Benchmarking Airside Assets of Western European Airports

A Data Envelopment Analysis

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F-GVHD (cn 145178) AF 5483 / KL 2043 to Strasbourg is taking off runway 18L with a good view of some airliners taxiing to the holding point at runway 24. Source: www.airliners.net
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“Everything should be made as simple as possible, but not simpler.”

Albert Einstein, 1879 – 1955
German - Swiss - American scientist and inventor

“The fewer the facts, the stronger the opinion.”

Arnold Glasgow, 1905 – 1998
American psychologist

“Obviously, the highest type of efficiency is that which can utilize existing material to the best advantage.”

Jawaharlal Nehru, 1889 – 1964
First prime minister of India
Preface

Schiphol, July 15th 2010

To the reader,

This report concerns my master thesis for graduation at the Infrastructure Systems and Services department of the Delft University of Technology, Faculty Technology, Policy and Management.

From an early age I have had a passion for the world of aviation, which has become the heart of my educational career. With the completion of this research I am about to graduate.

The subject of this research forms a perfect combination between my Bachelor’s degree in Aeronautical Engineering and Masters Studies. I could never have completed this research and report without the help, support and confidence of many. I would like to say thank you to;

- My parents and family, for giving me the opportunity and confidence to follow my own interests during my entire study and giving me the freedom to enjoy my university life.
- Annemarijn, for all your support during the period I was finishing my studies.
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- The Schiphol Group, for providing such a good and inspirational environment for doing my master thesis.

I hope you enjoy reading this report.

Yours sincerely,

Rogier Doffegnies
Summary

This thesis research for the Delft University of Technology, faculty of Technology Policy and Management is commissioned by the department of Infrastructures Systems and Services. The research is related to the Transport and Logistics (TLO) section. TLO is concerned with undertaking research with the intention to support policy and decision making on transport-, infrastructure-, and logistics issues. The research is also related to the section Economics of Infrastructures. The aim of this section is to make a contribution to the design of efficient and effective governance structures for infrastructure industries at the interface of economics and technology.

The research is conducted at the Schiphol Group, department Airport Development. The staff department Airport development advices and supports the management board and business units of the Schiphol Group in developing and safeguarding the airport’s strategy with respect to development of the airport. Airport Development is mainly concerned with the development of Amsterdam Airport Schiphol (AAS). AAS is the main operating location of the Schiphol Group, and the most prominent airport in terms of traffic in the Netherlands.

Research context

On April the 25th of 2007, the Dutch Competition Authority (Dutch: NMa) approved the new accounting principle for airports in the Netherlands. This accounting principle is based on a dual till accounting approach. Following this accounting approach, the airports aviation related services and non-aviation related services are treated distinctively. Revenues for aviation services are only allowed to cover the directly attributable costs of providing these services, including an appropriate return on assets that are used for these services. These assets are known as the Regulatory Asset Base (RAB). Aviation activities are thus closely related to their representative costs, and their returns are regulated by law.

Since the privatisation of airports, their competitive landscape has become more challenging for them. Historically, airports were regarded as public transport utilities; operational activities were considered as being fundamental for the development of the airport business and commercial activities were not of great importance. After the privatisation of airports, profitability has become a major driver, resulting in a greater emphasis on exploiting commercial activities. The Schiphol Group has the ambition to position AAS as Europe’s Preferred Airport. To support this mission, the airport management has defined a set of brand values; one of these values is efficiency.

One of the main components which determine the attractiveness of an airport is the visit costs for its customers. Cross finance incentives of aviation services (by means of non-aviation revenues) to strategically lower the visit costs for customers may contribute to a stronger competitive position for the airport. However, cross finance incentives put pressure on corporate profit margins because profits are reinvested in the organization; a short term solution since the costs of the aviation till are not lowered as such and revenues from non-aviation will not increase. Instead of lowering the costs in the aviation till, revenues in the aviation till are artificially nourished by means of (temporary) investments from the non-aviation till. This implies that corporate revenues decrease, which puts the corporate profit margins under pressure.
To temper this short term solution without altering the output of the airport, costs in the aviation till should be lowered. However, lowering these costs accompanies an increase in the capital efficiency of the RAB. An increase in the utilization of assets is thereby key. To do so, this research elaborates on a benchmark process as developed by Camp. This approach is later discussed in this summary.

**Thesis research**

This final thesis research develops knowledge and understanding on how Western European airports organize their Regulatory Asset Base. The research therefore investigates the efficiency of main airside assets at various airports. As the term *airside* suggests, the research is only concerned with the key assets located on the airside of the airport; that is the airport’s area directly involved in the handling of aircraft. The research provides a new insight in the mutual assessment of airports, thereby extracting best practices from the data. This knowledge is particularly used and applied to assess the main airside asset base of Amsterdam Airport Schiphol (AAS).

The main goal of this research is to learn and understand how airports organize their regulatory asset base. This goal is supported by two sub goals; first the research aims to understand how airports can be assessed relative to each other by means of benchmarking, then the research aims to understand the differences in capital efficiency of AAS versus that of its competitors. Related to the goal of this research are the research objectives. This research is built upon two objectives; the research puts forward a new way to extract best practices from a dataset, and second the research makes a distinction between performance and managerial controllability of assets. This distinction is later used to visualize the competitive landscape of AAS and to frame a set of strategies which are geared to improve the efficiency of its airside asset base.

This research is built upon a central research question, supported by five sub research questions. The main research question is formulated as; "How efficient is Amsterdam Airport Schiphol in using its main airside assets relative to its direct competitors?"

**Benchmarking using Data Envelopment Analysis**

Robert C. Camp (Camp, 1989) defined the benchmarking process from a scientific viewpoint; however, Camp did not define a leading benchmark model. This research uses the four benchmark steps as identified by Camp, to be known planning, analysis, integration and action.

Assessment of various benchmark reports and literature resulted in the conclusion that a commonly used benchmark model based on ratio analysis has a number of shortcomings. These shortcomings resulted in three challenges for which a potential model should comply. These challenges include;

- The benchmark model should have the ability to compose a *single numerical judgement of efficiency* from a *multiple input / multiple output* scenario;
- The benchmark model should be capable of extracting *best practices* from the data;
- The benchmark model should *exclude subjectivity* for as much as possible.

The above challenges resulted in a benchmark approach called Data Envelopment Analysis (DEA), formerly developed by Charnes, Cooper and Rhodes (Charnes et al., 1978). The DEA model is in fact a collection of models which developed over time. The DEA benchmark model provides an answer to the challenges described.
above and makes benchmarking a more valuable tool as the results are better interpretable. In contrast to other benchmarks, DEA allows one to incorporate multiple input and multiple output variables (independent of the variable’s nature) into an assessment of efficiency. The model measures relative efficiencies, thereby only using proven data. Since the model is built among the measurement of relative efficiencies, it assigns an efficiency score of 100% to those airports which are considered to be the best performers or known as the best in class. All other observations are compared to those who are the best. DEA results in a single numerical judgement of efficiency per observation, and provides a set of side products, such as a set of best practices per observation.

**Benchmarking Western European airports relative to Amsterdam Airport Schiphol**

The benchmark as performed in this research is based on a sample of eight Western European airports. This sample includes two sub samples; sub sample ‘A’ includes airports competing with Amsterdam Airport Schiphol (AMS) on the basis of its transfer passengers and includes London Heathrow (LHR), Paris Charles de Gaulle (CDG) and Frankfurt Airport (FRA). Sub sample ‘B’ consists of airports competing with AAS on its local Originating / Destination (O/D) market. This sample includes Brussels Airport (BRU), Brussels Charleroi Airport (CRL), Düsseldorf Airport (DUS) and Airport Weeze Niederrhein (NRN). Including Amsterdam Airport Schiphol (AMS), the sample contains eight observations / airports. Regarding the data, 2007 is used as the representative year since the financial crisis (2008 / 2009) and the ticket tax (2008) resulted in a bias in the data for 2008 and 2009 due to a shift and downturn in air travel demand.

To create a better understanding of how airports are organized regarding their airside asset base and to provide better insight in the ability to improve the performance of airside assets, a distinction is made between the one hand performance of airside assets, and on the other hand managerial controllability of these airside assets by airport managers. The latter reflects the effect of factors which are beyond managerial control of airport managers and affect the airport in the utilization of assets. An example is noise regulation. Both quantities are framed in the DEA model, the input and output variables are presented in the following two bullets:

- The analysis of performance is based on a set of inputs containing three variables, and a set of outputs containing two variables. The set of inputs is represented by the airside asset base (the runway system, the airside aerial and the gates). The set of outputs is represented by the number of Air Traffic Movements (ATMs) for 2007, and the declared peak hour capacity for 2007.
- The analysis of managerial controllability uses a set of inputs using three variables and a set of outputs of two variables. The input variables are; Average weather delay per ATM for 2007, the noise score as extracted from noise regulations, the number of citizens living within the airport’s 55db noise area. The output is determined by the number of Air Traffic Movements and the inverse of the number of runways (the inverse is taken since the number of runways is an undesired output).

The results of the analysis are presented in Figure 0-1. AAS (AMS) is represented by the following position; relative performance: 90,2% : relative managerial controllability 36,2%. Diseconomies of scale are recognizable at hub airports, especially at AMS. It is observed that hub airports (AMS, LHR and CDG) are also more restricted
in terms of managerial controllability than smaller airports. Only LHR is considered as an exception since the 
airport handles a large amount of traffic but is located in a very densely populated area. For AAS it is concluded 
that in order to become a more efficient airport, it should reduce its number of runways. Along with several 
other changes, this will result in an increase in the annual capacity, and a slight decrease of the peak hour 
capacity. However, strategically wise, other measures are advised (as will be explained).

As the results in Figure 0-1 suggest, it can be observed that AAS scores moderately good in performance, but 
low(est) in terms of managerial controllability. This implies that external factors (both environmental and 
political), have much influence on (1) how the airside of the airport is established in terms of its airside design, 
and (2) the nature of its operations. Given the information provided by the sample, performance assessment of 
AAS has shown that the airport can slim its airside asset base with 40% in terms of runways. Under constant 
returns to scale assumptions, its capacity remains unchanged. However, variable returns to scale assumptions 
are more likely to be considered, and result in a 9% annual increase of capacity, and a decrease of its declared 
peak hour capacity with 9%.

Since DEA uses proven data from a dataset, the model is adequate to inform one about those airports which 
are best comparable with AAS, independently from their size. These airports include Paris Charles de Gaulle, 
London Heathrow and Weeze Niederrhein. The model uses the information of these three airports (out of 
seven) to calculate the efficiency scores for AAS. It is advised to keep an eye on the developments of these 
airports.

**Strategies**

Following the idea of incorporating a dichotomy in the benchmark between on the one hand performance and 
on the other hand managerial controllability, four generic positions can be identified in the matrix representing 
the final scores of each airport (see Figure 0-2). Following these positions, several strategies can be applied. 
AAS is ranked as an expensive airport since the airport has increased its performance by means of investment 
which is geared to minimize the effects of a reduced state of managerial controllability. Its strategy to improve 
its performance from now on should be directed towards first increasing its managerial controllability in order 
to reduce its costs (arrow 4 in Figure 0-2). Then, if controllability is improved, the airport can improve the 
performance of its main airside assets. Note that first improving performance is a matter of ignoring the facts;
control is in the hands of some other (governmental) organization. (Public) policy marketing can be a powerful tool to match policy products with citizens’ requirements. Referring to Albert Einstein, unacquainted people have often the strongest opinions (Albert Einstein, 1879 - 1955). The easy interpretable results of this DEA analysis can be used in policy marketing incentives to ‘sell’ the airport’s policies to citizens and (local) government. Public policy marketing should be directed towards three focus areas, to be known as inform; convince; and create understanding.

Düsseldorf airport is identified as a high potential. Since its catchment area overlaps with the catchment area of AAS, is advised to keep a close eye on the strategic movements of this airport.

![DEA framework for four generic positions and inherent strategies](image)

**Figure 0-2: DEA framework for four generic positions and inherent strategies**

**Conclusions**

DEA is an adequate model to assess scenarios in which multiple inputs and multiple outputs are present. However, one should realize not to take these results literally since the sample is too small for that. The results provide however a good direction of thought and provide a good insight on which focus areas airport managers should concentrate their efforts. The initiated matrix in which both performance figures and managerial controllability figures are presented, brings forward a new way for identifying the competitive landscape for organizations in general and / or airports.

The focus area for AAS is to be found at increasing its managerial controllability. The relative inefficiency of AAS can than be turned into a benefit; its high buffer capacity for the future allows AAS to increase its production without altering its airside asset base. DEA provides a new view on mutual assessment (benchmarking) of airports. It is advised to use this method also for other benchmarks. To increase the reliability of the results, it is wise to enlarge the dataset regarding the number of airports.
New business models of airlines may be turned into a benefit of AAS. The airport therefore faces a continuous adjustment problem which requires the organization to be flexible and quickly react on market changes. Getting a better grasp on managerial control is thereby of paramount importance. This research provides a valuable method which allows one to get that better grasp, and puts forward the first efforts in doing so. One should however realize that improving the airside performance and / or capacity is not just a matter of expanding the airside asset base, but is in fact a result of an open discussion about the redistribution of managerial control. The strategy as presented may play an important role in this discussion.

This research comes with a set of potential improvements aimed on reducing the airside asset base while keeping the output constant. These improvements show that airport managers should concentrate their efforts on (1) the runway system, and (2) the number of gates and the size of the airport which are both in close relation to the peak hour capacity of the airport. The latter (argument 2) is subject to the pattern of demand over the day. It is observed that these patterns show substantial variation between airports. The suggested potential improvements come with a number of challenges. As the DEA of managerial controllability indicates, AAS copes with a set of powerful factors which are (far) beyond managerial control of airport managers. It is likely that intentions for improving the performance or the capacity of the airside without any intention to improve the state of managerial controllability poses problems. One of the main conclusions extracted from this research is that improving the airside performance is not just a matter of investment alone, but is in the case of AAS very much related to the state of managerial controllability the airport faces. It is thereby strongly suggested to first improve managerial controllability before making any additional investments to the airside.

The main research question for this research is formulated as;

“How efficient is Amsterdam Airport Schiphol in using its main airside assets relative to its direct competitors?”

The answer to this main research question is formulated as follows;

Amsterdam Airport Schiphol is moderately efficient in using its main airside assets relative to its peers. However, compared to its same sized peer airports (sub sample A), Amsterdam Airport Schiphol scores low in performance. It can be concluded that the low efficiency of AAS in terms of performance is partly a result of strongly reduced managerial controllability of airside assets.
Recommendations

The main recommendations of this research are;

- Do not take the inefficiencies as presented in this report for granted, but turn them into a benefit by using them in decision making processes.

- Use the potential improvements presented in this report as information to set (new) targets. Do not use the targets as presented in this report literally, but use them as a pointer to direct the efforts of airport managers on underperforming areas.

- Continue this research by expanding the sample with more airports, and include a wider range of assets.

- The low score in managerial controllability is a cause of low performance. It is however not the state of *managerial controllability* but the *performance* that dominates in the minds of public policy makers and the general public. This research has dissected performance and managerial controllability. Use this dichotomous difference for (public) policy marketing incentives.

- Keep a close eye on all modifications, diversifications and turns of those who are best-in-class and competing with AAS; Paris Charles de Gaulle, London Heathrow, and Weeze Niederrhein. Have a particularly close eye on Düsseldorf Airport since the airport is highly in managerial control over the utilization of its assets and most important, its catchment area overlaps with the catchment area of AAS.

- New aircraft (such as the A-380) and new business models (such as those of low cost carriers) may have a significant impact on particularly the exploitation of aprons and gates. The accommodated costs for adjusting these assets may be considerably high (such as Terminal 5 at LHR). Other aircraft, such as the Boeing 787 may have a reverse effect; lower demand because of increasing emphasis on point to point networks.

- The model provides new opportunities and new insights in mutual assessment. The model thereby comes with unique features not covered by other models. Use this model also for other assessments. It would be wise to acquire an appropriate DEA software tool.
Glossary

Air traffic movement: A measure for the amount of landings and take offs at an airport.

AirportCity: An efficiently designed international transport hub for both passengers and cargo with an urban character. Airport cities provide a growing number of services and facilities not directly related to actual transport functions.

Airside: The part of an airport directly involved in the arrival and departure of aircraft.

Asset: Any physical item with intrinsic an economic value owned by the organization. It are especially those items that could not be directly converted into cash on the short term.

Benchmarking: (1) A positive, proactive process to change operations in a structured fashion to achieve superior performance (Camp, 1989).

(2) The pursuit by the organization of enhanced performance by learning from the successful practices of others (Francis et al., 1999).

Catchment area: The area from which passengers travel to and from a specific airport by road or rail.

Decision Making Unit: The organization responsible for converting inputs into outputs.

General aviation: Generic term for small-scale, normally non-commercially aviation.

Hub-and-spoke: A transportation network where aircraft first go to a central location where passengers and goods change to another aircraft to reach their final destination.

Instrument Flight Rules: Regulations and procedures for flying aircraft by referring only to the aircraft instrument panel for navigation.

Landside: The area bounded by the points at which passengers and goods enter the airport grounds by modes of transport other than via the airspace and the point on the apron at which the aircraft is serviced and loaded.

Large investments: Investments larger than €100.000.000,-- and were it is expected that at the time of commissioning initial excess capacity is present.

Lumpy assets: Assets that cannot be acquired in small increments but must be obtained in large discrete units.

Main airside assets: Regulated operating assets which are related to aviation upon which the owners of the airport earn a return. A main aviation asset is part of the regulatory asset base.

Mainport: A metropolitan area that functions as an essential interface between international and national networks of persons, goods, and information flows.

O/D passengers: Originating and destination passengers. O/D passengers are those whose journey by air starts or ends at the airport for which one is determining the passenger profile.

Point-to-point: A transportation network where aircraft travel directly to a destination rather than going through a central hub.

Regulatory Asset Base: The proxy value of the airport’s regulated operating assets for aviation upon which the owners of the airport earn a return.

Transfer passengers: Passengers who change planes within 24 hours without leaving the customs area. Transfer passengers are counted both arriving and departing.

Transit passengers: Those who leave the airport on the same flight number as the one by which they arrived, without leaving the customs area are not counted incoming or outgoing, but stated separately.

Weighted Average Costs of Capital: A ratio that reflects the costs that a company makes for the capital of which (a part of) the company is financed.
## Abbreviations

**IATA codes:**
- **AMS**: Amsterdam Airport Schiphol
- **CDG**: Paris Charles de Gaulle Airport
- **LHR**: London Heathrow Airport
- **FRA**: Frankfurt Airport
- **DUS**: Düsseldorf International
- **BRU**: Brussels National
- **CRL**: Brussels Charleroi
- **NRN**: Niederrhein Airport Weeze
- **JFK**: New York John F. Kennedy International Airport
- **BCN**: Barcelona international airport

**a/c**: Aircraft
**AAS**: Amsterdam Airport Schiphol
**ACI**: Airport Council International
**AE**: Allocative efficiency
**AIP**: Aeronautical Information Publication
**AIS**: Aeronautical Information System
**BAA**: British Airport Authority
**BCC**: Banker, Charnes and Cooper
**BU**: Business Area
**CCR**: Charnes, Cooper and Rhodes
**CEO**: Chief Executive Officer
**CFO**: Chief Financial Officer
**Ch.**: Chapter
**CRS**: Constant Returns to Scale
**Db.**: Decibel
**DEA**: Data Envelopment Analysis
**DMU**: Decision Making Unit
**EAD**: European AIS Database
**Eq.**: Equation
**IATA**: International Air Transport Association
**ICA**: Intercontinental
**ICAO**: International Civil Aviation Organization
**ID**: Identification
**ILS**: Instrument Landing System
**LDEN**: Overall noise Level during Day-Evening-Night
**Max**: Maximize
**Min**: Minimize
**MRQ**: Main Research Question
**n/a**: Not available
**NMa**: Nederlandse Mededingingsautoriteit (Dutch Competition Authority)
**O/D**: Originating / Destination
**OE**: Overall efficiency
**Pax**: Passengers
**PE**: Price efficiency
**RATi**: Reed Air Transport Intelligence
**RWY**: Runway
**SRQ**: Sub Research Question
**SU**: Support Unit
**TE**: Technical efficiency
**TLO**: Transport and Logistics
**TPM**: Technology, Policy and Management
**VRS**: Variable Returns to Scale
**WS&V**: Verkeer & Waterstaat (Dutch Ministry of Transport, Public Works and Water Management)
**WLU**: Work Load Unit
**WLv**: Wet Luchtvaart (aviation act)
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Chapter 1 - Introduction


1 Introduction

Since the privatisation of the airport sector, airports find themselves in a continuous battle of competition. This privatisation started with the British Airport Authority (BAA) in 1987. Privatisation of the airport sector resulted in a battlefield which is no longer within the local region of an airport location, but encompasses continents. The continuous battle of competition and the capital intensive character of airport infrastructures require critical assessment of the exploitation of the airport’s asset base. Critical assessment is needed in order to verify if the specific airport still meets the needs for a healthy business, and if there is potential room for improvement. This final thesis research report is conducted for the Delft University of Technology, and is in collaboration with the Schiphol Group. This research investigates how Amsterdam Airport Schiphol utilizes its airside assets relative to its direct competitors. In particular, this research investigates what airport managers can learn from other airports.

This research compares Amsterdam Airport Schiphol with its direct competitors regarding its airside asset base. As a result, the research elaborates on a benchmark approach applied to Western European civil airports. The research explains a new view on how airport managers can recognize, extract and apply best practices from other airports to the airport one is aiming to optimize in terms of asset management.

This thesis research is conducted at Amsterdam Airport Schiphol (AAS), the largest and busiest civil airport in the Netherlands. AAS is operated by the Schiphol Group, but is in fact also a work area for 544 companies employing over 60.000 employees (Schiphol Group, 2009b). With its four business areas, AAS operates in an international airport market, characterized by its highly competitive character. The airport market provides room for striking international competition. In order to enforce the competitive position of an organization, most organizations apply cost cutting practices to increase the capital efficiency of that organization. Producing competitive quantities of output with even less resources per unit than the competitions increases the attractiveness of the firm for both investors and customers. This is no different at airports. Besides, the liberalisation of air transport in the European Union encouraged airlines and travellers to exploit the opportunities offered by competing airports, which puts tremendous pressure on increasing the firm’s attractiveness to the customer.

The deregulation of the aviation market has stimulated the development of reliable performance measures; the growth in the number of passengers raises the question whether this growth can and should be accommodated by using the existing infrastructure more intensively, or that the existing infrastructure should be expanded. To answer this question, full insight in the operating characteristics and (overall) efficiency of an airport is necessary to provide a reliable, valid and robust answer.

The geographical location of AAS in combination with the densely populated area near Amsterdam contributes strongly to interference of surrounding citizens and policy makers. Expeditiously comparisons to other airports (in for example adjacent countries, such as Germany, Belgium or the United Kingdom) are easily made. Arnold

---

1 To be known (1) Aviation, (2) Consumers, (3) Real Estate and (4) Alliances & Participations.
Glasgow once said; “the fewer the facts, the stronger the opinion” (Arnold H. Glasgow, 1905 - 1998). This statement is certainly applicable to AAS. It is not surprising that many people raise questions which are simple in nature, though very hard to answer. One may pose legitimate questions such as; is AAS making the best use of its resources?; is it possible to produce more with the same bundle of resources?; Is it possible to produce the same output with fewer resources?; or “Is AAS of the right size, and if not, is it too big or too small?

Although such questions should not be considered as central research questions, they were used as a trigger for this research. This report provides both a tool to answer such questions, and second this report provides a first start to assess such questions.

This final thesis for the Delft University of Technology is built along two central themes which are closely related to the goal and objectives of this research. The main theme of this research is to assess various Western European airports on the basis of their airside asset base relative to their performance. The second theme (which practically is researched in advance of the first theme) is built around presenting a new look at inter-organizational assessment of comparing performance at and between airports. This inter-organizational assessment of performance is based on a benchmark study, assessing eight airports on the basis of their main airside assets.

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2 In this context, an asset is defined as any physical item with intrinsic economic value owned by the organization. It are especially those items that could not be directly converted into cash on the short term.

3 Main airside assets are regulated operating assets which are related to aviation upon which the owners of the airport earn a return. A main aviation asset is part of the Regulatory Asset Base (RAB), and basically includes the runway system, taxiway system and all aprons.
1.1 Delft University of Technology

This thesis research for the Delft University of Technology, faculty of Technology Policy and Management (TPM) is commissioned by the department of Infrastructures Systems and Services. The research is related to the Transport and Logistics (TLO) section.

Delft University of Technology is the oldest and largest University of Technology in the Netherlands. The university was founded in 1842 by King William II. The university houses 8 faculties and offers 14 Bachelor’s programmes and 38 Master’s programmes (2009); the programmes offer comprehensive education and research (Delft University of Technology, 2008).

The Faculty of Technology Policy and Management wishes to make a contribution to sustainable solutions for social problems in which technology plays an important role. TPM does so by internationally oriented education and research. Since recent events have shown that a one-sided approach to complex social technological problems leads to insufficient results, TPM wishes to open new perspectives by achieving a unique co-operative relationship between the arts/social sciences and the exact sciences/technology. (Meer et al., 2008).

Transport and Logistics is concerned with undertaking research with the intention to support policy and decision making on transport-, infrastructure-, and logistics issues. The section thereby researches the impacts of policy options and future transport developments. It thereby critically assesses institutional change. TLO research addresses (new) approaches that combine the ambitions of the transport industry, transport companies, traffic managers, spatial developers, as well as governments at local and (inter)national level. Such approaches require integration at a system level, examining how pieces might fit together, given general transport goals, and how to proceed so that transport system development can reach its true potential (Annema et al., 2010).

This research is also related to the section Economics of Infrastructures. The aim of this section is to make a contribution to the design of efficient and effective governance structures for infrastructure industries at the interface of economics and technology. Economics of Infrastructures focuses on the interactions among technologies, markets and policies in traditional and evolving new infrastructures. It thereby assesses infrastructures in a dynamic context by considering them as distinct sectors of the economy, but with certain common characteristics. Economics of Infrastructures identifies infrastructures as providers of essential public services, which significantly affect the efficiency of economies and the welfare of societies (Delft University of Technology, 2010).
1.2 The Schiphol Group

The Schiphol Group can be ranked among the world’s leading airport companies. The Schiphol Group approach to airport development is based on the idea that an airport should be a seamless link in the travel process that offers the visitor a unique travel experience. The Schiphol Group calls this the AirportCity concept. Amsterdam Airport Schiphol (AAS) is the first and most prominent example of a successful airport city. AAS is in terms of traffic positioned among Europe’s busiest airports.

The strategic apex of the Schiphol Group is organized according to the structure presented in Figure 1-1. The research as presented in this report is conducted at the department Airport Development. The staff department Airport development advises and supports the management board and business units in developing and safeguarding the airport’s strategy with respect to airport development. Airport Development is thereby mainly concerned with the development of Amsterdam Airport Schiphol.

Amsterdam Airport Schiphol, the main operating location of the Schiphol Group, is one of the mainports of Europe. AAS (IATA code: AMS) is an infrastructural node that provides sophisticated services for airlines and its customers. For (a part of) 2009, AAS had 284 connections with European and intercontinental destinations spread over 93 countries. With 43.6 million passengers (2009), AAS took a fifth place on the European ranking

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4 The alliances and partnerships of the Schiphol Group include; Eindhoven Airport, Rotterdam The Hague Airport, Lelystad Airport, Aéroports de Paris (HubLink), Terminal 4 JFK New York, Reina Beatrix Aruba Airport and Brisbane international airport.

5 A mainport is a metropolitan area that functions as an essential interface between international and national networks of persons-, goods- and information flows.

6 IATA: International Air Transport Association.
of commercial airports in terms of the number of passengers served. With its declared peak hour capacity of 112 aircraft per hour (2008) and 458,050 Air Traffic Movements (ATM) per year (2008), AAS is positioned as one of the main high capacity airports of Europe (Kolkman and Korteweg, 2009b). The Schiphol Group charges the costs of developing, maintaining and utilizing its infrastructure (AAS) to the (individual) customer. The price paid by the customer (the airline, passenger and / or freight forwarder), has a significant influence on the competitive position of the airport relative to its close competitors.

The market in which AAS operates is a challenging market. The (Western) European airport market can be characterized as complex and subjective to a changing business environment. Due to liberalization of the airport sector, AAS copes with increasing levels of competition and a changing competitive landscape. One could recognize this by keeping up with the changes of airports. Still today airports are expanding, both physically and also in terms of connectivity to the world. Eurocontrol predicts that, dependant on the future scenario’s (as defined by Eurocontrol), primary airports will continue to enlarge; there will be between 7 to 15 airports in Europe with more than 250,000 annual departures in 2030, whereas there was only one of such type in 2007 (Eurocontrol, 2008). Also secondary airports are gaining a more successful market share (Eurocontrol, 2008). Secondary airports take advantage of the hybrid customer who is driven by the perceived value for money. In such a price driven market, evaluation of costs and performance is essential to stay successful and profitable. This strategic evaluation forms the backbone of this research.

The competitive landscape of the Schiphol Group changes and competition with other main ports increases every year. At the same time, new airports and aircraft types have an increasing effect on the competition. In the Schiphol Group 2008 annual report, CEO Jos Nijhuis states that the aviation charges of AAS are too high compared to its direct competitors (Schiphol Group, 2008). This results in the loss of customers and decreasing returns. Nijhuis also points out that the price to quality ratio at AAS is not developing well. Here, Nijhuis points at the charges, costs for security and governmental taxes versus the perceived quality ratio by its customers. Nijhuis also indicates that, while the perceived quality of AAS is stabilizing, other airports are investing heavily in quality improvement programs (Schiphol Group, 2009a).

The Schiphol Group aims to let AAS keep its mainport position by lowering the costs for customers, while maintaining a level volume of throughput (Schiphol Group, 2008). Therefore, efficiency assessment is of primary concern to the airport because remuneration must be provided through the price for utilizing the provided infrastructure.
1.3 Research context

On April the 25th of 2007, the Dutch Competition Authority (‘Nederlandse Mededingingsautoriteit'; NMa) approved the new accounting principle for airports in the Netherlands. This accounting principle is based on a dual till approach. By means of the dual till accounting approach, the airport’s aviation related services and non-aviation related services are treated distinctively (Schiphol Group, 2007). For aviation services, the dual till accounting principle requires that revenues cover the directly attributable costs of providing these services, including an appropriate return on assets that are solely used for these services, as well as a contribution to costs that are common to both aeronautical and non-aeronautical services. Aviation activities are thus cost based and the return on aviation assets is regulated by law.

Distinct treatment of aviation and non-aviation related services limits the abilities of cross finance incentives within the internal organization of airports. According to the approved accounting principle, cross financing is only allowed from non-aviation related services to aviation related services, and not vice versa. Thereby, the revenues for aviation services are bounded and may maximally equal the costs for exploitation of aviation activities plus the capital costs of fixed assets used for aviation activities; to be known as the Regulatory Asset Base\(^7\) (RAB). Cross finance incentives of aviation services to strategically lower prices may contribute to a stronger competitive position of the airport. However, cross financing incentives put pressure on corporate profit margins, since profits are re-invested in the organization; a short term solution since the costs of the aviation till are not lowered as such, and revenues from non-aviation will not increase. Instead of lowering the costs in the aviation till, revenues in it are artificially nourished by means of temporary investments from the non-aviation till. This implies that corporate revenues decrease, which puts the corporate profit margins under pressure.

With respect to the RAB, lowering the costs in the aviation till accompanies an increase in the capital efficiency\(^8\) of the RAB. An increase in the utilization of assets\(^9\) is therefore key. A remarkable observation is in the current situation, in contrast to AAS comparable airports use a different RAB to dispatch the arriving and departing aircraft. Table 1-1 serves as an example and displays that various comparable airports use a different runway system to dispatch aircraft.

It can be concluded from Table 1-1 that (by means of ratio analysis) AAS has a low efficiency in real terms of asset utilization. In fact, the same can be concluded from a more extensive study based on the same dataset of Table 1-1. Based on a sample of 24 European airports, AAS is ranked on place 20 (out of 24) with respect to the average annual capacity (2007) per runway (5 runway case). In the six runway case, AAS even drops to place 22

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\(^7\) The *Regulatory Asset Base* (RAB) is a proxy value of the airport’s regulated operating assets for aviation activities (fixed assets), upon which the owners of the airports earn a return.

\(^8\) the informal ratio of output divided by capital expenditure

\(^9\) In this context, an ‘asset’ is defined as any physical item with intrinsic economic value owned by the organization. It are especially those items that could not be directly converted into cash on the short term. ‘Main airside assets’ basically include (Jorge and Rus, 2004) the runway system, taxiway system and all aprons.
out of 24. In terms of annual capacity per runway (ATMs for 2007), AAS is ranked on place 15 (five runways), respectively place 19 (six runways) out of a sample of 24 airports (Kolkman and Korteweg, 2009b).

Table 1-1: runways versus declared peak hour capacity at various Western European airports (Kolkman and Korteweg, 2009b)

<table>
<thead>
<tr>
<th>Airport</th>
<th>Declared peak hour capacity</th>
<th>Number of runways</th>
<th>Average annual capacity per runway (2007)</th>
<th>Average peak hour capacity per runway (2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam Airport Schiphol</td>
<td>112</td>
<td>6 (5 main runways)</td>
<td>72662 (87195)</td>
<td>19 (22)</td>
</tr>
<tr>
<td>Paris Charles de Gaulle</td>
<td>112</td>
<td>4</td>
<td>135953</td>
<td>28</td>
</tr>
<tr>
<td>Madrid Barajas</td>
<td>96</td>
<td>4</td>
<td>240959</td>
<td>24</td>
</tr>
<tr>
<td>Rome Fiumicino</td>
<td>90</td>
<td>3</td>
<td>109393</td>
<td>30</td>
</tr>
<tr>
<td>München</td>
<td>98</td>
<td>2</td>
<td>203297</td>
<td>45</td>
</tr>
<tr>
<td>London Heathrow</td>
<td>87</td>
<td>2</td>
<td>237857</td>
<td>44</td>
</tr>
</tbody>
</table>

Although one may tend to conclude that the above results speak for themselves, further research is necessary. Since different ratios present different outcomes. Furthermore, research assessing specifically the airside asset base of AAS is legitimate because of reasons explained in the underneath paragraphs.

In its 2008 annual report, Schiphol Group’s Chief Executive Officer (CEO) Jos Nijhuis states that AAS is perceived as an expensive airport; its aviation charges are to high compared to its direct competitors (Schiphol Group, 2008). This results in the loss of customers and decreasing returns. Nijhuis also points at the fact that the price to quality ratio at AAS is not developing well. While the AAS perceived quality is stabilizing, other airports are investing heavily in quality improvement programs.

The business environment of the Schiphol Group is hit by setbacks which both hit AAS as an individual airport (such as the ticket tax), and which hit the sector as a whole (such as the economic downturn, started in 2008). However, setbacks also provide new opportunities as Nijhuis points out in its 2009 annual report. “…the crisis brings not only threats, but also a whole new constellation of opportunities. As a rule, recessions reward decisiveness and reveal weaknesses, penalise entrenched patterns and open new doors. They provide the impetus to replace old business models with new ones. In short, a crisis shakes things up, rather than slowing them down.” (Schiphol Group, 2009a).

The Schiphol Group has adopted a strategy to become Europe’s Preferred Airport (see also section 3.2.2). It therefore has chosen a set of brand values, one of these values is efficiency. In order to create sustainable value for shareholders and to strengthen the mission of AAS to become Europe’s Preferred Airport, the Schiphol Group is introducing changes to its main operating location AAS. A point of concern is the lock-in effect; in its past, the airport has created many dependencies between both airport and its customers, but also between the airport and its (legal) environment. These dependencies make potential adjustments hard to implement. Researching other airports may bring up new thoughts about how to organize the airside asset base of the airport to the surface. It is because of this that comparative research is of high importance to stay acquainted with the shifts and alterations in the competitive landscape of the airports. Although various studies in the

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10 In case of 5 runways; thereby not including RWY 04/22 which is primarily assigned to general aviation.
form of benchmarks have been carried out in the (recent) past, there is a lack of knowledge on comparing airports. The benchmarks as carried out by the Air Transport Research Society or the Dutch Ministry of Transport, Public Works and Water Management (Verkeer en Waterstaat) (Kolkman and Korteweg, 2009b) result in a large set of ratio’s, often providing contradictory information about the (overall) efficiency of an airport. Simple representations of airport efficiency assessment do not exist, and certainly no single numerical judgement which is easy to interpret.

Note: The above statement is further exemplified in section 4.4 – Problems arising when benchmarking airside assets of a set of Western European airports.

Summarized, the need for this research is twofold;

- First, there is an integral need for research within the Schiphol Group organization, pointing out the differences between airside efficiency of its competitive airports, thereby distilling best practices.
- Second, there is a need for knowledge on how to assess airports in such a way that this assessment is easy to interpret; meaning easy to understand, use and explain.

The results of this research provide more enhanced and detailed knowledge on the airside asset base of AAS. This knowledge can be used for (1) optimizing the overall airport performance and deciding how to develop the airside from now on to enhance a better competitive position. Furthermore (2), this knowledge is useful for public policy makers which can use it as a context in decision making processes.

Note: This report uses both the term performance and efficiency; they are closely related. The term efficiency refers to the ratio of output over input. Performance can be defined as the accomplishment of a given task measured against a preset standard. These standards are set by the ‘best in class performers’. Efficiency can be regarded as a form of performance; airport can be assessed by comparing the efficiency scores of an airport against the standard set by best performer.

1.4 Report structure

In succession to the introduction, this report continues with presenting the research approach in chapter two. This chapter also introduces the goal and objectives to the reader. The goal and objectives are supported by five research questions also introduced in chapter two. To gain a better knowledge of the context of this research and inherent report, the reader is informed about the airport sector in chapter three. This chapter (which is an introduction for those who are not fully acquainted with the aviation industry and / or Amsterdam Airport Schiphol), mainly discusses the role of airports, its design and competitive landscape. Chapter three also informs the reader about the most important aviation laws with respect to the subject of this report. The four sections of this chapter are independently readable. Note that the knowledge and understanding presented in chapter three is of concern in order to understand the conclusions and recommendations of this report. Chapter four then discusses the means of benchmarking in the airport sector. The chapter introduces the problems arising from other benchmarks. Second, the set of airports is introduced (called the sample)
which are mutually assessed. Finally, the chapter presents the problems arising from common benchmarks. It does so by means of a brief ratio assessment. **Chapter five** discusses the Data Envelopment Analysis benchmark model as is used in this research by first explaining the benchmark model in terms of its characteristics. The Data Envelopment Analysis is presented in **Chapter six**. This chapter first introduces the variables which are used in the model. Than the final efficiency scores in terms of performance and managerial controllability are presented. Chapter six also touches upon best practices, reference airports and input and output contributions. The **final chapter** puts forward the conclusions and recommendations of this research report and closes with a brief reflection.

**Note:**  *Chapter five and six are separated since the information presented in chapter five can be generalized and applied on other benchmark cases. Chapter six especially presents a benchmark for airside assets of a set of Western European airports.*

Figure 1-2 presents the logic behind the structure of this report. The figure informs (1) where certain information is introduced, and (2) where claims are made on earlier introduced information. So besides an accumulated use of information (meaning that the information introduced in chapter 1 is used in chapter 2), the figure informs the reader about explicit usage of information in subsequent chapters.
Chapter 2 – Research approach
2 Research approach

This chapter informs the reader about the underlying research logic of the research as presented in this report. This first sections (2.1 – 2.4) focus primarily on what is researched; section 2.5 focuses mainly on how the research is conducted. The latter section is descriptive in character.

For the correct interpretation of this chapter, the reader should be aware that the research goal is the general statement of intent of this research. The research objective(s) is (are) a more specific statement(s) about what the research actually intends. The research objectives are achieved by answering the research questions as presented in section 2.4.

2.1 Research goal

This section describes the goals of this research by first presenting the main goal of this research. The main goal is supported by two sub goals. These sub goals form the foundation to accomplish the main goal, see Figure 2-1.

This research on the airside asset base of AAS and its competitive airports brings about complexities inherent to the nature of managing lumpy airport assets in a high-tech environment. The research aims to provide value to airport managers and scientists by providing sophisticated knowledge on improving the airport’s performance i.e. price to quality ratios by lowering costs. This knowledge rests on introduced underlying knowledge on measuring relative performance of airports by means of benchmarking (see also Figure 2-1). This underlying knowledge can be used in all kinds of comparisons, and can therefore be considered as general knowledge to airport managers. The research provides also value to public policy discussions about the role and footprint of Amsterdam Airport Schiphol in the Netherlands.

The main goal of this research is to learn and understand how airports organize their regulatory asset base in order to generate, maintain or optimize revenues. This research explores the ways in which airports develop and use their main aviation assets with respect to the unique environment in which the airport is situated (such as the geographical location of the airport and the political / legal environment). The research main goal is defined as (see also Figure 2-1);

Main goal: Learn and understand how airports organize their regulatory asset base.
This research intends to anticipate on the difficulties of managing assets by conducting a research which exposes the differences in the (main) airside asset base of AAS versus that of its direct competitors. The research especially focuses on high investment assets with a lumpy\textsuperscript{11} character which are required to dispatch and handle aircraft. The research thereby introduces the unique operating environment of the airport to the comparison.

The main research goal is supported (see Figure 2-1) by two sub goals. The sub goals are not subordinate to the main goal, but form the foundation to accomplish the main goal. The sub goals of this research are to create knowledge and understanding about (1) how to assess airports relatively to each other by means of benchmarking, and (2) the differences in the capital efficiency of AAS main airside assets relative to its competitors.

**Sub goal 1:** Create better knowledge and understanding about how to assess airports relatively to each other.

**Sub goal 2:** Understand the differences in capital efficiency of Amsterdam Airport Schiphol and its direct competitors.

\textsuperscript{11} In this context, lumpy assets are capital intensive assets that cannot be acquired in small increments but must be obtained in large, discrete units (Besley & Brigham, 2009).
2.2 Research objectives

The main objectives of this research are threefold and rest against the building structure of goals, see Figure 2-2. First, the research intends to extract best practices from individual airports and their inherent settings in terms of asset management. Second, the research intends to provide new insight in the mutual assessment of airports by means of benchmarking thereby discriminating performance from managerial controllability of assets. Resting against his objective, the third objective of this research is to provide strategies to increase the performance of airside assets at airports. Summarized, the objectives of this research are:

**Objective 1:** *Extract best practices from an airside asset base dataset.*

**Objective 2:** *Discriminate performance from managerial controllability.*

**Objective 3:** *Provide strategies to increase the performance of airside assets.*

![Figure 2-2: Research goal and objectives](image)

Ultimately, this research investigates the opportunities of applicability of best practices on AAS. Advice will be provided on how to develop the airport from now on regarding the airside infrastructure. This advice is provided in the form of a strategy. Special attention is directed to the difficulties of managing lumpy assets with respect to a fluctuating demand for use in the short- and medium term.

In the practical sense, the benchmark model as ultimately presented is aimed to be an estimate of a complex quantity that varies widely with various factors. The presented benchmark can by typified as a relatively simple expression of two complex quantities; ‘capital efficiency (performance) of airside assets’ and ‘managerial controllability of airside assets’. The objectives of the benchmark are directed to serve primarily as a reference point on the state of Schiphol and competitive airports. The data and outcomes of the research can shape the decision making process that determines how to develop the airport from now on. The benchmark model is also aimed to provide a context for (public) policy discussions, because the outcome gives a succinct report on the current and future state of capacity at Schiphol relative to its competitive airports.
2.3 Research questions

The research goal and objectives of this research are supported by a main Research Question (MRQ). This main research question is answered following several (5) Sub Research Questions (SRQ’s).

The main research question for this research is defined in Table 2-1.

Table 2-1: Main research question

<table>
<thead>
<tr>
<th>Main research question</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) “How efficient is Amsterdam Airport Schiphol in using its main airside assets relative to its direct competitors?”</td>
</tr>
</tbody>
</table>

The support of the main research question is delivered in the form of sub research questions (presented in Table 2-2). These SRQ’s are answered prior to answering the main research question. After determining which airports are compared relative to AAS, special attention is directed to how to compare airports. More specific than other benchmarking studies, this research intends to understand the relationship between various variables without any prejudgement of preferences. The SRQ’s are therefore structured in such a way that prior to answering the main research question, knowledge is created on how to assess airports. The SRQ’s are answered sequential in order, creating cumulative knowledge.

Table 2-2: Sub research questions

<table>
<thead>
<tr>
<th>Sub research questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) “What are the most important characteristics of the European airport sector one should be aware of regarding the intention of this research?”</td>
</tr>
<tr>
<td>(2) “Which airports can be considered as direct and significant competitors of AAS?”</td>
</tr>
<tr>
<td>(3) “How can airports be compared regarding the efficiency of their airside asset base, thereby extracting best practices and minimizing the problems brought to the surface by other benchmarks?”</td>
</tr>
<tr>
<td>(4) “Which factors could explain the differences in benchmark results between airports (i.e. peers)?”</td>
</tr>
<tr>
<td>(5) “Which lessons can be learned from the benchmark results and how can they be applied to AAS?”</td>
</tr>
</tbody>
</table>
2.4 Approach
As exemplified in section 2.1, this research aims to learn and understand how airports organize their regulatory asset base. To do so, the research conducts a benchmark to mutually assess airports. The conducted benchmark is one of many components of this research, but since the benchmark is a key element in this research, it therefore requires a separate approach.

The approach describing the research process is called the research approach. The approach describing the followed benchmark process is called the benchmark approach. This benchmark process is a subordinate to the research approach. This section first introduces both approaches. Finally, this section elaborates on the evolvement of the research and discusses some of the choices made during the research (section 2.4.2).

Although it is not the leading research approach, it is stressed that this research has many interfaces with Environmental Management Accounting (EMA). Here the generation, analysis and use of both financial and non-financial information contribute to the attempts to optimise corporate environmental and economic performance and to achieve a sustainable business.

2.4.1 Research approach
Figure 2-3 is aimed to create an understanding about the research approach and its relationship to this report. The figure, and so the research approach, is built along four basic phases, conducted consecutively and in order. These four phases include definition of (1) scope and approach, (2) a literature research, (3) an analysis, and (4) a conclusions phase. As can be observed, the approach contains a research process, represented by multiple grey shaded boxes. As can be observed, the boxes include a reference to the corresponding section in this report. Furthermore, the scheme uses white labels, referring to the sub research questions. Note that these labels are closely related with section 0 (methodology). This section provides a research methodology per (sub) research question.

As can be observed from Figure 2-3, the approach starts with a dichotomy between two main research activities. These main research activities correspond to the themes as presented in the introduction of this report. The first research activity is directed to shape the context of this research. The activity investigates the organization of airports. The second activity is especially directed towards comparing airports. The first research activity and inherent documentation is particularly used to understand the comparison and conclusions as prepared in research activity two. The first research activity and inherent documentation is basically intended to shape the context for the unacquainted reader. The latter research activity forms the core of this research, and contains also a particular analysis phase. It is emphasized that one should be acquainted with the results of both research activities in order to fully understand the conclusions of this research.
Figure 2-3: Research approach
2.4.2 Benchmark approach

This research builds upon the basis benchmark process as identified by the scientific patriarch of benchmarking, Robert C. Camp. Although the pursuit of benchmarking is introduced later in section 4.2, the process of benchmarking is discussed here since it is not explicitly addressed further in this report. The practical benchmark approach is worth explicit attention since it is an important aspect of the framework on which this research is based.\(^\text{12}\)

Camp defined that benchmarking is a continuous process consisting of four repeating basic steps, to be known; (1) planning, (2) analysis, (3) integration and (4) action (Camp, 1989). This research follows the steps identified by Camp. The steps by Camp and its translation to this research are summarized in Figure 2-4.

This report focuses on three of the four benchmark steps, to be known; planning, analysis and (a part of) integration. Table 2-3 presents a translation of the benchmark steps as identified by Camp to this context of this report.

Table 2-3: The benchmarking framework of Camp (Camp, 1989) and a translation to this research

<table>
<thead>
<tr>
<th>Step:</th>
<th>Translation to research:</th>
<th>Reference:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Planning</td>
<td>Definition to what is benchmarked. This includes definition of input and output variables</td>
<td>See section 5.6</td>
</tr>
<tr>
<td></td>
<td>Definition of the peer group, also called the sample</td>
<td>See section 4.3</td>
</tr>
<tr>
<td></td>
<td>Data collection, reported gradually, see also the references</td>
<td>See references</td>
</tr>
<tr>
<td>2. Analysis</td>
<td>Benchmark analysis</td>
<td>See chapter 6</td>
</tr>
<tr>
<td></td>
<td>Presentation of best performers, these are the reference airports, those with a DEA efficiency of 100%</td>
<td>See section 6.2</td>
</tr>
<tr>
<td>3. Integration</td>
<td>Advice is provided in the conclusions</td>
<td>See chapter 7</td>
</tr>
<tr>
<td></td>
<td>Presentation of best practices / potential improvements</td>
<td>See section 6.2</td>
</tr>
<tr>
<td>4. Action</td>
<td>Step 4 of the framework of Camp is full part if this research. Attention is given to this step by means of strategies</td>
<td>See section 6.3</td>
</tr>
</tbody>
</table>

\(^{12}\) The main difference between the framework of Camp and the research approach is that the research approach elaborates on the process followed for this entire research. The framework of Camp on the other hand describes the process followed for specifically the benchmark process. Besides being used in this report, the benchmark process as defined by Camp can also be applied in any other benchmark process.
Although the framework of Camp defines the various steps of the benchmarking process, it does not define how to benchmark; that means that Camp did not define a leading benchmark model. It is observed from assessment of various benchmarks that ratio analysis is commonly used in benchmarks. The benchmarks assessed include:

- Kennisinstituut voor Mobiliteitseenheid - *Internationale benchmark capaciteit luchthavens* (Kolkman and Korteweg, 2009b);
- Air Transport Research International – *Airport Benchmarking Report* (Oum et al., 2009)

It is concluded that benchmarking using ratio analysis is inadequate for this research because of a number of reasons. These reasons include;

- Ratio analysis is not adequate to incorporate different returns to scale assumptions.
- The results of ratio analysis which may be contradicting to each other (see also section 4.4.2). Results are hard to interpret and final judgements are often subjective.
- Ratio analysis does not explicitly allow one to extract best practices from a dataset.

Based on these reasons, three challenges are formulated which form the basis for the search and development of an appropriate benchmark model. These challenges are presented in Table 2-4. More information of benchmarking as management tool is presented in chapter 4.

**Table 2-4: Challenges for developing an adequate benchmark model**

<table>
<thead>
<tr>
<th>Challenges for developing an adequate benchmark model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Definition of a single numerical judgement of the efficiency of a airport converting multiple inputs into multiple outputs;</td>
</tr>
<tr>
<td>2. Extraction of best practices from the data;</td>
</tr>
<tr>
<td>3. Disregarding subjectivity and personal preferences for as much as possible.</td>
</tr>
</tbody>
</table>
2.5 Methodology for answering the research questions

This section presents the research methodology as followed for answering each Sub Research Question (SRQ). The answer of the Main Research Question (MRQ) results from answering the SRQs.

SRQ 1. “What are the most important characteristics of the European airport sector one should be aware of regarding the intention of this research?”
   • Methodology; Literature research and informal interviews.
   • Reference; See chapter 3. The answer is summarized in section 3.5

SRQ 2. “Which airports can be considered as direct and significant competitors of AAS?”
   • Methodology; Selection process following several selection criteria extracted from market characteristics.
   • Reference; The answer is provided in section 4.3

SRQ 3. “How can airports be compared regarding the efficiency of their airside asset base, thereby extracting best practices and minimizing the problems brought to the surface by other benchmarks?”
   • Methodology; Literature research, analysis of available benchmarks, model testing, informal interviews and e-mail conversations with fellow researchers.
   • Reference; See chapter 5. The answer is summarized in section 5.8

SRQ 4. “Which factors could explain the differences in benchmark results between airports (i.e. peers)?”
   • Methodology; Data collection, Data Envelopment Analysis (DEA), validation of data and discussion of results.
   • Reference; See chapter 6. The answer is summarized in section 6.2 and 6.3. A more extensive discussion about the results and inherent conclusions is presented in chapter 7.

SRQ 5. “Which lessons can be learned from the benchmark results and how can they be applied to AAS?”
   • Methodology; Assessment of results, open discussion about results.
   • Reference; See chapter 6, Table 6-5, section 6.2.2 and chapter 7.

MRQ. “How efficient is Amsterdam Airport Schiphol in using its main aviation assets relative to its direct competitors?”
   • Methodology; Data Envelopment Analysis following the results from the sub research questions.
   • Reference; See chapter 7.
Chapter 3 – The airport sector
3 The airport sector

Commercial airports are capital intensive infrastructural nodes, characterized by their often impressive asset base which is utilized by its 24x7 operations\(^\text{13}\). This chapter will inform the reader about the most important characteristics of airports and the European airport sector. These characteristics are explained following four independent sections. In principle, these sections can be read without any prior knowledge. The central themes of this chapter are the regulative characteristics of the market (section 3.1), the integrity of airports (section 3.2), performance and capacity at airports (section 3.3), and a description of the competitive landscape of the airport sector (section 3.4).

The reader should be acquainted with the central themes of this chapter for multiple reasons. First, the sections as discussed introduce several principles, concept, terms and definitions to the reader which are needed in order to understand the successive chapters. Second, the chapter shapes the context of benchmarking in the airport sector. The reader should be aware of this context to have an understanding why benchmarking in the airport sector is so important, and what the limitations of benchmarking are (specifically for the airport sector). Third, the chapter also provides insight in related research as performed in science. As will be introduced later in this report, this research uses prior research as a starting point for enhanced research.

3.1 An introduction to the regulated airport sector

The regulation of airports throughout the world is based on the fact that the provision of aeronautical services embodies the characteristics of a natural monopoly, with decreasing long-run marginal costs and investment in lumpy assets\(^\text{14}\). Also the European airport market is regulated by law. Since this document is not a judicial report on itself, it is not fully necessary to understand the aviation laws and legislation in great detail. However, one has to understand the basic principles of aviation law and legislation, particularly affecting airports in its operations. The reader who is acquainted with the basics of aviation law in line with this research is better capable of understanding the results and conclusions of this research. This section will explain (1) how airport costs are related to airport charges according to the Dutch aviation law, and (2) it will touch upon the effects of regulation and legislation on operations.

The aviation law (established on January 15\(^{\text{th}},\) 1958) regulates the operations of aircraft and aerodromes in the Netherlands and beyond\(^\text{15}\). The aviation law (‘Luchtvaartwet’) was replaced by the aviation act (‘Wet Luchtvaart’), started in June 18\(^{\text{th}},\) 1992. The new aviation act is established after privatisation of the airport sector. The underlying objectives to the establishment of the aviation act were securing the mainport position of AAS, and second an economical regulation. The latter is the subject of this section.

\(^{13}\) Note that the nature of night operations may differ from (normal) day operations due to noise legislation. See also Table 6-2

\(^{14}\) lumpy assets: those assets that cannot be acquired in small increments but must be obtained in large, discrete units (Besley and Brigham, 2009).

\(^{15}\) ‘Beyond’ refers to aircraft operating in foreign countries but which are owned by Dutch airliners.
The exploitation of Amsterdam Airport Schiphol is economically regulated to prevent abuse of the airport’s dominant position in the Netherlands. Monitoring is authorized by two authorities, each having different perspectives. First, monitoring is the responsibility of the Netherlands Competition Authority (‘Nederlandse Mededingingsautoriteit’), and is especially directed to the establishment of charges and the conditions which the operator proposes. The Netherlands Competition Authority monitors the airport charges by comparing the delivered quality with respect to those charges. The main monitoring instrument is the annual compulsory consultation of users by the operator’s proposed rates and terms for next the fiscal year. Furthermore, the authority assesses the complaints of the users on the question as to whether the charges are conform to the legal requirements. The second authority responsible for monitoring is the Dutch Ministry of Transport, Public Works and Water Management (Ministerie van Verkeer en Waterstaat, V&W). The ministry monitors all operations and developments for AAS which are regulated by law.

To understand how airport charges are established, one should first have an understanding of the basic accounting systems used by airports. There are two distinct main accounting systems, they are known as the ‘single till’ accounting system and the ‘dual till’ accounting system. According to the dual till accounting system, the operator is forced to perform aviation activities and non-aviation activities as entirely standalone activities. Each activity has its own revenue and cost structure. Any cross subsidization is not allowed. The basis for such a dual till accounting system lies in the monopoly position of some airports such as AAS. Splitting aviation activities (monopolistic competition) from non-aviation activities (perfect competition) enables the legislature to regulate the airport charges. AAS is regulated according to the dual till accounting system, however, in setting the charges, the Dutch aviation act allows the operator of the airport to consider a contribution of non aviation activities (Dutch aviation act, article 8.25d, section 5).

The economic regulation and the establishment of charges of national airport operations are arranged in the Dutch aviation act, chapter 8. The exploitation of Amsterdam Airport Schiphol is specifically arranged in section 8.2. However in the context of this report, the following section of the Dutch aviation act (‘Wet Luchtvaart’ WLv) is of particular importance: chapter 8 airports / section 8.4; exploitation of the airport / paragraphs 8.24a to 8.25j.

The Dutch aviation legislature requires that Dutch airport operators set the airport charges and conditions at least once every year. To prevent any unauthorized cross subsidization between tills, the Dutch aviation act dictates that the airport charges are cost oriented for all aviation related activities and fixed assets (Dutch aviation act, paragraph 8.25d, section 3). The concept of the word ‘related’ include the work by or on behalf of the operator of the airport at the expense of aviation, and are charged to third parties. Generally, aviation activities are those activities of the airport operation in favour of the activities as presented in Table 3-1.
Table 3-1: Aviation activities according to Dutch aviation act (Eerste Kamer der Staten-Generaal, 2006)

<table>
<thead>
<tr>
<th>Aviation activities according to Dutch aviation act</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Take off and landing of aircraft, including at least the use of aircraft taxi, take off and landing runways and aprons</td>
</tr>
<tr>
<td>b. Parking of aircraft, including at least the use of aircraft parking at the airport</td>
</tr>
<tr>
<td>c. The handling of passengers and their baggage, including at least;</td>
</tr>
<tr>
<td>1°. The use of the passenger terminal</td>
</tr>
<tr>
<td>2°. The use of the roads</td>
</tr>
<tr>
<td>d. Implementation of the security of passengers and their baggage, which includes the facilities for border control</td>
</tr>
</tbody>
</table>

The airport’s tangible fixed assets in use for aviation activities are arranged according to assets exclusively used for aviation activities, and assets which are partly in use for aviation activities and accordingly be allocated. The value of tangible assets of the aviation activities specified is referred to as the Regulatory Asset Base (RAB). The RAB represents the proxy value of the airport’s regulated operating assets for aviation activities (fixed assets), upon which the owners of the airports earn a return. To prevent any unauthorized cross subsidization from aviation activities to other activities, the authorized revenues for aviation are limited and are fully cost oriented. This implies that the revenues from aviation may maximally equal the costs for aviation activities plus the capital costs for security and exploitation of the Regulatory Asset Base (RAB). One could therefore conclude that the RAB impacts the maximum allowed aeronautical charges.

The costs of capital (so as for the RAB) are also known as the Weighted Average Costs of Capital\(^{16}\) (WACC). The projected return (percentage) for the coming fiscal year should (by law) never exceed the WACC. The return on the RAB, after taxes for fiscal year \(t\) is calculated by dividing the aviation related results of fiscal year \(t\) by the value of the RAB. The aviation related results of fiscal year \(t\) is the summation of the revenue of the charges, other revenues from aviation activities, and the contribution of non-aviation activities. The aviation related costs is the summation of costs (operational costs + depreciation) and costs for large investments\(^{17}\). Here, depreciation includes depreciation of tangible fixed assets, excluding depreciation of large investments.

The efficiency gains in operational costs which the airport operator gains once a year (compared with the estimates), may be retained by the operator. This is an incentive to the operator to exploit the airport more efficiently. The effect of this incentive is that charges are adjusted which cause lower airport charges. Higher operational costs than originally were estimated are according to this principle at the expense of the operator (Eerste Kamer der Staten-Generaal, 2004-2005) (Eerste Kamer der Staten-Generaal, 2006).

\(^{16}\) The Weighted Average Costs of Capital (WACC) is a ratio that reflects the costs that a company makes for the capital of which (a part of) the company is financed. In the context of this report, the WACC is mainly composed by the represented value of the Regulatory Asset Base.

\(^{17}\) Large investments are those investments larger than €100.000.000,-- where it is expected that at the time of commissioning initial excess capacity is present.
3.2 The integrity of airports

Conceptually, airports can be seen as infrastructural nodes where aircraft land and take off. The Columbia Encyclopaedia defines an airport as; “a place for landing and departure of aircraft, usually with facilities for housing and maintaining planes and for receiving and discharging passengers and cargo”. Britannica Concise Encyclopaedia defines an airport as “a site and installations for the take off and landing of aircraft”. It is clear that both definitions consider the aircraft as the central entity at an airport. However, the functionality of an airport is much broader. This is especially true considering AAS. For this research, airports are defined as facilitators which enable one to handle aircraft and to exchange passengers and goods from different modes of transport from and to aircraft. To get an idea of both principles included in this definition (handling of aircraft and exchange of passengers and goods), the reader is referred to Figure 3-2.

In the context of this research, it is necessary to have an understanding of how airports are designed and how they are operated. Figure 3-2 provides a flow diagram (adapted from Ashford et al., 1996) which schematically depicts how airports are generally designed and organized. Conceptually, airports can be assessed by separating the airport in two distinct areas, to be known as the airside area and the landside area. The part of an airport directly involved in the arrival and departure of aircraft is defined as airside. The landside of an airport is on the other hand defined as the area bounded by the points at which passengers and goods enter the airport grounds by modes of transport other than via the airspace and the point on the apron at which the aircraft is serviced and loaded. The airside and landside areas are separated by a security filter; all persons and goods that access the airside of an airport are screened by a security filter.

For airside processes, one can assess the airport in terms of its productivity by means of aircraft movements, more formally Air Traffic Moments (ATM), defined as ‘any arriving or departing aircraft’. For landside processes, one could assess the airport by taking into account passenger streams. This research examines the airside area of an airport as defined by the shaded area in Figure 3-2.

The design of airsides differs from airport to airport. In the context of this research, the term typology is used to identify the physical characteristics of assets located on airsides according to their association with different categories. The main differentiators determining the typology of airports are;

- Runway system (parallel or tangential). Tangential runway systems often result in intersecting runways.
- Terminal (loose buildings (terminals) or contaticated terminals). Loose building result in additional aprons and taxiways.

The typology at airports is related to the utilization of centralized assets, such as the air traffic control tower, fire stations and de-icing platforms. The typology of airports is also strongly related to maintenance expenses; complex typologies often go apart with additional land and decentralized assets which have to be maintained. Although it is not the intention of this research to assess airports on a highly detailed level, the typology of airports is modeled in the benchmark as presented in chapter 6 (section 6.2.2), and is used to explain the variation amongst airports regarding their efficiency in chapter 7.
AAS faces a complex typology as a result of its sixth runway 18R/36L (‘Polderbaan’). As can be observed at Figure 3-1, an additional fire station, Air Traffic Control tower and de-icing platform had to be installed.

Figure 3-1: Typology of AAS and additional assets (schematic)

Figure 3-2: Flow diagram of a airport, adapted from: (Ashford et al., 1996)
3.2.1 Airside assets

The airport’s airside is used to handle arriving aircraft and make them ready to depart; often within a minimal time frame, called the turn around time. The airport’s airside is an intensive infrastructural area, containing a common set of fixed assets; mainly property, plant (installations), and equipment. Formally, assets are especially those items with intrinsic economic value owned by the organization, and which could not be directly converted into cash on the short term. Assets which are used for income generating operations of the business and fixed long-term assets are defined as operating assets. More specifically, airside assets as used or located just and only at or on the airside area with a lumpy character are called the main airside assets. Investment in main airside assets is capital intensive. According to Jorge and Rus, the main airside assets basically include the runway system, taxiway system and aprons (including gates). Note that this subdivision of assets is in line with Figure 3-2, and that main airside assets are part of the RAB (Jorge and Rus, 2004).

Airside assets come with costs. Jorge and Rus (2004) define airside costs as those costs that attribute to processing of aircraft through aprons, taxiways and runways (the main airside assets). Airside costs are infrastructure-intensive, creating significant long term fixed costs that give rise to cost economies. Jorge and Rus further define that conceptually, the relationship between throughput and unit cost could be disaggregated into three potential sources of cost economies (Jorge and Rus, 2004);

- **Economies of density:** Arising from increasing throughput through the existing infrastructure. 
- **Economies of scale:** Arising from increasing throughput by increasing infrastructure capacity, while keeping throughput density constant. 
- **Economies of scope:** Arising from combining different types of output through the existing infrastructure, while keeping density constant.

Especially economies of density could be expected on airports. Increase in the throughput and the lumpy character of (airside) assets make fast and / or temporarily expansion impossible. Economies of scale are not as obvious as it sounds. On the one hand there could be economies through more intensive use of centralized functions. On the other hand, airports will tend to expand capacity by exploiting the best next available location, so that the cost of each successive piece of infrastructure is higher than the preceding one. Such observations are especially true for airport such as AAS. In fact, diseconomies of scale are more obvious since the expansion of the existing infrastructure requires demolishment of assets, or acquisition of new land. Especially Economies of scope are not common in the airport sector (Jorge and Rus, 2004).

Tangible assets used for operating activities for AAS are amortized and depreciated on a straight line basis according to the schedule in Table 3-2. Depreciation is not charged over land (Schiphol Group annual report 2009). The amortization and depreciation periods applied by the Schiphol group is presented in Table 3-2. It is observed that the depreciation and amortization period of fixed assets is spread over a long period.

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18 The turnaround time is the amount of time an aircraft spends on the ground between flights.  
19 It are especially main airside assets since the lumpy character refers to the capital intensive character of those assets.  
20 Such as the construction of the sixth runway of AAS; ‘the Polderbaan’ (RWY 18R/36L)
Table 3-2: Depreciation and amortization of main aviation assets at AAS (Schiphol Group, 2009a)

<table>
<thead>
<tr>
<th>Depreciation and amortisation at Amsterdam Airport Schiphol</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Runways</td>
<td>15-60 years</td>
</tr>
<tr>
<td>Taxiways</td>
<td>15-60 years</td>
</tr>
<tr>
<td>Aprons</td>
<td>30-60 years</td>
</tr>
</tbody>
</table>

3.2.2 Schiphol Group and its strategy according to the ideas of Porter

Following the ideas of Michael Porter (Porter, 1980), the primary determinant of the airport’s profitability is the attractiveness of the industry in which it operates. Another determinant is the airport’s position in that industry; one of the focus areas of this research. Levering the strengths of the individual airport is a method for increasing the competitive position relative to the competitive landscape. Porter argues that the strengths of an organization (airport) fall either in the categories cost advantage or differentiation. Application of these strengths at the business unit level results in either one of three generic strategies; cost leadership, differentiation or focus. To position the Schiphol Group and especially the airside of AAS in Porter’s generic strategy framework, one first needs to develop an understanding of the Schiphol Group corporate strategy. This section therefore continues with a presentation of the Schiphol Group (corporate) strategy, followed by a brief discussion.

The Schiphol Group aims to be ranked among the world’s leading airport companies by creating sustainable value for stakeholders. To achieve this, the Schiphol Group creates airport cities, and aims to position AAS as Europe’s Preferred Airport. The Schiphol Group strategy is underpinned by two pillars: the socio-economic function played by the airport and entrepreneurial management.

The AirportCity formula is aimed at the integral development of aviation and non-aviation activities. These activities are carried out by four business areas which reinforce each other in creating growth and value. The AirportCity formula of AAS is a clear example of a differentiation strategy adopted by the airport. AAS is a pioneer of the successful AirportCity formula. This formula is part of a mainport strategy, which links the growth of the airport to the development of its network of destinations and the competitive power of the region.

Its ambition to become Europe’s Preferred Airport in Europe requires the Schiphol Group to be aware of the wishes and needs of passengers and other users at all times. The perspective of the passenger and other users is therefore key. To integrate this perspective into all decisions and actions, the Schiphol Group has chosen the following brand values for Amsterdam Airport Schiphol: hospitable, efficient, reliable, inspiring and sustainable. These values are the basic principles underlying the business of the Schiphol Group (Schiphol Group, 2009a).

Following Porter’s generic strategy model, one could position the Schiphol Group under the heading differentiation strategy (see also Table 3-3). The unique attributes offered by the Schiphol Group in the form of various products offered by its AirportCity (both core and supportive) are valued by its customers. The products of the Schiphol Group are perceived as better than, or different from, products of the competition. The value
added by the uniqueness of the product may allow the firm to charge a premium, for example rent. A differentiation strategy offers unique benefits to the corporate business of the Schiphol Group. The Schiphol Group has many of the differentiation strategies associated internal strengths. These include:

- Access to leading scientific research;
- A highly skilled and creative product development and support team;
- A strong sales team with the ability to successfully communicate the perceived strengths of the (aviation) products to the customers;
- Corporate reputation for quality and innovation.

The differentiation strategy of the Schiphol Group also comes with risks. The biggest risks include:

- Imitation by competitors;
- Changes in customer demand / tastes.

Besides a top-level assessment of the Schiphol Group corporate strategy, it is in the context of this research good to develop an understanding of how to position AAS (and specifically its airside) in Porter’s five forces framework. When taking the airside of the airport into consideration, one could conclude that (following its corporate strategy) the airside of AAS is developed by means of a differentiation strategy. Main reasons lie in the fact that the airside is designed such that it remains operational under various (weather) conditions. Second, there are various products and services distinguishable, such as specifically equipped piers for low cost carriers. Although the interface between differentiation strategies and cost leadership strategies is vague, one could conclude that airports such as London Stansted or London Luton are better placed under the heading cost leadership. Generally speaking, one could recognize that airports may be forced to differentiate because of either legislation, the environment or other factors. Although it is not intended to present an extensive strategy analysis, it is good to know which forces threaten the business environment of airports.

Table 3-3: Porter’s generic strategy framework (Porter, 1980)

<table>
<thead>
<tr>
<th>Target scope</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad, industry wide</td>
<td>Cost leadership</td>
</tr>
<tr>
<td>Narrow, market segment</td>
<td>Focus strategy on low costs</td>
</tr>
<tr>
<td></td>
<td>Differentiation strategy</td>
</tr>
<tr>
<td></td>
<td>Focus strategy on differentiation</td>
</tr>
</tbody>
</table>

Each generic strategy identified by Porter has attributes that can serve the organization to defend it against competitive forces. Porter identified five competitive forces, to be known; entry barriers, buyer power, supplier power, threat of substitutes and rivalry (see also Table 3-4)
Table 3-4: Porter’s industry forces (Porter, 1980)

<table>
<thead>
<tr>
<th>Industry force</th>
<th>Explanation</th>
<th>Differentiation strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry barriers</td>
<td>Threat of entry by new competitors</td>
<td>Customer loyalty can discourage potential entrants</td>
</tr>
<tr>
<td>Buyer power</td>
<td>Bargaining power of buyers (customers)</td>
<td>(Large) buyers have less power to negotiate because of few close alternatives</td>
</tr>
<tr>
<td>Supplier power</td>
<td>Bargaining power of suppliers</td>
<td>Better able to pass on supplier price increase to customers</td>
</tr>
<tr>
<td>Threat of substitutes</td>
<td>Pressure from substitute products</td>
<td>Customer’s become attached to differentiation attributes, reducing threat of substitutes</td>
</tr>
<tr>
<td>Rivalry</td>
<td>Intensity of rivalry amongst existing competitors</td>
<td>Brand loyalty to keep customers from rivals</td>
</tr>
</tbody>
</table>

The industry forces presented in Table 3-4 requires a brief discussion. AAS has basically two types of customers; **travellers** and **airlines**. Among travellers, a distinction can be made between **Origination / Destination (O/D)** passengers\(^{21}\), and **transfer** passengers\(^{22}\). Both types of customers have significant forces affecting the performance of AAS within the wider industry.

**Entry barriers**

The airport industry faces high barriers of new entry since the start up of an airport is a capital intensive matter (high costs of entry). Nevertheless, the industry faces an increasing threat of existing airports exploring the markets of others. This threat rises as the barrier to entry is reduced in the marketplace. This reduction can be recognized since travellers are exploiting the catchment area of other airports. Rail and or road connections to Germany and Belgium have (especially with the opening of borders within the European Union) increased the ability for O/D travellers to travel from other airports. In the transfer market, lower prices of competitors result in an entry of foreign airports to enter in the transfer market of AAS.

**Buyer Power**

There are basically two types of buyer powers recognizable concerning the Schiphol Group; the customer’s **price sensitivity** and **negotiation power**. The most important factors affecting these buyer powers are;

- The number of buyers; buyer power forces increase when the number of buyers is small. This is the case since the number of airlines at AAS is small and not proportionally divided (see bullet 2 and 3).
- Size of buyer; larger buyers have more power over suppliers than smaller buyers. This is especially the case with KLM Royal Dutch Airliners, the biggest buyer for AAS. KLM has significantly more (political) power than smaller airlines or the individual passenger.
- Purchase quantity; customers which purchase a large quantity of a suppliers output have more exercise more power over the supplier than smaller customers. This is also true for the Schiphol Group concerning KLM.

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\(^{21}\) Passengers with their origin or destination at the hinterland of the airport.

\(^{22}\) Passengers which change flights at the airport.
Supplier power
For (almost) all investments, AAS makes a purchase decision mainly based on price. The fewer suppliers available, the less leverage AAS has to negotiate a better price. One of the biggest factors determining the supplier power is the size of the AAS versus that of its supplier. The larger the buyer versus the suppliers, and the larger the purchase quantity, the less supplier power is left for suppliers to negotiate.

Main factors that determine supplier power include:

- The uniqueness of products and/or services; suppliers that produce products or services specifically for a company have more power than commodity suppliers.
- The supplier concentration; the fewer the number of suppliers for a given product, the more power they will have over the buying company.
- Switching costs; suppliers become more powerful as the cost to change to another supplier increases.

Threat of substitutes
An often overlooked threat is the threat of substitutes. The threat of substitutes mainly concerns the product types customers can buy instead of an airline ticket. The threat of substitutes can both be applied on airlines and travellers. Airlines may buy better priced products, such as low cost pier services. On the other hand, travellers may buy train tickets to travel to their destination.

Rivalry
Rivals are competitors within an industry. Whereas historically airports were seen as public transport utilities, they now become commercial organization with an emphasis on profitability. Since the privatisation of the airport sector, rivalry has become more intense. The most important factors concerning the threat of rivalry are:

- The number of airports; overlapping catchment areas and the substitutability for transfer passengers resulted in increased competition.
- Product differentiation; similar products are exposed to competition based on price. Differentiated products can reduce rivalry.
- Fixed costs; the higher the fixed costs per portion of total cost, the more products or services an airport must sell to cover those costs. This leads to an increase in market competition.

Conclusions
As becomes apparent from the assessment of industry forces, a lot of the power of AAS actually lies with external parties. In fact, for all completeness a sixth term should be added, which are political forces. These political forces can for example be recognized with the initiation of the ticket tax. One could clearly observe the interrelation between government, AAS and its biggest buyer KLM since this ticket tax was only introduced for O/D passengers and not for transfer passengers. Besides external parties, a part of industry powers actually lies within the environment. Congestion of the Randstad city region is a good example of decreasing entry forces since travellers are exploiting the catchment areas of other airports. One should be aware of the distribution of powers among external partners since this research will elaborate on these powers by means of controllability.
### 3.3 Performance and capacity at airports

This section discusses the performance and capacity characteristics of airports. Both principles (performance and capacity) are placed under the same heading since the principles are integrally related; the presumed relationship is that capacity is equal to the maximum performance attained by an infrastructure of facility.

#### 3.3.1 Airside performance

Performance management is a critical airport management accounting activity, both at the operational level of the individual airport and at the wider system level. The activity is important since it determines the amount of traffic the airport can handle. Humphreys and Francis examine in their 2002 article various performance measurement techniques. Humphreys and Francis emphasize the importance of performance measurement and came up with four important reasons for performance measurement (see Table 3-5).

<table>
<thead>
<tr>
<th>Reasons for performance measurement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. To measure efficiency from a financial and operational perspective</td>
<td></td>
</tr>
<tr>
<td>b. To evaluate alternative investment strategies</td>
<td></td>
</tr>
<tr>
<td>c. To monitor airport activity from a safety perspective</td>
<td></td>
</tr>
<tr>
<td>d. To monitor environmental impact</td>
<td></td>
</tr>
</tbody>
</table>

Changing ownership patterns of airports (a result of privatisation) have created a greater emphasis on commercialization of the sector. This in turn has led to the introduction of more financial (shareholder) oriented measures that are seen as being consistent with maximizing shareholder value. The introduction of new performance measures are aimed at reflecting new management goals. This may result in shifting managerial attention to what were traditionally seen as non-core activities (Humphreys and Francis, 2002). Humphreys and Francis state that measuring only operational performance is to crude; meaning that there is a tension in data collection between what is easy to measure and what is useful to measure but potentially more difficult (Humphreys and Francis, 2002). The shift of managerial attention to financial orientated measurement has shaded the evaluation of the core processes of airports; serving passengers and handling aircraft. Quality, reliability, connectivity are examples of measurement principles which gradually become underexposed by economic evaluations.

As Humphreys and Francis discuss in their 2002 article, assessing relative performance (that is the performance of airport ‘A’ versus the performance of airport ‘B’, ‘C’ and on) is generally performed on the basis of financial- or output oriented measures. These measures were initially based on some form of Work Load Unit (generally used up to the 1980’s where airports were seen as public service facilities), defined as one passenger processed or 100 kg of freight handled (Doganis, 1978). Some ratios which were used in order to express efficiency related to a single WLU are presented in Table 3-6.

---

23 The performance of the system (or network) of airports determines the amount of traffic which can be supported in the airspace.

24 Traffic schedules (slot coordination) are based (to a large extend) on performance estimates.
Modern performance measures emphasize on the commercialization of airports, and provide more financial oriented measures, particularly of interest to the shareholders of an airport. In order to improve the measurement values, airports tend to pay specific attention to what was previously a non-core activity (Humphreys and Francis, 2002), such as non-aviation services like the provision of real estate. Performance measurement of core activities, such as the provision of runways, taxiways and apron space are therefore snowed under simply because they are not of particular interest for the equity provider.

Forsyth concludes that there are substantial variations amongst airports in their productivity and the level of their charges. It is clear that airports in Europe and some in Asia are relatively high in their costs (Forsyth, 2007). To some degree this may be due to cost factors beyond managerial control of the airports; nevertheless there is likely to be scope for many airports to lower their costs (Forsyth, 2007). The variation in productivity of airports, as Forsyth concludes, can have multiple reasons; although it is not exactly clear which exactly. Various kinds of economies may play a role, but again it is not clear how these are related to the assets of an airport. However, following Holt et al., capital efficiency plays an important role in determining the firm’s performance (Holt et al., 2006).

### 3.3.2 Airside capacity

The capacity of an infrastructure or facility is the theoretical maximum throughput (in contrast, ‘production’ refers to the actual or realized throughput of the facility). The (theoretical) capacity of an airport refers to the ability of an airport to handle a given volume or magnitude of traffic (also known as the demand) within a specified time period. More specific, for airport airside capacity, the volume of traffic is determined in terms of Air Traffic Movements\(^{25}\) (ATMs) per time unit. The capacity of an airport aviation infrastructure is determined by three main components;

Table 3-7: Airside assets and theoretical capacity (Karlsson, 2009)

<table>
<thead>
<tr>
<th>Assets which determine the theoretical capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Runway system</td>
</tr>
<tr>
<td>b. Airport ground movement network</td>
</tr>
<tr>
<td>c. Aprons</td>
</tr>
</tbody>
</table>

The theoretical hourly capacity of the airport for daily operations (the throughput of the system) is determined by the lowest capacity of the runway system, the taxiway system or the aprons. The practical capacity is basically a factor which includes also factors which are beyond managerial control of airport managers. That is, the negative effect of a factor that is beyond managerial control of airport managers is hard to reduce by investment or optimization of processes alone.

\(^{25}\) Air Traffic Movement (ATM)
To increase the airside capacity, one should either optimize (airside) processes, or one should invest to expand the airside. Increasing the airside capacity could trigger large increases in the ability of the airport to handle aircraft (Jorge and Rus, 2004). An overall evaluation of capacity includes analysis of airspace-, airfield-, terminal- and ground access capacity. The throughput capacity of the airfield is the rate at which aircraft can operate at the runway- and taxiway system and aprons without regard to any delay.

Increasing capacity

The need to enhance or increase capacity at many airports within Europe is clear (Eurocontrol 2008). In many sectors and especially in the aviation sector, investment in new infrastructures takes time in order to resolve environmental, political and cost issues. Furthermore, the potential for significant increases in capacity appears limited. However, existing infrastructures are often underutilized because of inefficient practices and procedures, environmental issues or reserved (buffer) capacity for the future. The lumpy character of assets favours a visionary approach and a long term planning to acquire assets.

Airside projects (investment in projects) are geared to increase the capacity of the airport to handle aircraft movements. According to Jorge and De Rus, investment in assets or optimization of utilization of assets at the airside of an airport, will produce two potential benefits. First, enhanced airside capacity will enable an increase in both the frequency of departure and the range of routes available from the airport. This will yield the benefit of reducing the frequency delay (the difference in the average passengers’ preferred departure time and the closest flight departure feasible for the passenger), as well as potentially the trip duration. Both contribute to a reduction in the generalized cost of transport. Second, airside investments in aviation assets may speed the processing time for aircraft, reducing operating costs for airports (Jorge and Rus, 2004). These benefits both deliver a contribution of enhancing a better competitive position.
3.4 The competitive landscape of the sector

Today’s international aviation market is dominated by hybrid customers with high expectations. Hybrid customers are sensitive to the ticket price which one has to pay. The competition between airports is striking; incentives to lower prices in order to make the airport more attractive to airlines and travellers are essential to enhance a competitive position. Besides, the ability of airports to deliver increased capacity and improved service at reasonable cost to user will determine whether the industry as a whole is anticipated to growth. As concluded in this chapter, the optimization of capital efficiency (the informal ratio of output divided by capital expenditure) is essential for airports in order to minimize costs and to gain profit out of their operations.

3.4.1 An expanding market, the need for capacity

Despite the economic crisis which started recently in 2008, Eurocontrol (the European organisation for the safety of air navigation), predicts that demand for air travel will continue to grow. In its long term 2008 forecast, a traffic forecast for IFR\(^26\) flights for the period 2008-2030 based on economic and industry developments is presented. This forecasts shows that demand for IFR flights in Europe grows to between 16,5 million and 22,1 million\(^27\) in 2030, which is 1,7 tot 2,2 time more than the actual traffic in 2007. Furthermore, as defined by Eurocontrol, there will be more demand than capacity on the long term (Eurocontrol, 2008). Also in its medium term (2009-2015) traffic forecast, Eurocontrol is optimistic about potential growth. According to Eurocontrol, demand for traffic picks up growth by 2,0% in 2010, and 3,0% per year for the period 2009 – 2015 (Eurocontrol, 2009).

Also Airbus predicts strong growth; the world’s demand for air travel is predicted to double in the next 15 years. Due to unevenly distributed growth, in Europe demand for air traffic is determined to increase by between 2,0% and 3,3% per year. Global demand for traffic is forecasted to grow at 4,7% per annum for the period 2009 – 2028 (Airbus, 2009).

Although demand for air traffic is forecasted to grow in Europe, this may not be a reason to assume increasing demand for slots at European airports (Airbus, 2009). The overall long-term effects of the 2008/2009 financial crisis are expected to be more pronounced on network evolution than on demand for (local) growth. In the coming years, the routes that passengers actually fly will depend not only on the route they want to take, but also on what the airlines can profitably offer in a challenging market environment.

Based on traffic forecasts as presented above, one could draw the following conclusions (Eurocontrol, 2008):

- Growth will not be evenly distributed in terms of time, geographical dispersion and flight flows across Europe.
- Traffic growth goes hand-in-hand with network evaluation and requires a competitive strategy of airports in order to enhance a competitive position.

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\(^26\) Instrument Flight Rules (IFR); regulations and procedures for flying aircraft by referring only to the aircraft instrument panel for navigation. Most scheduled airline flights operate under IFR.

\(^27\) Dependant on scenario’s as defined by Eurocontrol.
Recent air transport forecasts speak for an increase in international air passenger traffic in Europe by an average of 3.6% per year between 2002 and 2020.

The traffic figures predicted by Airbus are slightly different to those predicted by Eurocontrol. In growth terms, the traffic on average increases 2.2%-3.5% a year. But this growth is not evenly distributed in time, across regions and flight flows. Geographically, growth is stronger in Eastern Europe.

3.4.2 Unevenly distribution of growth

Simple smooth curves often used in traffic forecasts predict that air traffic is a homogeneous mass swelling at a continuous rate of about 3-4% per year (Eurocontrol, 2008). Without putting the growth figures in the right context, one may believe that growth can be directed by just a firm hand to accommodate and manage it. However, this is not the case; on the contrary, air traffic demand is far from homogeneous.

In fact, the amount of air traffic growth is unevenly distributed over the world; so is the demand for airport capacity. Growth outside Europe is much stronger; especially growth of hubs in the Middle-East could reduce traffic flows in Europe (Eurocontrol, 2008). Underlying demand is based on moving people. So as the world’s population becomes increasingly urbanised, airlines may benefit economies of scale. Point-to-point traffic will then increase which is disadvantageous for hub airports like AAS, which are particularly focused on hub and spoke markets28.

Despite the economic crisis, markets in emerging economic countries are expected to continue to grow over the next 20 years (Airbus, 2009). Continued global liberalisation is giving greater market access to airlines, providing wider choice for passengers. Airbus states that changing dynamics, particularly network evolution and the role of mega-cities and congestion, are influencing the future of aviation (Airbus, 2009).

The impact for airports of a changing business environment is large. Most air traffic demand is specific to a place and time. However, the financial turmoil started in 2008 and the resulting downturn in the world economy has impacted passenger demand and traffic growth in the short term (Eurocontrol, 2009). However, over the 2009-2028 period the downturn represents a fairly short timeframe. Therefore, worldwide passenger traffic is expected to increase by 4.7% per annum and the number of frequencies offered on passenger routes will more than double. As identified by Eurocontrol, the contribution of individual airports to the additional traffic in Europe has been very uneven in the recent years (Eurocontrol, 2009). It is observed that a relatively small group of airports contribute by a large share to the overall traffic growth. It is however a challenging task to become and stay a member of this small group.

When the effects of downturns become recognizable on airports, congestion falls down the list of priority issues for many in the airport industry. But unfortunately, this means a return to delays, waste and cost as

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28 Point-to-point refers to a transportation network where aircraft travel directly to a destination, rather than going through a central hub. This differs from the hub-and-spoke network in which the aircraft goes to a central location where passengers change to another aircraft to reach their destination.
markets recover. This is an issue for passengers, airlines and many of the world’s most important airports and cities. Any future growth of traffic and frequencies will once again be an increasing challenge to airport infrastructures and air traffic management. This is especially true for an airport such as AAS, which is not a natural hub on itself. That is, the airport is highly dependant on the market of transferring passengers. The biggest threats for airports regarding the need for capacity are (Eurocontrol, 2008);

- Decreasing demand for slots due to **increasing oil prices**. Especially speculation on the oil market result in an oil price which is disconnected from its cost, making air travel more expensive.
- The threat of **terrorism** may harm demand for air travel.
- **Global environmental changes** could affect people’s priorities in their travel destinations.
- A **pandemic** may have a locking effect on international air travel.

### 3.5 Sub conclusions

Chapter three provides an overview of the most important characteristics of the airport market regarding scope of this research. Chapter three provides the answer to sub research question 1. The answer can be summarized by the following bullets;

- Since the privatisation of the airport market, airports have become more commercially oriented. Competition increased and airports have depleted their non-aviation revenue sources.

- Airports are regulated organizations. The exploitation of AAS is economically regulated. Aviation related revenues are discriminated from non-aviation related revenues.

- The airport’s airside area is directly involved in the handling of aircraft, and consists of several main airside assets (the Regulatory Asset Base). These are the **runway system**, **aprons and gates**, and the **taxiway system**. These main airside assets are directly related to the aviation related revenues of the airport.

- The Schiphol Group has adopted a mission to position AAS as Europe’s Preferred Airport. To strengthen this mission the Schiphol Group has chosen a set of brand values, one of these values is **efficiency**.

- The AirportCity product of the Schiphol Group fits closely with the differentiation strategy identified by Porter. AAS copes with significant industry forces. Especially buyer power and rivalry should not be underestimated. As an addition to Porters five industry forces model, one can observe that the airport also deals with explicit political forces, such as (noise) regulation.

- There is substantial variation amongst airports in their productivity and the level of their charges.

- As traffic figures indicate, the airport market is an expanding market. Expansion is not evenly distributed across regions and time. New business models require adjustments of the airport’s infrastructure.
Chapter 4 – Benchmarking airsides of Western European airports
4 Benchmarking airside assets of a set of Western European airports

This chapter, in combination with chapter 5 and 6, is considered as the core of this research. This chapter introduces the concepts of benchmarking to the reader. The chapter therefore defines a peer group which will be assessed later in this report. This chapter will also elaborate on the difficulties of benchmarking; these difficulties will be discussed along this chapter. Looking ahead to the successive chapters, the difficulties which arise in benchmarking airports are tackled according to an approach discussed in chapter 5.

4.1 Reasons for benchmarking

Organizations in general are no longer distinguishable on the basis of their intrinsic characteristics (Elnathan et al., 1996). This is the case since organizations form networks of organizations. These networks are characterized by dependencies, and streamlined by regulators. It is therefore that each organization part of a network has to deal with a large number of external parties. Organizations should therefore continuously ask themselves;

- How can I improve my internal operations;
- How can I become more externally competitive;
- How do I guarantee organizational survival.

To answer the above questions, one could either choose to improve its own business by means of research and development. However, this activity is capital intensive and comes with many risks; the final results might not be what the organization is looking for, or might simply not work. Another option to answer above questions is to learn from the experience of others. It is therefore that most organizations in search for answers on the above soon end up with benchmarking. In fact, benchmarking is a collective noun for competition research (further defined in section 4.2). Benchmarking is in fact a technique which enables one to distinguish organizations and to learn from others.

Mutual assessment of airports is a crucial management technique. In fact, it is part of the internal management accounting of the airport. Competitive research in which organizations look for what the competitive landscape is doing and what specific actors within that landscape are doing is a powerful instrument for mutual assessment. Regarding chapter three, one could imagine that questions such as stated above are straightforward ones for an organization such as the Schiphol Group. Here, the first two questions are of particular interest on the short to medium term. The third question is particularly applicable on the medium to long term business (5-10 years).
4.2 The concepts of benchmarking

Benchmarking is a management technique which was first introduced in 1979 by Xerox, an American company producing copiers. Xerox used the technique to learn from the experience of its biggest rival, Canon, a Japanese producer of copiers. Benchmarking was one of the great components which led to the revival of Xerox in the eighties. Since then, the technique was soon adopted by other companies such as Ford and Hewlett Packard.

The first scientific principles of benchmarking were established some 20 years ago. Robert C. Camp wrote one of the first articles about the principles of benchmarking. Camp is seen by many as the scientific patriot of benchmarking. In his 1989 article, Camp introduced the term for the very first time. Camp defined benchmarking as “a positive, proactive process to change operations in a structured fashion to achieve superior performance.” Camp further stated that “the benefits of using benchmarking are that functions are forced to investigate external industry best practices and incorporate those practices into their operations. This leads to profitable, high-asset utilization business that meet customer needs and have a competitive advantage” (Camp, 1989). It is especially the utilization of assets which is of prime concern in this research. Also research by Francis et al. resulted in a definition of benchmarking, to be known as “the pursuit by the organization of enhanced performance by learning from the successful practices of others” (Francis et al., 1999). Although benchmarking is a widely known management tool, there is substantial variation on what it exactly entails.

Summarizing the definitions of Camp and Francis, one could conclude that the overall aim of benchmarking is to search outside ones own organization for, and subsequently incorporation of, best practices into the enterprise’s own repertoire to gain a competitive advantage. In this context, benchmarking is often geared towards comparing the organization’s investments and / or operational activities (Francis et al., 1999). The full benchmark process is a continuous activity; key internal processes are adjusted, performance is monitored, new comparisons are made with the current best performers and further changes are explored.

‘Best practice benchmarking’, or ‘benchmarking’ for short helps organizations to improve strategically important processes, such as the development of the organization by for example expansion or cost cutting practices. As a matter of fact, the efforts of benchmarking are often directed towards operations management. The benchmark technique often favours a simple approach; benchmarking is often directed towards measuring outputs with no attempt to understand the process which led to them. That is to focus on results rather than the processes that drive them (Francis et al., 1999). In the context of benchmarking airports, it is observed that many efforts are directed towards measuring the organization’s overall performance. This may be perceived as window-dressing. Francis indicates that performance indicators and their benchmarking ratings as such act as a starting point for the benchmarking process. It is however difficult to assess how far organizations look ‘behind’ the figures and look at the process or environment that generate the figures. This insight knowledge can be generated by redesigning the benchmark models. Prime activity here is linking performance measures to their origin; in this case the core airside assets of an airport.
4.3 Defining the peer group

Note: From this section and further, airports will mostly be appointed on the basis of standardized IATA codes.

To identify which airports are compared in the benchmark, some special attention is directed towards the selection of a peer group for AAS. This peer group is called the benchmark sample or sample for short. The selection of an adequate sample is based on non-probability sampling. This implies that the sample is not selected randomly but selected based on selection criteria. This research is limited to a sample from the population of civil Western European airports which are member of the Airport Council International (ACI). This population includes 92 airports, spread over 8 countries (see also Table 4-1). The population is assessed by dividing it into two sub populations. These sub populations differ mutually in terms of target market relative to AAS. Both sub populations result in a sub sample. Sub sample ‘A’ plus sub sample ‘B’ together form the benchmark sample. Sub sample ‘A’ includes civil Western European airports with focus a on the transfer target market. Sub sample ‘B’ includes civil Western European airports with a focus on the local target market.

Table 4-1: Research population (Airport Council International, 2009)

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of ACI associated airports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Netherlands</td>
<td>5</td>
</tr>
<tr>
<td>Belgium</td>
<td>5</td>
</tr>
<tr>
<td>Spain</td>
<td>47</td>
</tr>
<tr>
<td>France</td>
<td>41</td>
</tr>
<tr>
<td>Germany</td>
<td>5</td>
</tr>
<tr>
<td>Ireland</td>
<td>1</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>5</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>16</td>
</tr>
</tbody>
</table>

Sub sample A- Transfer market competition

On the transfer market, AAS serves as an alternative transfer airport for indirect flights between two other airports. The relation between airports is schematically represented in Figure 4-1.

In the above diagram, Amsterdam Airport Schiphol (AMS) competes with Frankfurt (FRA) on the basis of transferring passengers between John F. Kennedy International Airport (JFK) (New York, United states of America) and Barcelona Airport (BCN) (Spain). In practice, passengers travelling from JFK to BCN can choose to either travel to BCN via AMS, or to travel to BCN via FRA. Note that this scheme also counts for passengers departing from BCN and travelling to JFK.

\[29\] And one heliport
The selection criteria for sample ‘A’ are defined as:

- The observations should serve a significant proportion of the number of destinations served by AAS; the number of common destinations of city pair AMS-XYZ ≥ number of destinations exclusively served (from city pair AMS-XYZ) by airport XYZ;
- The observations should be competing on the transfer market and have a significant transfer flow; transfer rate ≥ 30% of all terminal passengers;
- The observations should be certificated to handle IFR flights (CAT I and / or II and / or III).

**Sub sample B- Local market competition**

The catchment area of an airport is the area from which passengers travel to and from the airport by road or rail. It is also called the hinterland of the airport. Concerning its local market, the catchment area of AAS and observed airports overlap. This implies that passengers have either their origin or their destination at the hinterland of the airport.

![Figure 4-2: Schematic diagram of local competition (example)](image)

- The catchment areas (hinterland) of airports NRN (Weeze, Niederrhein Germany) and BCN are represented by the dotted circles in Figure 4-2. The overlap is represented by the grey shaded area. In practice, passengers travelling to BCN can either choose to depart from NRN or AMS. Note that this scheme also counts for arriving passengers.

The selection criteria for sample ‘B’ are defined as:

- The observations should have an overlapping catchment area with AAS. The European Commission defined the catchment area of Schiphol as a circle of two hours driving, bounded by the coast (European Commission's Fifth Framework Programme for Research Technological development and Demonstration). However, since an overlap is required in this selection criterion, the circle radius is set to 1 hour and 30 minutes driving at 100 kilometres per hour. The maximum mutual distance between two airports is then set to < 300 km (2 x 150 km). See also Figure 4-3;
- The observations should serve a significant proportion of the number of destinations served by AAS; number of common destinations of city pair AMS-XYZ ≥ number of destinations exclusively served (from city pair AMS-XYZ) by airport XYZ;
- The observations should be certificated to handle IFR flights (CAT I and / or II and / or III).
4.3.1 Selection analysis

**Note:** *The data presented in this section is reduced to only the data belonging to the final results.*

This section starts with presenting the results of the selection process. It is recommended to analyze the IATA codes (referring to specific airports) carefully as they are often used in this research report (a more detailed overview of the results is provided at the end of this section).

### Table 4-2: Sub sample results

<table>
<thead>
<tr>
<th>Sub samples and reference airport</th>
<th>IATA Code</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference airport;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol</td>
<td>AMS</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>Sub sample A;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paris Charles de Gaulle</td>
<td>CDG</td>
<td>France</td>
</tr>
<tr>
<td>London Heathrow</td>
<td>LHR</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Frankfurt Airport</td>
<td>FRA</td>
<td>Germany</td>
</tr>
<tr>
<td>Sub sample B;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Düsseldorf Airport</td>
<td>DUS</td>
<td>Germany</td>
</tr>
<tr>
<td>Brussels South Charleroi Airport</td>
<td>CRL</td>
<td>Belgium</td>
</tr>
<tr>
<td>Brussels Airport</td>
<td>BRU</td>
<td>Belgium</td>
</tr>
<tr>
<td>Airport Weeze Niederrhein(^\text{30})</td>
<td>NRN</td>
<td>Germany</td>
</tr>
</tbody>
</table>

**Passenger profile analysis:** The population is analyzed according to the selection criteria as presented. The profile of the passengers is determined to be either O/D or transfer. O/D passengers enter or leave the airport by a mode of transportation other than aircraft. Transfer passengers enter and leave the airport by aircraft. First, the transfer rates of the airports are analyzed using ACI data and data provided by the Schiphol Group\(^\text{31}\). The data is verified\(^\text{32}\) and mutually consistent. The transfer rates per airport are presented in Table 4-3.

### Table 4-3: Total terminal passengers and transfer rate for eight airports for 2006 – 2009

\(^{30}\) Weeze Niederrhein (NRN) is not represented on the ACI member list. The airport has however such a significant competitive threat for AAS that therefore an exception is made.

\(^{31}\) Department: aviation / market development / aviation statistics and forecasts.

\(^{32}\) Verification is performed by comparing the data with the airports own facts and figures for as far as applicable.
The eight observations as presented in Table 4-3 show that the airports AMS, CDG, LHR and FRA have a transfer share of >30% for at least the period 2006 - 2009. The airports BRU, CRL, DUS and NRN do not comply with this criterion. Note that for some airports of the latter group, the transfer share is not available since the airport simply does not have any transferring passengers.

**Catchment area analysis;** the catchment area criterion is assessed by calculating the mutual distance between airports. The distance is calculated under the criterion ‘driving distance for the quickest route’. The results of the analysis based on the catchment area criterion (maximum distance allowed is ≤ 300 km) are presented in Table 4-4.

**Table 4-4: Mutual distance in kilometres between airports**

<table>
<thead>
<tr>
<th>City pair</th>
<th>Driving time</th>
<th>Mutual distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam Airport Schiphol - Düsseldorf Airport</td>
<td>2 hour 9 minutes</td>
<td>228 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - Brussels South Charleroi Airport</td>
<td>2 hour 41 minutes</td>
<td>277 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - Airport Weeze</td>
<td>1 hour 48 minutes</td>
<td>178 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - Frankfurt airport</td>
<td>3 hour 56 minutes</td>
<td>438 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - Brussels Airport</td>
<td>1 hour 57 minutes</td>
<td>206 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - Paris Charles de Gaulle</td>
<td>4 hour 28 minutes</td>
<td>488 km</td>
</tr>
<tr>
<td>Amsterdam Airport Schiphol - London Heathrow</td>
<td>-</td>
<td>Overseas</td>
</tr>
</tbody>
</table>

It is observed that the airports DUS, CRL, NRN and BRU have an overlapping catchment area with AMS. These airports therefore comply with the criteria ‘overlapping catchment area’ required for sub sample B.

**Note:** The European commission determined that the number of potential passengers living in the catchment area of AAS is determined to be 12 million passengers (2002). (European Commission’s Fifth Framework Programme for Research Technological development and Demonstration).

**Destination analysis:** the destination analysis as performed in this research is based on data provided by the Dutch ‘Kennisinstituut voor Mobiliteitseenheid’ (the Dutch knowledge institute for transport) (Kolkman and Korteweg, 2009b). The used data sample is selected from the Airport database of Reed Air Transport Intelligence (RATI). The database is filled with data provided by Innovata, an organization which publishes
airline schedules. The destination analysis as presented in this section is based on a selected sample from the 13th till 19th of October 2008. For this sample, only non-stop flight destinations are taken into account. Furthermore, the sample only includes scheduled services.

**Note:** The data as used in this research are based on a one week sample. The data includes only non-stop destinations by scheduled services. Important to note is that all airports are assessed using exactly the same method. Although the data is not an exact representation of the services provided for a whole year by a certain airport, it is a good representation of the mutual differences and commonalities regarding the destination competitiveness between airports (this statement is prepared in conjunction with Joost Kolkman (Kolkman and Korteweg, 2009a).

![Unique destinations per citypair [2008]](image)

It is observed that all airports analyzed in the above figure have less unique destinations than the number of destinations served by the city pair AMS - XYZ. Meaning that from all destinations connected by airport XYZ, at least an equal share of the number of destinations is also served by Amsterdam Airport Schiphol.

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35 For reasons of data availability, see also the note.
ILS compliance analysis; The airports are analysed on Instrument Landing System (ILS) compliance using the European AIS Database (EAD), initiated by Eurocontrol (European AIS database, 2009). This database provides Aviation Information Services (AIS) in the form of Aeronautical Information Publications (AIPs). It is observed that all airports (as presented in Table 4-2), are ILS compliant.

Note: ILS (consisting of several discrete radio navigation aids) is used by pilots for approach guidance to specific airport runway, especially during times of limited visibility.

4.3.2 Reliability of the data regarding the year of measurement
The results of the evaluation of airports are strongly dependant on the research timeframe. Therefore, a brief analysis of the market environment is in place. This section discusses two critical factors which have a negative effect on the performance of the sample airports.

- Introduction of the ‘vliegtax’ (English; ticket-tax)
  The Dutch ticket-tax is a tax law introduced by the government on July 1st, 2008. The law was eliminated on July 1st 2009. The ticket-tax charged the ticket price for O/D passengers. All ticket prices for flights within the European Union or further than 2.500 km were charged at an additional rate of € 11,25. Flights further than 2.500 km were charged at an additional rate of € 45,00. The tax law was only applied to travellers starting their journey in the Netherlands.

  The ticket tax was introduced because of environmental reasons. Foreign airports benefited from the Dutch ticket-tax. Düsseldorf airport counted 62% more Dutch travellers. Also Brussels South Charleroi Airport counted 74% more Dutch travellers. On Weeze airport Niederrhein, the number of Dutch travellers grew with 300% (Dagblad de Pers, 2008). The ticket-tax was eliminated on July 1st 2009 because to enhance a better competitive position of the Dutch aviation industry (Veldhuis J, 2009). According to a Dutch newspaper De Pers and the Dutch news station RTL News, AAS lost a significant share of O/D passengers due to the ticket-tax; 3,6 % between 2008 and 2009

- Worldwide economical downturn;
  The worldwide economical downturn had a significant effect on the aviation industry. Still (2010) the world economy is affected by the downturn which started in 2008. The most significant effect for the airport industry is a decrease in demand for air travel, affecting both the aviation revenues, as well as non aviation related revenues.

  The effects of two major events had a significant impact on the aviation figures. For illustration of these effects, the total terminal passengers\(^{36}\) (excluding transit passengers) are summed up for the sample. By assessing Table 4-5 and Figure 4-5, one can clearly identify the effects of the economical downturn by identifying the decrease in total terminal passengers from 2008 to 2009 (-4,65% for the cumulative sum of the sample). The economical downturn resulted for both the total terminal passenger as well as for AMS specific in a decreasing

\(^{36}\) Total passengers who visit the terminal; both transfer passenger and O/D passengers, but excluding transit passengers.
number of terminal passengers. Second, the effects of the ticket-tax are remarkably identifiable. One can see that AMS had a decrease with respect to its terminal passengers in contrast with the total sum of passengers from all six airports. In 2008 – 2009, the effect of the economical downturn is strengthened by the effects of the ticket-tax, resulting in even more decrease (8.16%) of terminal passengers for AMS.

Table 4-5: Increase and decrease of terminal passengers for AAS and sample from 2006 - 2009

<table>
<thead>
<tr>
<th>Year</th>
<th>Increase (%)</th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample</td>
<td>3.64</td>
<td>0.01</td>
</tr>
<tr>
<td>AMS</td>
<td>3.82</td>
<td>-0.74</td>
</tr>
</tbody>
</table>

Figure 4-5: Total terminal passengers for 2006 - 2009

Table 4-6 displays graphically the negative impact of the effects (as described) on air travel per year. The most recent year for which a reliable dataset is available is 2007. It is therefore concluded that the data as required for this research is based on 2007.

Table 4-6: Decision matrix for the year of assessment

<table>
<thead>
<tr>
<th>Year</th>
<th>Data availability</th>
<th>Effects economical downturn</th>
<th>Effects ticket tax</th>
<th>Suitable</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>Yes</td>
<td>No effects</td>
<td>No effects</td>
<td>Yes</td>
</tr>
<tr>
<td>2006</td>
<td>Yes</td>
<td>No effects</td>
<td>No effects</td>
<td>Yes</td>
</tr>
<tr>
<td>2007</td>
<td>Yes</td>
<td>No effects</td>
<td>No effects</td>
<td>Yes</td>
</tr>
<tr>
<td>2008</td>
<td>Yes</td>
<td>High impact</td>
<td>High impact</td>
<td>No</td>
</tr>
<tr>
<td>2009</td>
<td>Hard to get</td>
<td>High impact</td>
<td>High impact</td>
<td>No</td>
</tr>
<tr>
<td>2010</td>
<td>Not available</td>
<td>Medium to high impact</td>
<td>Small impact</td>
<td>No</td>
</tr>
</tbody>
</table>

37 This is the sum of all traffic figures of the eight airports part of the sample
4.3.3 Results

This section presents the reference airport and the two sub samples of airports which will be examined in this research. The reference airport AAS, plus two sub samples determine the benchmark sample. Table 4-7 represents the reference airport AAS. Table 4-8 and Table 4-9 represent the sub sample as will be used for the benchmark analysis performed later in this report. These figures together also represent the answer to sub research question 2, defined as “Which airports can be considered as direct and significant competitors of AAS?” Figure 4-6 presents the geographical location of the airports. The aerodrome charts of the reference airport and sub sample ‘A’ airports are presented in Figure 4-7, Figure 4-8, Figure 4-9 and in Figure 4-10. For a better overview, the reader is referred to appendix A – Aerodrome charts.

Table 4-7: Reference airport

<table>
<thead>
<tr>
<th>Airport: Amsterdam Airport Schiphol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: Netherlands</td>
</tr>
<tr>
<td>IATA ID: AMS</td>
</tr>
<tr>
<td>ICAO ID: EHAM</td>
</tr>
<tr>
<td>Holding: Schiphol Group</td>
</tr>
<tr>
<td>Transfer rate (2007): 41.3%</td>
</tr>
<tr>
<td>Annual ATM (2007) (000s): 476</td>
</tr>
</tbody>
</table>

Table 4-8: Sub sample A

<table>
<thead>
<tr>
<th>Sub sample A; transfer market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport: Paris Charles de Gaulle</td>
</tr>
<tr>
<td>Country: France</td>
</tr>
<tr>
<td>IATA ID: CDG</td>
</tr>
<tr>
<td>ICAO ID: LFPG</td>
</tr>
<tr>
<td>Holding: Aéroports de Paris</td>
</tr>
<tr>
<td>Transfer rate (2007): 32.0%</td>
</tr>
<tr>
<td>Annual ATM (2007) (000s): 544</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airport: London Heathrow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: United Kingdom</td>
</tr>
<tr>
<td>IATA ID: LHR</td>
</tr>
<tr>
<td>ICAO ID: EGLL</td>
</tr>
<tr>
<td>Holding: British Airports Authority</td>
</tr>
<tr>
<td>Transfer rate (2007): 34.1%</td>
</tr>
<tr>
<td>Annual ATM (2007) (000s): 476</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airport: Frankfurt Airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: Germany</td>
</tr>
<tr>
<td>IATA ID: FRA</td>
</tr>
<tr>
<td>ICAO ID: EDDF</td>
</tr>
<tr>
<td>Holding: Fraport AG</td>
</tr>
<tr>
<td>Transfer rate (2007): 52.9%</td>
</tr>
<tr>
<td>Annual ATM (2007) (000s): 486</td>
</tr>
</tbody>
</table>

Table 4-9: Sub sample B

<table>
<thead>
<tr>
<th>Sub sample B; O/D market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport: Airport Weeze</td>
</tr>
<tr>
<td>Country: Germany</td>
</tr>
<tr>
<td>IATA ID: NRN</td>
</tr>
<tr>
<td>ICAO ID: EDDL</td>
</tr>
<tr>
<td>Holding: Flughafen Niederrhein GmbH</td>
</tr>
<tr>
<td>Distance AMS - NRN: 178 km</td>
</tr>
<tr>
<td>Annual ATM (2007) (00s): 100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airport: Brussels South Charleroi Airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: Belgium</td>
</tr>
<tr>
<td>IATA ID: CRL</td>
</tr>
<tr>
<td>ICAO ID: EBCI</td>
</tr>
<tr>
<td>Holding: N.V. Brussels South Charleroi</td>
</tr>
<tr>
<td>Distance AMS - CRL: 277 km</td>
</tr>
<tr>
<td>Annual ATM (2007) (00s): 727</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airport: Brussels Airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: Belgium</td>
</tr>
<tr>
<td>IATA ID: BRU</td>
</tr>
<tr>
<td>ICAO ID: EBBR</td>
</tr>
<tr>
<td>Holding: The Brussels Airport Company</td>
</tr>
<tr>
<td>Distance AMS - BRU: 206 km</td>
</tr>
<tr>
<td>Annual ATM (2007) (00s): 2.644</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Airport: Düsseldorf Airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Country: Germany</td>
</tr>
<tr>
<td>IATA ID: DUS</td>
</tr>
<tr>
<td>ICAO ID: EDDL</td>
</tr>
<tr>
<td>Holding: Flughafen Düsseldorf GmbH</td>
</tr>
<tr>
<td>Distance AMS – DUS: 228 km</td>
</tr>
<tr>
<td>Annual ATM (2007) (00s): 228</td>
</tr>
</tbody>
</table>
Chapter 4 – Benchmarking airside assets of Western European Airports

Figure 4-6: Geographical location of airports

Figure 4-7: Aerodrome chart (small scale version) Amsterdam Airport Schiphol

Figure 4-8: Aerodrome chart (small scale version) Paris Charles de Gaulle
Figure 4-9: Aerodrome chart (small scale version) Frankfurt Airport

Figure 4-10: Aerodrome chart (small scale version) London Heathrow
4.4 Problems arising when benchmarking airside assets of a set of Western European airports

4.4.1 Difficulties of comparing airsides; a brief discussion

Literature research has shown that investment in airside assets is capital intensive. Furthermore, airside assets of airports can be characterized as lumpy. In this context, lumpy assets are characterized as those assets that cannot be acquired in small increments but must be obtained in large, discrete units (Besley and Brigham, 2009). Holt et al. presents in his 2006 paper that capital efficiency assessment (such as the assessment of investment in main airside assets) poses particular challenges not posed by operational efficiency assessment. Comparative benchmarking of the efficiency of operational activities is common across several (infrastructure) sectors. However, measuring capital efficiency of an infrastructure is by nature more complex than measuring operational efficiency of that infrastructure. Transferring the methodologies developed by regulators over multiple reviews from operational to capital efficiency assessment has proven to be a challenging task, encountering substantial problems. Holt et al. has identified three approaches to capital efficiency assessment, which are (Holt et al., 2006);

- **Direct unit cost comparisons;** compare the unit costs of capital programs with firms that have completed comparable programs. Main points of concern:
  - While direct unit cost assessment can inform unit cost efficiency, they provide little or no information on the efficient scale of the capital program needed to deliver the outputs.
  - A unit cost efficiency assessment will typically reflect only a single output measure and so may not be indicative for an efficient outcome in relation with other drivers.
  - Direct unit cost comparisons are only capable of estimating catch-up efficiency relative to the best current performers in the industry.

- **Top-down modelling;** a top-down approach uses multiple variables and tests for an overall relationship with costs.

- **Process benchmarking;** a more involved approach to efficiency assessment examines discrete activities of the firm assessing them qualitatively against best practice.

Holt et al. concludes that these approaches are all subject to substantial challenges in implementation. This increases the difficulty of identifying suitable comparators, isolating exogenous cost drivers (the factors beyond managerial control of airport managers, such as weather or environmental capacity) and deriving appropriate measures of relative efficiency (Holt et al., 2006). This poses particular challenges of developing comparators to indicate the airport’s capital performance with respect to its airside assets. It is especially process benchmarking that is applied in this research.

Benchmarking in the aviation sector is a complex activity; this is especially true for benchmarking international Western European airports. The complexity lies in the fact that one should consider a number of issues to be

---

38 The informal ratio of output divided by capital expenditure
able to put the benchmark and its results into the right context. Besides acquiring accurate and valid data, some other issues make benchmarking in the aviation sector especially complex. Holt et al. discuss several of those. First, comparing the outputs of two or more different airports is challenging as they are not using standardized working units. Second, the lumpy nature of discrete, large scale capital expenditure programs imply that the unit costs may have varied considerably over time. This implies that by measuring the average efficiency over a longer period, the distortions are smoothed but the magnitude of data problems is increased. Third, the size of the Netherlands and the associated small number of comparable airports makes it necessary to incorporate international competitors. This substantially complicates the standardization problem issues (Holt et al., 2006). Finally, there is no common (international) consensus on the appropriate overall measure of capital efficiency for airports.

The above described issues are graphically represented by the abstract representation of two virtual organizations (called producers) in Figure 4-11. The producers in this figure are responsible for converting inputs into outputs. Comparing these producers without any consensus about what to compare is simply impossible. One should first find common ground for comparison; for example, one could compare the ratio of triangles versus circles for both producers. Such a ratio is also called the efficiency, since it measures the amount of output produced per unit of input. Both inputs and outputs are present at both producers. However the question is whether they are valued the same. As one could observe, this method causes problems since (1) not all inputs and outputs are represented by all producers, and (2) producers may value inputs and outputs differently. An advantage is that ratios also count for size, justifying the ability to compare large producers with smaller producers.\(^{39}\)

![Figure 4-11: The problem of comparing organizations](image)

Another problem in using models as presented in Figure 4-11 lies in the utility function; the use of utility functions in efficiency assessment is often problematic. The problem here is fourfold. The first problem is that the perception of the researcher affects the weights coupled to the variables, and so affects the outcome.

\(^{39}\) Note that ratios do not count for (dis)economies of scale.
Second, the resulting utility function may bear no relationship to each other. It may therefore become difficult to make comparisons from one decision context to another (Hayes, 2005). Thirdly, the utility function of form or process is often not known or is very hard to estimate. And finally, most utility functions do not allow any heterogeneity in the data.

In Environmental Management Accounting Literature (Bennett et al., 2002), a distinction is made between monetary information and physical information. Both information sources can be applied on the impact a firm has on its environment. Many of the problems described above cannot be solved by the use of monetary information. It is therefore that this research is conducted using physical environmental information expressed in physical units.

### 4.4.2 Pre-assessing the sample by means of ratio analysis

Prior to the DEA analysis as presented and analyzed in chapter 6, a pre-assessment of efficiency is presented in this section. This first assessment serves as a starting point for further DEA analysis. The results of the analysis as presented in this section contribute to the perception of the problem that different ratios give different outcomes.

**Efficiency** can be determined as a ratio of output over input;

\[
\text{Efficiency} = \frac{\text{output}}{\text{input}} \quad \text{eq. 1}
\]

The conclusions of the next three assessments criticize the efficiency of AAS relative to its peers. The data of this assessment is from 2007. The efficiency estimate is assigned according to the following scheme:

- Efficient; \( \text{If at least 50\% of the airports have a lower efficiency rank than AAS.} \)
- Inefficient; \( \text{If more than 50\% of the airports have a higher efficiency rank than AAS.} \)

**Runway assessment; (Data for 2007)**

The runways of an airport are essential assets for dispatching aircraft. The runways including its several systems (such as ILS and lighting) are capital intensive. It is observed that the airports part of the sample have other runway systems, mainly differing in the number of runways. Figure 4-12 presents a brief assessment of the number of runways versus the number of ATMs (2007). Note that AMS is assessed both including and excluding its sixth runway for general aviation\(^{40}\).

\[^{40}\text{General aviation refers to all civil aviation other than military and scheduled airline and regular cargo flights, both private and commercial.}\]
1) Relative scores;
   Sub sample A;    efficient    (1) LHR - (2) FRA - (3) CDG - (4) AMS
   Sub sample B;    efficient    (1) DUS - (2) BRU - (3) AMS - (4) CRL - (5) NRN

2) Results for AAS;
   Sample;         rank 6  (of 8)
   Sub sample A;   rank 4  (of 4)
   Sub sample B;   rank 3  (of 5)

3) Conclusion;
   Considering the runway system, AAS is positioned as relatively inefficient compared to the 7 peer airports.

Gate assessment; *(Data for 2007)*

Gates allow passengers to embark and disembark aircraft without having to go outside. For large airports, the majority of the passengers enters and leaves the aircraft via a gate\(^41\). The lower the ratio gates per (annual) ATM, the more important the handling process becomes, since the operator should handle more aircraft within a smaller time span. The number of gates is also interrelated with the (declared) peak hour capacity of the airport. The lower the (declared) peak hour capacity, the more storage space for aircraft (such as gates) is required.

---

\(^{41}\) Many airports serve also the possibilities to embark and disembark aircraft on the platform. Transport is than arranged by bus. However, this option is capital wise less intensive than the gates.
Analysis shows that AAS has a high ratio of annual ATMs per gate;

![Air Traffic Movements per gate (2007)](image)

Figure 4-13: Air Traffic Movements (ATM) per gate (2007)

1) Relative scores;
   - Sub sample A: **efficient** (1) AMS - (2) CDG - (3) FRA - (4) LHR
   - Sub sample B: **efficient** (1) AMS - (2) CRL - (3) DUS - (4) BRU - (5) NRN

2) Results for AAS;
   - Sample: rank 1 (of 8)
   - Sub sample A: rank 1 (of 4)
   - Sub sample B: rank 1 (of 5)

3) Conclusion;
   Considering the number of gates per ATM, AAS is positioned as relatively **efficient** compared to the 7 peer airports.

However, AAS has a low ratio of gates per runway;

![Gates per runway (2007)](image)

Figure 4-14: Number of gates per runway (2007)

1) Relative scores;
   - Sub sample A: **efficient** (1) AMS - (2) CDG - (3) FRA - (4) LHR
   - Sub sample B: **efficient** (1) NRN - (2) AMS - (3) CRL - (4) BRU - (5) DUS

2) Results for AAS;
   - Sample: rank 2 (of 8)
   - Sub sample A: rank 1 (of 4)
   - Sub sample B: rank 2 (of 5)
3) Conclusion;
Considering the number of gates per runway, AAS is positioned as relatively efficient compared to the 7 peer airports (Note that AAS uses a maximum of three runways during peaks).

Airside assessment; (Data for 2007)
The taxiway system is a main airside asset, and is therefore an interesting variable to compare mutually. However, due to a lack of data, this assessment cannot be performed for all airports. However, one could imagine that the typology of the taxiway system is related to the amount of gates and the amount of runways; taxiways are basically roads for aircraft connecting gates with runways. A good measure for this relationship is the airside area. Besides that the airside area is a good representation of the taxiway network, the area is also subject to a large amount of (daily) care, precaution and maintenance.

![Figure 4-15: Airside area per runway and per gate](image)

**Airside area per runway; (Data for 2007)** (see Figure 4-15)

1) Relative scores;
Sub sample A; efficient (1) AMS - (2) LHR - (3) FRA - (4) CDG
Sub sample B; efficient (1) CRL - (2) NRN - (3) AMS - (4) BRU - (5) DUS

2) Results for AAS;
Sample; rank 4 (of 8)
Sub sample A; rank 1 (of 4)
Sub sample B; rank 4 (of 5)

3) Conclusion;
Considering the airside area relative to the number of runways, AAS is positioned as relatively moderate efficient compared to sub sample B, however AAS is relatively efficient compared to sub sample A.

**Note:** The number of runways determines for the larger part the efficiency score. Since AAS has six runways, it scores relatively efficient. However, be aware that the overall efficiency of the utilization of the airside may prove otherwise.
Airside area per gate; *Data for 2007* (see Figure 4-15)

1) Relative scores;

Sub sample A; *efficient*               (1) LHR - (2) FRA - (3) **AMS** - (4) CDG  *inefficient*
Sub sample B; *efficient*               (1) DUS - (2) CRL - (3) BRU - (4) **AMS** - (5) NRN  *inefficient*

2) Results for AAS;

Sample; rank 6  (of 8)
Sub sample A; rank 3  (of 4)
Sub sample B; rank 4  (of 5)

3) Conclusion;

Considering the airside area in relation to the number of gates, AAS is positioned as relatively *inefficient* compared to the 7 peer airports.

**Note 2:** *AMS has a large airside area partly because RWY 18R/36L of AMS does not lie on the contiguous airside area (see also appendix A- Aerodrome charts).*

![Air Traffic Movements per airside acre (2007)](image)

Figure 4-16: Air Traffic Movements (ATM) per airside acre

1) Relative scores;

Sub sample A; *efficient*               (1) LHR - (2) FRA - (3) **AMS** - (4) CDG  *inefficient*
Sub sample B; *efficient*               (1) CRL - (2) DUS - (3) BRU - (4) **AMS** - (5) NRN  *inefficient*

2) Results for AAS;

Sample; rank 6  (of 8)
Sub sample A; rank 3  (of 4)
Sub sample B; rank 4  (of 5)

3) Conclusion;

Considering the airside area, AAS is positioned as relatively *inefficient* compared to the 7 peer airports.
As Figure 4-17 shows, estimating the efficiency of an organization causes problems. One of the main problems of using ratios for assessment is that different ratios can give different pictures of the organization. This can be ascertained following the above presented fivefold analysis. Furthermore, it is hard to combine the entire set of ratios into a single numerical judgement. The problem of comparing several ratios is especially true if the number of comparisons is increased by a number \( n \). Complex efficiency comparisons are often multi-input and / or multi-output cases. Ratio assessment does also not allow for incorporating the effects of variable returns to scale. The following figure underlines the above arguments. One could observe from Figure 4-17 that the five assessments as performed result in a different picture of the overall efficiency. It comes now to subjectivity and preferences to rate the airports relative to each other based on their overall performance.

### 4.5 Sub conclusions

The following sub conclusions are made concerning chapter 4;

- Benchmarking is often directed towards measuring results without any attempts to understand the process which led to them (Francis et al., 1999).
- Investment in the airside assets base is a capital intensive undertaking. Reason is that (main) airside assets are lumpy, meaning that they cannot be acquired in small increments but must be obtained in large, discrete units. Initial overcapacity is often expected.
- Benchmarking helps organizations to improve strategically important processes by looking at the best practices of others.
- Process benchmarking is an approach to efficiency assessment which examines discrete activities of the firm, by means of a qualitatively assessment against best practice.
- Sub research question 2 (“Which airports can be considered as direct and significant competitors for of AAS”) is answered by making a distinction between competitors on the transfer market, and on the O/D market. It is concluded that Paris Charles de Gaulle, London Heathrow and Frankfurt airport are representative for the first group. Düsseldorf Airport, Brussels South Charleroi Airport, Airport Weeze, and Brussels Airport are representative for the latter group.
- Ratio analysis make large claims on subjective judgement and preferences since different ratios present a different picture of the organization. Ratio analysis is therefore considered as an inappropriate tool for benchmarking.
Chapter 5 – Benchmarking using Data Envelopment Analysis
5 Benchmarking using Data Envelopment Analysis

In order to evaluate the performance of any organization (independent of whether the organization is a commercial firm, a non-profit organization, or government), one first needs to define the best (often the theoretical) performance. This best performance can then be used as a benchmark for assessment of the actual performance of the organizations one is assessing. Another option is statistical analysis based on central tendency assumptions. Here organizations are compared to an average producer. In contrast, DEA is an extreme point method and compares each producer with only the ‘best’.

Data Envelopment Analysis is an approach for benchmark analysis. The reason why it is an approach is that it can be considered as a basic idea of benchmarking, but in fact not fully defined in terms of a single model. DEA has the ability to handle multiple input and multiple output scenarios containing several kinds of data, making the model perfectly suited to compare airports by measuring their airside efficiencies. In fact, DEA measures relative efficiencies, meaning that the model uses proven data from a peer group as benchmark. The ability to extract best practices from the data makes the model a valuable steering compass for airport managers and (public) policy makers.

This chapter informs the reader about the basic principles of the DEA model and its application to this research. This chapter does so by discussing the characteristics of the model, the variables and the strengths and limitations of the model.

5.1 Introduction to the Data Envelopment Analysis (DEA) model

The first roots of Data Envelopment Analysis were formed some 30 years ago by Charnes, Cooper and Rhodes (Charnes et al., 1978). In their strictly theoretical paper, Charnes et al. exemplified a central philosophy that the efficiency of an organization should be assessed as high as possible by assessing favourable weights for that organization. The development and practical use of the model seemed kind of a struggle. Even to the present day, the model evolved and underwent several innovations. Today, DEA is widely used in operations research and management science. In May 2010, the search term ‘Data Envelopment Analysis’ provides 4,394 results on Scopus (a scientific article search engine). However, it is observed that the model is quite unknown in the Netherlands. Some applications are found in the assessment of hospitals and in the forestry. This chapter will briefly introduce DEA by discussing its features and highlighting its main strengths and weaknesses.

The foundations of efficiency assessment are established by Farrell. In his paper, Farrell explained that it is, in order to improve a firm, essential for economic theorists and economic policy makers to be able to make actual measurements of the efficiency (Farrell, 1957). According to the classical paper of Farrell, Overall Efficiency (OE) of a firm consists of two components, to be known;

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42 Between quotation stabs since the performance one is assessing is the relative performance compared to the peer group.
• Technical Efficiency (TE);  
   *The ability of a firm to obtain maximal output from a given set of inputs.*

• Price Efficiency (PE), also known as Allocative Efficiency (AE);  
   *The ability of a firm to use the inputs in optimal proportions, given their respective prices.*

Farrell identified that the primary reason why all attempts failed to improve the technical efficiency of an organization was due to failure in combining the measurements of multiple inputs into any satisfactory measure of efficiency. In 1957, Farrell introduced a nonparametric method to estimate technical efficiency. However, Farrell never succeeded to incorporate multiple inputs and multiple outputs in his efficiency assessment. Two input variables and one output variable was the highest number of variables Farrell was able to model.

The DEA model developed by Charnes, Cooper and Rhodes (CCR) was able to incorporate multiple inputs and multiple outputs in a single equation for efficiency. This model (known as CCR-DEA) forms the foundation of all DEA, and is the model from which many distractions have emerged. CCR-DEA has improved over time and recent development of the model has made it more suitable to incorporate various forms of data in efficiency analysis.

5.1.1 An illustration of Data Envelopment Analysis

DEA is often used as a tool in operations research. DEA requires a non-parametric specification of the production frontier. The piecewise surface over the data (the frontier) is then used to calculate individual efficiencies relative to this surface. Using a sample of actually observed input- and output data and these assumptions, DEA is able to approximate a benchmark output quantity with which the actual output of a firm can be compared for efficiency assessment (Ray and Lei Chen, 2009) (Coulli, 1996). Here, the measurement of efficiency of a (single) DMU is obtained as the maximum of the ratio; weighted outputs over weighted inputs. The DEA approach to efficiency assessment relies on a number of assumptions about the nature of the underlying production technology a DMU uses. A fundamental assumption on DEA is convexity (Anderson, 2004). See also footnote 43.

CCR labelled the organizations under study as Decision Making Units (DMU). Generally, the DMU is regarded as the organization responsible for converting inputs into outputs (Cooper et al., 1995). Different DMUs perform the same function in transforming (multiple) inputs into (multiple) outputs. According to Zhu, an efficient DMU is said to be robust to a given increase in input, or a given increase in an output, if the DMU remains an efficient point after change (Zhu, 1995).

As an illustration to the above, consider a situation were airports A to H produce a single output \( y \), using a single input \( X \). As can be observed from Figure 5-1, each airport A to H produces a different quantity of output per unit of input. Without any knowledge on the theoretical maximum output per unit of input, one could only conclude that the airports A, B produce the largest output per unit of input. Airports A and B are therefore relatively efficient; its relative efficiency is determined to be equal to 100%.
Now have a look at Figure 5-2. If it is assumed that convex combinations of airports are allowed, then the line segment connecting airports A and B shows the possibilities of virtual inputs that can be confirmed from the airports A and B under Constant Returns to Scale (CRS) assumptions. The dotted line segment connecting the 100% efficient airports is called the efficiency frontier. The hatched area in the figure then represents the relative inefficiency area. The efficiency frontier defines all combinations of output(s) that can be produced for the given amount of input.

The airports C, D, E, F, G and H lie below the efficiency frontier and are therefore relatively inefficient given the information (data) provided by the airports A to H. The efficiency of airports C to H can now be determined by comparing it to a virtual airport formed by the airports on the efficiency frontier. Figure 5-2 can also be used to explain the name data envelopment analysis, the efficiency frontier envelopes (encloses) all the data which is observed.

Considering airport C in Figure 5-3, its virtual reference airports (C’ and C”) are formed given the information provided by its peer airports A and B, both positioned on the efficiency frontier. Its efficiency is calculated by finding the fraction of input that the virtual airport C’ or C” (dependant on the input orientated or output

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43 A convex combination is a linear combination of points with non-negative coefficients and that sum up to 1. In the context of DEA, convexity implies that it is assumed that if a given DMU A is capable of producing $Y(A)$ units of output with $X(A)$ units of input, other producers (B’, C’ and on) should be capable of doing the same if they were operating efficiently.
orientated scenario as defined in section 5.5) would need in order to produce as many output as airport C actually produces.

Assessment of single input / single output scenarios is graphically easy to imagine. However, when the number of input- and / or output variables increases, graphical illustrations are not straightforward anymore. However, the method of mutual assessment remains the same. In the same way that one can assess single input / single output scenarios using Linear Programming (LP), one could do the same for multiple input / multiple output scenarios.

### 5.2 Strengths and limitations of Data Envelopment Analysis

DEA is a versatile model and comes with many benefits over other forms of efficiency assessment. However, DEA is and remains a scientific model based on assumptions. One should therefore be aware of the limitations of DEA. This section discusses both the strengths and limitations of DEA.

One of the main strengths of the DEA approach to efficiency assessment is that the technique enables the researcher to measure the relative performance or efficiency of a DMU where the presence of multiple inputs and outputs makes comparisons difficult. The method is thereby easier to apply than regression analysis. Because there are no exact engineering standards in the airport sector defining how much output can be produced from a given input bundle of resources (airside), benchmarking becomes an empirical question. However, DEA enables the researcher to define a relative performance benchmark. Relative in the sense that DEA does not benchmark against a theoretical optimum, but a practical (observed) best practice. This characteristic will be discussed in more detail later in this chapter.

DEA involves an alternative principle for extracting information about a population of observations. DEA assumes the legitimacy that units (DMUs) might value inputs and outputs differently (Seiford and Thrall, 1990) and therefore adopt different weights to their variables. DEA does not require any prior assumptions on the underlying functional relationships between inputs and outputs.

Although the DEA technique is able to solve complex problems, one has to take its limitations into account when discussing the DEA results. One of the limitations of DEA is that its final results are sensitive to the
selection of its variables (Berg, 2010). An implication if this limitation is that the number of efficient firms on the frontier tends to increase with the number of inputs and output variables. The prime reason for this is that the greater a number of input and output variables becomes, the higher the dimensionality of the LP solution space is. This on its turn leads to a less discerning DEA analysis. With respect to this research, this limitation is handled by using the theory of Jenskins et al. (2003) which put forward a technique to reduce the number of variables in DEA (see section 5.6 and 6.1.2).

Another limitation of DEA is related to the measurement of relative performance; one cannot test for the best specification of variables (Berg, 2010). DEA is good at estimating the relative performance efficiency of a DMU, but it converges slowly to true efficiency. In other words, DEA can tell one how well a DMU is performing compared to its peers, but not compared to a theoretical maximum. Since DEA is an extreme point technique, noise (such as measurement errors) can cause problems (Anderson, 2004).

Since DEA is an ongoing technique, statistical hypothesis tests are difficult and are the focus of ongoing research. Furthermore, DEA is a heavy model since it creates a separate linear program for each DMU. With respect to practical implications of DEA, one has to take into account that large problems can be computationally intensive.
5.3 Data Envelopment Analysis; constant returns to scale

The common measure of relative efficiency ($\theta$) as defined by Farrell is determined by eq. 2. This weighted ratio is the efficiency optimized by DEA.

\[
\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}} \quad \text{eq. 2}
\]

Which can be written as;

\[
\text{Efficiency of unit } j = \frac{\sum u_i Y_{ij} + \sum u_j Y_{ij} + \ldots}{\sum v_i X_{ij} + \sum v_j X_{ij} + \ldots} \quad \text{eq. 3}
\]

Where; $u_i$ = the weight given to output 1 $V_2$ = weight given to input 1 $Y_{ij}$ = amount of output 1 from unit j $X_{ij}$ = amount of input 1 to unit j

The model as proposed by Farell (Farell, 1957) is based on knowledge of the unit isoquant \(^{44}\) of the fully efficient firm. However, the production function of the fully efficient firm is often not known in practice but must be estimated from a set of observations of the population (Coulli, 1996). DEA enables the researcher to determine the production function from a set of observations. In the DEA methodology, formerly developed by Charnes, Cooper and Rhodes (1978) (CCR), efficiency is defined as a weighted sum of outputs to a weighted sum of inputs (see eq. 2). The weight structure of both inputs and outputs is calculated by means of LP. In the CCR DEA model, Constant Returns to Scale (CRS) are assumed (as will be explained later). In 1984, Banker, Charnes and Cooper (Banker et al., 1984) developed a model (BCC) with Variable Returns to Scale (VRS) (as will be explained later).

DEA measures the relative efficiency of Decision Making Unit (DMU) $j$ relative to those DMUs which are considered ‘best’. The model is thereby based on the following assumptions;

- **Maximise the efficiency of unit (DMU) $j_0$**
  - Each DMU strives to maximize its own efficiency $\theta$
- **Subject to the efficiency ($\theta$) of all units being; $\theta \leq 1$**
  - More than 100% efficiency is not realistic since one is assessing relative efficiency
- **The variables of the model are the weights most favourable to unit $j_0$**
  - The input / output combinations preferred by DMU $j_0$ are not necessarily of the same importance to all other DMU. Therefore, each DMU chooses its own weights, subjected to the weight restrictions.

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\(^{44}\) In economics, the isoquant is a contour line drawn through the set of points at which the same quantity of output is produced while changing the quantities of two or more inputs.
For each DMU, the virtual input and virtual output combination is determined by attaching weights $v_i$ for inputs $x_i$ and weights $u_r$ for outputs $y_r$. The total virtual input and output is determined by:

\[
\begin{align*}
\text{virtual input} &= v_1 x_1 + \ldots + v_m x_m \\
\text{virtual output} &= u_1 y_1 + \ldots + u_s y_s 
\end{align*}
\]

Consider an environment (dataset) in which a set of $n$ DMUs are present, which each DMU $j \ (j = 1, \ldots, n)$, using $m$ inputs $x_{ij} (i = 1, \ldots, m)$ and generating $s$ outputs $y_{rj} (r = 1, \ldots, s)$. Then, as defined by Charnes et al., if the multipliers (weights) $v_i$ and $u_r$ associated with inputs $i$ and outputs $r$ are known, the efficiency of DMU $j$ can be expressed as the ratio of weighted outputs and weighted inputs (Charnes et al., 1978):

\[
\frac{\sum_j u_r y_{rj}}{\sum_i v_i x_{ij}}
\]

In the absence of known multipliers, Charnes et al. (1978) defined the DEA model. This CCR-DEA model is able to solve a particular non-linear programming problem by solving the fractional problem as defined by eq. 6. Here, the optimization model determines the weights for DMO$_0$ by maximizing its ratio of virtual output to virtual input while keeping the ratios for all the DMUs ≤1.

\[
\max \ e_0 = \frac{\sum_r u_r y_{r0}}{\sum_i v_i x_{i0}}
\]

Which is subject to:

\[
\frac{\sum_j u_r y_{rj}}{\sum_i v_i x_{ij}} \leq 1, \quad j = 1, \ldots, n
\]

\[
u_r, v_i \geq \varepsilon \quad ; \quad r = 1, \ldots, s \quad ; \quad i = 1, \ldots, m
\]

Where; $y_{rj}$ (positive) is the known output of the $j^{th}$ DMU

$x_{ij}$ (positive) is the known input of the $j^{th}$ DMU

$\varepsilon$ is some small positive quantity ($\geq 0$) to avoid any input or output being totally ignored.
To analyze the problem as defined under eq. 6, the problem is transferred into a linear optimization problem. Using a linear optimization problem, one should be capable of finding the best (most efficient) DMU by selecting the optimal weights for each individual DMU. This transformation is based on applying the theory of fractional programming. This theory is based on a change in variables, to be known:

\[
\mu_i = t u_i, \\
v_i = t v_i
\]

were; \(t = \left(\sum v_i x_{io}\right)^{-1}\)

Using the new variables as defined in eq. 8, eq. 6, can be converted in a LP model;

\[
\text{max } e_0 = \sum_r \mu_r y_{ro} \tag{eq. 9}
\]

Eq. 9 is also referred to as the multiplier or dual problem. Eq. 9 is subject to;

\[
\sum_i v_i x_{io} = 1 \\
\sum_r \mu_r y_{rj} \leq \sum_i v_i x_{ij}, \quad \forall j \\
\mu_i, v_j \geq \epsilon ; \quad \forall r, i \tag{eq. 10}
\]

- The first constraint normalizes the denominator of the original objective to 1
- The second constraint is obtained by an algebraic manipulation of the constraint in the original formulation
- The \(\epsilon\)-constraint avoids any input or output to be ignored (by assigning it a small weight or a zero value)

**Note:** *Eq. 9 is known as the CCR input oriented model. Here, maximizing the objective function has the effect of achieving input minimization.*
Validity of CRS assumption

Ratio analysis of the sample shows that the CRS assumption is not appropriate in assessing airside efficiencies of airports. This statement is underpinned by assessing Table 5-1. This table presents the use of assets per ATM for 2007. It is observed that four analyzed return-to-scale ratios have high standard deviations relative to the mean. Also assessment of the difference in minimum observed value and maximum observed values puts forward that one can not speak of constant returns to scale. A graphical representation of the returns to scale ratios is presented in appendix B- Graphical representation of the returns to scale.

Table 5-1: Statistics for four key ratios for 2007

<table>
<thead>
<tr>
<th></th>
<th>Total ATM per year per</th>
<th>Total ATM per year per</th>
<th>Total ATM per year per</th>
<th>Total ATM per year per</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total runway length</td>
<td>Total number of</td>
<td>Number of gates</td>
<td>Airside acre</td>
</tr>
<tr>
<td>Mean value;</td>
<td>33,04</td>
<td>111.565</td>
<td>2958,43</td>
<td>246,83</td>
</tr>
<tr>
<td>Standard deviation;</td>
<td>17,13</td>
<td>68.760</td>
<td>1209,70</td>
<td>114,50</td>
</tr>
<tr>
<td>Minimum value;</td>
<td>4,10</td>
<td>10.009</td>
<td>1.51,13</td>
<td>37,99</td>
</tr>
<tr>
<td>Maximum value;</td>
<td>62,97</td>
<td>892.522</td>
<td>4.39,13</td>
<td>404,38</td>
</tr>
</tbody>
</table>

5.4 Data Envelopment Analysis; variable returns to scale

As is concluded in the previous section, assessing airports on the basis of their airside asset base is not valid under the CRS assumption. The alternative assumption is based on Variable Returns to Scale (VRS). The VRS assumption includes: Decreasing Returns to Scale (DRS) and Increasing Returns to Scale (IRS). Although the VRS is basically a collection of two returns to scale assumptions, VRS is assessed as a single assumption.

![Figure 5-4: Constant Returns to Scale (CRS) DEA versus Variable Returns to Scale (VRS) DEA](image_url)

The VRS model of Banker et al. (Banker et al., 1984) is basically an extension of the earlier work of Charnes et al. (1978). The model is named after its inventors Banker, Charnes and Cooper (BCC) (Banker et al., 1984). The BCC model differs from the CCR model by way of an additional variable, \( u_0 \). Using VRS efficiency assessment models, one could assess the efficiency of DMU\(_j\) in such environments were not (all of the) DMUs operate at optimal scales. Reasons which legitimate VRS include diseconomies of scale by for example imperfect competition and / or constraints on finance. The BCC model is defined as;
\[
\max e^*_0 = \frac{\sum_r u_r y_{i0} - u_0}{\sum_i v_i x_{i0}}
\]

Eq. 11 applies under the following conditions;

\[
\sum_r u_r y_{i0} \leq \sum_i v_i x_{ij}, \quad \forall j
\]
\[
v_r, v_i \geq \varepsilon ; \quad r = 1, \ldots, s ; \quad i = 1, \ldots, m
\]
\[
u_0 = \text{unrestricted in sign}
\]

Then the equivalent linear programming problem is defined as;

\[
e^*_0 = \max \sum_r \mu_r y_{i0} - \mu_o
\]

Which is subject to;

\[
\sum_i v_j x_{i0} = 1
\]
\[
\sum_r \mu_r y_{ij} - \mu_o - \sum_i v_i x_{ij} \leq 0, \quad \forall j
\]
\[
\mu_r, v_j \geq \varepsilon ; \quad \forall r, i
\]
\[
\mu_o = \text{unrestricted}
\]
5.5 Input orientation versus output orientation

In input oriented efficiency assessment, one could ask the question “by how much can input quantities be proportionally reduced without changing the output quantities produced” (Coulli, 1996). Input-oriented DEA measures have an input reducing focus. Whereas in the case of output oriented efficiency assessment, one could ask the question “By how much can output quantities be proportionately expanded without altering the input quantities used?” (Coulli, 1996). So, output-oriented measures have an output maximizing focus.

The DEA orientation is either focused at input or at the output. The input oriented DEA model is aimed at minimizing the level of input while maintaining the same level of output. The output oriented DEA model is aimed at maximizing output while maintaining the same amount of input. The difference in orientation has a significant influence on the objective of the research;

- **Input orientation;** be minimally expensive (how to save money?)
- **Output orientation;** be maximally effective (how to increase production?)

![Figure 5-5: Input orientated- versus output orientated DEA](image)

The difference between input- versus output oriented efficiency assessment is explained using the relatively simple single input / single output case as presented in Figure 5-5. Here, company C produces a single type of output \((Y)\) using a single kind of input \((X)\). The frontier measures the difference between inefficient DMUs and the frontier by identifying the residual. In Figure 5-5, the frontier is represented by a dotted linear line, intersecting both company A and B. Remember, there is no more efficient company than either A or B, those firms are therefore the relative efficient firms \((\theta = 1 \text{ or } 100\%)\). Firm C can be assessed according to input oriented DEA (holding the level of output constant), then its relative efficiency is determined by \(X_1 / X_2\). In a output oriented assessment (holding the level of input constant), the relative efficiency of company C is determined by \(Y_1 / Y_2\).

For the efficiency assessment of AAS, an input oriented efficiency assessment is assumed. Main reasons for this assumption lie in the nature of the airport. First, it is generally known that AAS is perceived as an airport with an impressive asset base relative to the number of ATMs handled per year. Besides, there are few airports around

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45 One could observe that the slope of efficiency frontier is not constant. In fact, there are three intervals; \([0 - A]\), \([A - B]\) and \([B - D]\) (D is not displayed). Therefore, VRS are assumed.
the world with six runways. It is therefore interesting to know if such a large asset base is really necessary. Furthermore, CEO Jos Nijhuis indicated that Schiphol’s price to quality ratio is not developing well (Schiphol Group, 2008). Improvement of this ratio can be done by either improving the quality to customers, or by lowering the prices. Since the costs of airside assets are embedded in the price charged to customers, it is more obvious to assess by how much AAS could lower its prices (by slimming the airside asset base). Last, assessment of the possibilities to increase output is meaningless if the demand for air traffic remains off.
5.6 Describing the selection process of variables

This section describes the process of selecting the appropriate variables of the DEA. This section precedes section 6.1 where the actual selection takes place. The variables are selected according to a selection process, consisting of three selection steps. This chapter explains these three steps in more detail by assessing the selection process.

The selection process for DEA variables is graphically depicted in Figure 5-6. The process starts with a large set of variables compiled by assessment of literature, reports, interviews and presentations. The process finally delivers a set of variables which is considered adequate for a valid DEA analysis.

![Figure 5-6: Selection process for DEA variables](image)

The total set of variables is distinguishable following two characteristics; input- versus output variables (step 1), and applicable on performance assessment or managerial controllability assessment (step 2). Following the selection process, variables are checked on these characteristics. Step 3 checks whether the incorporation of certain variables is useful, meaning that a specific variable is not dependant (to a certain extent) of other (already) incorporated variables. In this step, the variables are seen as information carriers. Only variables / information carriers which add unique information to the overall assessment are incorporated in the final analysis. Step 1, 2 and 3 are discussed in more detail in the second part of this section.

After the selection process, the variables are grouped according to the scheme as presented in Figure 5-7. An explanation of terms is presented in Table 5-2. The set of variables directly representing the performance of the asset is used for DEA analysis 1; performance assessment. The key requirement for these variables is that they are controlled by the airport. The set of variables representing the managerial controllability of airside assets by of airport managers is used for DEA analysis 2; managerial controllability assessment. The key requirement for these variables is that they are controlled by the airport’s (local / legal / etc.) environment. DEA analysis 1 and 2 are then represented in the DEA matrix as will be introduced later. This matrix allows one to better interpret the results out of which adequate strategies can be extracted.
Benchmarking Airside Assets of Western European Airports; a Data Envelopment Analysis

Figure 5-7: Categorization of variables

<table>
<thead>
<tr>
<th>DEA analysis</th>
<th>Performance assessment</th>
<th>Managerial controllability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1: Performance assessment</td>
<td>The performance measure represents the amount of output generated by the airside per unit of input.</td>
<td>The managerial controllability is a measure of the amount of influence airport managers have on the use of assets. A managerial controllability of 100% represents maximum control (relatively wise, so with respect to the sample) over how assets are used. The lower the managerial controllability, the more external factors are present having an effect on how assets are used. These external factors are defined as the factors beyond control.</td>
</tr>
<tr>
<td># 2: Managerial controllability assessment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5-2: Performance assessment versus managerial controllability assessment

Step 1; subdividing the variables into input- and output variables

A DMU is responsible for converting inputs into outputs. With respect to benchmarking airports on the basis of airside assets, one could define inputs and outputs as follows;

- **Input variables;** Input variables are used for or used in favour of producing the airport’s desired and undesired outputs.
- **Define output variables;** Output variables describe the organizations core product and inherent (undesired) side products.

Generally, an organization aims to minimize inputs, and to maximize outputs. However, this general statement might not always be the case. With undesired inputs or outputs, an organization aims to do exactly the opposite. An example is noise; noise can be regarded as an undesired output of a process which one aims to minimize. In the case of undesired variables, the variable is inverted by taking the inverse of the input or output variable.

Step 2; subdividing the variables; performance versus managerial controllability

In general, managers of organizations aim to have maximum control over the assets which are owned by that organization. Main reason is that managerial controllability favours the manager to accommodate supply with demand. However, most organizations deal with legislation and regulation putting legal constraints on how assets are used. Other constraints are determined by environmental factors such as the local weather conditions. Factors having an effect on the utilization of assets, and not in control of airport managers are called the factors beyond control. These factors beyond managerial control differ mainly across regions and per government. In order to analyze the asset base of an airport, one could...
measure the absolute performance of that (set of) assets as it actually is; the performance. Second, one could measure how assets can maximally be utilized versus how they actual utilization in operational terms. The latter measure is also called the managerial controllability of an asset.

Airports which have a (potential) negative effect on the environment and accommodating large numbers of employees and customers are in general associated with severe factors beyond managerial control, affecting the airport in its operations. Comparison of Western European airports requires an objective view on the performance of that airport. Step two of the selection process therefore discriminates the variables between on the one hand those who are on a overall level directly representative for performance assessment of that asset, and on the other hand the managerial controllability of airport managers over that asset.

- **Performance variables:** These variables are a measure for assets delivering a direct positive contribution to the production of the airport. Most of such variables as used in this report can be lined among the tangible fixed assets owned by the organization. Examples are size or quantity of a specific asset type.

- **Managerial controllability variables:** These variables are a measure for variables having a (forced) negative direct or indirect effect on the production and / or utilization of assets of the airport. Most of such variables as used in this report can be lined among variables beyond control of the airport. Examples are legislation, and surrounding housing and weather.

**Note:** Some variables can be both a measure of performance and a measure of managerial controllability.

**Step 3: Multivariate statistical analysis**

In DEA, the higher the number of input and output variables, the greater the LP solution space, and the less discerning the analysis. To select the most informative subset of variables, one could test for this relationship by applying a statistical analysis on the data. This research does so using the theory of Jenskins et al. First, background information of the procedure is presented.

The first approaches on reducing the number of variables were based on the correlation between variables; highly correlated variables were simply omitted (Jenskins and Anderson, 2003). Modern approaches are based on the same technique, but are then (in stead of an ad hoc approach) based on a more sound statistical technique. Jenskins et al. investigated whether a high correlation between the input and the output variables has a sufficient ground for omitting some of the variables. Jenskins et al. put forward a technique using multivariate statistics to identify which variables can be omitted without any loss of information to the DEA problem. The technique uses a multivariate statistical approach to

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46 Multivariate statistics is a form of statistics encompassing the simultaneous observation and analysis of more than one statistical variable.
reduce the number of variables in DEA based on the so called partial correlation of variables; a measure of information contained in each variable versus that of the set of variables.

The third step in assessing variables for this research is based on the theory as put forward by Jenskins et al. This theory checks whether a correlation between the input or the output variables (or both) is considered to have sufficient grounds for omitting some of the variables. If so, the theory defines which variables can best be omitted (Jenskins and Anderson, 2003).

In contrast with only looking at the correlation matrix of variables for deciding which high correlated variables can be omitted, the theory first normalizes the variables to have a mean of 0 and a variance of 1. Doing so implies that, in the absence of any other information, each input and output variable that has been selected is equally important to the DEA. Than, if all $m$ variables are normalized to have a unit variance of 1, then their total combined variance is simply $m$. The residual variance in the conditioned variables can now easily be monitored. It is now a simple task to decide how many variables reasonably represent the information in all $m$ variables (Jenskins and Anderson, 2003). Summarized, the higher the combined variance score for variable $m$, the more of its information is already explained by the entire set of variables. So the higher the combined variance score, the more sufficient ground to omit that variable.

**Note:** The selection of variables for this research following the process as presented in this section if presented in section 6.1.
5.7 The presentation of Data Envelopment Analysis results

The results of DEA analysis 1 (performance assessment) and DEA analysis 2 (managerial controllability assessment) are presented in a matrix. The matrix layout is presented in Figure 5-8. Note that the axes of the matrix are bounded by four constraints, see Table 5-3.

Table 5-3: DEA matrix boundaries

<table>
<thead>
<tr>
<th>DEA matrix boundaries</th>
<th>Performance assessment</th>
<th>Managerial controllability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical axe;</td>
<td>Lower boundary</td>
<td>DMU subunit with lowest efficiency score (dotted line in figure)</td>
</tr>
<tr>
<td></td>
<td>Upper boundary</td>
<td>Efficiency score 1 (100% efficient)</td>
</tr>
<tr>
<td>Horizontal axe;</td>
<td>Left boundary</td>
<td>DMU subunit with lowest efficiency score (dotted line in figure)</td>
</tr>
<tr>
<td></td>
<td>Right boundary</td>
<td>Efficiency score 1 (100% efficient)</td>
</tr>
</tbody>
</table>

Figure 5-8: DEA matrix

Note: The blocks (1, 2, 3 and 4) are symmetrical and of the same size.

The DEA matrix is structured by four blocks. These blocks allow one to analyse the performance of an airport quickly and easily. The fully efficient airport which is (relatively) in total control over its assets is located in the right upper hand corner. The (relatively) inefficient airport which is most affected in its control over assets is located in the lower left-hand corner. It is not by definition the case the latter airport is producing less output than its more efficient peers; the latter airport is only producing less output per unit of input. The only conclusion one could draw that the airport is affected more by external factors than the airport which is more in control over its assets. The externally affected airport should apparently invest more in its external relations to get things (such as expanding its infrastructure) done.
The blocks from Figure 5-8 could be described following the definitions as stated below;

**Block 1**: Uncontrollable efficient  
The airport is efficient in the utilization of its assets, but is affected by external control factors influencing the airport in its operations and/or asset utilization. The airport is thereby inefficient in terms of managerial controllability over their assets.

**Block 2**: Controllable efficient  
The airport is efficient in the use of its assets, and is not much affected by external control factors influencing the airport in its operations and/or asset utilization. The airport is thereby efficient in terms of managerial controllability.

**Block 3**: Uncontrollable inefficient  
The airport is inefficient in the utilization of its assets, and is also affected by external control factors influencing the airport in its operations and/or asset utilization. The airport is thereby inefficient in terms of managerial controllability over their assets.

**Block 4**: Controllable inefficient  
The airport is inefficient in the use of its assets, but is not much affected by external control factors influencing the airport in its operations and/or asset utilization. The airport is thereby efficient in terms of managerial controllability.

### 5.8 Sub conclusions

Sub research question three is answered in chapter 5. The chapter presents Data Envelopment Analysis; a benchmark model which is considered as adequate to compare a number of airport regarding their airside asset base. The model is suited to extract best practices from the data and excludes subjectivity to a very large extend.

Chapter 5 results in the following sub conclusions;

- Data Envelopment Analysis (DEA) is a model which allows one to incorporate multiple inputs and multiple outputs into a single numerical judgement of efficiency.
- DEA can be executed in different modes regarding the returns to scale. Second, DEA allows one to assess organizations in input and/or output oriented mode, referring to either maximization of output while holding the level of input constant or minimization of input while holding the level of output constant.
- DEA can inform the researcher by how much the input can be reduced holding outputs constant, or vice versa. It does so by extracting best practices from the data set.
- The main limitations of DEA are that DEA is sensitive to the selection of variables, and can not test for a theoretical maximum.
- In chapter 5, performance is discriminated from managerial controllability. Managerial controllability describes the state of managerial control airport managers have over airside assets.
- The selection process of variables consist of three steps; (1) a sub division between input or output variables, (2) a subdivision for performance or managerial controllability variables, and (3) a multivariate statistical analysis to check weather certain variables can be omitted to make the model more reliable.
Chapter 6 – Benchmark analysis: an application of Data Envelopment Analysis
6 Benchmark analysis: an application of Data Envelopment Analysis

This chapter builds on the knowledge as presented in chapter three, four and five. The benchmark analysis as performed in this research is based on the relative efficiency assessment of the sample.

6.1 Selection of appropriate variables

This section discusses the set of variables used in this report following the selection process as introduced in section 5.6. First section 6.1.1 describes the set of variables available. Than, section 6.1.2 arranges the variables following the three steps as introduced in section 5.6.

6.1.1 Description of main airside assets in terms of variables

This section describes the main airside assets in terms of variables. These variables either describe the airside assets in terms of performance or they describe the state of managerial controllability. This section provides additional information per variable were deemed necessary. The variables which are explained in more detail are marked by (*).

Runway system

First the runway system is exposed to subject to detailed analysis. Here, the term runway system represents the collection (set) of all runways on a specific airport. The following variables describe the runway system by means of its physical characteristics and the use of the system (see Table 6-1).

Table 6-1: Variables describing the runway system at airports

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of runways</td>
<td>[#]</td>
<td>-</td>
</tr>
<tr>
<td>Total runway length</td>
<td>[m]</td>
<td>Physical length</td>
</tr>
<tr>
<td>Total runway area</td>
<td>[m²]</td>
<td>Also count for runway width.</td>
</tr>
<tr>
<td>Total directions of preferential runway system (*)</td>
<td>[#]</td>
<td>Runways disaggregated to how they are used in terms of landing and take-off.</td>
</tr>
<tr>
<td>Weather delay (*)</td>
<td>[min / ATM]</td>
<td>Average delay per ATM(^{47})</td>
</tr>
<tr>
<td>Noise legislation (*)</td>
<td>[score]</td>
<td>Adapted from Boeing (Boeing Commercial Airplanes, 2010)</td>
</tr>
<tr>
<td>Noise contours</td>
<td>[number of inhabitants within noise contour]</td>
<td>Noise contours per LDEN(^{48}) contour (Anotec consulting, 2003),</td>
</tr>
<tr>
<td>Utilization of runway system(*)</td>
<td>[# / per runway]</td>
<td>Restrictions on use of runways because of housing</td>
</tr>
<tr>
<td>Declared peak hour capacity (*)</td>
<td>[ATM per hour]</td>
<td>Max amount of aircraft that can land or take-off from a runway (lowest)</td>
</tr>
<tr>
<td>Annual production</td>
<td>[ATM per year]</td>
<td>Actual number of aircraft which used the runway during a year for take-off or landing</td>
</tr>
</tbody>
</table>

Note: For physical characteristics of the runways for all airports part of the sample, see also appendix C – Operation airport and runway information per airport,

\(^{47}\) Source: Eurocontrol, Bruno Nicolas, Specialist ATFM Statistics, Central Flow Management Unit

\(^{48}\) Lday-evening-night, a unit which (together with Lnigh) is a European guideline for measuring environmental noise.
Utilization of the runway system

For aircraft operations, runways are assessed by assigning four functions to each runway; an inbound functionality (landing aircraft) and an outbound functionality (departing aircraft). Both functionalities are present at both directions of the runway, unless restricted (see also Figure 6-1). Some airports of the sample have a preferential runway system, meaning that the take off or landing activities are only allowed on specified runways to avoid residential areas.

Figure 6-1: Four identified options for the utilization of a runway

Following the pilot information as logged in the Aeronautical Information System (AIS), the airports of both samples range from inefficient to efficient regarding their usage of the runway system, see Figure 6-2. In this figure, 100% efficiency represents full availability of the runway system for both landing and take off in both directions. Any reduced number in Figure 6-2 are a result of environmental factors beyond managerial control of airport managers limiting the airport in the use of its runway system.

Figure 6-2: Directional use of runway system according to preferential runway system, adapted from: (European AIS database, February 2009)
Weather delay

Air traffic delays are logged by airports and marked with a cause. Weather delays are those delays specific assigned to delays caused by bad weather. Figure 6-3 presents the average weather delay per ATM for 2009.

Note: The data regarding weather delays is for 2009. Since the DEA model measures relative differences in data, the 2009 data for weather delays may be used as an estimate for weather delay also for the benchmark year 2007.

![Average weather delay per ATM for 2009](image)

Note: ‘‘Weeze Niederrhein did not generate any weather delays in 2009’’ (Nicolas B (specialist ATFM statistics) 2010)

Noise

Aircraft which perform operations produce noise during various phases of flight and on the ground. Noise is a main concern for airports since noise emissions are regulated. The most significant phases of noise emissions produced by aircraft are identified as;

- **Flight**
  1. Underneath and lateral to departure and arrival paths
  2. Takeoff and landing
  3. Over flying while en route

- **Ground**
  1. By taxi
  2. While parked and using the auxiliary power unit (APU)

For airports, the most significant noise emissions are produced by takeoff and landing. All eight airports from the sample are regulated concerning the emissions of noise. This report assesses noise by means of two measures; (1) by analyzing the population living in the noise contours of the airport (breakdown per noise value). (2) By calculating a noise score according to the noise regulations per airport as identified by Boeing.
(1). **Noise population**

For each airport, the noise Level Day-Evening-Night (LDEN) is an indicator of the overall noise level during the day, evening and night which is used to describe the annoyance caused by exposure to noise. LDEN contours represent the areas where the noise exposure falls within certain limits. This research uses four LDEN contours; (1) >55-60 db, (2) 60-66 db, (3) 65 – 40 db and (4) ≥70 db. Each LDEN contour is assessed by investigating the number of citizens living within the LDEN area.

(2). **Noise legislation**

Noise legislation is assessed following the noise database of Boeing (Boeing Commercial Airplanes, 2010). The noise score as used in this research is obtained according to the following procedure. First, the noise regime is subdivided in constraints regarding either the constraints on capacity, or constraints damping the demand for slots. Then, a weighing factor is coupled to each constraint, allocated according to the assumptions presented underneath. Finally, all airports are scored according to the weights as identified. The higher the final score, the more the airport is restricted concerning the emissions of noise.

- Weight factor 0 : No influence on operations and / or demand.
- Weight factor 1 : Some influence on operations, and / or some influence on demand.
- Weight factor 2 : Medium influence on operations, and / or some influence on demand.
- Weight factor 3 : Heavy influence on operations, and / or some influence on demand.

**Note:** The calculation of noise emission scores of the sample airports is based on several assumptions (in contrast to the identification of the population living within the noise contours of an airport). First, the allocation of weighing factors is subjective. Meaning that the weight components are based on the personal opinion of the author. Second, Niederrhein airport is closed at night, although it has a very low score on noise emission during its daytime regime, the airport receives full credits for its night time regime.

---

49 Although in consultation with colleagues
Conclusions: Following the final score for noise regulation, the airports are ranked according to the degree of regulation. Based on a sample of eight observations:

- The highest ranked (most regulated) airports are; BRU, AMS
- The middle ranked airports are; LHR, NRN, CDG
- The low ranked airports are (score <15); DUS, CRL, FRA

Note: Validation of Table 6-2 is performed by means of alternation of the weights. If all weights are set to 1, the following order of airports is extracted: (1) AMS and BRU, (2) NRN, (4) LHR, (5) CDG and DUS, (6) FRA. This ranking does not significantly differ from the ranking as presented in Table 6-2. It is therefore concluded that the data Table 6-2 is a good representation of the noise regulation at airports.

50 Note that NRN receives full scores for all specific night regime hours. If the airports are assessed not taking into account the night regime, NRN receives a noise score of 3, and is then ranked on place 8.
Figure 6-4: Noise scores per airport

→ Declared peak hour capacity

The declared peak hour capacity is a measure representing the ability of an airport to handle a certain amount of traffic per hour. The peak hour capacity varies per airport. Figure 6-5 presents the declared peak hour capacity per airport, whereas Figure 6-6 presents the average amount traffic per hour of the day for 2007 per airport (results are presented for sub sample A, for a complete overview see appendix D). One can clearly observe that the airports AMS and CDG have an unevenly distributed demand for capacity during the day, whereas FRA en LHR have a more even demand for capacity over the day.

Figure 6-5: Declared peak hour capacity for 2007

Note: See for a complete overview for the average number of ATMs per hour of the day appendix D – Distribution of ATMs over the day per airport.
Taxiway system

The taxiway system basically connects the runway system with the aprons of the airport. Data of the taxiway system is however not available for all eight airports. However, since the taxiways are nothing more than a connection between aprons and runways, the variables ‘number of runways’ and ‘number of gates’ contain a large part of the information incorporated in the variable ‘length of all taxiways’. An extra variable counting for the typology of the runway system and terminal system is added in the form of ‘total airside area’.

![Figure 6-7: The size of the airside area per airport and per runway per airport](image-url)
6.1.2 Selection analysis following the method as presented in section 5.6

Following the method of Jenskins and Anderson (Jenskins and Anderson, 2003), 28 input and 2 output variables are assessed.

Note: The variables presented in Figure 6-8 are selected from a larger set of variables (this includes many distracted variables). The variables presented are considered as the most valuable regarding this research.

![Figure 6-8: Variable selection process steps 1 and 2](image-url)
The results of the multivariate statistics (step 3) are presented in Table 6-3.

### Table 6-3: Variable selection process step 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit variance score</th>
<th>Variable</th>
<th>Unit variance score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runways</td>
<td>4,727</td>
<td>Weather statistics</td>
<td>2,214</td>
</tr>
<tr>
<td>Total runway length</td>
<td>4,920</td>
<td>Total 'noise population'</td>
<td>7,768</td>
</tr>
<tr>
<td>Number of gates</td>
<td>3,489</td>
<td>Noise score</td>
<td>3,120</td>
</tr>
<tr>
<td>Airside area</td>
<td>4,970</td>
<td>Weather delay 2009</td>
<td>3,226</td>
</tr>
<tr>
<td>Total runway surface</td>
<td>4,835</td>
<td>Used runway length for take off and landing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Noise LDEN &gt;55-60db</td>
<td>7,834</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Noise LDEN 60-65 db</td>
<td>7,436</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Noise LDEN 65-70db</td>
<td>7,660</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Noise LDEN &gt;=70</td>
<td>7,477</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Total noise</td>
<td>7,768</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Runway useable length per direction</td>
<td>0,428</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Preferred directions</td>
<td>3,007</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- directions per runway</td>
<td>5,476</td>
</tr>
<tr>
<td><strong>Combined variance score:</strong></td>
<td><strong>5</strong></td>
<td><strong>Combined variance score:</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>

The selection process results in the following combination of variables;

**Performance assessment:**

- **Input:**  
  - Number of runways
  - Number of gates
  - Total airside area
- **Output:**  
  - Annual number of ATM
  - Declared peak hour capacity

**Controllability assessment:**

- **Input:**  
  - Weather delay per ATM
  - Noise score
  - Total noise contour LDEN
- **Output:**  
  - Annual number of ATM
  - Declared peak hour capacity

**Note:** The variable ‘total noise population’ and the variables ‘noise LDEN’ are dependant. It is therefore that the variable ‘total noise population’ has a high unit variance score. A alternative analysis excluding the noise variables, except total noise population, puts forward the following result; unit variance score ‘total noise population’: 3,828 (combined variance score: 9).
6.2 Data Envelopment Analysis

This section presents the three independent DEA analyses as performed for the research described in this report. The presentation of the results follows the logic as gradually presented in this report, and consists of six elements. After the presentation of results (section 6.2.1), a discussion of the results is presented in section 6.2.2. Then, a verification of the model and results is presented in section 6.2.3.

6.2.1 Presentation of results

a. Efficiency summary; inputs, outputs and efficiencies.

The efficiency summary is an overview of the efficiency assessment. The summary provides (1) the input and output variables of the specific analysis. Furthermore, the summary provides (2) the weight restrictions of each variable, (3) the final efficiency scores (input oriented mode, both for CRS and VRS), and (4) a ranking of airports relative to their efficiencies.

Note: If an airport is inefficient (its efficiency score is < 100 %), then it should be capable to produce its current level of outputs with less input.

<table>
<thead>
<tr>
<th>Performance assessment (input oriented mode)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input:</strong></td>
<td><strong>Output:</strong></td>
<td></td>
</tr>
<tr>
<td>Number of runways</td>
<td>ATM for 2007</td>
<td></td>
</tr>
<tr>
<td>Airside area</td>
<td>Declared peak hour capacity 2007</td>
<td></td>
</tr>
<tr>
<td>Number of terminal gates</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scores (CRS):</strong></td>
<td><strong>Scores (VRS):</strong></td>
<td></td>
</tr>
<tr>
<td>AMS : 88,2 % (3)</td>
<td>AMS : 90,2 % (5)</td>
<td></td>
</tr>
<tr>
<td>CDG : 93,6 % (2)</td>
<td>CDG : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>LHR : 100,0 % (1)</td>
<td>LHR : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>FRA : 75,9 % (5)</td>
<td>FRA : 77,9 % (7)</td>
<td></td>
</tr>
<tr>
<td>DUS : 67,7 % (6)</td>
<td>DUS : 78,7 % (6)</td>
<td></td>
</tr>
<tr>
<td>BRU : 67,1 % (7)</td>
<td>BRU : 68,1 % (8)</td>
<td></td>
</tr>
<tr>
<td>CRL : 78,7 % (4)</td>
<td>CRL : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>NRN : 36,4 % (8)</td>
<td>NRN : 100,0 % (1)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Managerial controllability assessment (input oriented mode)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input:</strong></td>
<td><strong>Output:</strong></td>
<td></td>
</tr>
<tr>
<td>Average weather delay per ATM</td>
<td>ATM for 2007</td>
<td></td>
</tr>
<tr>
<td>Noise score</td>
<td>Number of runways (inverse)</td>
<td></td>
</tr>
<tr>
<td>Population living within 55 LDEN area</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scores (CRS):</strong></td>
<td><strong>Scores (VRS):</strong></td>
<td></td>
</tr>
<tr>
<td>AMS : 36,2 % (8)</td>
<td>AMS : 36,2 % (8)</td>
<td></td>
</tr>
<tr>
<td>CDG : 48,2 % (6)</td>
<td>CDG : 48,2 % (6)</td>
<td></td>
</tr>
<tr>
<td>LHR : 100,0 % (1)</td>
<td>LHR : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>FRA : 68,7 % (5)</td>
<td>FRA : 68,7 % (5)</td>
<td></td>
</tr>
<tr>
<td>DUS : 100,0 % (1)</td>
<td>DUS : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>BRU : 37,2 % (7)</td>
<td>BRU : 37,2 % (7)</td>
<td></td>
</tr>
<tr>
<td>CRL : 100,0 % (1)</td>
<td>CRL : 100,0 % (1)</td>
<td></td>
</tr>
<tr>
<td>NRN : 75,7 % (4)</td>
<td>NRN : 75,7 % (4)</td>
<td></td>
</tr>
</tbody>
</table>
b. Potential improvements;

As indicated earlier in this report, this study aims on extracting best practices from the peer group. Applying these best practices results in a set of potential improvements to the reference airport AMS. These potential improvements indicate by how much and in what areas the inefficient unit can improve in order to be 100% efficient (relatively). The potential improvements are in fact the most favourable combination of assets for a specific airport in order to maximize its efficiency. This information can help managers to set targets to improve inefficient practices in order to improve.

Table 6-5: Potential improvements extracted from data by means of DEA

<table>
<thead>
<tr>
<th>Variables</th>
<th>CRS</th>
<th>VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of runways</td>
<td>-39,2%</td>
<td>-41,7%</td>
</tr>
<tr>
<td>Airside area</td>
<td>15,6%</td>
<td>22,1%</td>
</tr>
<tr>
<td>Number of terminal gates</td>
<td>15,6%</td>
<td>22,1%</td>
</tr>
<tr>
<td>ATM for 2007</td>
<td>0,00%</td>
<td>9,2%</td>
</tr>
<tr>
<td>Declared peak hour capacity 2007</td>
<td>0,00%</td>
<td>-9,2%</td>
</tr>
</tbody>
</table>

c. Reference airports;

Each inefficient airport has a set of reference airports. These reference airports are situated on the efficiency frontier and include those airports to which the airport under comparison (AMS) has most directly been compared when calculating its efficiency score. The reference airports contribute to the determination of the final efficiency score. The table as presented displays the extent which each reference airport had (per variable) in determining the efficiency score of the airport under analysis.

The peers for AMS are CDG, LHR, and NRN

Table 6-6: Reference airports DEA

<table>
<thead>
<tr>
<th>Airport: AMS</th>
<th>CDG</th>
<th>LHR</th>
<th>NRN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CRS</td>
<td>VRS</td>
<td>CRS</td>
</tr>
<tr>
<td>Number of runways</td>
<td>78,9%</td>
<td>92,5%</td>
<td>4,4%</td>
</tr>
<tr>
<td>Airside area</td>
<td>89,9%</td>
<td>95,6%</td>
<td>3,7%</td>
</tr>
<tr>
<td>Number of terminal gates</td>
<td>84,2%</td>
<td>22,1%</td>
<td>11,4%</td>
</tr>
<tr>
<td>ATM for 2007</td>
<td>89,9%</td>
<td>92,5%</td>
<td>1,4%</td>
</tr>
<tr>
<td>Declared peak hour capacity 2007</td>
<td>72,1%</td>
<td>89,2%</td>
<td>6,2%</td>
</tr>
</tbody>
</table>
d. Input / output contributions;

The contributions of inputs and outputs represent the emphasis an (inefficient) airport puts on certain variables in order to be as efficient as possible within the boundaries of the analysis (restrictions on weights and efficiencies)\textsuperscript{51}. The contributions of inputs and outputs are a measure for the amount of information which a variable delivers to the final efficiency score. This information can be used to validate the final efficiency score.

Table 6-7: Input / output contributions DEA

<table>
<thead>
<tr>
<th>Airport: AMS</th>
<th>CRS</th>
<th>VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of runways</td>
<td>50,0 %</td>
<td>50,0 %</td>
</tr>
<tr>
<td>Airside area</td>
<td>12,0 %</td>
<td>13,7 %</td>
</tr>
<tr>
<td>Number of terminal gates</td>
<td>8,0 %</td>
<td>36,3 %</td>
</tr>
<tr>
<td>ATM for 2007</td>
<td>62,5 %</td>
<td>50,0 %</td>
</tr>
<tr>
<td>Declared peak hour capacity 2007</td>
<td>37,5 %</td>
<td>50,0 %</td>
</tr>
</tbody>
</table>

e. Variation in weights

To analyze the effect of weight restrictions, each variable is altered and both increased and decreased with 5 or 10 percent\textsuperscript{52}. Assessment of the variation in the final efficiency scores allows one to better interpret the sensitivity of each variable with respect to weights. The less alteration of the final score, the more robust the analysis is.

Note: The percentages presented in Table 6-8 present by what percentage the final efficiency score under CRS of VRS assumption is altered when weight limitations change. A 0,0% change represent no change in the final score when the weight limitation changes. Less change in final scores mean a higher validity of the model.

Table 6-8: Variation in weights DEA

<table>
<thead>
<tr>
<th>Airport: AMS</th>
<th>Weight variation</th>
<th>CRS</th>
<th>VRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of runways</td>
<td>+ 10 % ⇒ 60 %</td>
<td>;</td>
<td>- 9,2 %</td>
</tr>
<tr>
<td></td>
<td>- 10 % ⇒ 40 %</td>
<td>;</td>
<td>+ 5,5 %</td>
</tr>
<tr>
<td>Airside area</td>
<td>+ 5 % ⇒ 15%</td>
<td>;</td>
<td>- 2,9 %</td>
</tr>
<tr>
<td></td>
<td>- 5 % ⇒ 5%</td>
<td>;</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Number of terminal gates</td>
<td>+ 5 % ⇒ 15%</td>
<td>;</td>
<td>0,0 %</td>
</tr>
<tr>
<td>ATM for 2007</td>
<td>+ 10 % ⇒ 60 %</td>
<td>;</td>
<td>0,0 %</td>
</tr>
<tr>
<td></td>
<td>- 10 % ⇒ 40 %</td>
<td>;</td>
<td>0,0 %</td>
</tr>
<tr>
<td>Declared peak hour capacity 2007</td>
<td>+ 5 % ⇒ 15%</td>
<td>;</td>
<td>0,0 %</td>
</tr>
<tr>
<td></td>
<td>- 5 % ⇒ 5%</td>
<td>;</td>
<td>0,0 %</td>
</tr>
</tbody>
</table>

Note: See for a full overview for all airports appendix E – Validation of DEA analysis, a alteration of weights.

\textsuperscript{51} These restrictions guarantee that at least all variables are included and that the efficiency of the airports do not exceed the 100% limit.

\textsuperscript{52} Dependant on the current value of the weight. Weights ≤ 20% are altered by 5%. Weights >20% are altered by 10%.
f. Graphs

The efficiency scores for controllable performance and performance beyond control are plotted in a matrix. See for more information about the logic behind this matrix also section 5.7.

Note: all DEA are performed in input oriented mode.

![DEA for CRS](image1)

![DEA graph for VRS](image2)

Figure 6-9: DEA matrix for constant returns to scale DEA

Figure 6-10: DEA matrix for variable returns to scale DEA
6.2.2 Discussion of results

A discussion of the results as presented in section 6.2.1 is in place to frame the position of airports relative to each other and to better understand the mutual differences between airports.

It can be recognized that at both sub samples (A and B), variation between airports is observed concerning both performance figures and managerial controllability figures. Diseconomies of scale are recognizable concerning AMS; the airport utilizes a maximum of three runways during peaks, while it has actually six runways in place. Hub airports (AMS, LHR and CDG) are on average more restricted in terms of managerial controllability than smaller airports. Main reasons lie particularly in the field of noise; larger airports are more intensively regulated, and are located at more densely populated areas. At the same time, these densely populated areas are apparently also one of the reasons why such airports have become the bigger players in the market.

Hub airports face more intense buyer powers than smaller airports since large buyers (airlines) have often a home base at the airport (such as KLM at AAS), while smaller airports handle other types of airlines which do not have one particular home base (such as Ryanair). A lock-in effect is present since the switching costs for airlines such as KLM are too high. This lock-in effect also negatively affects the managerial controllability of the airport.

Concerning Table 6-6, it is observed that AMS is best compared to CDG (note that AMS and CDG have an 8% share in each other). This fact can also be observed by assessment of the relative position of both airports in Figure 6-9 and Figure 6-10. However, concerning the number of gates in relation to peak hour capacity, AMS is better compared to LHR. Reasons lie in the in the spread of average demand over the day which is different at hubs than it is at smaller airports with a focus on O/D traffic.

Since AMS is also compared with NRN, one can raise the question what AMS can learn from a small airport such as NRN. The answer can particularly be found in the field of returns to scale ratios at airports. As one can observe, AMS is better comparable with NRN under CRS assumptions than under VRS assumptions. Under VRS assumptions, the model uses the data of other large airports which also face diseconomies of scale to estimate the efficiency scores for AMS. Diseconomies of scale are present at large airports since it is observed that the larger an airport is, the more complex its typology becomes. This results in more intersections of main airside assets such as runways, and an increase in indirect costs such as maintenance. So as the complexity of typology increases, diseconomies of scale are unavoidable for two main reasons; (1) the airside asset base is less intensively utilized as assets (such as runways) often intersect and cannot be used simultaneously. (2) As peak hour demand becomes more important, the airport capacity is increased and reliability becomes more important. Both increase in capacity and reliability often result in an increase of the complexity of typology; buffer capacities are unavoidable at periods of low demand. This buffer capacity affects the overall efficiency of the system. By critical assessment of the asset utilization at basic (small) airports facing less diseconomies of scale, AMS should be better capable of increasing the logic behind its airport design. It may for example conclude that a parallel runway system results in a higher asset utilization since the runways do not intersect.
A difference between CRS assumptions and VRS assumptions is observed concerning the emphasis the model puts on the use of assets to compose its estimation of efficiency. Under VRS assumptions, more emphasis is put on the gate capacity than under CRS assumptions. Reasons for this can be found when considering the potential improvements; it is observed that under VRS assumptions, the peak hour capacity at AMS reduces with 9% which is a result of a reduction in the number of runways of 40%. Since the peak hour capacity of the runway system reduces, the gate capacity should increase to ‘store’ a larger number of aircraft waiting for a take off slot.

Note that concerning the data, several interrelationships are present. For example, the extensive runway system of AMS is negatively related to the average delay per ATM due to bad weather. One could stress that the number of runways has a positive effect on reducing the average delay per ATM due to severe weather. However, note that these interrelationships are not one to one, since for example AMS has three parallel runways in place and is strongly restricted in the utilization of them. Part of the results should also be explained regarding legal and / or operational restrictions. The most remarkable consideration is the accepted cross wind component at runways at LHR. At LHR, higher crosswind components are accepted than at AMS, resulting in less weather delays per ATM.

A last clear observation is that concerning the managerial controllability, the model does not make a distinction between CRS and VRS. In the practical sense, this implies that the model provides the same results for two independent analyses (CRS and VRS). Main reason for this fact is that the nature of variables is not linked to scale assumptions. For example, regulations do count for each airport, independent of their size.

Verification of the weight limitations shows that an alteration in the limitation does not significantly result in a change in the final result. The succeeding section 6.2.3 elaborates on the verification of results.
6.2.3 Verification

Verification of results is performed to check the accuracy, correctness, or truth of the results. As an addition to the verification of results presented in Table 6-8, a second analysis is add to this research for verification. This additional analysis is especially geared to the runway system. Besides for means of verification, the second analysis can also be regarded as an extension of understanding of the performance and efficiencies at airports. The second analysis therefore specifically assesses the runway systems of the eight airports also included in the initial analysis (see section 6.2).

Note: The second analysis is presented in appendix F – Validation of DEA analysis, a second analysis. This section will mainly discuss the results of the additional analysis with respect to the results of the initial analysis as presented in section 6.2.

It can be concluded from the second analysis that the DEA scores are sensitive to the selection of variables. This conclusion is based on the fact that the final scores resulting from analysis two are different than the scores of the initial analysis. However, the relative order of airports concerning their performance and managerial controllability remains (approximately) unchanged. This is an important observation, since it confirms the correctness of the model. A difference in final score is the result of relative efficiency measurement; values change since theoretical maximums do not exist, in fact, the best performance is determined by the best performer.

Also in the second analysis, AAS scores low in performance and managerial controllability. However, there is more variation between on the hand the CRS analysis and on the other hand the VRS analysis. This is particularly recognizable concerning the airports CRL and NRN. The explanation of this fact is that one of the main components determining the efficiency scores is the number of Air Traffic Movements for 2007. Both NRN and CRL face a huge buffer capacity. This fact plays a less important role in the initial analysis since the effect is mitigated by other means, such as the peak hour capacity.

Table 6-8 proves that the model is not very subject to alterations of weights. This proves that the model is accurate. Although analysis 1 (section 6.2) and 2 (verification, see for more details appendix F) differ because of different variables, there are common characteristics which make the models valid. However, one should realize that the models measure relative efficiencies. Meaning that the efficiency of AAS is dependant on the competitive landscape i.e. the efficiency of others. Second, the model is sensitive for the chosen variables. Final conclusion is that analysis 1 (section 6.2, measuring the efficiency of main airside assets) is a good representation of the position of AAS with respect to its 7 direct competitors.
6.3 Strategic positions of airports and inherent strategies

This section presents a number of generic strategies for airports to increase their efficiency and/or capacity. These strategies are geared to make the business more efficient, and are based on the dichotomy of performance versus managerial controllability. First, a six generic positions are added to the framework as presented in section 5.7. Then, for three of these four generic positions, a one- or two-step strategy is briefly discussed. Last, AAS is framed according the framework as presented in this section.

This section introduces six generic positions divided over four groups, to be known (1) the star, (2) the expensive airport or the lucky airport, (3) the underperforming airport and (4) the high potential or sleeper. See also Figure 6-11.

Figure 6-11: DEA framework of generic positions

Following Figure 6-11, four generic positions are recognizable. These positions are coupled to inherent strategies. The generic positions and inherent strategies are now discussed;

Star:
The star has maximum managerial control and a high performance. The star can therefore adjust its supply (capacity) to its demand in a short time span; flexibility is a key issue. Increasing the output of the business does not result in major problems for the star. Potential improvements for stars are to be found in the field of exploring new markets, or to become an excellent leader in the market, setting new standards.

Expensive airport or lucky airport:
The lucky airport has a high performance, but low managerial controllability. This combination is mainly a result of a cooperative environment. The expensive airport is positioned on the same position as the lucky airport; however its high performance is a result of major investments in its infrastructure. The expensive airport and lucky airport differ in nature by means of the differentiator capital efficiency. The expensive airport has in
contrast to the *lucky airport* invested in performance. These investments are often geared towards minimizing the effects of reduced forms of managerial controllability. Its asset base per unit of output is therefore larger than that of the *lucky airport*. In other words, the *lucky airport* has a higher capital efficiency than the *expensive airport*. The *expensive airport* should direct its efforts to improve its managerial controllability in order to lower its costs and/or to change (expand) its airport. The *lucky airport* can remain its position, unless it aims to change (expand) its business. The strategic directions of the *lucky airport* and *expensive airport* are identified by arrow 4 in Figure 6-11.

**Underperformer:**
The *underperformer* has both a low performance and a low managerial controllability. Its efforts should be directed following a two-step approach (arrow 1 in Figure 6-11). To increase its performance, the *underperformer* should first direct its efforts to increase its managerial controllability. From its position as high potential, the underperformer should direct its efforts to boost its performance to become a *star*. For *underperformers*, there are two potential threats; first, the *underperformer* which first invests to increase its performance runs the risk of becoming an *expensive airport*. Second, the *underperformer* which invests first in managerial controllability without having a clear vision runs the risk of becoming a *sleeper*. These two risks can be mitigated by defining a vision and developing a predefined master plan.

**High potential or sleeper:**
The *high potential* has high managerial control over its assets; however, it does not (yet) result in outstanding performance. With extra efforts, the high potential can position itself as a star. The high potential which is unaware of its position is called a sleeper. The differentiator distinguishing the *high potential* from the *sleeper* is awareness of managerial controllability.

The sleeper has a high potential for improving its performance, however, sleepers will not bring this into practice. The transformation of a *high potential* into a *star* is identified by arrow 2 in Figure 6-11. *Sleepers* can become *high potentials* by first developing awareness (vision) of their high managerial controllability; they first have to ‘wake up’ before performance can be increased (arrow 3 in Figure 6-11).

**Conclusions**
AMS and CDG are positioned in the same block; they are considered to be *expensive airports or lucky airports*. It is interesting to assess AMS versus LHR considering the size of their airside asset base versus their state of managerial controllability. It can be observed that the asset base of AMS is by far larger than the asset base of LHR (in 2007). Second, assessing the geographical area of the airports LHR and AMS shows that LHR is situated in a more densely populated area, but actually handles more traffic than AMS. Apparently, the noise restrictions at LHR are less strict than they are at AMS. Comparing AMS with CDG results in the following conclusion; CDG is both in terms of managerial controllability as well as in terms of performance slightly more efficient than AMS. Note that both airports have a significant large airside asset base. However, it is observed that there are living more people within the 55 db LDEN area at CDG than at AMS; however, the noise regulations at CDG are less severe than they are at AMS. Both AMS and CDG are *expensive airports*. 
Improvement for AMS lies particularly in the field of its managerial controllability. In order to become a star, AMS should first direct its efforts to make a horizontal transformation; an increase of its managerial controllability. Then, a vertical transformation is legitimate. A direct vertical transformation is considered as a potential pitfall. Additional investments are robust and future proof if both performance and managerial controllability increase with additional investments.

![DEA graph for VRS](image)

**Figure 6-12: DEA generic positions of airports**

<table>
<thead>
<tr>
<th>IATA code;</th>
<th>Generic position within framework;</th>
<th>Explanation;</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>Expensive airport</td>
<td>AMS has significantly invested in capacity; however its airside asset base is underutilized. Its densely populated area restricts the airport in the utilization of runways. The airport is dependant on a peak distribution of air traffic.</td>
</tr>
<tr>
<td>CDG</td>
<td>Expensive airport</td>
<td>CDG has a significantly large airside area and has four operational runways. The airport is thereby driven by a peak distribution for air traffic handling. The moderately low noise score of CDG results in a slightly higher managerial controllability of CDG than LHR and AMS.</td>
</tr>
<tr>
<td>LHR</td>
<td>Star</td>
<td>LHR operates on a small (airside) aerial and has only two runways which are fully utilized. Its intense densely populated area has some restrictions on the utilization of runways, but does not result in a strong reduction of ATMs.</td>
</tr>
<tr>
<td>FRA</td>
<td>On the interface between high potential and underperformer</td>
<td>FRA lies on the interface between high potential and underperformer. Regarding its airside asset base it should be capable to handle more ATMs. Its managerial controllability is moderately good due its medium densely populated surrounding area and its fairly well noise regulation. Since its airside asset base is in place, it can be expected that the airport can increase its performance relatively well.</td>
</tr>
<tr>
<td>DUS</td>
<td>High potential</td>
<td>DUS is a high potential airport. The airport has only two runways located on a small airside aerial. The airport handles 48% of the traffic LHR handles (LHR has also a parallel runway system). Its annual capacity can potentially be increased since the airport has a moderately good state of managerial controllability.</td>
</tr>
<tr>
<td>BRU</td>
<td>Underperformer</td>
<td>BRU copes with significant noise regulations. With its 3 runways, the airport handles only 60% of ATMs handled by AMS, and only 55% of ATMS handled by LHR. Its low performance is partly a result because of the bankruptcy of Sabena. Second, BRU copes with severe noise regulations which affects the airport in its operations.</td>
</tr>
<tr>
<td>CRL</td>
<td>Star</td>
<td>CRL is under VRS conditions a star. The airport has favourable noise regulations. With its single runway, the airport handles 16% of the traffic handled by AMS.</td>
</tr>
<tr>
<td>NRN</td>
<td>Star</td>
<td>NRN is under VRS conditions a star. The airport has favourable noise regulations. With its single runway, the airport handles 2% of the traffic handled by AMS. NRN has a (very) small airside area, but due to its ex-military state an adequate infrastructure on hand. NRN has a large catchment area.</td>
</tr>
</tbody>
</table>

Table 6-9: Generic position in framework per airport and explanation
Chapter 7 – Conclusions, recommendations and reflection
Chapter 7 – Conclusions, recommendations and reflection

7 Conclusions, recommendations and reflection

This final thesis research is concentrated around two main themes. These themes are linked to the goals as formulated in section 2.1, and to the objectives as formulated in section 2.2. The central themes of this research are:

- A search and development of a new alternative method to assess efficiencies of airports, thereby discriminating performance from managerial controllability;
- Assessment of the airside asset base of Amsterdam Airport Schiphol versus that of its direct competitors, thereby extracting best practices from the dataset.

This final chapter of this research report presents the conclusions and recommendations from the research. The conclusions will touch upon the main research question and main goal of this research. The final section of this chapter includes a brief reflection on the research process.

Note: The main conclusions are indicated by; (C-#)

7.1 Conclusions

Benchmarking is a continuous process of measuring performance followed by improvement. This report mainly presents a method for measuring the performance of airports. Second, the report provides the first incentive for improvement of that performance. The reader should realize that benchmarking is a continuous activity and thus should not stop after a single iteration. The benchmark is therefore by definition not finished given the results of this research.

Model

Comparing airports has always come with substantial challenges; the main problem with benchmarking can be framed as the problem of comparing apples with oranges, resulting in a tremendous amount of ratios. As most benchmark reports show, the assessment of relative efficiency of airports is problematic since one can and may not judge about preferences and / or incorporate (its own) subjectivity. If one does so, the benchmark becomes less reliable and less useful. Furthermore, theoretical maximums are figures that are accountable for discussion since theoretical maximums are often not feasible and (realistic). Second, theoretical maximums are proven sometimes to be underestimates since organizations might look for creative solutions. Proven data are therefore more realistic and more reliable.

Data Envelopment Analysis provides a new view on mutual assessment of Western European airports. DEA comes with many strengths, however its strengths also determine its limitations; DEA is based on proven data, and cannot test for a theoretical maximum. All efficiencies are relative. The statement of Francis et al. (Francis et al., 1999) that benchmarking is often geared towards measuring outcomes without understanding the processes which led to them is offset by means of DEA. The DEA model provides a good estimate of the specific elements which lead to (in)efficiencies.
It is concluded that DEA makes comparisons possible without attaching any personal perspectives, opinions, feelings, beliefs, or desires to the data, known as subjectivity. Thereby, the possibility of extracting best practices from the peer group provides new steering parameters (such as potential improvements / targets) to innovate the organization under assessment. (C-1) Data Envelopment Analysis is therefore a valuable tool for airport managers to assess various processes at airports. Efficient DMUs (those who are located on the efficiency frontier) can be assessed on robustness by means of DEA following the theory of Zhu (Zhu, 1995).

In line with the statements of CEO Jos Nijhuis (Schiphol Group), the DEA for this research is performed in input oriented mode. The Variable Returns to Scale assumption is most appropriate. This can best be explained following a short example; the fact that AAS has six runways does not per definition imply that it therefore can handle six times more traffic than any airport using just one runway. The main practical reason is that at most airports, runways intersect as the number of runways increases and / or the typology of the airport gets more complex. In the case of this research, the returns (in terms of Air Traffic Movements) are not linearly related to the amount of runways present.

**Efficiency assessment of Amsterdam Airport Schiphol**

Until the privatisation, reducing the operating costs of airports was not a prime priority for many airports. After privatisation of the sector (including the sample), airports have become more commercially oriented. Competition increased and airports have depleted their non-aviation revenue sources.

It is concluded that (C-2) the capital intensive and lumpy character of the main airside asset base of an airport requires high attention by airport managers to prevent it from being a cash guzzler. This is especially true for Amsterdam Airport Schiphol; its impressive asset base is larger than that of its competitors, while its output is comparable. Its brand value *efficiency* should therefore serve as a trigger for critical assessment of the airside asset base.

This research discriminates *performance* from *managerial controllability*; a new dimension of benchmarking. (C-3) It is vital for both regulators and airport managers to have sufficient information about both performance and managerial controllability of airside assets. Second, airport managers, public policy makers and Dutch citizens should be aware of this strong relationship. Those who are aware and know how to influence the managerial controllability of an airport’s (main) airside asset base can turn it into their benefit. However, airport managers should be aware that each of these stakeholders can use this knowledge to both the advantage but certainly also to the disadvantage of AAS. (Public) policy marketing can be a constructive tool to match policy products with the requirements of citizens. (C-4) Public policy marketing could enable the airport to ‘sell’ its policies to citizens and (local) government, based on non-commercial marketing exchanges specific to the context of public administration. Public policy marketing should at least be directed towards three focus areas; provide information, convincing and creating understanding.

The challenges lying ahead for AAS are defiant; like other airports, (C-5) AAS faces a continuous adjustment problem. In order to stay competitive, the airport has to react on shifts and changes in demand, aircraft types, environment, regulation and more. For AAS, this adjustment problem requires extra attention since the airport
is not a natural hub in itself; its local market is too small for a healthy business considering its airside asset base, the airport is therefore dependant on its transfer market. Shifts in demand puts tremendous pressure on facilities, this may result in high peaks of demand versus extreme times of under-utilization of assets. Both in the short- and long term, capacity and cost problems regarding the exploitation of the airside asset base requires smart and effective solutions. In the short term, recovery and the allocation of airport capacity is (as the traffic forecasts show) required. As may be concluded from various traffic forecasts, demand grows and runway capacity remains unchanged. This may in the long run result in congestion. Although expansion of airport capacity is difficult in the short term, the utilization of (main) airside assets can be improved.

**Data Envelopment Analysis results**

Assessment of AAS in terms of its main airside assets by means of Data Envelopment Analysis results in the following conclusion; **(C-6)** AAS is performing moderately good relative to its peers. Another conclusion is that **(C-7)** AAS scores low(est) in terms of managerial controllability relative to its peers. The effect of these observations is that **(C-8)** AAS behaves in an extremely delineated environment, subject to many and powerful factors beyond managerial control of the own organization.

In a strict comparison to sub sample A (LHR, CDG and FRA), it is concluded that AAS has the lowest airside asset performance. Also in terms of controllability, AAS scores lowest of these four airports. One should however realize that these two facts are interrelated; the impressive asset base is a result of managerial decisions made in a delineated environment, subject to both political and environmental pressure.

The overall assessment of efficiency (which is defined as a combination of performance and controllability) asks for attention and explanation. **(C-9)** The moderate efficient performance of AAS is mainly a result of its extensive runway system. However, on the other hand, the airports terrain is not extensively larger than it is at its peers (such as CDG). **(C-10)** This is mainly a result of its concatenated terminals. On the other hand, the airside of AAS includes additional terrains. This is mainly a result of its typology; take for example the location of runway 18R/36L (*Polderbaan*) which makes the airside larger than strictly necessary. Compared to its smaller peers airports (sub sample B), AAS scores relatively good in terms of performance. The underlying reason can be found by looking at the peer airports from sub sample B. One could observe that is especially the low output of those peers which reduces their efficiency. In terms of managerial controllability, one could observe that AAS copes with a large set of factors beyond control. These include mainly noise regulations and (severe) weather conditions at AAS which reduce the managerial controllability over the use of main airside assets. Runways for example are at AAS not used up to their maximum (hourly) capacity (as at London Heathrow; which (concerning their runway system) comes very close). Their operational utilization is restricted to limit the number of citizens disturbed by noise.

The typology of airports is captured in terms of three variables; airside area, number of gates and number of runways. The model however does not count for additional assets acquired as a result of an unaccustomed typology. Regarding AAS, a comment regarding these additional assets is definitely in place. The location of runway 18R/36L (*Polderbaan*) resulted to the need of an additional air traffic control tower, (two) de-icing
platforms and a fire station. **(C-11)** Such a duplication of assets due to a unaccustomed typology of the airport is not common across the other airports of the sample, and makes AAS even more capital inefficient.

**Implications**

**(C-12)** Inefficiency at airports can be reduced in two ways, to be known;

- Reducing the input (the airside asset base) while keeping outputs constant;
- Increasing the output while keeping inputs constant.

**(C-13)** Moderate performance efficiency can be turned into a benefit when considering the (long term) changes in the airport market. One should however first change its thoughts about ‘inefficiency’. As the DEA model indicates, according to the DEA results, **(C-14)** AAS should be capable of producing the same output with less input. The transformation here is that AAS should be capable of producing more outputs without altering its inputs. Triggered by a quote of Jawahalal Nehru, efficiency can also be increased when utilizing the existing material (infrastructure) to the best advantage (Jawahral Nehru, 1889 - 1964). **(C-15)** Since there is a buffer capacity present at AAS, efficiency can be increased by increasing the output by means of a more efficient utilization of (main) airside assets, making additional (large) investments superfluously.

Since this research is performed in an input oriented mode, the model comes with a set of potential improvements aimed on reducing the asset base while keeping the output constant. These improvements show that airport managers should concentrate their efforts on **(C-16)** (1) the runway system, and (2) the ratio of gates versus the typology of the airport (i.e. airside area). **(C-17)** The latter is subject to the pattern of demand over the day. It is observed that these patterns show substantial variation between airports. The suggested potential improvements show that the number of runways at AAS can be reduced by 40%. For its six runway system, this implies that 2,4 runways can be divested. **(C-18)** In practice, 3 to 4 runways are strictly required, which is in line with the peak hour utilization of runways based on a three runway system. The suggested potential improvements come with a number of challenges. As the DEA of managerial controllability indicates, **(C-19)** AAS copes with a large set of powerful factors beyond control of airport managers. It is likely that any attempts to improve the efficiency or the capacity of the airside of AAS will cause problems. One of the main conclusions extracted from the assessment of managerial controllability is that **(C-20)** improving airside performance and / or capacity is not just a matter of expanding the airside asset base, but is in fact a result of an open discussion about the redistribution of managerial control between the commercialized airport AAS, both federal and local government and even citizens (i.e. the people who are living in the disturbed noise area of the airport). This redistribution of managerial control is in line with the privatisation of the sector. A better and comprehensive understanding of the powers of control influencing the performance of the airside asset base of the AAS has an effect on the license to grow of the airport.

**Strategy**

One of the main conclusions extracted from this research is that **(C-21)** one can distinguish performance from managerial controllability. **(C-22)** A representation of these two measures in a matrix is a new identification of the competitive landscape of a sector. Airport managers who are aware of this distinction and know how to position their own airport with respect to the competitive landscape, can use this knowledge and turn it into a
benefit. It can be concluded that (C-23) improving the airside performance is not just a matter of investment, but in the case of AAS starts with improving the managerial controllability of airport managers.

Future considerations
As CEO Jos Nijhuis states, the financial crisis gives rise to new opportunities. The financial crisis calls for resettlement of demand, increasing the opportunities to utilize the airside asset base more efficiently. A spread of demand over the day (as observed at London Heathrow) may increase the average output per runway as runways are more intensively used during periods of low demand. This may yield the potential for expanding the daily capacity. Also (C-24) new business models of airlines may be turned to the benefit of AAS. Emerging low cost airlines favour low visit costs and are therefore prepared to use less popular slots.

The traffic figures and resettlement of the market call for attention. Airports in general, and certainly AAS, face an adjustment problem; AAS has to anticipate on demand for new products, the emergence of new business models, and the changes and innovations made by competitors. (C-25) The effects of new routes and uneven increase of traffic over the world can potentially be turned into a benefit for AAS as the airport uses its buffer capacity as a marketing tool. In order to anticipate on changes in the market, an understanding of how close competitors are organized in terms of their airside asset base may prove valuable.

This research brings forward a framework in which four generic positions can be recognized. (C-26) AAS is considered to be an expensive airport. In order to become more efficient, (C-27) the airport should reduce its costs by first increasing its managerial controllability.

Although airports may seem monopolistic in nature, they are responsible for their own success. The privatisation of the airport sector requires one to treat airports as businesses. Therefore, (C-28) getting a better grasp on managerial control is of paramount importance. This research provides the method which allows one to get this better grasp, and puts forward the first efforts in doing so.

Answer to main research question
The main research question for this research is formulated as;

“How efficient is Amsterdam Airport Schiphol in using its main airside assets relative to its direct competitors?”

The answer to this main research question follows from chapter 6. The answer to the main research question is formulated as follows;

Amsterdam Airport Schiphol is moderately efficient in using its main airside assets relative to its peers. However, compared to its same sized peer airports, Amsterdam Airport Schiphol scores low in performance. It can be concluded that the low efficiency of AAS in terms of performance is partly a result of strongly reduced managerial controllability of airside assets.
7.2 Recommendations

This research report comes with the following recommendations for Schiphol Group:

- Do not take the inefficiencies as presented in this report for granted. Use the focus areas as presented in this report to turn inefficiencies into benefits for the airport; exploit the opportunities as provided by the current asset base. Think carefully about acquiring new lumpy assets and their specific contribution to increase the efficiency and / or capacity at AAS. Even more important, have a critical look at potential increase or decrease of managerial controllability when acquiring new assets. Look for opportunities to adjust current assets so that they comply with (new) market opportunities.

- Use the potential improvements presented in this report as information to set (new) targets. As becomes apparent from this analysis, it is not only the physical presence of assets which labels AAS as inefficient, but certainly also the utilization of those assets which have a negative effect on the overall efficiency. Use the targets in this paper not literally, but as a pointer to focus the efforts of airport managers on underperforming areas. (Public) policy marketing can be a constructive tool to match policy products with the requirements of the (local) government and citizens. Use this marketing instrument explicitly to ‘sell’ the airport’s policies to citizens and (local) government.

- This research is conducted using an input oriented analysis. The relative inefficient position of AAS can be regarded as an opportunity. An output oriented analysis will show that AAS should be capable of producing more output given the airside asset base. With the knowledge that demand for air traffic will increase, AAS can benefit from its buffer capacity by using it more efficiently. Enhancement of its managerial controllability is therefore recommended.

- The low score in managerial controllability causes a low performance of airside assets for AAS. It is especially performance that dominates at policy makers and citizens. This research has dissected performance and managerial controllability. Use this dichotomous difference for policy marketing incentives.

- Keep a close eye on all modifications, diversifications and turns of those airports which are considered best-in-class which are competing with AAS; Paris Charles de Gaulle, London Heathrow and Weeze Niederrhein. Have a particularly close eye on high potential airports with an overlapping market. Be aware of the strategic moves of Düsseldorf Airport since it is highly in managerial control of the utilization of its assets and most important, its catchment area overlaps with the catchment area of AAS.

- To increase the reliability of the DEA model, incorporate more observations (airports) in it. Be aware of the fact that the incorporation of new observations may bring forward new best performers. These new best performers may (slightly) change the strategic positions of airports in the DEA matrix since the model is based on the measurement of relative efficiencies.
• New aircraft (such as the A-380) and new business models (such as those of low cost carriers) may have a significant impact on particularly the exploitation of aprons and gates. The accommodated costs for updating these assets may be considerably high (such as Terminal 5 at LHR). Other aircraft, such as the Boeing 787 may have a reverse effect; lower demand because of increasing emphasis on point to point networks.

• The model provides new opportunities and new insights in mutual assessment. The model thereby comes with unique features not covered by other models. Use this model also for other assessments. It would be wise to acquire an appropriate DEA software tool.

**Further research**

It is recommended to continue this research. The following issues concerning future research are recommended;

• Include more observations (airports) in the DEA analysis, making the model more reliable.

• Investigate how performance and managerial controllability are related. Managerial controllability limits the potential improvements for performance. This knowledge should be incorporated in a modified model.

• It would be very interesting to include also other lumpy assets in the benchmark. It is recommended to include the baggage system of the airport and the terminal complex. The research can be extended using the schematic flow diagram of airports (see Figure 3-2).

**Preview of future research**

It is expected that the efficiencies of landside assets are not related to the efficiencies of airside assets. Main reason is that the design and utilization of landside assets is concerned with other factors affecting the managerial controllability. As is presented in this report, the design and utilization of airside assets is affected by mainly environmental factors. For landside assets, it is expected that mainly customers (airlines) have an effect on design and utilization. Any future research should clearly define this kind of managerial controllability since it is not one to one comparable with managerial controllability issues concerning airside assets.

**7.3 Reflection**

Starting on February 8th with this research, the full focus was on benchmarking airports. However, although time was reserved for framing the benchmark model, it was not foreseen on beforehand that finding and developing a adequate benchmark model was such a challenge. This reflection discusses briefly some practical decisions which were made regarding the accomplishment of this research and report.

As introduced, finding and developing an adequate model was a challenge since it was recognized that existing benchmarks had a number of shortcomings. Although it took some more time than initially planned, the search for new ways of benchmarking resulted in satisfying results. With the features of DEA as presented in this
research, the research become much broader in the sense that it is not only a benchmark that is presented in this report, but also a new look at the way of benchmarking airports.

Although extra time was required to develop and frame the benchmark model, the additional time was later caught once the model functioned. The research is performed within time limits. Reflecting this research brings foreword the following conclusions;

- Redoing this research would not have resulted in an entire different research approach. The recognition of shortcomings present at existing benchmark and a translation to three challenges was key;
- It is concluded that more time was spend on exploring the features of DEA than initially planned. It is afterwards concluded that this task could have been slightly shortened which benefits the benchmarking of AAS and peer airports;
- Postponing some of the prior research tasks to January 2010 was a good decision and helped to get acquainted with the topic and matter;
- Regarding the process, different tasks resulted in separate documents, databases and programmes. It would have been wise to start integrating these products in a final report some what earlier. That would have made communication easier;
- The initial planning and process which was documented in the research proposal was realistic.
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Appendices
Appendices

Appendix A: Aerodrome charts

Appendix A presents the official aerodrome charts of the sample. Note that the scales may vary between airport charts.
Aerodrome chart Amsterdam Airport Schiphol (AMS)
Aerodrome chart London Heathrow (LHR)
Aerodrome chart Frankfurt (FRA)
Aerodrome chart Brussels Airport (BRU)
Aerodrome chart Brussels Charleroi Airport (CRL)
Aerodrome chart Düsseldorf Airport (DUS)
Aerodrome chart Weeze Niederrhein Airport (NRN)
Appendix B: Graphical representation of the returns to scale

Returns to scale - returns of runway system

Returns to scale - returns per airside acre

Returns to scale - gates

Returns to scale - runways
Appendix C: Operational airport and runway information per airport

Amsterdam Airport Schiphol

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- **Type:** Civil
- **Magnetic Variation:** 000° W
- **Near city:** Amsterdam
- **Operating Agency:** CIVIL GOVERNMENT
- **Operating Hours:** 24 HOUR OPERATIONS
- **Daylight Saving Time:** Last Sunday in March to last Sunday in October

#### Runways
- **Oostbaan**
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  - **Landing distance:** 2014 m
  - **Takeoff distance:** 2293 m
  - **Overrun length:** 279 m
  - **Overrun surface:** Asphalt
  - **Displaced Threshold Length:** 250 m
  - **Lighting system:** MIRL/A2
- **Kaagbaan**
  - **Runway:** 06/24
  - **Dimensions:** 3500 x 45
  - **Surface:** Asphalt
  - **PCN:** 082RCXT
  - **ILS:** Yes
  - **True Heading:** 58.0°
  - **Latitude:** 52°18’50.49” N
  - **Longitude:** 004°48’10.89” E
  - **Elevation:** -4 meters
  - **Landing distance:** 3250 m
  - **Takeoff distance:** 3500 m
  - **Overrun length:** 3363 m
  - **Overrun surface:** Asphalt
  - **Displaced Threshold Length:** 3453 m
  - **Lighting system:** TDZL/A2/PAPI
- **Buitenveldertbaan**
  - **Runway:** 09/27
  - **Dimensions:** 3453 x 45
  - **Surface:** Asphalt
  - **PCN:** 095FCWT
  - **ILS:** Yes
  - **True Heading:** 87.0°
  - **Latitude:** 52°18’59.92” N
  - **Longitude:** 004°44’46.85” E
  - **Elevation:** -4 meters
  - **Landing distance:** 3303 m
  - **Takeoff distance:** 3453 m
  - **Overrun length:** 3453 m
  - **Overrun surface:** Asphalt
  - **Displaced Threshold Length:** 3453 m
  - **Lighting system:** TDZL/HIRL/CL/PAPI

#### Runways
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  - **Runway:** 18R/36L
  - **Dimensions:** 3800 x 60
  - **Surface:** Asphalt
  - **PCN:** 095FCWT
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  - **Elevation:** -4 meters
  - **Landing distance:** 2825 m
  - **Takeoff distance:** 3400 m
  - **Overrun length:** 3303 m
  - **Overrun surface:** Asphalt
  - **Displaced Threshold Length:** 270 m
  - **Lighting system:** TDZL/HIRL/CL/PAPI
- **Aalsmeerbaan**
  - **Runway:** 18L/36R
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  - **Lighting system:** TDZL/HIRL/CL/PAPI
- **Zwanenburgbaan**
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Charles de Gaulle

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CIVIL GOVERNMENT, (LANDING FEES AND DIPLOMATIC CLEARANCE MAY BE REQUIRED)

**Operating Hours**

24 HOUR OPERATIONS

**International Clearance Status**

Airport of Entry

**Daylight Saving Time**

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**Operating Agency**

CIVIL GOVERNMENT, (LANDING FEES AND DIPLOMATIC CLEARANCE MAY BE REQUIRED)

**Operating Hours**

24 HOUR OPERATIONS

**International Clearance Status**

Airport of Entry

**Daylight Saving Time**

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### Brussels Natl. Zaventem

<table>
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<tbody>
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<tr>
<td>Latitude</td>
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<td>Type</td>
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<tr>
<td>Magnetic Variation</td>
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<td>24 HOUR OPERATIONS</td>
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#### Runways

<table>
<thead>
<tr>
<th>Runway</th>
<th>Dimensions (m) x (m)</th>
<th>Surface</th>
<th>PCN</th>
<th>ILS</th>
<th>True Heading</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Type</th>
<th>Magnetic Variation</th>
<th>Slope</th>
<th>Landing distance (m)</th>
<th>Takeoff distance (m)</th>
<th>Overrun length (m)</th>
<th>Displaced Threshold Length (m)</th>
<th>Lighting system</th>
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<td>02/20</td>
<td>2987 x 50</td>
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<td>3211 3211</td>
<td>3336 3336</td>
<td>46</td>
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<tr>
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<td>3336 3336</td>
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### Brussel South / Charleroi

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<td>Near city</td>
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#### Runways

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<th>Surface</th>
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<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Type</th>
<th>Magnetic Variation</th>
<th>Slope</th>
<th>Landing distance (m)</th>
<th>Takeoff distance (m)</th>
<th>Overrun length (m)</th>
<th>Displaced Threshold Length (m)</th>
<th>Lighting system</th>
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<td>2550 2550</td>
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*Page 128*
## Weeze Niederrhein

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<td><strong>Latitude</strong></td>
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<td><strong>Longitude</strong></td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
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<td><strong>Type</strong></td>
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<td><strong>Longitude</strong></td>
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<td></td>
<td>Q Q</td>
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Appendix D: Distribution of ATMs over the day per airport
Appendix E: Validation of DEA analysis, a alteration of weights

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<th>CDG</th>
<th>LHR</th>
<th>FRA</th>
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<td>-2.9%</td>
<td>-0.8%</td>
<td>-4.8%</td>
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<tr>
<td>- 5%</td>
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<td>4.8%</td>
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<td>Number of terminal gates</td>
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<td>0.0%</td>
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<td>0.0%</td>
<td>0.0%</td>
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<td>0.0%</td>
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<td>0.0%</td>
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<td>0.0%</td>
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<tr>
<td>- 10%</td>
<td>0.0%</td>
<td>1.9%</td>
<td>0.0%</td>
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<tr>
<td>Declared peak hour capacity 2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ 5%</td>
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<table>
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<th>BRU</th>
<th>CRL</th>
<th>NRN</th>
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<td>VRS</td>
<td>CRS</td>
<td>VRS</td>
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<td>Number of runways</td>
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<tr>
<td>+ 10%</td>
<td>-3.9%</td>
<td>-10.3%</td>
<td>-4.9%</td>
<td>-3.2%</td>
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<tr>
<td>- 10%</td>
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<td>Airside Area</td>
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<td></td>
<td></td>
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<tr>
<td>+ 5%</td>
<td>-0.9%</td>
<td>-9.2%</td>
<td>-1.1%</td>
<td>-0.6%</td>
</tr>
<tr>
<td>- 5%</td>
<td>0.7%</td>
<td>-8.9%</td>
<td>1.1%</td>
<td>0.7%</td>
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<td>Number of terminal gates</td>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<tr>
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<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
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<tr>
<td>ATM for 2007</td>
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<tr>
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<td>0.0%</td>
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<td>1.2%</td>
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<tr>
<td>Declared peak hour capacity 2007</td>
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<td></td>
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<td>+ 5%</td>
<td>0.0%</td>
<td>-10.1%</td>
<td>0.0%</td>
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<tr>
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<td>-8.0%</td>
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Appendix F: Validation of DEA analysis, a second analysis

The following analysis is used for validating the DEA analysis as presented in chapter 6.

### Analysis # 2

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<th>Input:</th>
<th>Output:</th>
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<tbody>
<tr>
<td>Total runway length</td>
<td>ATM for 2007</td>
</tr>
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</table>

**Performance assessment (input oriented mode)**

| Scores (CRS): |AMS | 52,8 % (7) |CDG | 91,1 % (2) |LHR | 100,0 % (1) |FRA | 81,9 % (3) |DUS | 62,9 % (5) |BRU | 62,3 % (6) |CRL | 64,1 % (4) |NRN | 6,4 % (8) |
|AMS | 53,3 % (8) |
|CDG | 100,0 % (1) |
|LHR | 100,0 % (1) |
|FRA | 83,6 % (5) |
|DUS | 76,9 % (6) |
|BRU | 67,2 % (7) |
|CRL | 100,0 % (1) |
|NRN | 99,0 % (4) |

**Input:**
- Noise score
- Weather variance
- Number of runways
- ATM 2007

**Output:**
- ATM for 2007
- Designated length for take off and landing

**Scores (VRS):**
- AMS 50,30%
- CDG 100,0%
- LHR 100,0%
- FRA 100,0%
- DUS 89,6%
- BRU 68,6%
- CRL 100,0%
- NRN 94,5%

**Managerial controllability assessment (input oriented mode)**

| Scores (CRS): |AMS | 45,20% |CDG | 70,30% |LHR | 100,00% |FRA | 100,00% |DUS | 54,70% |BRU | 43,90% |CRL | 26,20% |NRN | 3,50% |
|AMS | 50,30% |
|CDG | 100,0% |
|LHR | 100,0% |
|FRA | 100,0% |
|DUS | 89,6% |
|BRU | 68,6% |
|CRL | 100,0% |
|NRN | 94,5% |

**Input:**
- Noise score
- Weather variance
- Number of runways
- ATM 2007

**Output:**
- ATM for 2007
- Designated length for take off and landing

**Scores (VRS):**
- AMS: 50,30%
- CDG: 100,0%
- LHR: 100,0%
- FRA: 100,0%
- DUS: 89,6%
- BRU: 68,6%
- CRL: 100,0%
- NRN: 94,5%

### b. Potential improvements;

**Airport: AMS**

**Performance (input orientation)**

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<th>VRS</th>
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<td>-35,7 %</td>
<td>-35,4 %</td>
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### c. Reference set;

The peers for AMS are CDG and CRL

**For AMS, performance**

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<th>VRS</th>
<th>CRS</th>
<th>VRS</th>
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<td>96,4 %</td>
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e. Graphs;

DEA graph #2 CRS

Controllability

DEA graph #2 VRS

Controllability
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<th></th>
<th>Average</th>
<th>Total runway length [m]</th>
<th>Runway length [m]</th>
<th>Number of gates [n]</th>
<th>Total surface area [m²]</th>
<th>APAR area [ha]</th>
<th>NARCS statistics</th>
<th>ONA TNCs [pct]</th>
<th>Noise score</th>
<th>Weather score</th>
<th>Used runway length for take off and landing</th>
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<td>0.42</td>
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<td>-0.33</td>
<td>-0.28</td>
<td>-0.29</td>
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<td>-0.42</td>
<td>-0.34</td>
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<td>-0.14</td>
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<td>Noise LDEN &gt;50-55dB</td>
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<td>-0.41</td>
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<td>-0.19</td>
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<td>0.67</td>
<td>0.16</td>
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<tr>
<td>Total noise</td>
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<td>-0.30</td>
<td>0.34</td>
<td>-0.15</td>
<td>-0.29</td>
<td>-0.04</td>
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<td>Runway length 2000 [m]</td>
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<td>-0.16</td>
<td>-0.44</td>
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<td>-0.27</td>
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<td>0.61</td>
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<tr>
<td>Preferred direction</td>
<td>0.79</td>
<td>0.71</td>
<td>0.69</td>
<td>0.49</td>
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<td>-0.13</td>
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<td>ATM readiness</td>
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<td>0.71</td>
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<td>0.47</td>
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<td>Declared ATM maximum</td>
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<td>0.71</td>
<td>0.51</td>
<td>0.54</td>
<td>0.47</td>
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<td>Number of gates [g]</td>
<td>Total runway surface [m²]</td>
<td>Areal area [ha]</td>
<td>Weather statistics</td>
<td>Total ‘noise population’</td>
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Benchmarking Airside Assets of Western European Airports

A Data Envelopment Analysis

Rogier Doffegnies