrm{c_k}\mu t} \quad 2)$$

$$\beta(\mathrm{c_k}, t) = 1 + \frac{\mathrm{c_k}\mu e^{-\lambda_k t} - \lambda_k e^{-\mathrm{c_k}\mu t}}{\lambda_k - \mathrm{c_k}\mu} \text{ with } \lim_{\lambda_k \to \mathrm{c_k}\mu} \beta(\mathrm{c_k}, t) = e^{-\mathrm{c_k}\mu t}(e^{\mathrm{c_k}\mu t} - 1 - \mathrm{c_k}\mu t) \quad 3)$$

$$P^{\mathrm{c_k}}_{m,n,0}(i, j, t) = \quad 4)$$

$$= \binom{N-m}{i-m} e^{-(N-i)\lambda_k t} \sum_{r=0}^{\max(i-m, m-n)} \binom{i-m}{r} [\alpha(\mathrm{c_k}, t)]^{i-m-r} [\beta(\mathrm{c_k}, t)]^r *$$

$$* \binom{m-n}{j-n-r} e^{-(m-j+r)\mathrm{c_k}\mu t} * (1 - e^{-\mathrm{c_k}\mu t})^{j-n-r}$$

By the transient probability distribution it is possible to estimate the transient distribution of the number of passenger in the system, $Y(t_{k+1}) = \mathrm{A}(t_{k+1}) - \mathrm{S}(t_{k+1})$, as well as the expected number of passengers in the system at t_{k+1} $E(Y(t_{k+1}))$.

$$E(Y(t_{k+1})) = (N-m)\alpha(\mathrm{c_k}, t_{k+1}) + (m-n)e^{-\mathrm{c_k}\mu_k t_{k+1}} \quad 5)$$

Moreover, if a time interval, not necessary equal to the entire length $[t_k, t_{k+1}]$ is considered, assuming that at time t_k, m passengers have arrived and n served given $\mathrm{c_k}$ counters, the number of passengers who have been waiting a time equal to the length $[t_k, t_{k+1}]$ can be defined by (M. Parlar, 2008):

$$W_k(\mathrm{c_k}) = \left[\left(\frac{\lambda_k(N-m)}{\lambda_k - \mathrm{c_k}\mu}\right) + (m-n)\right]\frac{\left(e^{-\mathrm{c_k}\mu t_k} - e^{-\mathrm{c_k}\mu t_{k+1}}\right)}{\mathrm{c_k}\mu} + \frac{(N-m)}{\lambda_k - \mathrm{c_k}\mu_k}\left(e^{-\lambda_k t_{k+1}} - e^{-\lambda_k t_k}\right) \quad 6)$$

Given these equations, for each occurrence of (m, n) at each sub-interval it is possible to calculate the operational conditions of the system, depending on the value of $\mathrm{c_k}$. Different values of $\mathrm{c_k}$ correspond to different operational conditions of the check-in system and different costs. Therefore, the decision on the number of counters to open needs to balance these two aspects. Moreover, the (probabilistic) evolution of the system states from (m,n) to (i,j) across the subintervals and the necessity of considering how the system performs during the whole time T, requires to evaluate the influence of the $\mathrm{c_k}$ choice on the operation conditions and costs of the current interval as well as of the following ones.

The importance of including in the estimation methodology the evolution of the system across the sub-intervals and both the operational conditions and the costs incurred, requires the use of Dynamic Programming (DP) that optimizes a defined objective function.

To define the objective function the costs incurred by the airport within the check-in operation have been modelled. The operative conditions derived from the QT (Queuing Theory) have been adapted and introduced in the cost function as cost's parameters.

5.2.2.2 Dynamic Programming

The DP model considers the open-close desks policy, observing the system at the beginning of each sub-interval, considering at the same time its entire evolution during T. The open-close policy assumes that for each sub-interval of time it is possible to determine and use the optimal number of counters to process passengers. The decision to open or close a check-in counter at the beginning of a subinterval is taken in order to minimize the expected total cost function, defined not only for the present subinterval, but also for the entire sequence of subintervals, according to the DP's results.

Hence, a key aspect of this formulation is that the decisions cannot be viewed in isolation or according to an independent sub-interval. Because at each stage, decisions are valued based on the sum of the present cost and the expected future cost.
The DP technique rests on the principle of optimality, which suggests that an optimal policy can be constructed progressively by creating an optimal policy for a subdivided-problem occurring in the last stage first, and then extending the optimal policy to the last two stages, and continuing in doing so until an optimal policy for the entire problem is raised. More detailed information on the DP is available in (Bertsekas, 1987).
For the initial state (m, n) of each sub-interval the cost function is equal to the sum of the cost of the current period plus the expected cost of the following period. The expected cost of the following period are given with respect to the probability distribution to reach the next state and the minimized cost associated to that state.
The DP algorithm used in this thesis solves the problem backward in time.
The backward technique requires quantifying the final cost of the system, which in this case represents the cost of unprocessed passenger still in the check-in at the end of the time window planned to check-in the passenger. This final cost is given by $h(i-j)$, where $(i-j)$ indicates the number of passenger left at the end of the last interval, i.e. the cost at T.
The DP algorithm equation is the following, where $\Phi_k(c_k)$ represent the deterministic cost given from the current system state and $\sum_{i=m}^{N}\sum_{j=n}^{i} P_{m,n,t_k}^{c_k}(i,j,[t_k,t_{k+1}]_K) * J_{k+1}(i,j)$ the expected cost for the next subinterval.

$$J_k(m,n) = \min_{1<c_k<c_{k,max}} \left[\Phi_k(c_k) + \sum_{i=m}^{N}\sum_{j=n}^{i} P_{m,n,t_k}^{c_k}(i,j,[t_k,t_{k+1}]_K) * J_{k+1}(i,j) \right] \quad 7)$$

The decision is constrained between a minimum and a maximum number $c_{k,min} < c_k < c_{k,max}$ of counters determined by their availability in the terminal. The decision is made at the beginning of each sub-interval, in order to determine the optimal number of counters to open during the sub-interval for each given state (m, n).
The solution of the DP algorithm defines the optimal policy of counters to open over the subintervals for any combination of the state variables (m,n) at the beginning of the period of observation $[t_k, t_{k+1}]$.

5.2.2.3 Cost function Φ

The minimisation of the cost function is used to determine the number of counters to open over the time. The cost function is built from the airport point of view and includes the “ownership costs” and the “operating costs”. The “ownership costs” refer to the cost that the airport directly incurs due to the rental of counters to airlines. Although the airport receive a rent for the leasing of counters, the area in the

check-in hall occupied by the desks and the front-area where the passengers stand represent a cost of lost opportunity for the airport.
The "operative costs" refer to the cost, which the airport incurs while the passengers check-in is operated. Although the airport is not directly involved in the operational processes, the operative conditions offered to the passengers (service quality) contribute to the airport brand promotion inefficiency in delivering the processes will be a cost for the airport in the long run. Therefore, the missed accomplishment of level of service expected from the passenger can be included in the cost function as a penalty cost. Hence, from the operative conditions derived from the QT, $E\big(\mathrm{Y}(\mathrm{t}_{k+1})\big)$ and $W_k(\mathrm{c}_k)$ are used to indicate the crowding at the check-in area and waiting time in the model. In Table 5-II are summarised the check in cost according to the definitions given above:

Ownership Costs	**Cost of space, c_A**	Opportunity cost of not renting the area to other businesses
	Cost of energy $c_{e,m}$	Cost of the electricity due to the electrical equipment connected to the electricity network of the airport (computers at desks, baggage belt..)
	Rent, r	Source of income for the airport coming from the rent of desks
Operative Costs	**Cost of waiting time, c_W**	"Penalty-cost" for let a passenger wait more than a target waiting w^* time considered reasonably acceptable, related with LoS
	Cost of overcrowding c_S	"Penalty-cost" coming from an over-crowded check-in area, related with a low LoS offered.

Table 5-II Costs included in the cost function

To summarise the cost-function for the sub-intervals $K = [t_k, t_{k+1}]$ is defined for every state (m, n) and minimized varying the number of counters opened.

$$\forall\,(m,n) \quad \Phi_K = c_A(c_k) + c_W(c_k) + c_S(c_k) + c_{e,m}(c_k) - r(c_k) \qquad 8)$$

5.2.3 Input values estimation

This section illustrates the procedure used to estimate the values of the model parameters. Referring to the general descriptions of the queuing and cost function parameters above, the methods suggested to determine the numerical values for real check-in counters estimation problem are described below:

Number of passengers, N

The model of the departing aircraft defines the number of passengers by the number of seats available on the plane. The aircraft model also defines the numbers of passengers for each travel class.

Time window to check-in passengers, T

The airlines normally define, for each departing flight, the time window for checking in, based on a few factors such as the destination and passenger type (international, national, holiday or business destination).

Number of subintervals, K

The number of subintervals is determined by the number of time that the counters opening-closing decision is meant to be taken. The value K is strictly related to the time difference $[t_k, t_{k+1}]$ between two decisions.

Passengers arrival rate, λ

The passenger arrival rate can be derived by empirical observation and statistical data collected in the past for the same departure flight. Every flight and every airport have their own idiosyncrasies; moreover, the time of the departure might influence the arrival rate as well.

Service rate, μ

The service rate can be defined by observing the check-in process, or by using historical data. To define the value of the service rate, beside the technology used, other aspects which need to be considered, are:

- the type of passengers (average number of bags, experience with the process, single or group),that can be guessed by the flight destination;
- the check-in services (options offered, quality of the services offered by operators), that can be derived from the airline business model;
- the variability of the process (range of expected value of μ) which depends on the above-mentioned aspects and on the standardisation of the processes.

Space available to each passenger standing in queue, A_{pax}

The estimation of the space for each passenger depends on the level of service that the airport is willing to provide and the expected type and number of bags carried by passengers.

The area can be estimate by the empirical observation of the average space required by each passenger or using the value provided by aviation authorities or airlines association such as IATA. Figure 5-III illustrates an example of area estimation.

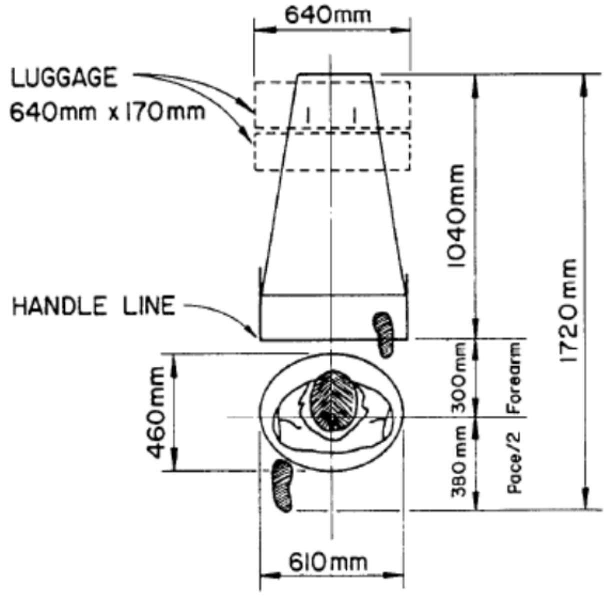

Figure 5-III Example of passengers occupied space (IATA Manual, 2004)

Cost of space, c_A

A cost per m^2 is assigned to the terminal hall, based on the income that a m^2would generate if allocated to other businesses. The space is counted as the sum of the space occupied by:

- the counters;
-the counters front area
-the bag conveyor and bag drop belt.

In Figure 5-IV is illustrated an example of area estimation.

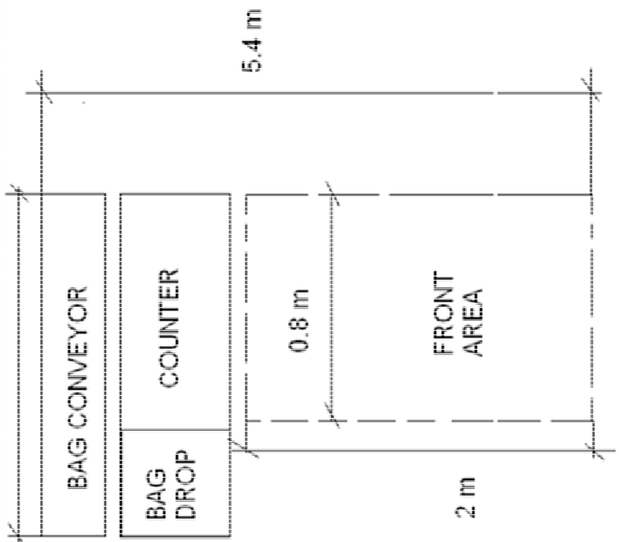

Figure 5-IV Example of Check-in counter area dimension

Cost of energy, $c_{e,m}$

The cost of the energy takes into account the energy consumption per unit of time of the single desk equipment (counter, computer, conveyor, etc) and the cost of the energy per unit of time. The subinterval of time during which the counter is used multiplied by these values give the cost of energy per single desks equipment in each K subinterval.

Rent, r

The rent cost for the airline is a value of public domain available on the airport report.

Cost of waiting time, c_w

The cost of waiting time is defined with regard to the LoS that the airport aims to provide for the passengers. The cost of waiting time can be defined as the negative perception derived when a passenger waits for too long. A maximum waiting time t_w^* that a passenger is disposed to wait is defined and when this constrained is passed, a "malus", i.e. a penalty cost is assigned.

This cost is not occurred by the airport in the reality, but is set to represent a target, which is largely better to achieve. t_w^* can be defined through passengers surveys, data available from the airport or from other associations such as IATA. In IATA manual a waiting time guideline is provided for different operations in the terminal.

The waiting time suggested for check-in operations varies based on the travel class considered: for check-in economy class short-acceptable waiting time in minutes is between 0'-12', acceptable to long is between 12'-20'. For check-in business class the values are respectively 0'-3' and 3'-5'.

The "penalty cost" is assigned based on the importance of avoiding an extra waiting time.

Cost of overcrowding c_s

The cost of overcrowding is associated to the lack of space to accommodate the passenger in the system. The front desk area available to host the passengers is compared to the area occupied by the passengers in the system (A_{pax} multiplied by the expected number of passengers).If the area needed by the present passengers exceeds the available area the LoS decreases and based on the importance of avoiding ~~the~~ crowding a "penalty cost" is assigned.

Range of counters numbers $c_{k,min}$, $c_{k,max}$

The minimum number of counters to open is 1 if other requirements do not exist; the maximum number depends on the airport's decision. Generally the maximum number is less than 10 counters per flight, however the empirical observation on the airport policy is needed to assign a vale to $c_{k,max}$.

5.2.4 Input values assignment for the exploratory case study at MA

This section illustrates the numerical values assigned to the parameters in order to apply to the check-in operation at MA based on the methodology that was developed above. The aim of applying the model is to conduct an exploratory case study that demonstrates how the model can be used and how the results can be analyzed.

To achieve this some assumptions and simplifications have been made to the numerical values of the parameters. More detailed information is required to output the effective resources estimation for MA check-in hall.

The values assigned to the parameters are summarized below.

Number of passengers , N

The number of passenger has been set equal to 10. Without considering the real size of the plane. This simplification has been done to facilitate the explanation of the outputs, but does not have any influence on the model's validity. However, given the low number of passenger and the long time available, the number of counters needed would intuitively result in one needed counter throughout the process, which eliminates the chance to elaborate other scenarios.

Following this, the numerical values of some input parameters in the model have been assigned according to the low number of passengers so that the calculated parameters are scalable (e.g. low service rate).

Time window to check-in passengers, T

The time window to operate the check-in has been set to 90 minutes.

Number of subintervals, K

According to the values of the arrival rate (see below) the time interval has been divided in K=3 subintervals, of equal length. $[t_k, t_{k+1}]_{K=1}$, $[t_k, t_{k+1}]_{K=2}$, $[t_k, t_{k+1}]_{K=3}$, where: $[t_k = 0]_{K=1}$ and $[t_{k+1} = T]_{K=3}$

Passengers arrival rate, λ

The estimation of the arrival rate has been done according to the arrival earliness distribution documented by IATA which is based on the percentage of passengers that show up at the check-in counter throughout the check-in time window: Figure 5-V.

The IATA arrival earliness distribution attempts to incorporate factors such as flight type (daytime, short or long haul, business or leisure) that might influence the fluctuation of inflow of passengers.

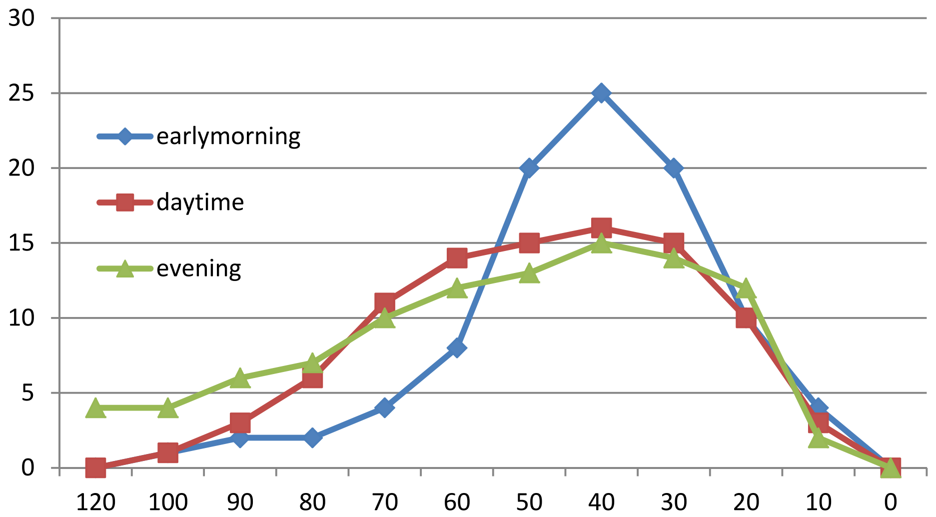

Figure 5-V Earliness distribution derived from IATA statistical data, note: early in the morning before 10 AM, daytime, between 12 AM an 5 PM, evening after 5 PM

For each arrival a profile has been identified which includes a set of three different λs that can be considered constant within that particular time interval.

The numerical results obtained through the estimation are reported in Table 5-III.

This set of data allow us to:

- Attribute appropriate arrival rate to different flights, based on the departure time during the day;
- Use non-stationary arrival rates, i.e. the three arrival rates from each distribution will be applied as the input data in the DP. and for each sub-interval the number of desks needed to be opened will be optimized accordingly.

	average λ [passenger/time]		
Interval's length	**Departure in the early morning hours (EM)**	**Departure in the daily hours (D)**	**Departure in the late evening hours (N)**
90-60Minutes before flight departure	$\lambda_{1,M}$ 0.125	$\lambda_{1,D}$ 0.25	$\lambda_{1,N}$ 0.525
60-30 Minutes before flight departure	$\lambda_{2,M}$ 1.425	$\lambda_{2,D}$ 1.4	$\lambda_{2,N}$ 1.25
30-0 Minutes before flight departure	$\lambda_{3,M}$ 0.85	$\lambda_{3,D}$ 0.7	$\lambda_{3,N}$ 0.7

Table 5-III Arrival rates used in the model

The unit used for the arrival rate of passengers is [passenger/time], where time is the time length of each interval$[t_k, t_{k+1}]$.

Service rate, μ

The variability in the service rate due to both the airlines and to the stochastic nature of the process of serving passengers have been considered by implementation of different values of service rate μ in the model. The estimations of the applied service rate is according to the IATA Manual, the Report from MAG and the values adopted by (M. Parlar, 2008).

Three airlines have been selected as representative of three different business models: Airline A, B and C. Expected value of service, $\bar{\mu}$, has been identified for each of them.For each of them the expected value of service rate has been identified based on their operational policy. This value is varied between two other expected value of service rates $\mu_1 < \bar{\mu} < \mu_2$ to reproduce the variability of the service time.

The unit used to express the arrival rate of passenger is [passenger/interval], where interval refers to the time length of the interval$[t_k, t_{k+1}]$.

For example, μ is the service rate of the passengers per time unit, that is, if the service interval is 90 minutes and if mu = 5 passengers/interval, means that the check in agent will serve, on average, 5 passengers per 90 minutes. This translates to 18 minutes of service, on average.

Table 5-IV lists the value of the service rates used in the model and Table 5-V translates the service rate in [pax/time] to [pax/minute] to better express the estimation in the service time assumed in this example.

Airline	μ_1 [pax/time]	$\bar{\mu}$ [pax/time]	μ_2 [pax/time]
A	6	5.5	5
B	6.5	6	7
C	4	4.5	5

Table 5-IV Service time for different airlines

Service rate	[pax/time]	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Total time	[minute]	90						
Service time	[minute]	22.50	20.00	18.00	16.36	15.00	13.85	12.86
Service rate	[pax/minute]	0.04	0.05	0.06	0.06	0.07	0.07	0.08

Table 5-V Conversion of service rate in [pax/time] to [pax/minute]

Space available to each passenger standing in queue, A_{pax}
To define the space/passenger needed in the cost function, has been used the IATA Manual, which provides the estimated values for the physical occupancy of the passenger (IATA, 2004). The space standards of the sqmeter/occupant has been set to 1.6 $[m^2/passenger]$ in order to guarantee the highest LoS to the passengers.

Cost of space, c_A
To each desk has been assigned a total area of 21$[m^2]$. A cost of 10£/$[m^2]$ has been assigned based on the values proposed by (E. Ahyudanari, 2005).

Cost of energy, $c_{e,m}$ and Rent, r
The airlines are charged for renting the desks, but the rent does not include the energy and maintenance cost paid by the Airport itself. The value of the rent received from the airlines is fixed at 9.2 [£/h] according to MA Annual Report 2010 which considers equal cost for electricity and maintenance. Therefore, the overall sum of these three terms (electricity maintenance and rent) is null and none of them is included in the cost function.

Cost of waiting time, c_w
The maximum queuing time suggested in the IATA guideline has been considered as boundary condition for the LoS.
In this model the differences among the travel classes are not considered and the waiting time has been imposed to be maximum equal to 10’. If in any sub-intervals a passenger waits for more than 10’ a high penalty, fixed to 1000 [£], is introduced in the cost-function. Such a high value of cost is imposed to avoid that any passenger waits more than 10’.

Cost of overcrowding, c_s

The number of expected passengers in the system has been multiplied by $\mathrm{A_{pax}} = 1.6$ and the result is compared to the space available in front of the desks and set to a value of 15 $[\mathrm{m}^2]$. A "penalty" cost equal to 1000 [£] has been associated every time the space needed to accommodate the passengers exceeds the available desk front area. Similarly, to the previous cost, also this penalty is very high, and the reason is to avoid the presence of overcrowded area in the terminal.

Range of counters numbers $c_{k,min}$, $c_{k,max}$

The values of $c_{k,min}$ and $c_{k,max}$ have been set respectively equal to 1 and 6.

5.2.5 Details of implementation

In this section, the procedure followed to develop the resource estimation planning is illustrated. The estimation methodology proposed is not limited to a single flight resource estimation, but also generates the resource estimation plan within a day and also through longer time periods such as weekly and monthly plans.

The estimation model can be used to calculate the number of counters $\overline{c_{k,open}}$ needed by an airline for a time period for example a week if the weekly flights scheduling is available.

The initial intention was to estimate the weekly resources needed by an airline for each of the subintervals $[t_k, t_{k+1}]$. This is achievable by finding the optimal set of counters to open during each sub-interval $(c_{k=1}, c_{k=2}, c_{k=..})$ which maximizes the resource utilisation.

Since the flight departing times are spread throughout the time window, it is possible to exploit the variability of the c_k thus for a particular time interval. If $c_{k=i} < c_{k=i+1}$, an additional desk is necessary which can be borrowed from another flight that does not need it for that interval $[t_i, t_{i+1}]$.

And if $c_{k=i} > c_{k=i+1}$, an extra desk is available that can be given to another flight that needs more resources at that interval.

This sharing system would have been proposed to use both across the flights of an airline and across different airlines.

However, three main reasons have limited the implementation of this resource allocation methodology:

i. The structure of the flight timetable, in which the departure flights are not planned at regular intervals and thereby the sub-intervals of T do not begin or end at the same period when check-in counters are opened and closed. Moreover, the length of T for each flight normally depends on the destination and airline; different T translate in different time intervals $[t_k, t_{k+1}]$ and make the matching of overlapping flights complicated;
ii. The impracticality of moving passengers every $[t_k, t_{k+1}]$ from a set of counters $c_{k=i}$ dedicated to check-in to the other $c_{k=i+1}$, and the logistic problems that occur switching the settings of the counter from checking in the passengers of one flight to the other one.

iii. The physical limitation within the terminal does not allow the sharing airlines to be in the close vicinity of each other. This problem becomes more important with heavier flight schedule.

Given these complexities, it was decided not to apply the detailed information of the number of counters needed by an airline during each time interval. Instead, the maximum number given for a longer time period such as a day was applied as a decisive parameter for resource allocation. In other words by decreasing the details of information which could introduce lots of impracticalities to the process, a number which summarizes the details given by the optimization model will be applied.

5.2.6 Counters estimation procedure

In this section the procedure applied to estimate the weekly resource plan for an airline, given its flights timetable is described, Figure 5-VI summarises the main steps of the estimation procedure.

The first step starts by estimating the number of counters needed in each subinterval for each flight of an airline.

The second step considers the flights overlapping during the day. The entire day time window is divided into subintervals of length $[t_k, t_{k+1}]$. The objective is to define for each of the subintervals the total amount of resources needed by the airline based on the distribution of the flights within a day.

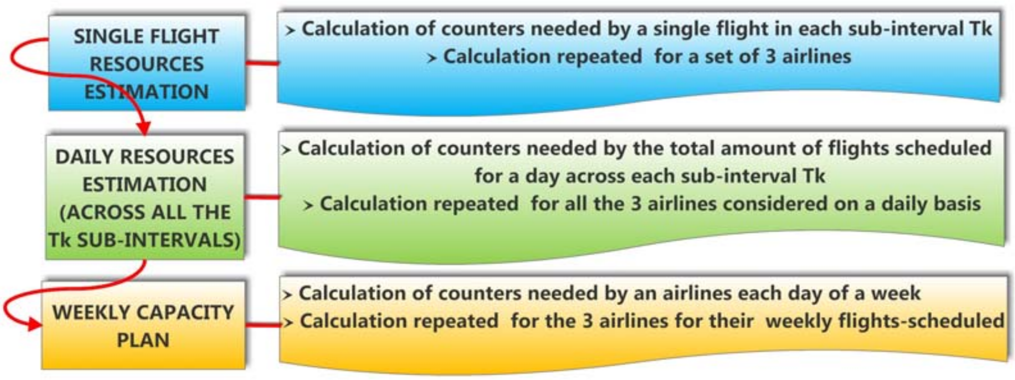

Figure 5-VI Counters estimation Procedure

The third step defines the number of counters needed in a day, without considering the variability of the resource demand in each subinterval. This number corresponds to the maximum among the values found from the previous step. If the same procedure is applied for all the airlines operating in the terminal hall the overall weekly capacity plan for the airport can be done accordingly.

5.2.7 Preliminary results analysis

This section is dedicated to a preliminary analysis of the output data of the model. This section is constituted of two parts, the former of describes how to apply the output values and the second validates the data achieved by the model.

5.2.7.1 Data processing

The results outputted by a run of the estimation model are organised in three matrixes, one for each sub-interval $[t_k, t_{k+1}]$. The rows and the columns of the matrix represent respectively different values of m and n, and the dimension of the matrix turns to be [(m+1)×(n+1)], since m and n go from 0 to N, $0 < m < N$ and $0 < n < m$..
Crossing the m-row with the n-column is the cell that contains the system state (m,n) at t_k the optimal number of counters to open if that state occur.
Given the fact that the number of passenger processed has to be smaller than the number of passenger arrived, only the cells where n<m have a physical meaning. For every possible combination of the value of m and n, it is possible to find the optimal number of counters to process the passengers.If the check-in system was monitored and arrived and serviced passenger were counted, the initial state would be known as well as the number of counters to be opened over the time interval. However, in the real case at MA, it is not feasible to monitor the check-in system and find out the initial state and the optimal number of desks to open over the time $[t_k, t_{k+1}]$.
It can be assumed that the decision to open or close a counter needs to find a single number from each matrix and thus state the number of resources to set up regardless of the real time occurrences of (m,n) at time t_k. Although doing this number-selection is not possibly guaranteeing the optimal number of counters for all the states (m,n), it seems a reasonable decision on a single number for each time period $[t_k, t_{k+1}]$.
This single number can be the expected value of counters, calculated by the probability of occurrence of the state (m,n). If the state's probability distribution is assumed to be uniform, the expected value is simply the average of the number of counters corresponding to each cell. However, the validity of the assumption of a uniform probability distribution has not been investigated and proven here due to the time constrains of this work. Thereby, another approach has been applied by this thesis: the calculation of the mode from the numbers of counters contained in a matrix. The value that recurs more times, the mode, is selected as the number of counters to open, independently from the occurrences of m,n. Hence, the mode value of the numbers in the matrix represents the desks' number, which, given all the possible initial states (m,n), optimises the cost-function more times. Although the system states are not well known, the mode value would accomplish the optimal conditions more times when the (m,n) states occur.
Through the mode is also easier to compare the results obtained by different scenarios. However, it can happen that the mode does not change from one scenario to the other, though some of the numbers in the cell changed. To facilitate the comparison of the results and highlight if changes in the optimal number of counter occur given different input data, the average of each matrix is also calculated. Hence, weighting each number equally the average reveals if any

change in the matrix numbers occurs. Except from this, any further consideration is carried out through the mode.
Overall, the mode for each subinterval, represents the recommended value of counters $c_{k=1}, c_{k=2}, c_{k=3}$, to open at each period $[t_k, t_{k+1}]$. It is possible to define the vector $\overline{c_{k,open}} = (c_{k=1}, c_{k=2}, c_{k=3})$ as the resource estimation result for a single flight.

5.2.7.2 Model Verification

This section reports the results obtained setting appropriate parameters in the model in order to verify the proposed model. Before starting the analysis of the model outputs the model is tested and some general conclusions are carried out accordingly.
Eight different scenarios have been generated and the results have been compared with the value expected from the physics of the problem.
The inputs that have been changed in these trials are: λ, μ, the interval length $[t_{k+1} - t_k]$ and the number of passengers N.
The effects on the number of counters based on the variation parameters is known as *a priori* due to the physical laws governing the check-in process. For all the trials, the numerical values of the costs have not been changed.
For the first trial, the parameters are set as follow:

λ=0.185 [passenger/time]	μ=4.5 [passenger/time]	$[t_{k+1}t_k]$=30’	N=10

This basic scenario is then compared with each of the eight scenarios, in which a single parameters at a time is changed. Table 5-VI reports the changing parameter and the expected changing result in terms of the number of counters to open. In the last column of the table a “thick” is signed if the expected result has been confirmed by the model together with the corresponding number given by the table in Appendix M showing the results obtained.

PARAMETER	EXPECTED RESULT	PROOF
λ	λ increases, counters number increases	✓ tables I
	λ decreases, counters number decreases	
μ	μ increases, counters number decreases	✓ tables II
	μ decreases, counters number increases	
Interval length, IL=$t_{k+1} - t_k$	IL increases, counter number decreases	✓ tables III
	IL decreases, counters number increases	
N of booked passengers	N decreases, counter number decreases	✓ tables IV
	N increases, counters number increases	

Table 5-VI Verification runs of the model

5.2.8 Outputs of the model

In this section, the results obtained by the implementation of the model to MA case study are discussed. The check-in counter estimation procedure to develop the weekly capacity plan for the airport is described systematically with the support of the results found by the model. The estimation for the week demand of resources is carried out considering three different airlines A,B,C representative of three different business models which is characterised by different service time. All the results are reported in Appendix P, whereas in this section are reviewed only the values considered important for the understanding of the procedure.

The section is divided to three parts, the former of which present the single flight estimation of resources, the second the daily and the third the weekly one.

5.2.8.1 Single flight estimation of resources

The procedure followed to estimate the flight demand of resources is summarised as follow:

1) The values of the arrival rates at each sub intervals has been set according to the appropriate arrival distribution given the departure hour;

2) The values of the service rates have been set according to the airlines' operational policy. For each airlines three values of service rate have been used to estimate the resources taking into account the stochasticy nature of the service process;

3) For each of the 9 matrices obtained (Table 5-VIII) have been calculated the mode values, M*. A mode value M* corresponds to each $\lambda_{i,M}$ $\exists$ $\lambda_M = (\lambda_{1,M}, \lambda_{2,M}, \lambda_{3,M})$and varies according to the μ value of the airline $\mu_{airline} = (\mu_1, \bar{\mu}, \mu_2)$).

4) From the mode values obtained from the matrixes the corresponding value of the mode of the previously obtained mode for the same arrival rate but different service rate is calculated (Table 5-VII);

	AIRLINE B			MODE
Arrival rate [pax/time]	μ=7 [pax/time]	μ=6.5 [pax/time]	μ=6 [pax/time]	
0.125	2	2	2	2
1.425	3	3	3	3
0.85	2	3	3	3

Table 5-VII Selection of $\overline{c_{k,open}}$

5) The vector of the modes calculated in step 4 is the $\overline{c_{k,open}}$ for a flight departing in the morning.

6) Steps from 1. to 5. are repeated for the different arrival distributions and the different airline's service rate sets.

m/n	0	1	2	3	4	5	6	7	8	9	10
	service rate=7										
	0.125= λ_(1,M)										
0	1								M* 2		
1	2	1							a1.83		
2	2	2	1								
3	2	2	2	1							
4	2	2	2	2	1						
5	2	2	2	2	2	1					
6	2	2	2	2	2	2	1				
7	2	2	2	2	2	2	2	1			
8	2	2	2	2	2	2	2	2	1		
9	3	2	2	2	2	2	2	2	1	1	
10	3	2	2	2	2	2	2	2	2	1	1
	1.425= λ_(2,M)										
0	4								M* 3		
1	3	3							a2.51		
2	3	3	3								
3	3	3	3	3							
4	3	3	3	3	3						
5	3	3	3	3	3	3					
6	3	3	3	3	3	2	2				
7	3	3	3	3	2	2	2	2			
8	3	3	3	2	2	2	2	2	2		
9	3	3	2	2	2	2	2	2	2	1	
10	3	2	2	2	2	2	2	2	2	1	1
	0.85= λ_(3,M)										
0	3								M* 2		
1	3	3							a2.30		
2	3	3	3								
3	3	3	3	2							
4	3	3	3	2	2						
5	3	3	3	2	2	2					
6	3	3	2	2	2	2	2				
7	3	3	2	2	2	2	2	2			
8	3	3	2	2	2	2	2	2	1		
9	3	3	2	2	2	2	2	2	2	1	
10	3	2	2	2	2	2	2	2	2	1	1

m/n	0	1	2	3	4	5	6	7	8	9	10
	service rate=6.5										
	0.125= λ_(1,M)										
0	1								M* 2		
1	2	1							a 1.98		
2	2	2	1								
3	2	2	2	1							
4	2	2	2	2	1						
5	2	2	2	2	2	1					
6	2	2	2	2	2	2	1				
7	3	2	2	2	2	2	2	1			
8	3	3	2	2	2	2	2	2	1		
9	3	3	3	2	2	2	2	2	2	1	
10	3	3	3	3	2	2	2	2	2	2	1
	1.425= λ_(2,M)										
0	4								M* 3		
1	4	4							a 2.69		
2	3	3	3								
3	3	3	3	3							
4	3	3	3	3	3						
5	3	3	3	3	3	3					
6	3	3	3	3	3	3	2				
7	3	3	3	3	3	2	2	2			
8	3	3	3	3	3	2	2	2	2		
9	3	3	3	3	2	2	2	2	2	1	
10	3	3	3	3	2	2	2	2	2	2	1
	0.85= λ_(3,M)										
0	3								M* 3		
1	3	3							a 2.53		
2	3	3	3								
3	3	3	3	3							
4	3	3	3	3	2						
5	3	3	3	3	2	2					
6	3	3	3	3	2	2	2				
7	3	3	3	3	2	2	2	2			
8	3	3	3	3	2	2	2	2	1		
9	3	3	3	3	2	2	2	2	2	1	
10	3	3	3	3	2	2	2	2	2	2	1

m/n	0	1	2	3	4	5	6	7	8	9	10
	service rate=6										
	0.125= λ_(1,M)										
0	1								M* 2		
1	2	1							a 2.12		
2	2	2	1								
3	2	2	2	1							
4	2	2	2	2	1						
5	3	2	2	2	2	1					
6	3	3	2	2	2	2	1				
7	3	3	3	2	2	2	2	1			
8	3	3	3	3	2	2	2	2	1		
9	3	3	3	3	2	2	2	2	2	1	
10	3	3	3	3	3	2	2	2	2	2	1
	1.425= λ_(2,M)										
0	4								M* 3		
1	4	4							a2.80		
2	4	4	3								
3	3	3	3	3							
4	3	3	3	3	3						
5	3	3	3	3	3	3					
6	3	3	3	3	3	3	2				
7	3	3	3	3	3	3	2	2			
8	3	3	3	3	3	3	2	2	2		
9	3	3	3	3	3	3	2	2	2	1	
10	3	3	3	3	3	2	2	2	2	2	1
	0.85= λ_(3,M)										
0	3								M* 3		
1	3	3							a 2.60		
2	3	3	3								
3	3	3	3	3							
4	3	3	3	3	2						
5	3	3	3	3	2	2					
6	3	3	3	3	3	2	2				
7	3	3	3	3	3	2	2	2			
8	3	3	3	3	3	2	2	2	1		
9	3	3	3	3	3	2	2	2	2	1	
10	3	3	3	3	3	2	2	2	2	2	1

Table 5-VIII Airline B estimation for a flight departure early in the morning, variable μ

5.2.8.2 Daily Estimation of Resources

For the daily estimation of resources, it is needed that the flight departure timetable and the procedure are summarised as below (the whole set of results obtained is available in Appendix N):

1) The departures have been classified according with the hour in early morning flights, daytime flight and evening flight (Table 5-IX);

06:45 07:10 09:00 11:45 09:55	12:45 13:50 14:50 14:50 16:50	17:20
EARLY MORNING	**DAY TIME**	**EVENING**

Table 5-IX Flight timeframe classification in Early morning, day time and evening

2) To each flight has been assigned the arrival rate and the airline that operates it, the $\overline{c_{k,opt}}$ (Table 5-X).

Time sub-interval	**$\overline{c_{k,opt}}$.AIRLINE A**			**$\overline{c_{k,opt}}$.AIRLINE B**			**$\overline{c_{k,opt}}$.AIRLINE C**		
	EARLY MORNING	**DAY TIME**	**EVENING**	**EARLY MORNING**	**DAY TIME**	**EVENING**	**EARLY MORNING**	**DAY TIME**	**EVENING**
Tk1	2	2	3	2	2	2	3	3	3
Tk2	3	3	3	3	3	3	3	3	3
Tk3	3	3	3	3	3	3	3	3	3

Table 5-X $\overline{c_{k,open}}$ for each airline and each timeframe

3) The day has been divided into subintervals of 30', and the $\overline{c_{k,opt}}$ have been assigned to each flight according to the related time-window (Table 5-XII).

11:45		**12:45**	**12:50 -**		**13:50**		**14:50**
					2	3	3
2	3	3			2	3	3
			2	3	3		

Table 5-XI Desks assignment for each flight

4) When an overlapping of flights occurs, the total resources needed has been calculated by the sum of the resources needed in each sub-interval (Table 5-XIII).

11:45		**12:45**	**12:50 -**		**13:50**		**14:50**
					2	3	3
2	3	3			2	3	3
			2	3	3		
2	3	3	2	3	7	6	6

Table 5-XII Hourly desks demand

5) The maximum of these values has been assumed as the daily amount of resources needed by the airline (Table 5-XIIII).

2	3	3	2	3	7	6	6	7=MAX

Table 5-XIII Daily desks demand

Steps 2.,3.,4.,5.,6. have been repeated for all the airlines.

5.2.8.3 Weekly Estimation of Resources

For the weekly resource estimation the procedure is described below:

1) The time table of MA the flights over the same week for airline A,B,C have been observed, Table 5-XIV is the timetable for airline B:

	S	M	T	W	T	F	S
	1	2	3	4	5	6	7
06:45	06:45	06:45	06:45	06:45	06:45	06:45	06:45
07:10	07:10				07:10		
09:00	09:00	09:00	09:00	09:00	09:00	09:00	09:00
11:45	11:45	11:45	11:45	11:45	11:45	11:45	11:45
09:55	09:55	09:55	09:55	09:55	09:55	09:55	09:55
12:45	12:45	12:45	12:45	12:45	12:45	12:45	12:45
13:50	13:50	13:50	13:50	13:50	13:50	13:50	13:50
14:50	14:50	14:50	14:50	14:50	14:50	14:50	14:50
14:50	14:50	14:50	14:50	14:50		14:50	14:50
16:50	16:50	17:50	18:50	19:50	20:50	21:50	22:50
17:20	17:20	17:20	17:20	17:20	17:20	17:20	17:20

Table 5-XIV Weekly flights timetable for airline B

2) For each day the daily resource estimation is defined following the procedure illustrated in section 5.2.9.2.

3) The week estimation is carried out for each of the airlines considered.

5.2.9 Results analysis

In this section are summarised the results outputted following the procedure illustrated to estimate the daily counters needs for each airline.

The Table 5-XV,Table 5-XVI and Table 5-XVII report the values of the counter estimation output by the model. It can be noticed that the request for counters over the days is not constant by airlines A and B. As expected, different loads of flights over the days carries different daily demand for counters.

If only one value for the number of counters should be picked and agreed in the contract by both airline and airport that number is the highest given by the model. This is to ensure that even during the busiest day the resources would be enough to process the passengers. Therefore, the number of desks to rent for the whole week corresponds to the highest daily request.

AIRLINE A						
S	M	T	W	T	F	S
3	6	6	6	3	6	7
3	6	6	6	3	6	6
3	6	6	6	3	6	6
3	6	6	6	3	6	7

Table 5-XV Weekly counters estimation for airline A

AIRLINE B						
S	M	T	W	T	F	S
6	3	3	3	6	3	3
7	3	3	3	5	3	3
3	3	3	3	3	3	3
7	3	3	3	6	3	3

Table 5-XVI Weekly counters estimation for airline B

AIRLINE C						
S	M	T	W	T	F	S
	3	3	3	3		3
3	3	3	3	3	3	3
3	3	3	3	3	3	3
3	3	3	3	3	3	3

Table 5-XVII Weekly counters estimation for airline C

5.3 Resources Allocation Methodology

5.3.1 Allocation problem description

The resources allocation consists of assigning the amount of resources needed by the airlines to process the passengers of a departing flight. The objective of the resource allocation is to distribute the resources among the airlines in order to satisfy their requests and maximise the resource utilisation under the variability of the resources demanded during the time.

The current allocation method does not consider the variability of the demand across the days, and defined by contracts, the number of counters to allocate to the airlines is fixed over a defined period of time that generally is one or two weeks.

The problem to solve for the new allocation methodology configuration proposed is to allocate the counters to the airlines in such a way that meets the daily demand of counters.

Meeting the airlines demands in shorter times, increases the utilisation of resources. The fact that the daily traffic load for some airlines happen to be complementary suggests that developing a pooling reconfiguration system between the airlines can increase the efficiency of the process and the capacity utilisation.

Also from the results obtained from the resource estimation model it has been noticed that the desks demand profile, influenced by the load of flights operated during the day, is not uniform. Different airline might have peak in traffic on certain days of the weeks. Consequently, the resources demanded is characterised by peaks. If those peaks happen on different days over the weeks, the resources profiles of the airlines could be levelled through the sharing of resources, as shown in Figure 5-VII.

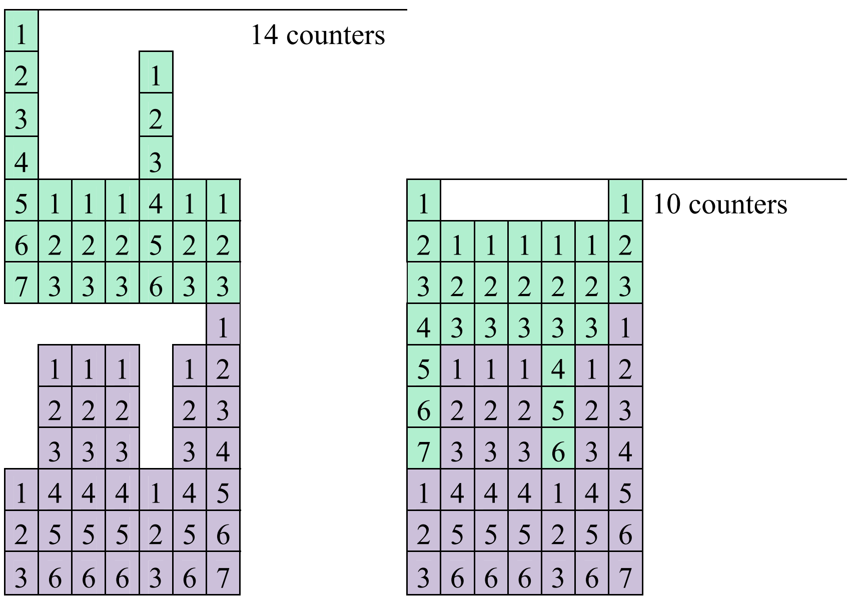

Figure 5-VII Example of resource levelling

It can be recognized that a "pooling system "could allow the airport to save some resources and dedicate them either to other departure flights or convert the space in the terminal to other businesses.

Sharing the resources over the days require less managerial efforts than the ones required in a resource sharing over the sub-intervals $[t_k, t_{k+1}]$. At the beginning of a new day, each airline will have exactly the amount of resources required, and the departure time of the flights, or the allocation of area of each flight can be determined as usual. Every airline can set and arrange the equipment for the operation on the counters available for that day.
To implement the “pooling system” it is essential to identify the airlines that present a staggered counter demand profile, i.e. the peak distributions of the flights over the days is out of phase.
Firstly, a method is needed to be developed to match the airlines is with non-similar demand distribution, and then it is necessary to find a model that supports the mutually beneficial decision making of the counter distribution to the airlines. Hence, the contract signed between airlines and airport still refer to a fixed value across over more days of contract duration, however, if the pooling system perform correctly, the number of counters rented would be lower.

5.3.2 Allocation problem formulation

In this section it is described the approach to the pooling system inclusive of the mathematical approach by an Integer Linear Programming, applied to distribute the resources to the airlines part of the pooling system.

5.3.2.1 Pooling Partners selection

The pooling system consists of the resources shared by two airlines. The candidates to the pooling system are all the couple of airlines operating in a specific check-in hall. Hence, to share the counters it is necessary for the airlines to be allocated close to the other one within the terminal area. In this section it is proposed an approach to identify two possible airline sharing resources, called PPs (Pooling Partners).
The PPs selection proposed requires to identify for each airline the daily check-in desks demand $C_{a,g}$, where a indicate the airline and g the day, see Table 5-XVIII.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day..	
$C_{I,1}{}^*$	$C_{I,2}{}^*$	$C_{I,3}{}^*$	$C_{I,4}{}^*$	$C_{I,5}{}^*$	$C_{I,6}{}^*$	$C_{I,7}{}^*$	..	$C_{I,g,max}{}^*$
$C_{II,1}{}^*$	$C_{II,2}{}^*$	$C_{II,3}{}^*$	$C_{II,4}{}^*$	$C_{II,5}{}^*$	$C_{II,6}{}^*$	$C_{II,7}{}^*$	..	$C_{II,g,max}{}^*$
$S_{I,II,1}$	$S_{I,II,2}$	$S_{I,II,3}$	$S_{I,II,4}$	$S_{I,II,5}$	$S_{I,II,6}$	$S_{I,II,7}$	..	$S_{I,II,g,max}$
$\Delta C_{I,II,1}$	$\Delta C_{I,II,2}$	$\Delta C_{I,II,3}$	$\Delta C_{I,II,4}$	$\Delta C_{I,II,5}$	$\Delta C_{I,II,6}$	$\Delta C_{I,II,7}$	..	

Table 5-XVIII PPs table

Where:

$$C_{I,g}{}^* + C_{II,g}{}^* = S_{I,II,g} \qquad 9)$$

$$C_{I,g}{}^* - C_{II,g}{}^* = \Delta C_{I,II,g} \qquad 10)$$

$$\max_g C_{I,g} = C_{a,g,max}{}^{*} \quad 11)$$

$$\max_g C_{II,g} = C_{II,g,max}{}^{*} \quad 12)$$

$$C_{I,g,max}{}^{*} + C_{II,g,max}{}^{*} = S_{I,II,g,max} \quad 13)$$

Airlines I and II are potential PPs (pooling partners) if:

- $\Delta_p \approx \Delta_n$, where Δ_n=number of times when $\Delta C_{I,II,k}<0$ and Δ_p= number of time when $\Delta C_{I,II,k}>0$;
- $S_{I,II,g,max} > S_{I,II,g}$

Among the possible matches of potential PPs, the two airlines that allow saving the highest number of counters and balancing the shared resources between the airlines is the couple, which set:

- The value of $\frac{\Delta_n}{\Delta_p}$ closest to 1;
- The highest difference of $S_{I,II,g,max} - S_{I,II,g}$

Respectively these two elements of the PPs selection aim at ensuring the airlines and airport advantage of the "pooling system". The advantage for the airline would be essentially the saving of the rent costs, and to ensure the same benefits to both the PP, the value of shared resources should be balanced; this is the reason for $\Delta n/\Delta p$ to be close to 1.
The advantage for the airport as already discussed reflects in the higher resources utilization such as space and counters. Therefore, the more desks saved, the higher the difference $S_{I,II,g,max} - S_{I,II,g}$ will be which highlights more financial advantage to the airport by the "pooling system".

5.3.2.2 Integer Linear Programming

Once the PPs have been selected, an allocation methodology to estimate the number of counters to allocate to each airline for the CD must be developed. This section present the ILP applied to that purpose.
The variables of the ILP are the numbers of counters to assign to each PP for the CD.
Given the counters demand profiles over the defined number of days for both of the airlines the maximum value of the daily sums of the counters $C_{1,k}{}^{*} + C_{2,k}{}^{*} = S_{I,II,g}$ demand is known. Since this number has been proved to be sufficient to process the daily passengers load of both of the airlines and since the airport's intention is to minimize the amount of resources dedicated to the airlines, $S_{I,II,g,max}$ has been used as a constrain (c.1) in the model. The number of counters to allocate to each airline $d_{a,g}$is the same over the g days, as agreed in the contract between airline and airport. This condition express as $d_{a,g} = d_a \; \forall g$ is the second set of constrains (c.2) modeled in the ILP. The last constrain of the model refer to the range of values that d_a can take; the minimal number is necessary 1 and the maximum is $S_{A,B,g,max} - 1$, the reason for"-1"is given by the lower boundary of the d_a of the other airline. $1 \leq d_a \leq S_{I,II,g,max} - 1, \forall a$ is the third set of constrains (c.3) for the proposed

model. The objective of the counter allocation is to distribute the number of desks to the PP. The PP present their desks demand of counters for a defined number of g days (in this example g is assumed 7), and the airport given the airlines requests $C_{a,g}$ and the constrain (c.1)- (c.2)- (c.3) decides the number of counter $d_{a,g}$ to allocate to the PP. The choice is based on the minimization of the difference between the requested $C_{a,g}$ and the allocated counters $d_{a,g}$.
To guarantee the linearity of the objective function, the differences between the values $d_{a,g}$ and $C_{a,g}$ have been modeled as $d_{a,g}/C_{a,g}$.
The formalization of the linear programming and the results obtained by the implementation of the model for airlines I and II are reported below:

$a = I, II$; PP
$g = 1..G$:day index ;
$d_{a,g}$: number of desks allocated by the airport; $d_a \in \mathbb{N}$
$C_{a,g}$: number of desks daily required by the PP;
$S_{I,II,g} = \sum_a^A C_{a,g}$;
$S_{I,II,g,max} = \max_g S_{I,II,g}$ total number of desks allocated by the airport

$$\min \sum_{a=I}^{II} \sum_{g=1}^{G} \left| \frac{d_{a,g}}{C_{a,g}} \right| \qquad 14)$$

$$\sum_a^{II} d_a = S_{I,II,g,max} \qquad \forall g \qquad (c.1)$$
$$d_{a,g} = d_a \qquad \forall g \qquad (c.2)$$
$$1 \leq d_a \leq S_{I,II,g,max} - 1 \qquad \forall a \qquad (c.3)$$

5.3.3 Data exploratory case study

The resource allocation methodology has been applied to the exploratory case study of MA. The results obtained in section 5.2 for the weekly resources estimation of the airlines A,B and C have been used as inputs of the allocation methodology. The duration of the contract is assumed to be 1 week. Table 5-XIX reports the values of one week resource estimation obtained by the estimation model proposed in section 5.3.2. It can be noticed from the values in Table 5-XIX that if the number of counter correspond to the maximum need over the days, when the demand is lower, the airport incur an underutilization of the resources.

	S	M	T	W	T	F	S		
A	3	6	6	6	3	6	7	7	MAX
B	7	3	3	3	6	3	3	7	MAX
								14	SUM,MAX

Table 5-XIX Weekly resource plan at MA

A daily pooling system can be developed among airlines A and B, and these airlines can share some counters, if their demand distribution support this. Hence, the high demand of counters from airline A should be balanced by a low demand of counters from airline B and vice-versa.
If the resource pooling occur the total number of counters needed from the airport by the two airlines together is determined considering the daily demands of each airline, summing those values day by day and selecting the maximum among those seven sums, as shown in Table 5-XX.

	S	M	T	W	T	F	S		
A	3	6	6	6	3	6	7	7	MAX
B	7	3	3	3	6	3	3	7	MAX
	10	9	9	9	9	9	10	14	SUM,MAX

Table 5-XX Weekly resource plan for the Polling system

Adopting the pooling system, the improvement in the resource utilisation is evident: in this case, MAG would be able to save 4 desks a week. Hence, instead of 14 counters MAG need to provide to the airlines a total sum of 10.
How those 10 counters will be allocated to the airlines will be discussed in the next section. It worth to highlight that the consequences of this pooling system in the airlines' operational policy and the issues related with the airlines acceptance of the "pooling system" will not be investigated in this work.

5.3.4 Details of implementation

To apply properly the methodology proposed to find PPs, the resource profiles for all the airlines operating at MA should be calculated. However, as exploratory trials, the demand profiles of airlines A,B,C which has been estimated above can be implemented to choose the PPs, among the possible (A,B),(B,C),(A,C), see Table 5-XXI, Table 5-XXII and Table 5-XXIII.
By the use of the PPs methodology, the couple B,C and A,C are definitely to be excluded as possible PP, whereas the only couple of airline that might be able to share resources in the "pooling system" are A and B. However the low value of Δ_n/Δ_pleaves some concerns on the convenience for the airlines A and B to accept the "pooling".

	S	M	T	W	T	F	S
A	3	6	6	6	3	6	7
B	7	3	3	3	6	3	3
		$S_{I,II,g,max} - S_{I,II,g} = 14 - 10 = 4$		$\Delta_n/\Delta_p = 2/5 = 0.4$		%saving 4/14=28%	

Table 5-XXI PP selection methodology for airlines A,B

	S	M	T	W	T	F	S
A	3	6	6	6	3	6	7
C	3	3	3	3	3	3	3

$S_{I,II,g,max} - S_{I,II,g} = 10 - 10 = 0$	$\Delta_n / \Delta_p = 0$

Table 5-XXII PP selection methodology for airlines A,C

	S	M	T	W	T	F	S
C	3	3	3	3	3	3	3
B	7	3	3	3	6	3	3

$S_{I,II,g,max} - S_{I,II,g} = 10 - 10 = 0$	$\Delta_n / \Delta_p \rightarrow \infty$

Table 5-XXIII PP selection methodology for airlines C,B

The ILP described in the next section will be tested to allocate the resources to airlines A and B. For that purpose the airline A and B can be assumed PPs.
According to this model, the resources allocated to the PP selected are:

$$d_A = 6 \text{ and } d_B = 4$$

The pooling system performed on these two provides benefits both to airline A and airline B. Airline B saves more in terms of renting that airline A, although the maximum number of desks is the same for both. That confirms the fact that in the allocation methodology other aspects are important, such as the number of days when an airlines requires an higher number of counters compared to the other.
For the example considered, the airport reduces the number of counters to lease up to 28% just for two airlines.
Due to the variability of the time schedules and the multiplicity of airlines available, the results obtained by this allocation methodology are highly PPs dependent.
Moreover, after applying the allocation methodology proposed, the airport authority might need to take in consideration additional aspects, such as the physical constraints imposed by the size and layout of the terminal halls or the need for a buffer, i.e. additional counters, between the airlines.

On the basis of the counter estimation results provided for airlines A and B, more numerical experiments have been done using the pooling allocation methodology.
The numbers of check-in desks required by airline A and B have been slightly modified in each of the following trials, in order to:

- Show the saving for the airport in different scenarios;
- Investigate the influence of Δn and Δp in the allocation model;
- Formulate conclusions on the methodology developed.

The alternative scenarios portrait real situations whose occurrence might affect the airline's need of counters. Examples of these situations could be the changes in the departure time schedule, variation of counters

needed due to seasonality in the passengers' number or their baggage (e.g sport equipment such as ski), modification in the operators' service time due to change in the airlines business model or services offered at the desks.
The purpose of the following data analysis is also to show the benefit of such an allocation methodology for whatever amount of counters is resulted by the estimation methodology.
The values in Table 5-XXI have been modified to simulate different scenarios for airlines A and B. The results obtained from this sensitivity analysis are reported below.
The values that have been changed are coloured in red and italicised.

	S	M	T	W	T	F	S	Counters allocated
A	3	6	6	6	3	6	7	7
B	*8*	*4*	*4*	*4*	*7*	*4*	*4*	4
	$S_{I,II,g,max} - S_{I,II,g} = 15 - 11 = 4$			$\Delta_p/\Delta_n = 5/2 = 2.5$				%saving 4/15=26%

Table 5-XXIV Higher demand of counters from B

	S	M	T	W	T	F	S	Counters allocated
A	*4*	*7*	*7*	*7*	*4*	*7*	*8*	7
B	7	3	3	3	6	3	3	4
	$S_{I,II,g,max} - S_{I,II,g} = 15 - 11 = 4$			$\Delta_p/\Delta_n = 5/2 = 2.5$				%saving 4/15=26%

Table 5-XXV Higher demand of counters from A

	S	M	T	W	T	F	S	Counters allocated
A	*4*	*7*	*7*	*7*	*4*	*7*	*8*	7
B	*8*	*4*	*4*	*4*	*7*	*4*	*4*	5
	$S_{I,II,g,max} - S_{I,II,g} = 16 - 12 = 4$			$\Delta_p/\Delta_n = 5/2 = 2.5$				%saving 4/16=25%

Table 5-XXVI Higher demand for both A and B

	S	M	T	W	T	F	S	Counters allocated
A	3	6	6	6	3	6	7	6
B	*14*	*6*	*6*	*6*	*12*	*6*	*6*	11
	$S_{I,II,g,max} - S_{I,II,g} = 21 - 17 = 4$			$\Delta_p/\Delta_n = 1/2 = 0.5$				%saving 4/21=19%

Table 5-XXVII Double demand of counters from B

	S	M	T	W	T	F	S	Counters allocated
A	*6*	*12*	*12*	*12*	*6*	*12*	*14*	14
B	7	3	3	3	6	3	3	3
	$S_{I,II,g,max} - S_{I,II,g} = 21 - 17 = 4$			$\Delta_p/\Delta_n = 5/1 = 5$				%saving 4/21=19%

Table 5-XXVIII Double demand of counters from A

	S	M	T	W	T	F	S	Counters allocated
A	*6*	*12*	*12*	*12*	*6*	*12*	*14*	12
B	*14*	*6*	*6*	*6*	*12*	*6*	*6*	8
	$S_{I,II,g,max} - S_{I,II,g} = 28 - 20 = 8$			$\Delta_p/\Delta_n = 5/2 = 2.5$				%saving 8/28=28%

Table 5-XXIX Double demand of counters from A and B

Table 5-XXIV, Table 5-XXV,Table 5-XXVI, Table 5-XXVII describe different scenarios occurring when the counters estimation for airlines A and B changes. Since the numeric variation of counter is limited to one counter per airline (Table 5-XXIV, Table 5-XXV) or for both (Table 5-XXVI) the percentage of savings from the airport perspective seems not to be highly affected. From the initial 28% of savings, the new percentage turns to be between 25% and 26% .

If the demand increase consistently (e.g. become double) for solely one airline, as shown in Table 5-XXVIIand Table 5-XXVIII, the saving for the airport proportionally decrease. In both the scenarios indeed, the percentage of counters saved by the airport is approximately 19%.

However, if the demands from both A and B increased up to 100% even the airport savings proportionally increase, as illustrated in Table 5-XXIX.

This observation suggests that higher savings are expected if two airlines with roughly the same demand of counters occur to be paired, additionally the highest are both their demands the highest is the airport benefit. The first implication of this aspects is that the airport managers while matching the airlines should also take into account the volume required by the airlines and, under other equal conditions, couple the ones with a higher demand.

Furthermore, this aspect highlights that the overall proportional savings from the airport is highly dependent from the choice of PP's. Indeed, almost the same percentage of savings can be reached in two different scenarios although the number of counters required has been doubled, see Table 5-XXIvs. Table 5-XXIX.

This last consideration on the appropriate selection of PPs proves the effectiveness of the algorithm proposed to this purpose. Can also be observed that the ratio Δ_p/Δ_n influences the counters allocated: the lower it is, the higher is the advantage for the airline I, in this case A, to adopt the pooling system, since allows it to save more counters than

airline II. This situation however could have some negative implications in the pooling system, essentially in the unbalanced savings between the airlines.
The followings experimentations have been run to investigate deeper the influence of Δ_p/Δ_n on the results from the allocation.
The following tables (from Table 5-XXX to Table 5-XXXII) review additional results obtained by varying the number of counters demanded by the airlines. Again, these scenarios are generated to simulate real events at the airport, but depict single day changes. The best example of these changes is the replacement of an aircraft and the consequent variation of its size and thereby number of passengers to be processed.
It has been shown how these changes affect the savings; here is investigated the influence of Δ_p/Δ_n on the allocation's results.

	S	M	T	W	T	F	S	Counters allocated
A	3	6	3	6	3	6	7	4
B	7	3	7	3	7	3	3	6
	$S_{I,II,g,max} - S_{I,II,g} = 14 - 10 = 4$			$\Delta_p/\Delta_n = 4/3 = 1.3$				%saving 4/14=28%

Table 5-XXX Variation in the demand of A and B

	S	M	T	W	T	F	S	Counters Allocated
A	3	6	3	2	3	6	7	3
B	7	3	7	3	7	3	3	7
	$S_{I,II,g,max} - S_{I,II,g} = 14 - 10 = 4$			$\Delta_p/\Delta_n = 3/4 = 0.75$				%saving 4/14=28%

Table 5-XXXI Variation in the demand of A

	S	M	T	W	T	F	S	Counters Allocated
A	3	6	3	2	3	5	7	3
B	7	3	7	3	7	6	3	8
	$S_{I,II,g,max} - S_{I,II,g} = 14 - 11 = 3$			$\Delta_p/\Delta_n = 2/5 = 0.4$				%saving 3/14=21%

Table 5-XXXII Variation in the demand of A and B

	S	M	T	W	T	F	S	Counters allocated
A	3	6	6	7	3	7	7	8
B	7	3	3	3	6	3	3	2
	$S_{I,II,g,max} - S_{I,II,g} = 14 - 10 = 4$			$\Delta_p/\Delta_n = 5/2 = 2.5$				%saving 4/14=28%

Table 5-XXXIII Variation in the demand of A

	S	M	T	W	T	F	S	Counters Allocated
A	3	7	3	6	3	6	7	4
B	7	3	7	3	7	3	3	6
	$S_{I,II,g,max} - S_{I,II,g} = 14 - 10 = 4$			$\Delta_p/\Delta_n = 4/3 = 1.3$				%saving 4/14=28%

Table 5-XXXIV Variation in the demand of A and B

The first three tables of this set (Table 5-XXX, Table 5-XXXI and Table 5-XXXII) confirm what pinpointed above by proving that if the variation of counters is able to affect Δn, Δp and thereby Δ_p/Δ_n,the amounts of desks are re-allocated to the clients. This happens although the peaks for both the airlines are still the same.

By this observation emerged that the lowest the value of Δ_p/Δ_n, (see 5.3.2.1.where airline I is airline A) is, the little is proportionally the number of counters allocated to the first airline.

This aspect also justifies the importance for the airport to choose PP's with an appropriate value of Δ_p/Δ_n. Indeed, situations in which is only one of the two airlines to take advantage from the pooling should be avoided.

Table 5-XXXIII and Table 5-XXXIV highlight that the number of times that the peak demand also affect the counters allocation. Indeed, the more frequent is the occurrence of the maximum in the demand of an airline, more are the counters assigned. Table 5-XXXIV shows a combined effect of "peak" frequency and variation of Δ_p/Δ_n.

The weekly distribution of the demand showed in Table 5-XXXII suggests a final recommendation for the use of this methodology.

It could happen that many counters are requested by both the airlines for several days. Although the upper constrain $C_{I,g,max}{}^{*} + C_{II,g,max}{}^{*} \leq S_{I,II,g,max}$ is satisfied and the counters utilization is maximized, a congestion in the check-in area for airlines A and B might be experienced. Thereby, especially if the number of passengers, i.e. the number of counters expected is quite high, the airport, as preventive action, should evaluate the possibility to add a buffer (additional counter) in between the two airlines for the entire contract length.

5.3.5 Conclusions

The fundamental utilities of the tool proposed for an airport capacity plan can are:

- To have a better visibility and understanding on the number of counters that the airlines require to process the passengers and the variables that might affect their choice;
- To predict the amount of counters that an airline could request and take it into account when a new flight needs to be scheduled. This information, indeed, can be helpful for the airport authority to associate to the flight the departure time, departure slot as well as terminal more appropriate based on the overall load at the airport.
- To pinpoint the airport's savings in which airport authority incur by using the pooling system.

The capacity plan so developed has indeed allowed:

- To model the resources requirements coming from the airlines (QT) and the financial objectives coming from the airport (objective function of the DP);
- To exploit the variability in the traffic load to distribute the resources according to the daily need of an airline.

The outcome of the approach proposed here is more reconfigurable software. The new configuration presented is able to implement in the model quickly and cost-less the requirements and the volatile demand. At the same time it has been shown the ability of the model to increase the utilisation of the resources, particularly by using the pooling system.
Overall, can be concluded that the new software configuration proposed has been able to:

- Consider the variability in requirements of customers of different airlines such as service time and LoS expected.
- Make use of the fluctuation in the traffic and the consequent variation in the resources required;
- Optimize the airport financial performance (of check-in);
- Improve the utilisation of the resources;
- Exploit the reconfigurability of the system throughout the pooling system (see first paragraph of this section 5.3.5)

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6 CONCLUSIONS

This Chapter will begin with a brief review of the main phases of the work and then present the key findings of the research (section 6.2) and discusses its implications and limitations (section 6.3).

6.1 Summary

This work investigated airport check-in re-configurability and the overall process of check-in reconfiguration. The research was carried out in 4 phases.

Phase 1 - Initial problem analysis: Following from an investigation of the current configuration and trends of airport check-in operations, problems related to these operations have been identified. A case study at MAG has been used to confirm these problems and has been used as an empirical base to the addressed problems. The main operational problems of current check-in systems consist of (i) the rigidity of configuring the check-in operations, and (ii) the underutilization of check-in resources.

Phase2 - Literature review: Related works to the problem of re-configurability has been reviewed while considering the airport operations and the manufacturing perspectives. The identified conventional approaches for resource allocation to support the airport operations showed substantial gaps in the literature. The literature review highlighted the need for developing new methodologies to address the issue of the utilisation of check-in resources. Manufacturing literature offered, overall guidelines for the assessment of re-configurability in service systems, which follows the same principles and paradigms developed around the concept of an RMS.

Phase3 - Hardware: A methodology to generate and evaluate alternative configurations was developed as guidance to the decision makers in the new configuration design. This methodology focuses on system re-configurability features and the real time and cost efforts required in shifting from the actual configuration to a new one. The collaboration with S.Shah has also allowed development of a tool with a duple scope. The first scope consists of the analysis on the existent check-in equipment and its functionality. The second scope concerns the design of new configurations.
A set of KPI measurements was proposed to compare alternative configurations. This was based on concepts such as OEE, Airport Management Time, Operator Performance, Duplication of Operation, Redundancy, Acquisition Cost and Disposal Cost.

Phase 4 - Software: A novel methodology to estimate and allocate check-in counters was developed. A queuing model of passenger flow and a cost optimization approach based on dynamic programming were applied to determine the necessary number of resources needed in the operation. This results in avoiding the assignment of extra-capacity to the airlines and improving the financial performance of the airport.

6.2 Conclusions from the Research

This section presents the key conclusions of this research, by revisiting the underlying research questions formulated in chapter 1.

Research Question 1: *What are the key technological features of a check-in configuration that make it reconfigurable?*
Answer: Diversity, modifiability, responsiveness and fault tolerance are the key system features that ensure the accomplishment of re-configurability in check-in operations. Alternative hardware configurations for the check-in were presented and described, It was found that the key features listed above are differently fulfilled by each of the configuration options. The key system features and the configuration options that better represent them are discussed as following.

- The diversity in the check-in system is important to meet the present diversification in the passengers' requirements and their future changes. Therefore, the configurations that enable the passengers to choose between several check-in processes offer more re-configurability options. Consequently, the replacement of the traditional technology of counters does not necessarily represent the best solution. It is however the presence of more check-in alternatives, such as online check-in, e-ticketing, curbside or self-service check-in that will ensure a broaden satisfaction of passengers' needs and desires.
- The modifiability of the system ensures its adaptability to changes in a short time. Related to modifiability is the concept of 'modularity' of operation equipment. Indeed, the lower the number of equipment modules, i.e. connections between elements, the easier (swifter and cheaper) is the reconfiguration process, particularly referring to the decoupling and recoupling steps.
- Movable desks and self-service kiosks separated from the bag-drop are two solutions that facilitate further modification in the process, movement and rearrangement of the configuration.
- The responsiveness of the system is mainly guaranteed by common-use of resources, which allow spreading the peak in the demand across the counters available in the check-in hall. The decentralization of resources from the check-in terminal to other check-in points (counters at the curb-side or at the station, home boarding pass) also contribute to the responsiveness of the system, since they smooth the fluctuations of check-in demand and reduce the impact of the stochastic arrival rate of passengers.

- Portable devices provide the best way to ensure fault-tolerance of check-in operations. However, the effectiveness of the use of portable devices by movable operators around the terminal could at the same time represent an additional reason for the terminal congestion and thus hinder operational performance.

Research Question 2: *What are the key features of a check-in resource estimation and allocation methodologies that allow the check-in process to be considered reconfigurable?*

Answer:

A methodology for adopting a more reconfigurable use of the available check-in resources was developed, indeed a dynamic method for estimating and allocating the resources been found necessary. This methodology focuses on the implementation of reconfigurability in the system by removing all the "rigidities" that would not allow to adapt to future evolving requirements.

The critical observation of the current software configuration highlighted the current limitations and deficiencies (chapter 5), which by contrast supported the definition of the key features:

- The primary key feature in the resources estimation and allocation methodology refers to the ability of modelling all the requirements that frequently change and whose changes affect the system.
- The second key feature refers to the ability to consider the time dependency of the inputs in order to maximise the resources utilisation. The capacity plan was shown to be highly dependent on the flights load in the departure timetable. It is also important to take into account the volatility of departures, as it is a fundamental basis for the system reconfigurabilty and for its utilisation.

Another aspect to consider during resources estimation and allocation is the elasticity in the agreements between airport and airlines (e.g. short-term contract variable amount of resources to rent during the period of contract...).

In order to introduce these key features in the new methodology:

i. Airport financial interest, passenger expected LoS and airlines requirement were modelled as variables in the estimation process;
ii. A "pooling system" based on desks sharing between two airlines during the day was proposed. This has been identified as the major contributor to increase the utilization of the resources in the check-in hall.
iii. The contract policy between the stakeholders involved in the check-in operation was investigated and reviewed, in order to support the introduction/implementation of system re-configurability.

6.3 Limitations

Three main limitations of the work are as follows: Firstly, the work involving the use of the DSM to measure the actual times and costs of a reconfiguration action suffered from the availability of detail numerical data. This is why no realistic case validating the DSM-based approach is given at the end of Chapter 4. This numerical validation step will be addressed during the next phase of the Airport Operations project.

Secondly, two further limitations regarding the estimation and allocation of check-in capacity need to be addressed in future research. More precisely, the estimation model could be expanded by addressing the following:

- Consider additional variables to represent airline-specific details, such as the service time, the type of services provided, the additional equipment used and technologies adopted.
- Consider additional passengers' variables, such as the presence of groups or of passengers, that needs particular care and attention, as PRM (People with Reduce Mobility).
- Consider additional types of check-in technologies, such as self-service kiosk, baggage self-service tag and so on.
- Consider the physical constraints of the terminal building and the counters layout in the check-in hall, as mention in section 2.3.3.

Further validation of the allocation methodology is necessary to provide the airport and airlines with a clear case for adoption of the check-in sharing policy proposed in chapter 5 and with an unambiguous "pooling partners" selection methodology.

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Appendixes

APPENDIX A: IATA, GLOBAL AIR TRAFFIC DEMAND, 2011

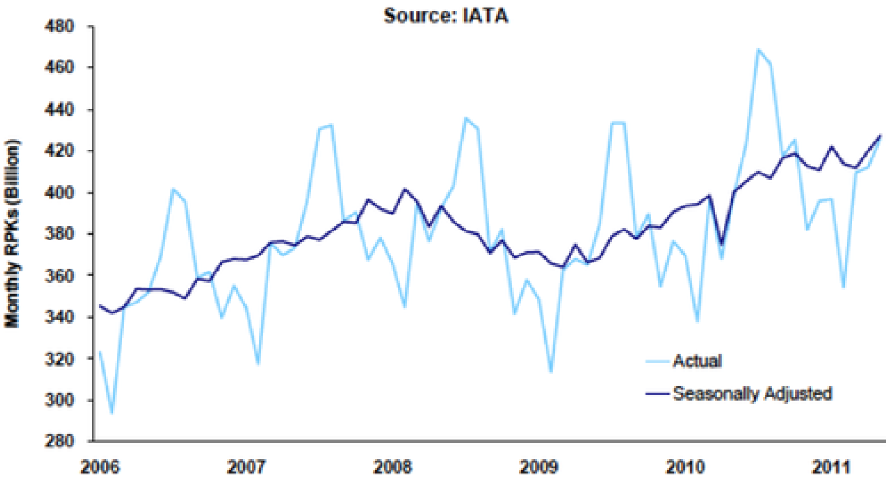

Figure 1 Total passenger market (domestic and international): 2006 to 2011 Source : http://www.centreforaviation.com

APPENDIX B: PROCESSES MAPPING

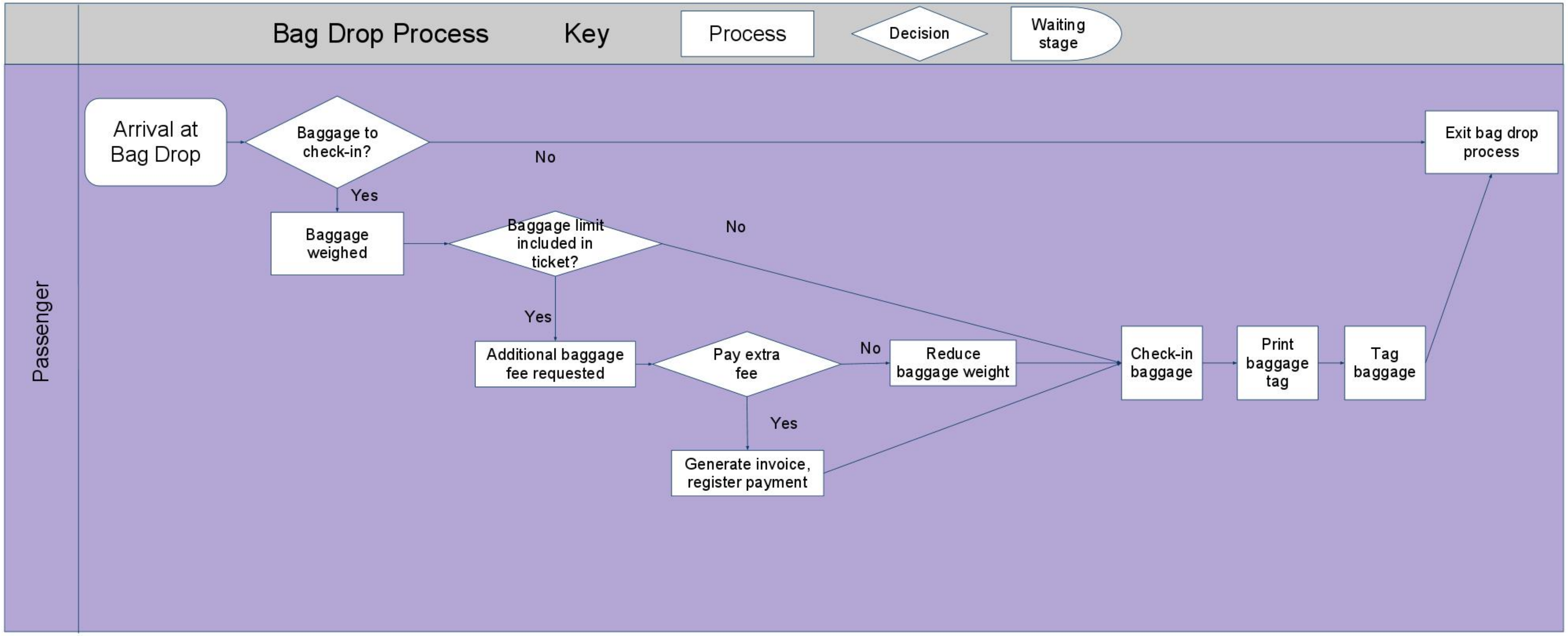

Figure 2 Manned Check-in Process

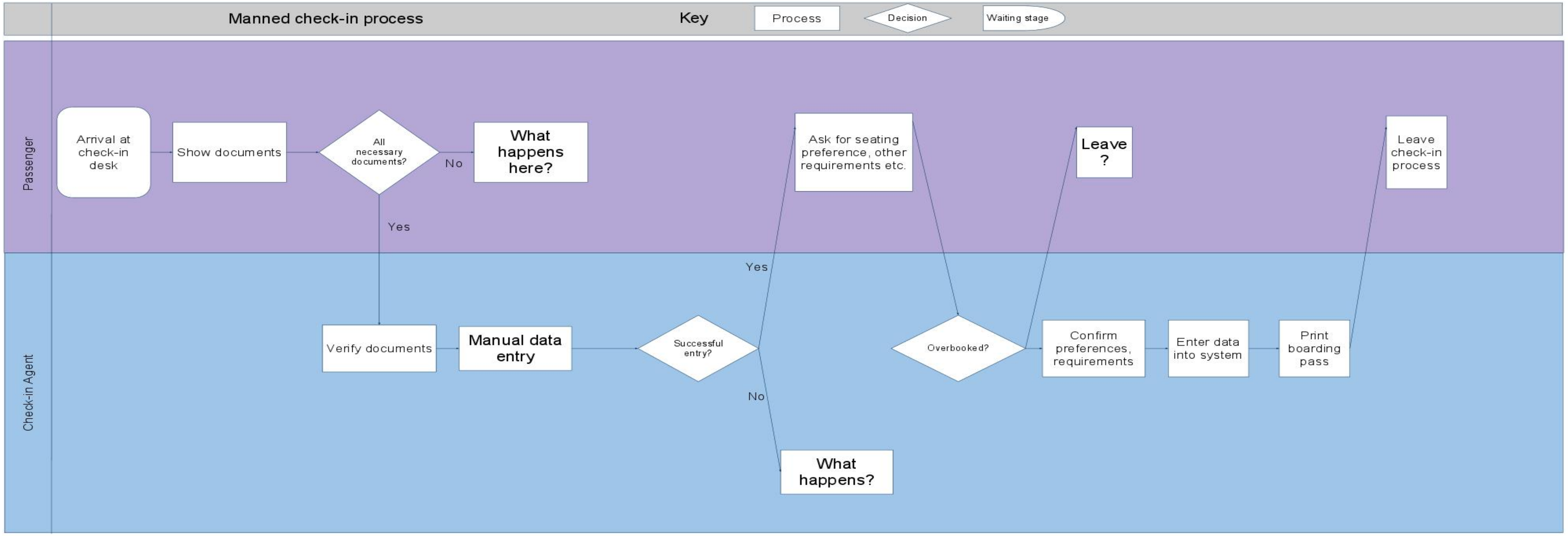

Figure 3 Self-served Check-in Process

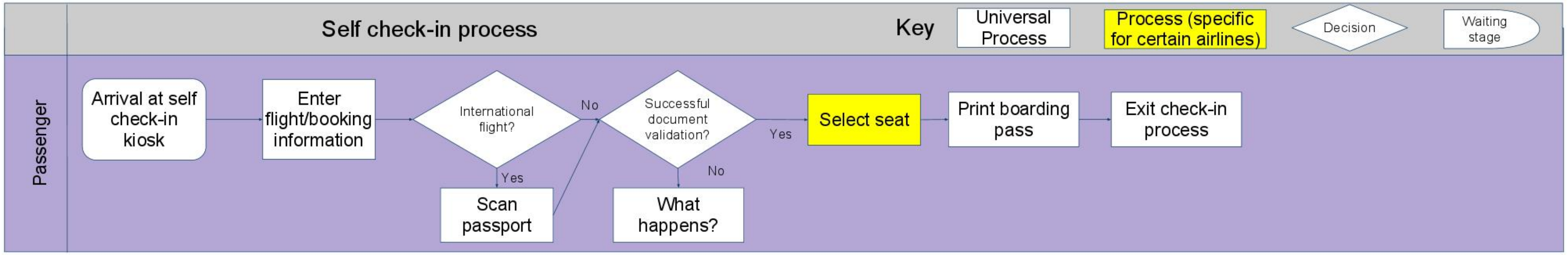

Figure 4 Drop Box Process

APPENDIX C: UML CLASS DIAGRAM

A class diagram in the Unified Modeling Language (UML) can be adopted to accomplish the purpose of defining the check-in process as a huger system comprehensive of all the elements that define its operation and management. A brief description of the elementary concepts of UML is given here in order to understand the meaning of the diagram

UML Class Diagram is a type of static structure diagram that describes the structure of a system by showing the system's classes. To each class are assigned its attributes, operations and the relationships between the classes. UML provides mechanisms to represent class members, such as attributes and methods, and additional information about them. A UML classes is the descriptor for a set of objects with similar structure, behavior and relationships.

The UML representation of a class is a rectangle containing three compartments stacked vertically, as shown in the figure. The top row shows the class's name. The middle compartment lists the class's attributes. The bottom compartment lists the class's operations. Attributes is a logical data value of an object. Operation represents the functions or tasks that can be performed on the data in the class. For example, an airline flight can be modeled as a UML class as follow: the name is Flight, and in the middle compartment we see that the Flight class has three attributes, flightNumber, departureTime, and flightDuration. In the bottom compartment, the Flight class has two operations: delayFlight and getArrivalTime.

Flight
flightDeparture:Integer departureTime:Date flightInformation:Minutes
delayFlight:Date getArrivalTime:Date

Figure 5 Example of class in UML

Classes can be logical connected by different kind of relationship that is indicated by the use of row and by the use of a verb.

An association is a linkage between two classes. Associations are always assumed to be bi-directional; this means that both classes are aware of each other and their relationship, unless you qualify the association as some other type. A solid line between the two classes indicates a bi-directional association. At either end of the line, the name of the role and a multiplicity value can be placed. The multiplicity is the number of objects that participate in the association. Another kind of association is the aggregation, used to model a "whole to its parts" relationship. As a type of association, an aggregation can be named and have the same adornments that an association can. However, an aggregation may not involve more than two classes. Aggregation can occur when a class is a collection or container of other classes, but where the contained classes do not have a strong life cycle dependency on the container (if the container is destroyed, its contents are not). More specific than aggregation is the composition. Composition (filled diamond shape) usually has a strong life cycle dependency between instances of the container class and instances of the contained class/es (if the container is destroyed, normally every instance that it contains is destroyed as well).

Symbolism	Meaning	Feature
Attributes	Logical data value of an object	Middle compartment of the class
Operation	Functions or tasks that can be performed on the data in the class	Bottom compartment of the class
Class	Rectangle containing three compartments stacked vertically	Top compartment shows the class's name
Association	Linkage between two classes, assumed to be bi-directional On the line can be specified the nature of relationship with a verb. At either end of the line, the name of the objectives of the relationship	Solid line between the two classes
Multiplicity	Number of objects that participate in the association	Both end of the association
Aggregation	Does not involve more than two classes, occurs when a class is a collection or container of other classes, but where the contained classes do not have a strong life cycle dependency on the container (if the container is destroyed, its contents are not).	Solid line and empty diamond shape at one end
Composition	More specific than aggregation, usually has a strong life cycle dependency between instances (if the container is destroyed, normally every instance that it contains is destroyed as well).	Solid line and filled diamond shape at one end

Table 1 Note for the UML Class Diagram

APPENDIX D: FUNCTIONAL REQUIREMENTS' TOOL

Ticket already booked	**Persons of Reduced Mobility**										
Y	N		Passenger arrives at terminal					Register at PRM desk	Engage PRM services	Escort through check-in	Proceed to check-in
N	N		Passenger arrives at terminal	Passenger queues at customer service desk	Flight options shown to passenger	Passenger selects flight	Airline collects payment				Proceed to check-in
Functional Requirements			Space for arrival	Waiting for customer service desk	Display flight options	Selection interface	Payment system	Visibility of PRM desk	PRM services	PRM services	Visibility of check-in area
System resources	**Subsystem resources**										
Overhead display	Screens										x
	Projectors										x
PRM reception	PRM desk sign							x			
	PRM handlers								x	x	
Customer service desk	Agent				x	x					
	Debit/credit card reader						x				
	Area around customer service desk										

Figure 6 Tool used to display functional requirements of stage 1 of check-in (pre check-in).

Checked-in online?	Printed boarding pass?	Prefers self service kiosk?	International flight?											
Y	Y	N/A	Y											Proceed to bag drop
Y	N	Y	Y		Queue for kiosk		Enter booking details		Scan passport				Print boarding pass	Proceed to bag drop
Y	N	N	Y			Queue for desk		Show booking details	Scan passport				Print boarding pass	Proceed to bag drop
N	N/A	Y	Y		Queue for kiosk		Enter booking details		Scan passport		Select seat		Print boarding pass	Proceed to bag drop
N	N/A	N	Y			Queue for desk		Show booking details	Scan passport			Seat allocated	Print boarding pass	Proceed to bag drop
Y	Y	N/A	N											Proceed to bag drop
Y	N	Y	N		Queue for kiosk		Enter booking details						Print boarding pass	Proceed to bag drop
Y	N	N	N			Queue for desk		Show booking details		Show photo ID			Print boarding pass	Proceed to bag drop
N	N/A	Y	N		Queue for kiosk		Enter booking details				Select seat		Print boarding pass	Proceed to bag drop
N	N/A	N	N			Queue for desk		Show booking details		Show photo ID		Seat allocated	Print boarding pass	Proceed to bag drop
Functional Requirements							Communicate information	Communicate information	ID verification	ID verification	Communicate information	Communicate information	Issue boarding pass	
System resources	**Subsystem resources**													
Self service kiosks	Graphical user interface GUI						x				x			
	Kiosk printer												x	
	Passport scanner								x					
	Area around check-in kiosks													
Check-in desks	Handler									x	x	x		
	Graphical user interface GUI							x						
	Luggage tag printer													
	Boarding pass printer												x	
	Passport scanner								x					
	Feeding luggage conveyor													
	Area around check-in desks													

Figure 7 Tool used to display functional requirements of stage 2 of check-in (check-in).

Special luggage	Luggage exceeds ticket limit?	Pay extra fee?													
N	N/A	N/A													Exit bag drop process
Y	N	N/A		Queue at desk	Show flight information	Show ID	Weigh luggage				Print luggage tag	Tag luggage	Move to baggage inspection desk	Check-in luggage	Exit bag drop process
Y	Y	Y		Queue at desk	Show flight information	Show ID	Weigh luggage		Request baggage fee	Register payment	Print luggage tag	Tag luggage	Move to baggage inspection desk	Check-in luggage	Exit bag drop process
Y	Y	N		Queue at desk	Show flight information	Show ID	Weigh luggage	Reduce baggage weight			Print luggage tag	Tag luggage	Move to baggage inspection desk	Check-in luggage	Exit bag drop process
Functional Requirements					Communicate information	ID verification	Weight measurement	Waiting for baggage inspection desk	Communicate information	Payment registration and receipt generation	Generate unique luggage identifier	Attach identifier to luggage	Path to baggage inspection	Path for luggage transfer	Path for passenger flow to security
System resources	**Subsystem resources**														
Check-in desks	Handler					x									
	Graphical user interface GUI														
	Luggage tag printer				x										
	Boarding pass printer														
	Passport scanner														
	Feeding luggage conveyor														
	Area around check-in desks			x			x				x				
Baggage inspection desk	Baggage inspector								x						
	Luggage belt									x					
	Printer														
	Area around baggage inspection desk								x						
Customer service desk	Agent														
	Debit/credit card reader														
	Area around customer service desk						x	x			x				

Figure 8 Tool used to display functional requirements of stage 4 of check-in (special bag drop).

APPENDIX E: AIRLINES MODULES

The notation adopted in the module's representation is the following:

- N number of passengers given by the Aircraft seats
- f the first, b business and e economy class passengers;
- o online check-in, k self service kiosk and d traditional check-in desk;
- b presence of a bag to drop, wb absence of bag to drop

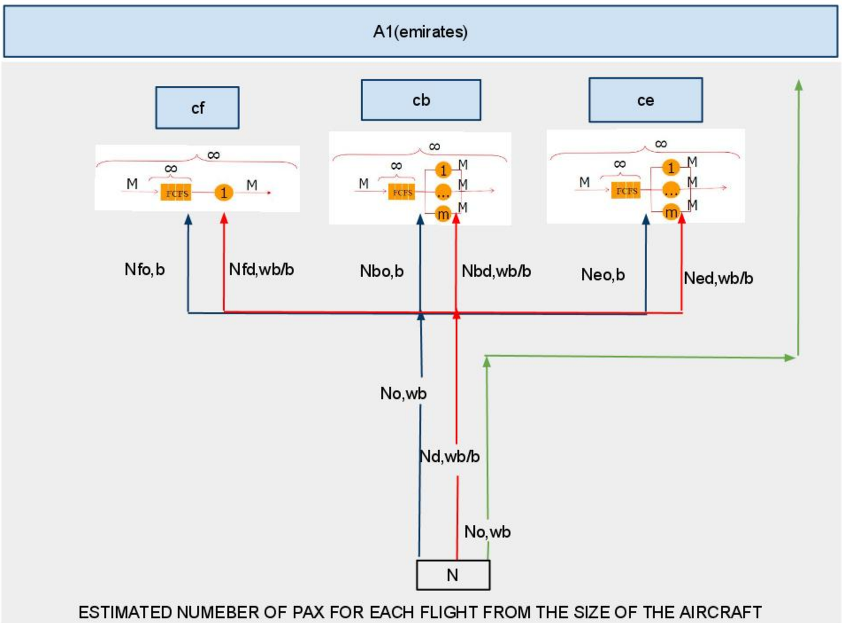

Figure 9 Emirates check-in module at MA Terminal 1

Three flights a day: No overlapping
Total number of passengers are divided by travel classes and assigned to different desks, no network just queues
Passenger with online check-in and without bags are not counted in the system, passengers with on line check-in and with bag, are added according to their travel class to the dedicate desks.

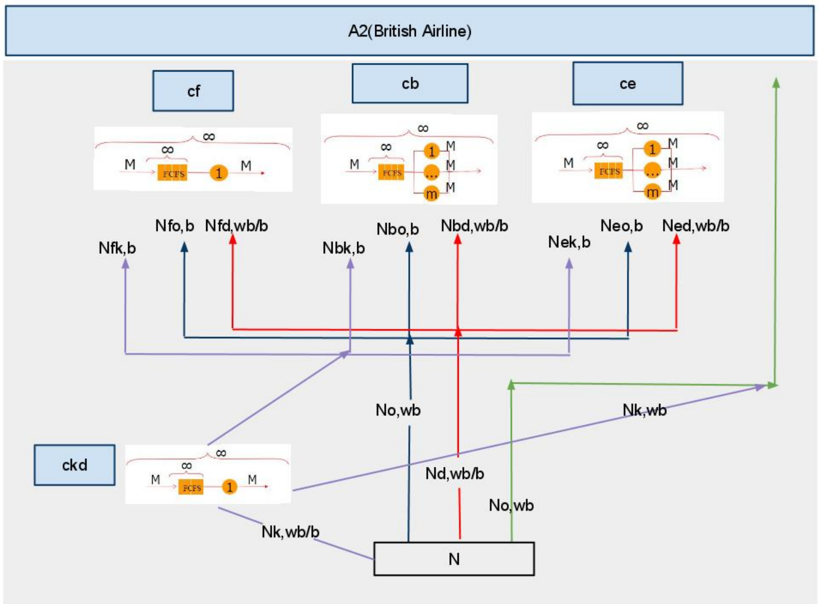

Figure 10 British Airways check-in module at MA Terminal 3

Three flights a day: any time any flight any desk.
Total number of passengers are divided by travel classes and assigned to different desks
Passengers with on line or kiosk self service boarding pass and with bag, need to be re-processed in the traditional desks to drop the bag, although they already have the boarding pass, causing a redundancy in the operation.

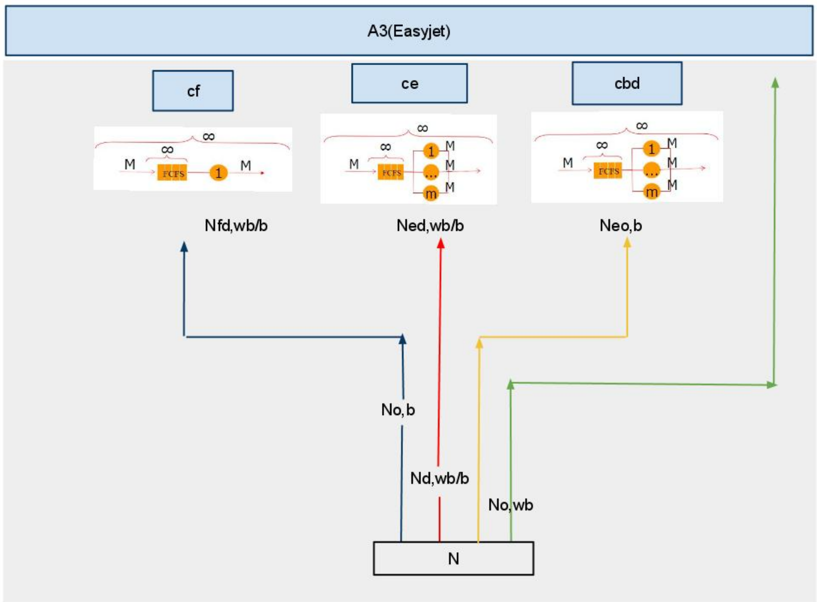

Figure 11 Easy jet check-in module at MA Terminal 3

More flights a day: window of time to check-in, any flight any desk.
Total number of passengers are divided by travel classes and assigned to different desks
Passengers with on line boarding pass and with bag have dedicate desks to drop the bag

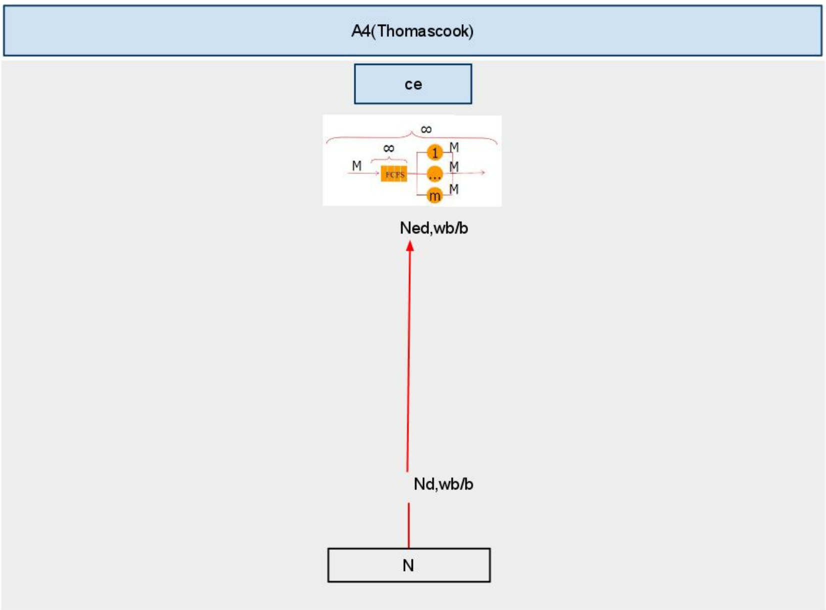

Figure 12 Thomas Cook check-in module at MA terminal 1

More flights a day: window of time to check-in, desks dedicated to each destination. No overlapping among flights, for each of them is defined the number of desks needed. One travel class:unique type of checking in

APPENDIX F – AIRLINE QUESTIONNAIRE

The first aim of this visit is to map the current check-in processes offered by you to your passengers at Manchester Airport. All of the different types of passengers should be mapped, since this information you kindly provide us with will be used to derive what are the overall processing capabilities you require from the airport. Thereby the need to answer, at first, the following question.

Question 1

The flowchart in the next page represents the process map for the check-in. Does it represent your check-in processes at Manchester Airport, for all of your types of passengers?

YES___ NO____

If NO, then would you be available to help us to produce the correct map? (the idea is to quickly build together the correct picture during our forthcoming site visit). YES___ NO____

Please add below any comment or draw on the map any modification, if relevant.

____
____
____

The second aim of this visit is to help us to understand a few operational aspects of your check-in processes at Manchester Airport. We are not interested in evaluating your performance, but to deepen our understanding of your current and future requirements in terms of infrastructure, buildings and equipments, for what concerns your check-in processes only. The following questions have exactly this purpose.

Question 2

At Manchester Airport, do you provide check-in services to your passengers by yourself or do you work with any of the available handlers in particular?

BY OURSELVES___WITH HANDLER____

Please add below any comment, if relevant.

____
____
____

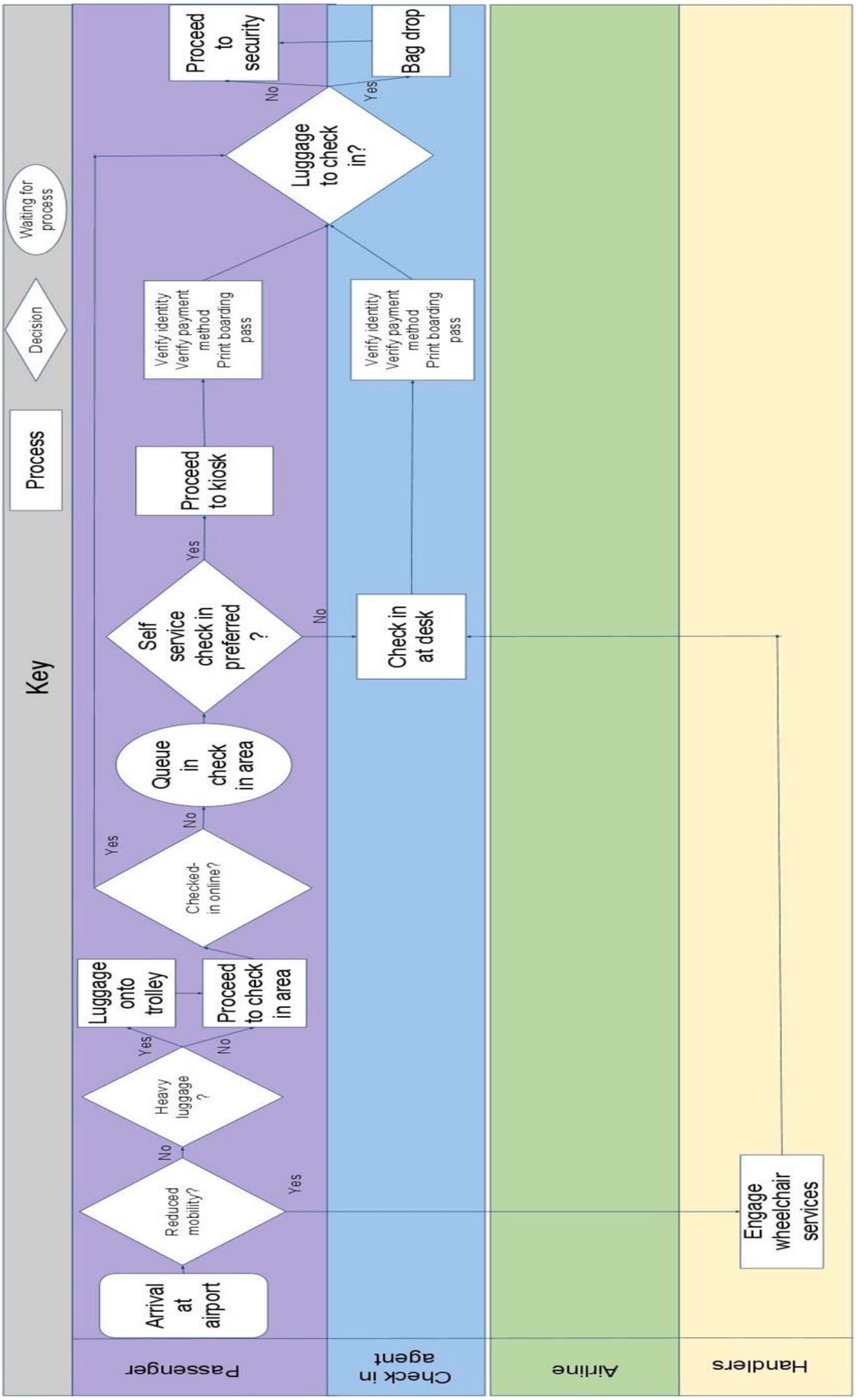

Figure 1. Proposed check-in process. Columns show responsibility for performing each step.

Question 3

Please tick the boxes that correspond to true statements, concerning your check-in processes at Manchester Airport.

Area / Equipment / System	We OWN it	We RENT it	We OPERATE it	We MAINTAIN it
Screen on the check in area				
Area in front of check-in desks				
Area where kiosks are located				
Other areas (Please specify name here and comment below) *Name:*				
Check-in desks				
Kiosks				
Software (sw) systems at check-in desks				
Software (sw) system at kiosk				
Other hardware (hw) equipment / system (Please specify name here and comment below) *Name:*				
Other software system (Please specify name here and comment below) *Name:*				

Please add below any comment, if relevant.

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Question 4

Please cross/tick the boxes that correspond to true statements, concerning your check-in processes at Manchester Airport.

	Area / Equipment / System / Passenger requirements	YES	NO
	The area (desks + kiosks + front area) that is allocated to our check-in processes is fixed, for all of our flights.		
	The area (desks + kiosks + front area) that is allocated to our check-in processes is fixed, for most of our flights, but for some of our routes we operate on additional desks that are allocated to us on a just-in-time / just-in-need basis.		
	We do not have any area in the terminal that is specifically allocated to our check-in processes		
	Check-in desks (hw + sw) have the right functionality to enable us to provide the right dedicated service to each class of passenger / customer, within any existing time constraints.		
	Kiosks (hw + sw) have the right functionality to enable us to provide the right dedicated service to each class of passenger / customer, within any existing time constraints.		
Desks	For the current number of passengers/routes we operate at Manchester Airport, we have		
Desks	• the right number of check-in desks currently allocated to us.		
Desks	• too few check-in desks currently allocated to us.		
Desks	• more check-in desks currently allocated to us than what we would need.		
Desks	For the current number of passengers/routes we operate at Manchester Airport, we have more check-in desks currently allocated to us than what we would need, and we deliberately have an overcapacity to cope with peak requests and any disruption.		
Kiosks	For the current number of passengers/routes we operate at Manchester Airport, we have		
Kiosks	• the right number of kiosks currently allocated to us.		
Kiosks	• too few kiosks currently allocated to us.		
Kiosks	• more kiosks currently allocated to us than what we would need.		
Kiosks	For the current number of passengers/routes we operate at Manchester Airport, we have more kiosks currently allocated to us than what we would need, and we deliberately have an overcapacity to cope with peak requests and any disruption.		

The proportion of our passengers that will choose to do *SELF* check-in in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that will choose to do *CURBSIDE* check-in in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that are Persons of Reduced Mobility (*PRMs)* in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that will choose to do *MOBILE (PHONE/TABLET/ETC.)* check-in in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that will choose to do *curbside check-in AT THE TRAIN STATION* in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that will choose to do *curbside check-in AT THE COACH/BUS STATION* in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		
The proportion of our passengers that will choose to do *HOME / WEB CHECK-IN* will increase in the next 20 years, compared to the current figures • will increase • will decrease • will remain stable		

Please add below any comment, if relevant.

____

____

Question 5

What are the main factors (pieces of information) that enable you to define the different classes in which your passengers / customers are divided, with regards to the check-in process? - Please fill in the blank cells of the following table with any other piece of information that is relevant in this classification and that is not there already. After that, please check/tick the YES/NO answer that applies to each piece of information.

Note: A 'class' of passengers is defined as such because it requires a sequence of steps in the check-in process that is distinctive and typical of that class only.

Information	We collect this information before check-in	
Nationality (visa needs/language spoken, etc.) of each passenger	YES	NO
Age of each passenger	YES	NO
Size of travelers groups	YES	NO
Number and type of items carried by each passenger	YES	NO
Purpose of the flight of each passenger	YES	NO
	YES	NO
	YES	NO
	YES	NO
	YES	NO
	YES	NO
	YES	NO
	YES	NO

Please list below the pieces of information that, among those for which you ticked the YES answer in the previous table, they are collected in advance specifically to better plan your check-in resources / staff requirements over time.

____
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Please list below the pieces of information that, among those for which you ticked the NO answer in the previous table, they should be collected in advance (assuming it will be technically possible and for free) in the future specifically to better plan your check-in resources / staff requirements over time.

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Please list below the pieces of information that, among those for which you ticked the NO answer in the previous table, it is very unlikely that they will ever be collected in advance in the future, because of practical/economical constraints. If possible, give a brief description of such constraints.

Question 6

Can you please list (name and/or brief description), in the table below, all of the different classes of passengers (defined as in Question 5 – i.e. with respect to check-in passengers requirements only) you process at the moment and will be transporting (or will be likely to transport) in the next 20 years? - Please add the names of these classes in the left column and then circle the relevant answer in the left columns.

Passengers class	With respect to the current situation, the proportion of this class of passengers is expected, in the next 20 years …		
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease
	To increase	To remain stable	To decrease

	To increase	To remain stable	To decrease

Question 7

Are you currently offering any additional services to your customers, directly at the check-in desk, at the moment?

YES___ NO____

If YES, which ones?

____

____

If NO, would you do it in the future?

YES___ NO____

Please specify below what services would you like to add to your portfolio, that will be provided directly while checking-in passengers at the counter / kiosks / etc.

____

____

Question 8

Please list, in the table below, any relevant Regulation (local, national, European, etc.) or *de-facto* standard that you have to take into account to manage and operate your check-in services, now and (if known / expected) in the next 20 years. Please add in the blank cells of the table any relevant characteristic of check-in service that we have missed out and that requires following regulations/standards.

Characteristic of check-in service	Relevant regulations	Relevant *de-facto* standards
Passengers personal information		
Size of baggage		
Number of pieces of baggage		
Security questions		

Question 9

What essential information or items is it necessary to obtain from/give to EVERY passenger during the check in process regarding:

Security

____

____

____

____

Identification

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____
____
____

Baggage

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____
____
____

Flight Information

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____
____
____

<u>Question 10</u>

Please list, in the left column of the table below, any relevant operational inefficiency you experience from managing your check-in services. Please then add in the central column a brief description of how frequently you experience this inefficiency, and in the right column any suggestion of what airport infrastructural characteristic(s) could eliminate / reduce, according to you, the frequency and magnitude of these inefficiencies.

Operational inefficiency	How frequently?	Characteristic(s) in the infrastructure (terminal building / check-in halls / equipment / check-in technologies / airport infrastructure more in general) that could be eliminated / reduced.

Question 11

What are the check-in performance measures that you record and that represent a relevant operational Key Performance Indicator (KPI) for you? Please add in the blank cells any measure that is not listed.

Time spent in queue by each passenger	NO, it is not recorded	YES, it is recorded
Physical length of the queue	NO, it is not recorded	YES, it is recorded
Time needed to process all passengers of a given flight	NO, it is not recorded	YES, it is recorded
Number of passengers that show up over time	NO, it is not recorded	YES, it is recorded
Average time to check-in per passenger (divided by class?)	NO, it is not recorded	YES, it is recorded
Planned number of desks to be used for each flight	NO, it is not recorded	YES, it is recorded
Actual number of desks used for each flight	NO, it is not recorded	YES, it is recorded
Planned time of usage of each check-in desk per flight	NO, it is not recorded	YES, it is recorded
Actual time of usage of each check-in desk per flight	NO, it is not recorded	YES, it is recorded
	NO, it is not recorded	YES, it is recorded
	NO, it is not recorded	YES, it is recorded
	NO, it is not recorded	YES, it is recorded
	NO, it is not recorded	YES, it is recorded
	NO, it is not recorded	YES, it is recorded

Question 12

What are your expectations in terms of airport infrastructure (check-in halls, terminal buildings more in general, check-in hw/sw resources available to you and the handlers, etc.), for the next 20 years, more specifically in support of your check-in processes? Please give a brief description trying to identify specific characteristics/KPIs that you see/foresee as the most desirable to operate your flights at Manchester Airport.

____

____

____

Question 13

What are the technologies that, according to you, will change the future of the check-in process? Why? Please give a brief description below, either for the technologies that already exist but are not yet mature, or for those that you would like to see being developed in the near future, either way to improve the Operational KPIs that you identified above and any other more strategic KPI you have in mind.

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APPENDIX G: AIRPORT QUESTIONNAIRE

Question 1

Please identify the different costs of providing check-in related infrastructure/service/equipment into the relevant category according to the following definitions:

- Fixed – costs incurred which are independent of the check-in configuration options (e.g. Construction of check-in hall)
- Variable – costs which scale with:
  - Annual passenger volume
  - Number of classes of passenger in a given year (e.g. Business/leisure, Person of Reduced of Mobility (PRM)/non-PRM, etc.)
  - Number of flights per year
  - Number of classes of flight per year (e.g. Short haul/long haul, etc.)
  - Number of different airlines serviced
  - Number of classes of airline serviced (eg low cost carriers/cargo)
- Lost opportunity cost - lost opportunity from not having additional shops/promotional areas using the same space.

Fixed	Variable	Lost Opportunity Cost

Question 2

The flowchart in the next page represents the process map for the check-in. Do you agree on this representation of the processes as it is carried out at Manchester Airport, for ALL of your types of passengers?

YES___ NO____

If NO, then would you be available to help us to produce the correct map? (the idea is to quickly build together the correct picture during our forthcoming site visit).

YES___ NO____

Please add below any comment or draw on the map any modifications, if relevant.

____
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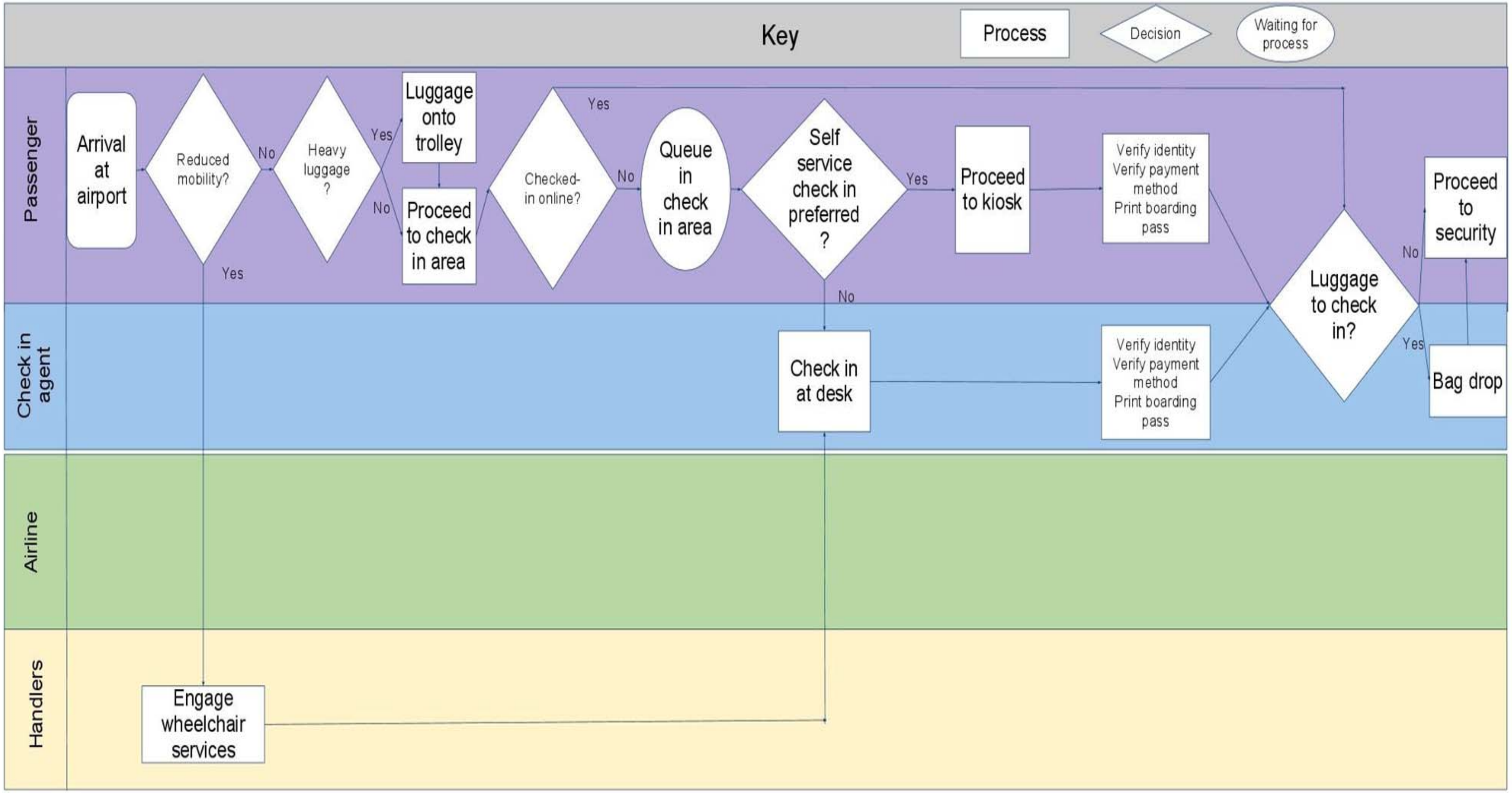
Key
Process
Decision
Waiting for process
Passenger
Check in agent
Airline
Handlers
Arrival at airport
Reduced mobility?
No
Yes
Heavy luggage ?
Yes
No
Luggage onto trolley
Proceed to check in area
Checked-in online?
Yes
No
Queue in check in area
Self service check in preferred ?
Yes
No
Proceed to kiosk
Verify identity
Verify payment method
Print boarding pass
Check in at desk
Verify identity
Verify payment method
Print boarding pass
Luggage to check in?
No
Yes
Proceed to security
Bag drop
Engage wheelchair services

Question 3

Please tick the boxes that correspond to true statements, concerning your check-in processes at Manchester Airport.

Area / Equipment / System	We OWN it	We RENT it	We LEASE it	We OPERATE it	We MAINTAIN it
Terminal area dedicated to check in					
Screens in the check in area					
Area in front of check-in desks					
Area where kiosks are located					
Other areas (Please specify name here and comment below) *Name:* ____________________					
Check-in desks					
Kiosks					
Software (sw) systems at check-in desks					
Software (sw) system at kiosk					
Other hardware (hw) equipment / system (Please specify name here and comment below) *Names:* ____________________					
Other software system (Please specify name here and comment below) *Names:* ____________________					

Please add below any comment, if relevant.

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Question 4

Please tick the boxes that correspond to true statements, concerning check-in Area / Equipment / System available at Manchester Airport.

Area / Equipment / System / Passenger requirements	YES	NO
The area (desks + kiosks + front area) that is allocated is fixed, for all flights.		
The area (desks + kiosks + front area) that is allocated to our check-in processes is fixed, for most of flights, but for some of our routes/time table we assign additional desks on a just-in-time / just-in-need basis.		
One of the constraints we have in moving airlines from one area in the long term		
is due to the Airline request in terms of		
• position in the Check in Terminal area		
• distance from gates		
• proximity to shops		
• proximity to other airlines		
other factors, such as:		
• ______________________________		
• ______________________________		
We do not have any area in the terminal that is allocated to a specific airline		
We do not have any constraints in moving airlines from one area to the other in the short term (daily, weekly or monthly), we just have to provide the requested number of desks		
For the current number of flights/airlines that operate at Manchester Airport, we have		
• the right number of check-in desks.		
• too few check-in desks.		
• more check-in desks than needed and we deliberately have an overcapacity to cope with peak requests and any disruption.		
• more check-in desks than needed and we should reduce this inefficient use of capacity.		
Failure to meet airlines' requests result in penalties to the airport.		
We cannot influence the request of number of desks demanded by the airline.		
We cannot refuse to give the number of desks demanded by the airline.		
For the current number of flights/airlines that operate at Manchester Airport, we have		
• the right number of kiosks.		
• too few kiosks.		
• more kiosks than needed and we deliberately have an overcapacity to cope with peak requests and any disruption.		
• more kiosks than needed and we should reduce this inefficient use of capacity.		

The airlines are allowed to introduce and use their own kiosks at the airport.		
If 'YES' to previous question:		
• there is a maximum number of kiosks allowed by contract		
• there is a fee to pay for using the kiosks based on their resource consumption (e.g. electricity, internet).		
• there is a fee to pay based on the space required.		
The number of check in desks required by airlines over the next 20 years will:		
• increase		
• decrease		
• remain stable		
The number of kiosks required by airlines over the next 20 years will:		
• increase		
• decrease		
• remain stable		

Please add any relevant comments below.

____

____

Question 5

What are the main factors that enable you to define the different classes of airline, which affect the check-in process in terms of its requirements for space/time etc.? Please fill in the blank cells of the following table with any other factor that is relevant in this classification and that is not there already. After that, please tick the YES/NO answer that applies to each factor.

Note: A 'class' of airlines is defined as such because it requires a homogenous set of requirements in terms of specific equipment/service/infrastructure that are distinctive and typical of that class only.

Information	We collect this information before signing contract	
Flight schedule for specified time period (please specify eg monthly)	YES	NO
Aircraft size	YES	NO
Aircraft type	YES	NO
Proportion of business vs leisure travellers	YES	NO
	YES	NO
	YES	NO
	YES	NO

For those factors ticked YES, please list below if they are collected in advance specifically to plan your check-in resources or capacity design.

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For those factors ticked NO, please list below if they should be collected in advance or recorded (assuming it will be technically possible and for free) in the future specifically to better plan your check-in resources or capacity design.

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Question 6

Please indicate whether the listed aspects of check-in are given some level of differentiation between airlines. Add other aspects of check-in to the blank rows which are not already listed.

Aspect of Check-in	No	Yes	Please indicate WHY and HOW this is done.
Check in area			
Advertising equipment			
Baggage service equipment/infrastructure			

Question 7

Are you currently offering any equipment to airlines that allow them to offer additional services at the check-in desk other than check-in services (e.g. Ticketing etc.)?

YES___ NO____

If YES, which ones?

____

____

If NO, would you do it in the future?

YES___ NO____

What additional services WOULD YOU LIKE to provide while checking-in passengers at the desks/kiosks etc?

____

____

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APPENDIX H: AIRPORTS COMPARABLE IN TERM OF ANNUL PASSENGERS WITH MA

Airport	City	Passengers 2010
London Heathrow Airport	London	65881660
Paris-Charles de Gaulle Airport	Paris	58164612
Frankfurt Airport	Frankfurt	53009221
Barajas Airport	Madrid	49863504
Amsterdam Airport Schiphol	Amsterdam	45211749
Leonardo da Vinci-Fiumicino Airport	Rome	36337050
Munich Airport	Munich	34721605
Atatürk International Airport	Istanbul	32145619
Gatwick Airport	London	31375290
Barcelona El Prat Airport	Barcelona	29209595
Paris-Orly Airport	Paris	25203969
Zürich Airport	Zürich	22878251
Domodedovo International Airport	Moscow	22253529
Antalya Airport	Antalya	21996601
Copenhagen Airport	Copenhagen	21501750
Palma de Mallorca Airport	Palma de Mallorca	21117270
Vienna International Airport	*Vienna*	*19691206*
Sheremetyevo International Airport	*Moscow*	*19123007*
Oslo Airport Gardermoen	*Oslo*	*19091113*
Düsseldorf International Airport	*Düsseldorf*	*18988149*
Malpensa Airport	*Milan*	*18947808*
London Stansted Airport	*London*	*18573803*
Dublin Airport	*Dublin*	*18431625*
Manchester Airport	*Manchester*	*17759015*
Brussels Airport	*Brussels*	*17181000*
Stockholm-Arlanda Airport	*Stockholm*	*16962416*
Athens International Airport	*Athens*	*15411099*
Berlin Tegel Airport	Berlin	15025600
Lisbon Portela Airport	Lisbon	14035273
Hamburg Airport	Hamburg	12962429
Helsinki-Vantaa Airport	Helsinki	12883399
Málaga Airport	Málaga	12064616

		Vienna International Airport	Sheremetyevo International Airport	Oslo Airport Gardermoen	Düsseldorf International Airport	Malpensa Airport	London Stansted Airport
n. of pax[milion]		19.7	19.3[1]	19.1	18.9	17.3	19.9
n.of aircraft movments,10^3		246	184	219	215	213	177
number of airlines		95	44	30	73	80	33
peak time		5:45-10:45	5:05-10:00	6:00-11:00	5:50-11:00	6:15-11:00	
n. of flights in the peak time		131	56	128	107	77	
hub for		Austrian Airline,Niki	Aeroflot,Arinova,Nordavia,Nordwind Airlines	Scandinavian Airlines,Norwegian Air Shuttle,Widerøe	Air Berlin,Eurowings, lufthansa	AirItaly,AirOne,Blue Panorama,easyJet,Lufthansa Italia,Neos Air,Star Alliance	
runway(s) length [m]							
	1st	3500,ICAO Cat. I,	3700, ICAO Cat. III	2 950,ICAO Cat. 4E	3 000,100/R/B/W/T	3920,ICAO Cat. 3B	3048,86/R/C/W/T
	2nd	3600,ICAO Cat. I, 3B	3550, ICAO Cat. IIIA, ILS	3600,ICAO Cat. 4E	2700,100/R/B/W/T	3920,ICAO Cat. 3B	
number of terminals*		3	5	1	4	2	1
number of destinations		258	20	139	271	168	150
avarage route distance [km]		2830	3042	1640	2834	2307	1766
Aircraft size max		E	no one	E+	B747	B747-400	B747-8/A380
Operating hours		24 hours	24 hours	24 hours	24 hours	24 hours	24 hours
number of check-in desks		111 LINE	237 LINE	64 ISLAND	61 ISLAND	226	120 ISLAND
Self-service IN THE Airport		all airlines	6 airlines	Airlines'choice		x	x
Self-serviceOUTSIDE THE Airport		88%airlines CAT	Railway station				
	other	*previous day*	*Separate Bagdrop*	*34 new counters*	*Late-Night-Check-in*		
		express service		*Check-in via SMS*			
		classics service					
		priority vip priority					

[1] Massive expansion expected, up to 30% in 5 years ("Sheremetyevo International Airport Annual Report,2010)

		Dublin Airport	Manchester Airport	Brussels Airport	Stockholm-Arlanda Airport	Athens International Airport
n. of pax[milion]		18.4	17.7	16.9	16.9	16.2
n.of aircraft movments [thousand]		160	159	231	192	183
number of airlines		68	55	100	71	80
peak time		6:40-11:00		5:05-10:00	7:00-11:35	5:00-10:00
n. of flights in the peak time		73		101	38	62
hub for		Aer Lingus,Aer Lingus Regional,CityJet,Europe Airpost,Monarch Airlines,Ryanair,Thomson Airways	British Ariline	Brussels Airlines,El Al Cargo,Eva Air Cargo,Jet Airways,Jetairfly	Nextjet,Norwegian Air Shuttle,Scandinavian Airlines,Skyways Express,TUIfly Nordic	Aegean Airlines,Hellenic Imperial Airways,Olympic Air,Viking Hellas
runway(s) length [m]						
	1st	2637,ICAO Cat. 3	3 048, ICAO Cat. 4E	2 984,ICAO Cat. E	3 301, 97/R/B/X/T	4 000, 64/F/B/W/T
	2nd	2072,ICAO Cat. 3	3 048, ICAO Cat. 4E	3 211,ICAO Cat. E	2 500, 90/F/B/X/T	3 800, 64/F/B/W/T
	3rd	1339,No ILS		3638,ICAO Cat. E	2 500, 78/R/B/X/T	
number of terminals*		2	3	2	4	2
number of destinations		244	256	184	140	380
avarage route distance [km]		2649	2518	2487	1569	1876
Aircraft size max		no one	A380	B747/AN-225	B747	B747-400
Operating hours		24 hours	24 hours	24 hours	24 hours	24 hours
number of check-in desks		76 ISLAND/LINE	220 LINE	120 ISLAND	62 LINE	157 LINE
Self-service IN THE Airport						
	other				*Check-in via SMS for some airline*	

APPENDIX I: KEY PERFORMANCE INDICATORS

Factors of performance from pax 's point of view	Factors of performance from operator's point of view	Factors of performance from airline's point of view
Compactness - curb-to-gate distance - curb-to-gate time - difficulty (level changes, choice points, etc.) **Delay** - service times: check-in, baggage claim - waiting times - variability of wait **Service Reliability** - service levels variation - required time before departure - connecting time - f light alternatives: airlines, flights **Service** - signing or sightlines reasonableness - spatial logic - service "justice" (first in, first out) **Cost** - food and drinks - departure fees - connection fees (interline,interterminal) - other concession prices **Comfort and Diversion** - crowding - sound levels, clarity, and noise , temperature, humidity levels	**Operational** - passengers served per unit time - effectiveness - people accommodated per unit time - passenger service levels over time - baggage handled per unit time - baggage service reliability over time - flight ground delays **Efficiency** - gate utilization - space utilization - labour utilization - power, fuel consumption **Risk** - security effectiveness - life safety, public health - crime (theft, smuggling) **Functionality** - reliability - maintainability **Finances** - revenue yield - operations, maintenance expenses - debt coverage **Flexibility** - architectural (new passenger demands) - operational (new aircraft, airlines services)	**Operational effectiveness** - aircraft turnaround, flight service time - baggage transfer reliability - passenger service times **Station cost** - terminal fees - labour costs - equipment costs - inventory costs **Corporate image** - control of space, design - maintenance of service levels - market share **Flexibility** - operational (new services and aircraft) - architectural (image and passenger accommodation)

Table 2 Key performance indicators [source (Lemer, 1992)]

APPENDIX L: CONFIGURATION AND RECONFIGURATION KPIS

CONFIGURATION KPIs (£)

TIME	PHYSICAL INDICATOR	average time to reach the shopping area	average time to reach security	time spent in managing process	average time in process (queue + desk)
	FINANCIAL INDICATOR	cost opportunity	lost revenue/cost opportunity	cost opportunity	cost/pax/time cost/bag/time
SPACE	PHYSICAL INDICATOR	discrepancy between available area and required area	check in hall available for pax and visitors	distance between related processes	space available for future expansion
	FINANCIAL INDICATOR	cost opportunity	cost opportunity	cost opportunity	cost opportunity
HUMAN RESOURCES	PHYSICAL INDICATOR	number of airport operators	task flexibility of operators		
	FINANCIAL INDICATOR	number of salaries	salary depending on operator qualifications		
EQUIPMENT RESOURCES	PHYSICAL INDICATOR	utility/energy consumption	reliability		
	FINANCIAL INDICATOR	operating cost	maintenance cost / lost availability		

Table 3 Configuration KPIs proposed at MAG

RE-CONFIGURATION KPIs (£)						
TIME	time spent in implementing new configuration	time for initial troubleshooting	time to gain familiarity with the new configuration	time to decide the new configuration		PHYSICAL INDICATOR
	cost due to system stop	cost due to unexpected delays	cost of training operators	cost of delaying decision		FINANCIAL INDICATOR
SPACE	additional space required for re-configuration work	impact on other process layout and location				PHYSICAL INDICATOR
	cost opportunity	cost of adjusting other processes				FINANCIAL INDICATOR
HUMAN RESOURCES	number of additional operators required in the change	job enlargement and enrichment	change in the agreements with stakeholders			PHYSICAL INDICATOR
	number of salaries	cost of training operators	cost of renewing contracts			FINANCIAL INDICATOR
EQUIPMENT RESOURCES	equipment change	integrability				PHYSICAL INDICATOR
	cost of acquisition and disposal/revenue from residual value	cost of installation and integration with supporting infrastructure				FINANCIAL INDICATOR

Table 4 Re-configuration KPIs proposed at MAG

APPENDIX M: RESULTS FROM THE MODEL VERIFICATION

Tables I Variation of arrival rate proportional to the number of counters

	$service\ rate = 4.5$ $\lambda = 0.125$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	3	2	1										
m=3	3	3	2	1									
m=4	3	3	3	2	1								
m=5	3	3	3	2	2	1							
m=6	3	3	3	3	2	2	1						
m=7	3	3	3	3	3	2	2	1					
m=8	3	3	3	3	3	3	2	2	1				
m=9	3	3	3	3	3	3	3	2	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	2.43

	$service\ rate = 4.5$ $\lambda = 1.425$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	4												
m=1	4	4											
m=2	4	4	4										
m=3	4	4	4	4									
m=4	4	4	4	4	3								
m=5	4	4	4	4	3	3							
m=6	4	4	4	3	3	3	3						
m=7	4	4	4	3	3	3	3	2					
m=8	4	4	3	3	3	3	3	3	2				
m=9	4	4	3	3	3	3	3	3	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	3.30303

	$service\ rate = 4.5$ $\lambda = 0.85$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	4												
m=1	4	3											
m=2	4	3	3										
m=3	4	3	3	3									
m=4	4	3	3	3	3								
m=5	4	3	3	3	3	2							
m=6	4	3	3	3	3	3	2						
m=7	4	3	3	3	3	3	2	2					
m=8	4	3	3	3	3	3	3	2	1				
m=9	4	3	3	3	3	3	3	3	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	2.95

Tables II Variation of service rate

	$service\ rate = 4.5$ $\lambda = 0.125$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	3	2	1										
m=3	3	3	2	1									
m=4	3	3	3	2	1								
m=5	3	3	3	2	2	1							
m=6	3	3	3	3	2	2	1						
m=7	3	3	3	3	3	2	2	1					
m=8	3	3	3	3	3	3	2	2	1				
m=9	3	3	3	3	3	3	3	2	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	2.43

	$service\ rate = 7$ $\lambda = 0.125$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	2	2	1										
m=3	2	2	2	1									
m=4	2	2	2	2	1								
m=5	2	2	2	2	2	1							
m=6	2	2	2	2	2	2	1						
m=7	2	2	2	2	2	2	2	1					
m=8	2	2	2	2	2	2	2	2	1				
m=9	3	2	2	2	2	2	2	2	1	1		mode	2
m=10	3	2	2	2	2	2	2	2	2	1	1	average	1.83

Tables III Variation of the time interval length

	$service\ rate = 4.5$ $\lambda = 0.125 \quad t_{k+1} - t_k = 30'$											
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	3	2	1										
m=3	3	3	2	1									
m=4	3	3	3	2	1								
m=5	3	3	3	2	2	1							
m=6	3	3	3	3	2	2	1						
m=7	3	3	3	3	3	2	2	1					
m=8	3	3	3	3	3	3	2	2	1				
m=9	3	3	3	3	3	3	3	2	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	2.43

	$service\ rate = 4.5$ $\lambda = 0.125 \quad t_{k+1} - t_k = 40'$											
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	2	2	1										
m=3	2	2	2	1									
m=4	2	2	2	2	1								
m=5	3	2	2	2	2	1							
m=6	3	3	2	2	2	2	1						
m=7	3	3	3	2	2	2	2	1					
m=8	3	3	3	3	2	2	2	2	1				
m=9	3	3	3	3	2	2	2	2	2	1		mode	2
m=10	3	3	3	3	3	2	2	2	2	2	1	average	2.12

	$service\ rate = 4.5$ $\lambda = 0.125 \quad t_{k+1} - t_k = 20'$											
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	3	1											
m=2	3	3	1										
m=3	4	3	2	1									
m=4	4	4	3	2	1								
m=5	4	4	4	3	2	1							
m=6	4	4	4	4	3	2	1						
m=7	4	4	4	4	4	3	2	1					
m=8	5	4	4	4	4	4	3	2	1				
m=9	5	5	4	4	4	4	4	3	2	1		mode	4
m=10	5	5	5	4	4	4	4	4	3	2	1	average	3.18

Tables IV Variation of the number of passengers N

	$service\ rate = 4.5$ $\lambda = 0.125 \quad N = 10$												
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10		
m=0	1												
m=1	2	1											
m=2	3	2	1										
m=3	3	3	2	1									
m=4	3	3	3	2	1								
m=5	3	3	3	2	2	1							
m=6	3	3	3	3	2	2	1						
m=7	3	3	3	3	3	2	2	1					
m=8	3	3	3	3	3	3	2	2	1				
m=9	3	3	3	3	3	3	3	2	2	1		mode	3
m=10	4	3	3	3	3	3	3	3	2	2	1	average	2.43

	$service\ rate = 4.5$ $\lambda = 0.125$ $N = 20$																				
	n=0	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8	n=9	n=10	n=11	n=12	n=13	n=14	n=15	n=16	n=17	n=18	n=19	n=20
m=0	4																				
m=1	4	4																			
m=2	4	4	4																		
m=3	4	4	4	4																	
m=4	4	4	4	4	4																
m=5	4	4	4	4	4	4															
m=6	4	4	4	4	4	4	3														
m=7	4	4	4	4	4	4	4	3													
m=8	4	4	4	4	4	4	4	3	3												
m=9	4	4	4	4	4	4	4	3	3	3											
m=10	4	4	4	4	4	4	4	4	3	3	3										
m=11	4	4	4	4	4	4	4	4	3	3	3	3									
m=12	4	4	4	4	4	4	4	4	3	3	3	3	3								
m=13	4	4	4	4	4	4	4	4	4	3	3	3	3	2							
m=14	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2						
m=15	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2					
m=16	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	2	2				
m=17	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	1			
m=18	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	1		
m=19	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	2	2	1	
m=20	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	1
										moda	4									moda	4
										media	3.94									media	3.58

APPENDIX N: RESULTS OF DYNAMIC PROGRAMMING FOR A RANGE OF ARRIVAL AND SERVICE RATES

Tables I Early morning arrival rates

ARRIVALRATE 0.125

service rate=7

1										
2	1									
2	2	1								
2	2	2	1							
2	2	2	2	1						
2	2	2	2	2	1					
2	2	2	2	2	2	1				
2	2	2	2	2	2	2	1			
2	2	2	2	2	2	2	2	1		
3	2	2	2	2	2	2	2	1	1	
3	2	2	2	2	2	2	2	2	1	1
									mode	2
									averag	1.83

service rate=6.5

1										
2	1									
2	2	1								
2	2	2	1							
2	2	2	2	1						
2	2	2	2	2	1					
2	2	2	2	2	2	1				
3	2	2	2	2	2	2	1			
3	3	2	2	2	2	2	2	1		
3	3	3	2	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1
									mode	2
									avera	2.05

service rate=6

1										
2	1									
2	2	1								
2	2	2	1							
2	2	2	2	1						
3	2	2	2	2	1					
3	3	2	2	2	2	1				
3	3	3	2	2	2	2	1			
3	3	3	3	2	2	2	2	1		
3	3	3	3	2	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mod	2
									aver	2.121

ARRIVALRATE 1.425

service rate=7

4										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	2	2				
3	3	3	3	2	2	2	2			
3	3	3	2	2	2	2	2	2		
3	3	2	2	2	2	2	2	2	1	
3	2	2	2	2	2	2	2	2	1	1
									mode	3
									averag	2.52

service rate=6.5

4										
4	4									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	2	2	2			
3	3	3	3	3	2	2	2	2		
3	3	3	3	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1
									mode	3
									avera	2.7

service rate=6

4										
4	4									
4	4	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	2	2	2		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mod	3
									aver	2.803

	service rate=5.5											service rate=5											service rate=4.5										
ARRIVALRATE 0.125	1											1											1										
	2	1										2	1										2	1									
	2	2	1									2	2	1									3	2	1								
	2	2	2	1								3	2	2	1								3	3	2	1							
	3	2	2	2	1							3	3	2	2	1							3	3	3	2	1						
	3	3	2	2	2	1						3	3	3	2	2	1						3	3	3	2	2	1					
	3	3	3	2	2	2	1					3	3	3	3	2	2	1					3	3	3	3	2	2	1				
	3	3	3	3	2	2	2	1				3	3	3	3	3	2	2	1				3	3	3	3	3	2	2	1			
	3	3	3	3	3	2	2	2	1			3	3	3	3	3	3	2	2	1			3	3	3	3	3	3	2	2	1		
	3	3	3	3	3	3	2	2	2	1		3	3	3	3	3	3	3	2	2	1		3	3	3	3	3	3	3	2	2	1	
	3	3	3	3	3	3	3	2	2	2	1	3	3	3	3	3	3	3	2	2	2	1	4	3	3	3	3	3	3	3	2	2	1
										mode	3										mode	3										mod	3
										avera	2.26										avera	2.364										med	2.439

ARRIVALRATE 1.425	4											4											4										
	4	4										4	4										4	4									
	4	4	4									4	4	4									4	4	4								
	4	4	3	3								4	4	4	4								4	4	4	4							
	3	3	3	3	3							4	4	4	3	3							4	4	4	4	3						
	3	3	3	3	3	3						4	4	3	3	3	3						4	4	4	4	3	3					
	3	3	3	3	3	3	3					4	3	3	3	3	3	3					4	4	4	3	3	3	3				
	3	3	3	3	3	3	3	2				3	3	3	3	3	3	3	2				4	4	4	3	3	3	3	2			
	3	3	3	3	3	3	3	2	2			3	3	3	3	3	3	3	2	2			4	4	3	3	3	3	3	3	2		
	3	3	3	3	3	3	3	2	2	1		3	3	3	3	3	3	3	2	2	1		4	4	3	3	3	3	3	3	2	1	
	3	3	3	3	3	3	3	2	2	2	1	3	3	3	3	3	3	3	2	2	2	1	4	3	3	3	3	3	3	3	2	2	1
										mode	3										mode	3										mod	3
										avera	2.94										avera	3.061										med	3.303

ARRIVALRATE 0.85

service rate=7										
3										
3	3									
3	3	3								
3	3	3	2							
3	3	3	2	2						
3	3	3	2	2	2					
3	3	2	2	2	2	2				
3	3	2	2	2	2	2	2			
3	3	2	2	2	2	2	2	1		
3	3	2	2	2	2	2	2	2	1	
3	2	2	2	2	2	2	2	2	1	1
									mode	2
									averag	2.30

service rate=6.5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	2	2					
3	3	3	3	2	2	2				
3	3	3	3	2	2	2	2			
3	3	3	3	2	2	2	2	1		
3	3	3	3	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1
									mode	3
									averag	2.53

service rate=6										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	2	2					
3	3	3	3	3	2	2				
3	3	3	3	3	2	2	2			
3	3	3	3	3	2	2	2	1		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mod	3
									aver	2.606

ARRIVALRATE 0.85

service rate=5.5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	2					
3	3	3	3	3	2	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									avera	2.71

service rate=5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	2					
3	3	3	3	3	3	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	3	2	1		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									avera	2.758

service rate=4.5										
4										
4	3									
4	3	3								
4	3	3	3							
4	3	3	3	3						
4	3	3	3	3	2					
4	3	3	3	3	3	2				
4	3	3	3	3	3	2	2			
4	3	3	3	3	3	3	2	1		
4	3	3	3	3	3	3	3	2	1	
4	3	3	3	3	3	3	3	2	2	1
									mod	3
									med	2.955

Tables II Day time arrival rates

ARRIVALRATE 0.25

service rate=7

2										
2	2									
2	2	1								
2	2	2	1							
2	2	2	2	1						
2	2	2	2	2	1					
2	2	2	2	2	2	1				
2	2	2	2	2	2	2	1			
2	2	2	2	2	2	2	2	1		
3	2	2	2	2	2	2	2	2	1	
3	2	2	2	2	2	2	2	2	1	1
									mode	2
									average	1.88

service rate=6.5

2										
2	2									
2	2	1								
2	2	2	1							
2	2	2	2	1						
2	2	2	2	2	1					
3	2	2	2	2	2	1				
3	3	2	2	2	2	2	1			
3	3	2	2	2	2	2	2	1		
3	3	3	2	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1
									mode	2
									average	2.05

service rate=6

2										
2	2									
2	2	1								
2	2	2	1							
3	2	2	2	1						
3	3	2	2	2	1					
3	3	2	2	2	2	1				
3	3	3	2	2	2	2	1			
3	3	3	3	2	2	2	2	1		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mode	2
									average	2.20

ARRIVALRATE 1.4

service rate=7

4										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	2	2				
3	3	3	3	2	2	2	2			
3	3	3	2	2	2	2	2	2		
3	3	2	2	2	2	2	2	2	1	
3	2	2	2	2	2	2	2	2	1	1
									mode	3
									average	2.49

service rate=6.5

4										
4	4									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	2	2	2			
3	3	3	3	3	2	2	2	2		
3	3	3	3	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1
									mode	3
									average	2.7

service rate=6

4										
4	4									
4	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	2	2	2		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mode	3
									average	2.79

ARRIVALRATE 0.25

service rate=5.5

2										
2	2									
2	2	1								
3	2	2	1							
3	3	2	2	1						
3	3	3	2	2	1					
3	3	3	2	2	2	1				
3	3	3	3	2	2	2	1			
3	3	3	3	3	2	2	2	1		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									average	2.33

service rate=5

2										
2	2									
3	2	1								
3	3	2	1							
3	3	3	2	1						
3	3	3	2	2	1					
3	3	3	3	2	2	1				
3	3	3	3	3	2	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									average	2.4

service rate=4.5

2										
2	2									
3	2	1								
3	3	2	1							
3	3	3	2	1						
3	3	3	3	2	1					
3	3	3	3	3	2	1				
3	3	3	3	3	3	2	1			
3	3	3	3	3	3	2	2	1		
4	3	3	3	3	3	3	2	2	1	
4	3	3	3	3	3	3	3	2	2	1
									moda	3
									media	2.53

ARRIVALRATE 1.4

service rate=5.5

4										
4	4									
4	4	4								
4	4	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	3				
3	3	3	3	3	3	3	2			
3	3	3	3	3	3	3	2	2		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									average	2.94

service rate=5

4										
4	4									
4	4	4								
4	4	4	4							
4	4	4	3	3						
4	4	3	3	3	3					
4	3	3	3	3	3	3				
3	3	3	3	3	3	3	2			
3	3	3	3	3	3	3	2	2		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									average	3.1

service rate=4.5

4										
4	4									
4	4	4								
4	4	4	4							
4	4	4	4	3						
4	4	4	4	3	3					
4	4	4	3	3	3	3				
4	4	4	3	3	3	3	2			
4	4	3	3	3	3	3	3	2		
4	4	3	3	3	3	3	3	2	1	
4	3	3	3	3	3	3	3	2	2	1
									moda	3
									media	3.30

ARRIVALRATE 0.7

service rate=7

3										
3	3									
3	3	2								
3	3	2	2							
3	3	2	2	2						
3	3	2	2	2	2					
3	3	2	2	2	2	2				
3	3	2	2	2	2	2	1			
3	3	2	2	2	2	2	2	1		
3	3	2	2	2	2	2	2	2	1	
3	2	2	2	2	2	2	2	2	1	1

mode	2
average	2.22

service rate=6.5

3										
3	3									
3	3	3								
3	3	3	2							
3	3	3	2	2						
3	3	3	2	2	2					
3	3	3	2	2	2	2				
3	3	3	2	2	2	2	1			
3	3	3	2	2	2	2	2	1		
3	3	3	3	2	2	2	2	2	1	
3	3	3	3	2	2	2	2	2	2	1

mode	3
average	2.42

service rate=6

3										
3	3									
3	3	3								
3	3	3	2							
3	3	3	2	2						
3	3	3	3	2	2					
3	3	3	3	2	2	2				
3	3	3	3	2	2	2	1			
3	3	3	3	3	2	2	2	1		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1

mode	3
average	2.53

ARRIVALRATE 0.7

service rate=5.5

3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	2	2					
3	3	3	3	3	2	2				
3	3	3	3	3	2	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1

mode	3
average	2.65

service rate=5

3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	3	2					
3	3	3	3	3	2	2				
3	3	3	3	3	3	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1

mode	3
avera	2.7

service rate=4.5

3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	3	2					
4	3	3	3	3	3	2				
4	3	3	3	3	3	2	1			
4	3	3	3	3	3	3	2	1		
4	3	3	3	3	3	3	3	2	1	
4	3	3	3	3	3	3	3	2	2	1

moda	3
medi	###

Tables III Evening arrival rates

service rate=6										
3										
3	2									
3	3	2								
3	3	2	2							
3	3	3	2	2						
3	3	3	2	2	2					
3	3	3	2	2	2	1				
3	3	3	3	2	2	2	1			
3	3	3	3	2	2	2	2	1		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mode	3
									average	2.42
4										
4	4									
3	3	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	2	2	2		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mode	3
									average	2.76

service rate=5.5										
3										
3	2									
3	3	2								
3	3	3	2							
3	3	3	2	2						
3	3	3	3	2	2					
3	3	3	3	2	2	1				
3	3	3	3	3	2	2	1			
3	3	3	3	3	2	2	2	1		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									averag	2.545
4										
4	4									
4	4	3								
3	3	3	3							
3	3	3	3	3						
3	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	3	2	2			
3	3	3	3	3	3	2	2	2		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									averag	2.833

service rate=5										
3										
3	3									
3	3	2								
3	3	3	2							
3	3	3	3	2						
3	3	3	3	2	2					
3	3	3	3	3	2	1				
3	3	3	3	3	3	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									avera	2.636
4										
4	4									
4	4	4								
4	4	4	3							
4	4	3	3	3						
4	3	3	3	3	3					
3	3	3	3	3	3	2				
3	3	3	3	3	3	3	2			
3	3	3	3	3	3	3	2	2		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									avera	2.985

service rate=4.5										
3										
3	3									
3	3	3								
3	3	3	2							
3	3	3	3	2						
3	3	3	3	3	2					
3	3	3	3	3	2	2				
3	3	3	3	3	3	2	1			
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4	3	3	3	3	3	3	2	2	1	
4	3	3	3	3	3	3	3	2	2	1
									moda	3
									averag	2.758
4										
4	4									
4	4	4								
4	4	4	4							
4	4	4	3	3						
4	4	4	3	3	3					
4	4	4	3	3	3	3				
4	4	3	3	3	3	3	2			
4	4	3	3	3	3	3	2	2		
4	4	3	3	3	3	3	3	2	1	
4	3	3	3	3	3	3	3	2	2	1
									moda	3
									averag	3.242

ARRIVALRATE 0.7

service rate=6										
3										
3	3									
3	3	3								
3	3	3	2							
3	3	3	2	2						
3	3	3	3	2	2					
3	3	3	3	2	2	2				
3	3	3	3	2	2	2	1			
3	3	3	3	3	2	2	2	1		
3	3	3	3	3	2	2	2	2	1	
3	3	3	3	3	2	2	2	2	2	1
									mode	3
									average	2.53

service rate=5.5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	2	2					
3	3	3	3	3	2	2				
3	3	3	3	3	2	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	2	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									averag	2.652

service rate=5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	3	2					
3	3	3	3	3	2	2				
3	3	3	3	3	3	2	1			
3	3	3	3	3	3	2	2	1		
3	3	3	3	3	3	3	2	2	1	
3	3	3	3	3	3	3	2	2	2	1
									mode	3
									avera	2.697

service rate=4.5										
3										
3	3									
3	3	3								
3	3	3	3							
3	3	3	3	2						
3	3	3	3	3	2					
4	3	3	3	3	3	2				
4	3	3	3	3	3	2	1			
4	3	3	3	3	3	3	2	1		
4	3	3	3	3	3	3	3	2	1	1
4	3	3	3	3	3	3	3	2	2	3
									moda	2.821
									average	