Master of Science Thesis

Modelling Network Contribution Under Changing Capacity For A Hub & Spoke Carrier

J.E. Potjer

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TU Delft

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to obtain the degree of Master of Science in Aerospace Engineering,
at the Delft University of Technology,
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This thesis is confidential and cannot be made public until July 27, 2021

TU Delft

Preface

This report is a Master of Science Thesis to obtain the degree of Master of Science in Aerospace Engineering, at the Delft University of Technology, the Netherlands. This report is confidential and cannot be made public within five years after date of signing.

During this project I have gained a lot of knowledge and experiences, in as well a personal as a professional sense. In the consideration of the interests of the Delft University of Technology and Kenya Airways I have encountered my primary challenge in keeping as well the scientific as the practical relevance as high as possible. The international set-up of this project, with the privilege of traveling back and forth between the Netherlands and Kenya, is an experience which I will never forget.

I would like to thank my supervisor Bruno Santos for his patient guidance and advices that he has provided me throughout my project. I also would like to express my gratitude to Kenya Airways for supporting this project and providing expert knowledge, real airline data and guidance. In particular, I would like to thank Thomas Omondi, Marco van Vliet, Stephen Ngamau, Ezekiel Odour, and Moses Oduma for the support provided.

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Jordi Potjer
July 27, 2016
Delft, the Netherlands

Executive Summary

The main characteristic of a hub-and-spoke network is that many passengers will reach their final destination via a connection at the hub, instead of a direct flight in case of a point-to-point network. An airline operating such a hub-and-spoke network thus has a significant ratio of transfer passengers on its flights. This means that each flight leg or route should be viewed as part of greater system rather than an individual item.

The use of a hub-and-spoke network entails that air travel demand is defined for an Origin and Destination (OD) market, while the supply is provided in the form of flight leg departures in the network. This implies that there exists a dichotomy of airline demand and supply in an individual OD market.

Currently, most of the airlines base their performance assessment on a route-based analysis. However, since one flight leg or route may serve multiple itineraries through the network, not only the performance of that individual flight leg or route has to be analyzed but also the role of the flight leg or route in the network.

Despite of the fact that some research on this subject has already been performed, a network-based performance analysis is still not commonly used by airlines operating a hub-and-spoke network. This entails that an airline operating a hub-and-spoke network, such as Kenya Airways (KQ), is not capable of fully analyzing the performance of their routes considering their value in the network.

Research Design

This research is contributing to the problem, that airlines operating a hub-and-spoke network are not able to fully analyze the performance of their routes considering its value in the network, by the development of a Network Performance Assessment Framework (NPAF) with Graphical User Interface (GUI). Therefore, the research objective for this research is defined as follows:

> *The research objective is to contribute to the development of a NPAF with GUI by making a more comprehensive assessment of the performance of a route considering its value in the network.*

The literature review revealed that the existing network performance measures mostly apply several levels in the profitability of a flight leg in a greater system, while the predecessor of this research does not apply this principle. Therefore, the Network Value (NV) of the predecessor of this research does not allow for analyzing sources and areas of profitability in addition to the mere profitability of a flight leg. This research is applying multiple intermediate levels of profitability in the NV and is performing a more comprehensive assessment of the contribution of a segment or route to a greater system. This is referred to as the Network Contribution (NC) concept. Furthermore, the NV purely allows for analyzing the cancellation of a segment or route. Therefore, the NC will be analyzed under adjustments in capacity, without changing the capacity to zero. The capacity is changed by changing the frequency on a segment or route, or changing the type of aircraft operated on a segment or route.

Due to the practical background of this research, also a practical research – in the form of a questionnaire and interviews using the Delphi-method – is conducted to obtain experiences and information from the field.

This practical research revealed that there is a need for a network performance measure which allows for analyzing the effects of the cancellation of, and the adjustment of the capacity on, a segment or route in the strategic and operational network planning area. This network performance measure will be mainly based on the revenues and costs of the segment or route. Furthermore, the current practice of KQ also reflects the application of several levels in the profitability of a flight leg in a greater system. The interviews revealed a more advanced method for determining the costs that connecting passengers are making on the connecting segments. An interview at Royal Dutch Airlines (KLM), on their common practice, revealed that some airlines using a hub-and-spoke network can have a proper understanding on the performance of their routes considering their value in the network. The point of improvement for their method is indicated to be the cost allocation of the costs to the segments.

Network Contribution (under Changing Capacity)

At first, in the Network Value Analysis, several intermediate levels in the NV have been applied. In this separation, an intermediate profitability level is introduced which prorates a share of the connecting revenues based on Direct Operating Costs (DOC), instead of the commonly used mileage-based proration method, before applying the full-fare proration method. Using this proration method, the prorated connecting revenues will be linked to the cost allocation of the DOC itself, which shares the point of improvement of KLM from the practical research.

In this research, it is assumed that none of the Indirect Operating Costs (IOC) are discarded in case of the cancellation of a segment. The DOC can be subdivided into fixed costs, which are not dependent on the number of passengers, and variable costs which are dependent on the number of passengers. It is discussed that as well the local as the connecting passengers are incurring DOC on a segment. However, despite of the fact that the DOC of a segment are shared by as well the local as the connecting passengers, the fixed costs shared by the connecting passengers are not discarded in case of the cancellation of a connecting segment. Therefore, purely the variable costs of the connecting passengers are discarded in case of the cancellation of a segment. In this, the Network Contribution Value (NCV) is proposed, which indicates the monetary value which is at risk in case of the cancellation of a segment. Using the Network Contribution Value Analysis, multiple levels in the NCV have been applied, in order to be able to identify the source and areas of (un)profitability.

Despite of the ability to identify the sources and areas of (un)profitability, and having an improved indication of the contribution of a segment or route to a hub-and-spoke network, this analysis purely considers the cancellation of a segment or route, rather than changing the capacity. Therefore, the effect of the change of capacity on the NC is considered without changing it to zero. The capacity is changed by changing the frequency on a segment or route, or changing the type of aircraft operated on a segment or route. The model from Schot (2015) has been used for the prediction of the OD market size as a constraint for the demand in the concept of the NC under changing capacity. The S-curve market share model has been used to determine the market share of the airline in the market, with an alternative implementation with respect to Schot (2015), in order to be consistent among various networks with different routes. In case of the sample network, no effect of seasonality has been incorporated. In the concept of the change of aircraft, the model from Schot (2015) and Lammens (2014) has been used for the calculation of the replacing fixed costs for the replacing aircraft, in which Schot (2015) is used as the primary source. In the implementation of the change in frequency, a standard change in frequency of 10% has been applied, for the sake of convenience. No feedback in the change of the number of flights per week has been provided here. From this, it is more intuitive to compare the changes in frequency among the various routes. In the implementation of the change of aircraft, the Boeing 777, Boeing 787, Boeing 737, and Embraer 190 are the types of aircraft taken into account.

Application & Validation

The model is applied to the full KQ network for the year 2015 for each month separate. Due to the type of routes taken into account, a tag-end route with three segments in both directions is not explicitly taken into account in the model. Furthermore, due to the segment-based approach, any overlap between routes is also not taken into account. In the implementation, a least-square approximation method has been used to determine the potential demand for the year 2015 based on the potential demand for the separate years 2012 up to and including 2014 due to the lack of data. A simple reflection of market share and seasonality have been incorporated for the sake of simplicity in calculations and obtaining information.

A case-study on a hypothetical cancellation of the standard spoke route on ABV (Abuja, Nigeria) confirmed the consideration of KQ to cancel that route. This analysis, however, also indicated that some other routes may need more attention. An equivalent analysis based on the NV invalidates the metric from the predecessor of this research.

A case-study on recent change of frequency on standard spoke routes on TNR (Antananarivo, Madagascar) and LOS (Lagos, Nigeria) revealed that the saturation Load Factor (LF) of 75% is quite high and should be adjusted to the specific airline and corresponding markets. An improved prediction of the OD market size could give an adjusted saturation LF to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The occurrence of negativity is observed in the variable costs, which yields the corresponding errors to be prominent.

Recommendations & Future Work

In the input data for the model in this research some inconsistencies have been encountered. An issue on negative costs remained unsolved in this research. This issue has also been observed in the application, which yields the corresponding errors to be prominent. It is recommended to KQ to solve this internal issue, and thereby improve the results from the model in this research.

In the Network Contribution Value Analysis, several intermediate levels in the NCV have been applied. In this separation, an intermediate profitability level is introduced which prorates a share of the connecting revenues based on DOC, instead of the commonly used mileage-based proration method, before applying the full-fare proration method. This method, however, has not been adequately validated in this research. Therefore, a suggestion for future work is the proper validation of this method.

An application of the NC under changing capacity revealed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. An improved prediction of the OD market size could give an adjusted saturation LF to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could also give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The model for the prediction of the OD market size could be improved in terms of competitive and schedule related variables, such as average ticket price and sensitivity of connecting times respectively. For example, in case of a drastic increase in frequency, the average ticket price could be lowered due to economies of scale. In considering the schedule related variables, the potential demand for a route can be boosted in case the connecting times with some prominent connecting routes is optimized, and the overlap of another route in the network, which influences the flow of passengers significantly.

At least, the model in this research could be improved by incorporating a route-based or flight-based approach rather than a segment-based approach. In these cases, it is possible to identify the contribution of an individual route or flight on a segment respectively. In case of a flight-based approach, it is also possible to incorporate the sensitivity of connecting times. For example, the potential demand for a flight can be boosted in case the connecting times with some prominent connecting flights is optimized.

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List of Abbreviations

AF	Air France
ALLF	Average Leg Load Factor
ANLF	Average Network Load Factor
ASA	Air Service Agreement
ASK	Available Seat Kilometer
ATC	Air Traffic Control
ATO	Air Transport and Operations
BELF	Break Even Load Factor
CASK	Cost per Available Seat Kilometer
DOC	Direct Operating Costs
FC	Feeder Concentration
FH	Flight Hours
GUI	Graphical User Interface
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IOC	Indirect Operating Costs
ISA	International Standard Atmosphere
JV	Joint Venture
KE	Korean Air
KES	Kenyan Shilling
KL	Royal Dutch Airlines
KPI	Key Performance Indicator
KQ	Kenya Airways
LC	Local versus Connecting
LF	Load Factor
MIT	Massachusetts Institute of Technology
MSc	Master of Science
MTOW	Maximum Take Off Weight
NB	Negative Binomial
NC	Network Contribution
NCV	Network Contribution Value
NE	Net Earnings
NEF	Net Earnings plus Flow contribution
NPA	Network Profitability Analysis
NPAF	Network Performance Assessment Framework
NRM	Network Risk Matrix
NV	Network Value
OD	Origin and Destination
OEW	Operating Empty Weight
OI	Operation of Interest
OLS	Ordinary Least Squares
OTP	On-Time Performance
PC	Profit Contribution

PDS	Potential Demand Served
PPML	Poisson Pseudo Maximum Likelihood
RPA	Route Profitability Analysis
RPK	Revenue Passenger Kilometer
RTK	Revenue Tonnes Kilometer
SFC	Specific Fuel Consumption
SID	Standard Instrument Departure
TC	Traffic Concentration
VBA	Visual Basic for Applications
VE	Variable Earnings
VEF	Variable Earnings plus Flow contribution

Chapter 1

Introduction

In this chapter, the background of the research problem and the problem itself will be described. Therefore, in Section 1.1, the research context starts off with a description of performance measurement for an airline using a hub-and-spoke network. After that, in Section 1.2, the problem to be addressed in this research is set out. Subsequently, in Section 1.3, the structure of the upcoming literature study is laid out.

1.1 Research Context

Nowadays, approximately 72% of the yearly offered capacity (ASK)[1] is offered by a network legacy carrier operating a hub-and-spoke network. The low-cost carriers operating a point-to-point network contribute to approximately 22% of the yearly capacity offered. The main characteristic of a hub-and-spoke network is that many passengers will reach their final destination via a connection at the hub, instead of a direct flight in case of a point-to-point network. An airline operating such a hub-and-spoke network thus has a significant ratio of transfer passengers on its flights. This means that each route should be viewed as part of a greater network, rather than an individual route.

An example of a network legacy carrier operating a hub-and-spoke network is Kenya Airways with its hub at Jomo Kenyatta International Airport in Nairobi, Kenya. Currently, Kenya Airways is operating a number of 62 destinations[2] among which 55% of the passengers are transferring at the hub (Backker, 2013, p. 13), confirming there is a significant amount of interdependencies between the routes in the network.

This brings us to the fundamental problem in this research. The use of a hub-and-spoke network entails that air travel demand is defined for an Origin and Destination (OD) market, while the supply is provided in the form of flight leg departures in the network. This implies that there exists a dichotomy of airline demand and supply in airline economic analysis, which means that there is an inherent inability to directly compare demand and supply in an individual OD market. From this, it is quite difficult to answer seemingly simple economic questions concerning, for example, the profitability of a certain flight leg in a network (Belobaba, 2009a, p. 57).

Currently, most of the airlines base their performance assessment on a route-based analysis. However, since one route may serve multiple itineraries through the network, not only the performance of that individual route has to be analysed but also the role of the route in the network. For example, when cancelling one route, not only the local passengers on that specific route are lost, but also the transferring passengers that are using that route to connect to another route at a hub airport. It is also possible that a route by itself does not generate value for the airline, but after adding the value of the connecting passengers, the network value of the route is positive. These network effects are not visible when assessing the performance on a route-based analysis.

[1] According to Airline Data Project from MIT Global Airline Industry Program, 2014. The ASK is a measure for airline output, which will be discussed in more detail in the next chapter.

[2] According to SkyTeam Fact Sheet, March 2015.

An understanding of the profitability of a product is something every business must do in order to maximize the value of its assets and deploy those assets in the most efficient manner. In the airline industry, most of the assets are movable. Therefore, a well-designed profitability analysis can provide fundamental information for an airline its decision making processes in the areas of route planning, scheduling, pricing and fleet planning. However, it is also shown that strategic aspects have a significant influence on that decision making process.

Despite of the fact that some research on this subject has already been performed, a network-based performance analysis is still not commonly used by airlines operating a hub-and-spoke network.

1.2 Problem

The research context entails that an airline operating a hub-and-spoke network, such as Kenya Airways, is not capable of fully analyzing the performance of their routes considering their value in the network. Although, some research has already been performed, a more comprehensive network performance assessment framework is lacking. This framework could support a better decision making in the network management of an airline operating a hub-and-spoke network. Furthermore, a more analytical and graphical representation of such a framework could help the airlines to make decisions more intuitive.

1.3 Structure Thesis

The structure of the rest of this thesis is as follows. Based on the previously defined context and problem for this research, Chapter 2 will provide a review of the literature on airline performance measures. This literature review will start with a more thorough description of the initial cause of the problem, namely the hub-and-spoke network together with its main characteristics and the considerations (not) using it. Thereafter, the basic route-based performance measures used in the airline industry will be described, together with the issues arising when using them to assess the performance of a route considering its value in the network, before the existing literature on the measurement of the performance of a route considering its value in the network will be addressed. Subsequently, in Chapter 3, the research design will be elaborated on in terms of the conceptual design and the technical design. Due to the practical background of this research, a practical research - in the form of a questionnaire and interviews - is performed to obtain experiences and information from the field. In Chapter 4, the design and results of this practical research will be discussed. In Chapter 5, the base model for this research will be constructed, which is a duplicate of previous research, but which will serve as a point of supply for the ensuing modelling. In Chapter 6, an improved concept for the analysis of the performance of a route considering its value in the network will be elaborated on. Subsequently, in Chapter 7, the concept from the previous chapter will be used to analyse the performance of a route considering its value in the network under changing capacity. Until this point, the concept and its modelling will be verified upon a sample hub-and-spoke network. In Chapter 8, the model from the previous chapters will be applied to the full Kenya Airways network. In this, for the purpose of validation, a case-study will be discussed. Ultimately, in Chapter 9, the conclusions and recommendations from this research will be presented.

Chapter 2

Literature Review

In this chapter, the fundamental base from the literature is laid. This base should be used in the rest of the research to contribute to the solution of the problem. The problem addressed in this research would not exist if there was no hub-and-spoke network. Therefore, in Section 2.1, the main characteristics and the considerations (not) using such a network are explained. First, in Section 2.2, the standard performance measures used in air transport operations are listed. Thereafter, in Section 2.3, the existing literature in attempting computing the performance of a route considering its value in the network is set out. In Section 2.4, the conclusions from the literature review are drawn to support the design of the research in the next chapter.

2.1 Hub-and-Spoke Network

The main principle of a hub-and-spoke network is providing many individual services feeding passengers into a central airport, where passengers subsequently transfer to another connecting service (Frainey, 1999, p. 162). This principle allows airlines to serve many Origin and Destination (OD) pairs with fewer flight departures, and thereby fewer aircraft, in comparison with a point-to-point network with the same amount of OD pairs (Belobaba, 2009d, p. 163). This can be illustrated using the following example. In Figure 2.1, a point-to-point (1) and a hub-and-spoke (2) network with the same amount of OD pairs are depicted. The point-to-point network uses far more arcs (or flight legs) to connect all the OD pairs than the equivalent hub-and-spoke network.

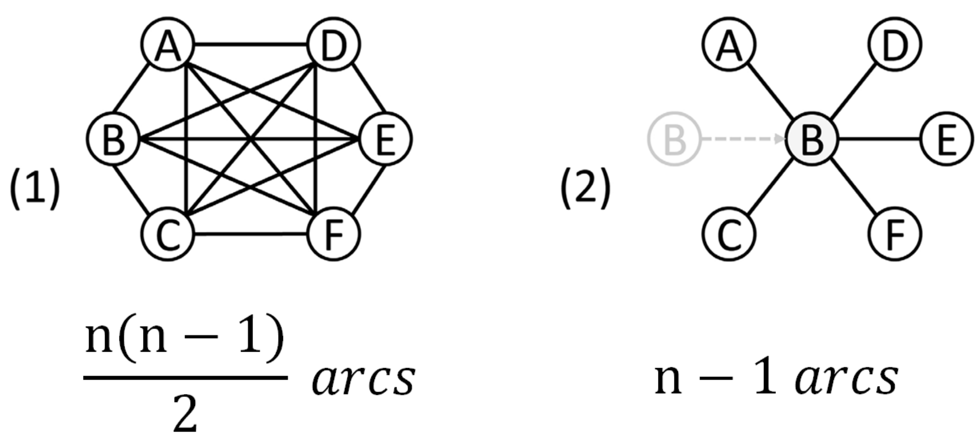

Figure 2.1: Point-to-Point versus Hub-and-Spoke (Adapted from Backker, 2013, p. 16)

An airline operating such a hub-and-spoke network ensures the connection of the transferring passengers at the hub by using a so-called connecting bank at the hub. A connecting bank refers to an operation in which the hub first experiences a wave of incoming flights, after which the passengers and cargo can connect between flights, followed by a wave of outgoing flights (Belobaba, 2009d, p. 163).

Despite of the benefit of requiring fewer flight departures with respect to a point-to-point network with the same amount of OD pairs and the drawback of the dichotomy of airline demand and supply, there are respectively more advantages and disadvantages for using a hub-and-spoke network. In the rest of this section below, the main advantages and disadvantages for using a hub-and-spoke network are discussed.

Advantages

An advantage of using a hub-and-spoke network is that it requires less base locations for its aircraft maintenance and personnel, resulting in reduced costs regarding maintenance activities and personnel. Furthermore, the considerable amount of operations at the hub airport leads to economies of scale (Belobaba, 2009d, p. 165). This latter concept refers to the advantage obtained when long-run average cost decrease with an increase in the quantity produced, which is common in highly capital industries such as the airline industry. For example, the hubs are extremely costly operations. Therefore, airlines have a strong incentive to use their hubs as intensively as possible. The more efficient the airline uses its assets, like its hub, the greater the economies of scale that are achieved. An airline can also achieve economies of scale by operating a minimum number of aircraft types (Vasigh et al., 2013, p. 112-113,124-125).

In operating a hub-and-spoke network, rather than a point-to-point network, also economies of scope and density are realized. The first concept refers to the fact that multiple processes can be more cheaply when done together rather than individually by sharing the resources. In the hub-and-spoke network, this means that one flight leg serves several OD pairs. The concept of economies of density is achieved through the consolidation of operations. In the hub-and-spoke network, this means that the traffic is concentrated on fewer routes than in a point-to-point network (Vasigh et al., 2013, p. 114-116,125-126). These concepts also contribute to the ability for an airline using a hub-and-spoke network to serve low demand markets (Cook and Goodwin, 2008, p. 53).

Disadvantages

One of the downsides of using a hub-and-spoke network is the reduced and uneven utilization of aircraft and crew compared to a point-to-point network. An aircraft serving a spoke relatively close to the hub usually has to stay longer on the ground at the spoke to await the next connecting bank at the hub. Furthermore, the aircraft usually stays longer on the ground than necessary at the hub to allow all passengers and cargo to have adequate connection times (Belobaba, 2009d, p. 165). The concept of a rolling hub could help to increase the utilization of the aircraft as well as the economies of scale by more efficiently using the hub and the aircraft (Vasigh et al., 2013, p. 125).

The use of connecting banks also contributes to the uneven utilization of the hub. Namely, the many resources used during the connecting banks, are underutilized in off-peak times. This contributes to missed economies of scale and the risk of congestion of the hub airport due to the fact that all aircraft arrive at once. These connecting banks are also more sensible to delays and missed connections due to its complexity (Cook and Goodwin, 2008, p. 54).

The concept of a rolling hub could help to increase the utilization of the aircraft and the hub, and thereby the economies of scale, by using these resources more efficient (Vasigh et al., 2013, p. 125). A rolling hub refers to an operation in which the fixed connection banks are eliminated and the flight arrivals and departures are more even distributed. In this, the aircraft do not wait for a fixed time to accommodate connections (Belobaba, 2009d, p. 166).

2.2 Performance Measures

In this section, the basic performance measures used in the air transport industry are explained. The performance measures are subdivided into the operational, financial and others such as quality of service and environmental measures. In this section, the priority is given to the most used performance measures in accordance with an empirical study performed by Francis et al. (2005). The empirical study consisted of a questionnaire among the 200 largest airlines in terms of number of passengers for 2001. The questionnaire had a return rate of 23%, implying that 43 questionnaires were returned. In each of the performance measures, both the suitability to assess the performance of a network and an individual route will be tested.

2.2.1 Operational

In this subsection, the most commonly used operational performance measures are discussed. According to the empirical study of Francis et al. (2005) these measures are the Available Seat Kilometer (ASK), the Cost per Available Seat Kilometer (CASK), the Revenue Passenger Kilometer (RPK) and the Load Factor (LF). Together with the yield, which is not addressed by the empirical study of Francis et al. (2005), these terms are also referred to as Key Performance Indicator (KPI). These KPI will be explained in more detail below.

Available Seat Kilometer

The most common measure in quantifying the airline its output is the ASK. As represented in Equation 2.1, the ASK indicates the number of seats made available per flown distance. Thus, one ASK is defined as one available seat offered for one kilometer (Belobaba, 2009a, p. 48).

$$\text{ASK} = \text{number of seats} \times \text{distance flown in kilometers} \tag{2.1}$$

According to the empirical study of Francis et al. (2005), the ASK is used by 93% of the analyzed airlines. Usually, the airlines record the ASK on a flight leg basis. Despite of the ability of the ASK to give an idea about the capacity and or the distance traveled, it is not a well-defined indicator as objective in optimization.

Cost per Available Seat Kilometer

The CASK, as formulated in Equation 2.2, is indicating the average operating costs per unit of output, in which the latter was already referred to as ASK (Belobaba, 2009a, p. 48). The CASK is also referred to as the unit costs.

$$\text{CASK} = \frac{\text{Cost}}{\text{ASK}} \tag{2.2}$$

In accordance with the empirical study of Francis et al. (2005), the CASK is used by 90% of the airlines, which normally record the CASK on a flight leg basis. Despite of the ability to give an impression about the unit costs, the CASK by itself could be a misleading measure of airline success. Namely, a low CASK is of little value for the airline if yield and/or LF are low as well (Belobaba, 2009a, p. 50).

Revenue Passenger Kilometer

As the ASK is representing the capacity offered, the RPK is measuring the capacity that is used. As represented in Equation 2.3, the RPK indicates the number of paying passengers transported per flown distance. Thus, one RPK is defined as one paying passenger transported for one kilometer (Belobaba, 2009a, p. 48).

$$\text{RPK} = \text{number of passengers} \times \text{distance flown in kilometers} \tag{2.3}$$

According to the empirical study of Francis et al. (2005), the RPK is used by 95% of the analyzed airlines. Usually, the airlines record the RPK on a flight leg basis. Despite of the ability of the RPK to give an idea about the number of passenger transported and or the distance traveled, it is not a well-defined indicator as objective in optimization.

Yield

The yield, as formulated in Equation 2.4, is a measure of the average fare paid by all passengers per distance flown (Belobaba, 2009a, p. 48). The yield could also be presented by the acronym RRPK, but this is not commonly used in the airline industry. As the airlines document the yield on a flight leg basis, it is not intuitive how it is composed with respect to the measurement of the revenue on a flight leg basis.

$$\text{Yield} = \frac{\text{Revenue}}{\text{RPK}} \tag{2.4}$$

In the questionnaire of Francis et al. (2005), the yield is not addressed. The yield is generally a poor indicator of airline profitability by itself. For example, a high yield could indicate that only a few passenger pay a very high price, while having a low LF which does not cover the total operating costs (Belobaba, 2009a, p. 50). As a consequence, a high yield together with a high LF could gain more information with respect to the profitability.

Load Factor

The ratio between the capacity used and the capacity offered is called the LF, which is thus representing the proportion of the airline its output that is consumed. From Equation 2.5, it can be seen that the standard LF is thus the ratio of the RPK over the ASK. The value of the LF varies between zero and one (Belobaba, 2009a, p. 48-49).

$$\text{LF} = \frac{\text{RPK}}{\text{ASK}} \tag{2.5}$$

In accordance with the empirical study of Francis et al. (2005), the LF is used by all the analyzed airlines. This indicator represents the LF of a single flight or flight leg. However, assuming the airline is operating more than one flight or flight leg, there is a need to express a total average LF of a network of flights. The most common ways to compute this are the Average Leg Load Factor (ALLF) or the Average Network Load Factor (ANLF). Both measures are used in different ways. The ALLF, as formulated in Equation 2.6, is used for the analysis of passengers against capacity on a series of departures on multiple flights or flight legs (Belobaba, 2009a). The ANLF, as formulated in Equation 2.7, is used for reporting with respect to financial and traffic information of network wide airline performance (Belobaba, 2009a).

$$\text{ALLF} = \frac{1}{n}\sum_{i=1}^{n} \text{LF}_i \tag{2.6}$$

$$\text{ANLF} = \frac{\sum_{i=1}^{n} \text{RPK}_i}{\sum_{i=1}^{n} \text{ASK}_i} \tag{2.7}$$

The LF, or any of its equivalents above, tells us little about the profitability of an airline. The variant of the LF that could help the airline to gain some information with respect to the profitability, is the so-called Break Even Load Factor (BELF). The BELF, as formulated in Equation 2.8, is the average percentage of seats that has to be filled on an average flight at the current average fares for the airline passenger revenue to break even with the airline operating costs (Goodfriend, 2003).

$$\text{BELF} = \frac{\text{CASK}}{\text{Yield}} \tag{2.8}$$

The formula for the BELF is derived from Equation 2.5 with substitution of Equation 2.2 and Equation 2.4, by assuming the revenues is equal to the cost.

Other

The other operational performance measures used by at least half of the respondent airlines (Francis et al., 2005, p. 212) are the On-Time Performance (OTP) per operation, the average fleet age, the average turnaround time, the labour cost as a ratio of the total operating costs and the daily aircraft utilization.

The OTP per operation is considered to be most relevant. In accordance with the empirical study of Francis et al. (2005), the OTP per operation is used by all the analyzed airlines. Some intensive research on this subject has been performed (Schellekens, 2011; Enk, 2010; Buutfeld, 2012; Goethem, 2013; Bos, 2013; Schotte, 2014; Wormer, 2013). The main drivers for the OTP per operation are considered to be the network connectivity, the turnaround process, the airport and Air Traffic Control (ATC) restrictions, the technical state of the aircraft and the weather conditions (Schellekens, 2011, p. 9). Therefore, the average turnaround time and partly the average fleet age are considered to be part of the OTP per operation.

Furthermore, the average fleet age and the daily aircraft utilization can be used as a metric in the fleet planning in favor of the unit costs. This will be more elaborated on in the next section. The labour cost as a ratio of the total operating costs is not considered to be relevant.

2.2.2 Financial

In this subsection, the most commonly used financial performance measures are discussed. The most used financial performance measures, in accordance with the empirical study of Francis et al. (2005), are the operating costs, the operating revenue and the operating profit. These will be explained in more detail below.

Operating Cost

The operating costs of an airline are normally broken down in order to classify the different types of cost. The cost breakdown provided in the literature is ambiguous. On the one hand, the traditional approach from the International Civil Aviation Organization (ICAO) is used (Doganis, 2010), while on the other hand the airline costs can be categorized among administrative and functional costs (Belobaba, 2009c). The manner in which an airline breaks down and categorizes its costs depends on the purpose for which they are being used. For example, a cost breakdown developed for general management and accounting purposes may be of little help in making operating decisions. Therefore, an airline tends to break down its cost in two or more different ways depending on the purpose for which they are being used (Doganis, 2010, p. 64).

The structure of airline cost described by Doganis (2010) is broadly based on the cost categorization traditionally used by the ICAO. In Figure 2.2, the traditional ICAO cost breakdown is presented.

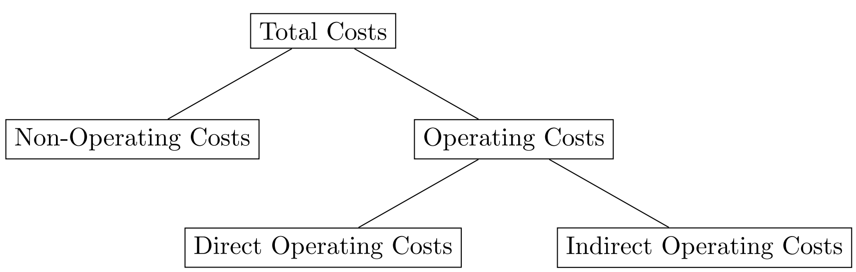

Figure 2.2: ICAO Cost Breakdown (According to Doganis, 2010, p. 66)

In the upper division, the total costs are broken down into non-operating and operating costs. The non-operating costs include the gains or losses from the retirement of property or equipment, the interests paid on loans or received on deposits, the profits or losses from affiliated companies and the governmental subsidies or taxes (Doganis, 2010, p. 65). These non-operating items will not be further taken into account in the remainder of this section.

The operating costs are further subdivided into Direct Operating Costs (DOC) and Indirect Operating Costs (IOC). In theory, the distinction between these two cost categories is fairly clear. The DOC should include all operating costs that are associated with, and dependent on, the type of aircraft being operated. The IOC are all those costs which will remain unaffected by a change of aircraft type, because they are not directly dependent on aircraft operations (Doganis, 2010, p. 66-67). In Appendix B, the more detailed division of the operating costs among the DOC and the IOC is listed.

The traditional cost classification method discussed above is of considerable value for general management and accounting purposes. However, the main disadvantage of this method is the limited use for an economic evaluation of a particular route. In order to assist in this kind of decision making, the concept of escapability is introduced. The degree of escapability is determined by the time period required before a particular cost can be avoided (Doganis, 2010, p. 78). The most usual means airlines use to represent the concept of escapability in their cost classification method is by taking the elements of cost generally accepted as the DOC, together with some of the IOC, and further subdivide them into fixed and variable costs (Doganis, 2010, p. 79). The variable costs are costs which are directly escapable in the short term, while the fixed costs are the costs which in the short term do not vary with particular flights (Doganis, 2010, p. 79). In Appendix C, one possible approach for the partition of the DOC, and some elements of the IOC, among the variable and fixed costs is more elaborated.

The partitioning of airline cost described by Belobaba (2009c) is based on the definition of functional or administrative cost categories. In Figure 2.3, these two cost allocations are illustrated. Although, the administrative approach is consistent with general accounting principles and the functional approach is useful for cost comparisons across airlines, the approach do not allow for more detailed analysis of the airline its specific operations (Belobaba, 2009c, p. 115-116). Therefore, these cost allocation methods will no longer be used in the remainder of this report.

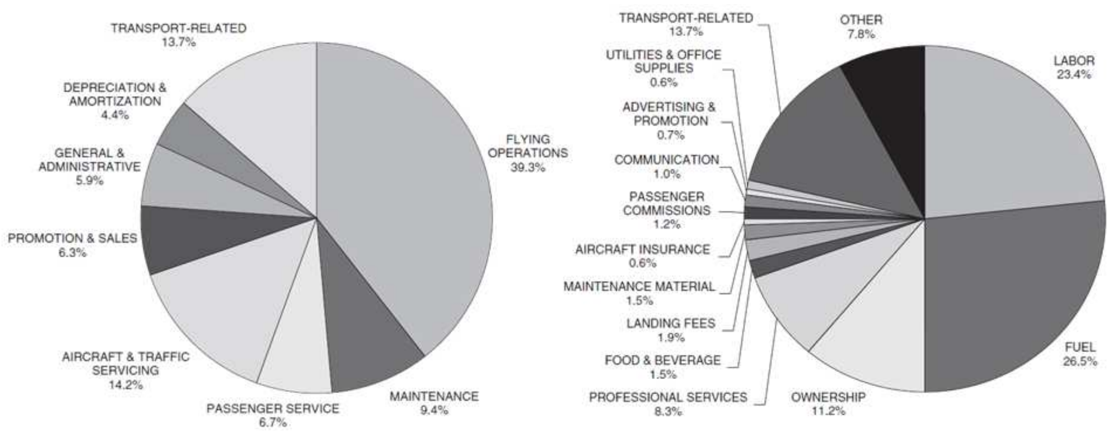

Figure 2.3: Functional versus Administrative Cost Categorization (Belobaba, 2009c, p. 117,115)

In accordance with the empirical study of Francis et al. (2005), the operating costs are used by 95% of the analyzed airlines. The majority of the information with respect to the operating costs is already gathered by the airline its accounting department. However, some of the costs are collected at the flight level, while others can not directly be assigned to a flight leg and need to be allocated. This allocation is typically based on offered capacity (ASK), block hours or number of landings or departures (Frainey, 1999, p. 165). The incremental costs are those costs that an airline incurs by offering a specific service. These costs should not be shared by the greater system, because those costs are driven by the activity of the particular service and not the system (Frainey, 1999, p. 167).

Operating Revenue

The operating revenue of an airline is primarily based on the passenger revenue, namely the revenues generated from the price paid by the passengers for their tickets. In addition, some airlines also generate revenue from cargo, such as belly cargo. Many airlines, however, fail to emphasize the importance of revenues generated from cargo. The additional revenue generated by cargo may turn an unprofitable flight into a profitable one (Frainey, 1999, p. 163). The passenger revenue of an airline is controlled by the pricing and revenue management. The pricing refers to the determination of the price levels, in combination with various service amenities and restrictions, for a set of products in an OD market. The revenue management is the following process of determining how many seats to make available at each price level (Belobaba, 2009b, p. 73).

The airline prices are defined for an OD market, not for an airline its flight leg. This relates to the dichotomy of airline demand and supply, which has been addressed in the previous chapter. Therefore, markets are distinct and separate, which means that the prices in one market can mostly not be related to the prices in another market. The prices in an OD market primarily depend on the volume and characteristics of the demand in the market, the nature of airline supply in the market and the competitive characteristics in the market (Belobaba, 2009b, p. 74).

The majority of the airline pricing strategies reflect the principle of differential pricing. The use of differential pricing allows the airline to explore the consumers its willingness to pay by presenting a range of product options with particular restrictions and product convenience. The willingness to pay can be understood as the maximum price that each consumer is willing to pay for a specified product. The use of the practice of differential pricing is an attempt to make the consumer with a higher willingness to pay purchase the product with fewer restrictions and more product convenience. In theory, the total revenue in an OD market is maximized when each consumer pays a different price equal to its willingness to pay. In practice, however, the degree of success of the use of differential pricing depends on the airline its capability to recognize the different demand segments (Belobaba, 2009b, p. 78-79).

After the application of the principle of differential pricing, the revenue management department of an airline determines the number of seats to make available at each price level on a flight. The main principle of the revenue management is to protect seats for high-fare passengers, which normally book their tickets later than the low-fare passengers. The revenue management is the last chance for an airline to maximize its revenue. On the contrary, too much emphasis on yield can lead to overly severe limits on low-fare passengers and low LF, while too much emphasis on LF will decrease the yield. In summary, revenue maximization is the appropriate target, and since the fixed operating cost associated with a flight represent a significant share of the total operating costs, the objective of revenue maximization is effectively one of profit maximization (Belobaba, 2009b, p. 88-89).

Although, the previously described revenue management is designed to maximize revenues on each flight, this method does not maximize the revenues of the total network of the airline. In general, a seat can be taken by a passenger flying only one short-haul leg or by a passenger on a long-haul connecting itinerary. In the current revenue management, a short-haul leg with a dominant local demand can create a bottleneck that prevents a long-haul connecting passenger to have a seat on that flight leg, even though this passenger has a higher network revenue with respect to the local flight leg revenue. Therefore, airlines are evolving to the so-called 4^{th} generation revenue management system. This system provides OD control, in addition to all the existing revenue management capabilities, which gives the airline the capability to manage its seats by the revenue value of the passenger its OD itinerary on the airline its network rather than a flight leg. One of the current OD control mechanisms is the bid price control. In the bid price control mechanism, each flight leg in the network is assigned a bid price which represents the minimum acceptable fare for a passenger on that flight leg. In the request of a passenger for a certain itinerary for a certain price, the availability for the ticket will be determined based on the bid price for that itinerary (Belobaba, 2009b, p. 105-107). Since the revenue management is at the end of the network management process, at a stage in which the decisions regarding the network and it routes already have been made, this research will not contribute to an OD control mechanism in the revenue management process. However, this research can address the feasibility to use the principle of the bid price control in the development of a decision-making framework regarding the performance of a route considering its value in the network.

According to the empirical study of Francis et al. (2005), the operating revenue is used by 93% of the analyzed airlines. The revenue is mostly already gathered at the flight coupon level by the airlines its accounting department (Baldanza, 1999, p. 152). The operating revenue associated with a flight leg consists of two points of supply, namely the revenue from local passengers and the revenue from transferring passengers to connecting flight legs. The first source is straightforward and can easily be collected from the revenue data. In case of the second source a proration method is needed to split the OD revenue into its components (Baldanza, 1999). The two revenue proration methods widely used in the airline industry are the full fare and the mileage-based prorated fare allocation. In the first method, each flight leg in the itinerary is assigned the full revenue of the itinerary. In the second method, each flight leg in the itinerary is assigned a fraction of the total revenue, proportional to the ratio of the flight leg its length to the total length of the itinerary (Barnhart et al., 2002).

The operating revenue associated with a particular service is also referred to as the incremental revenue. This means, that if the particular service is being canceled, that the associated revenue is lost. However, if the airline is operating multiple services in the same market, it is possible to recapture some of the revenue from the cancellation of the individual service on alternative itineraries (Baldanza, 1999, p. 149).

Operating Profit

The profit is equal to the revenue minus the cost. In Equation 2.9, the basic profit equation used in the airline industry is presented (Belobaba, 2009a, p. 49). Each of the terms in this equation are explained in the previous subsection.

$$\text{Operating Profit} = \text{RPK} \times \text{Yield} - \text{ASK} \times \text{CASK} \tag{2.9}$$

As explained in the previous subsection, the individual terms in the basic airline profit equation can be misleading measures for the performance of an airline. No single term can be varied without affecting other terms, and in turn the overall profit (Belobaba, 2009a, p. 49-50).

The operating profit is one of the leading KPI used in the airline industry. In accordance with the empirical study of Francis et al. (2005), the operating profit is used by 93% of the analyzed airlines. The operating profit is a reliable performance measure for as well the overall network as a route in that network. However, as may be clear at this point, obtaining the profit of an individual route in a greater system is a challenge in the airline industry.

Other

The other, less used, financial performance measures considered by the empirical study of Francis et al. (2005) are the cash flow, the return on capital employed, the debt to equity ratio and the revenue to expenditure ratio. Only those performance measures which are used by at least the half of the respondent airlines on the empirical study of Francis et al. (2005) are considered here. Despite of their importance in the general accounting principles of an airline, these terms are not considered to be relevant for the profitability analysis of a flight leg in a hub-and-spoke network, since the terms can not be assigned to the operation of a single flight leg.

2.2.3 Other

The questionnaire of Francis et al. (2005) also addresses other less commonly used performance measures, which are categorized as quality of service and environmental performance measures. Those performance measures, which are used by at least the half of the respondent airlines, will be addressed below.

The quality of service performance measures used by at least the half of the respondent airlines on the empirical study of Francis et al. (2005) are the level of service, the baggage delivery time, the lost baggage, the check-in waiting time and the consumer complaints. Despite of the importance for the costumer loyalty, most of the terms can not be assigned to the operation of a single flight leg. Particularly, the consumer complaints could help to identify the performance of a route. However, until it is proven that the consumer complaints can be assigned to the operation of a particular flight leg, this performance measure will be excluded from this research.

The environmental performance measures used by at least the half of the respondent airlines on the empirical study of Francis et al. (2005) are the percentage of departures on track and the fuel consumption and efficiency in terms of grams per Revenue Tonnes Kilometer (RTK). The RTK is the weight-based equivalent of the RPK. Since this is an environmental performance measure, it is assumed that a departure on track refers to the geographical sense with respect to the Standard Instrument Departure (SID), in which it minimizes the emissions for surroundings. From this, the percentage of departures on track will be excluded from this research. The fuel consumption and efficiency could be of more interest for the analysis regarding the performance of a route. However, until it is proven that the fuel consumption and efficiency can be assigned to the operation of a particular flight leg, this performance measure will be excluded from this research.

2.3 Network Performance Measures

In this section, the existing contributions in the literature to compute the performance of a route considering its value in the network are presented. There is not much literature available on this subject, probably due to the practical background of this research. The available contributions will be presented in chronological order. The attempt to find applications (Dall'asta et al., 2006; Lordan et al., 2015; Verma et al., 2014), also in other industries (Ouyang et al., 2015; Guihaire and Hao, 2008), turn out to concern complex network theories. However, since this research aims at the development of a network performance assessment framework for a better and more intuitive decision making process in the network management of an airline operating a hub-and-spoke network, the complex network theories are disregarded in this phase of this research.

The existing network performance measures will be tested upon a sample network, as depicted in Figure 2.4, which consists of one hub (A) with two spoke services (A-B-A and A-C-A), one tag-end service (A-F-G-F-A) and one round-robin service (A-D-E-A). A tag-end service is a flight routing with a segment beyond the main spoke segment, that is not a spoke to another hub, which is normally operated in two directions. A round-robin service is a flight routing that starts and ends at the same point (Francis et al., 2005, p. 162). In the sample network, it is assumed that the round-robin service is operated clockwise.

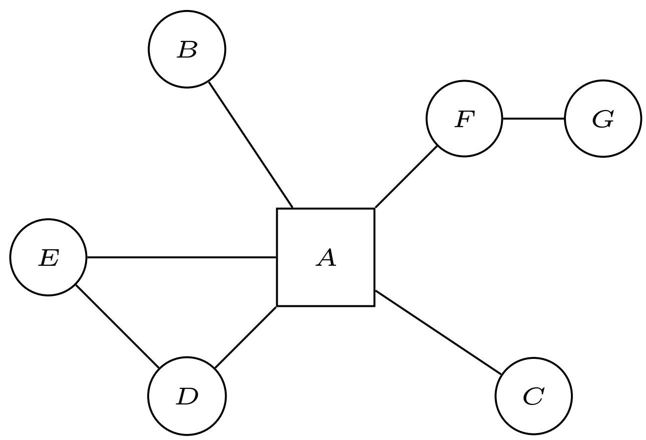

Figure 2.4: Sample Network

The sample network is accompanied with the basic performance measures as described in Section 2.2. Namely, the ASK, the CASK, the RPK, the LF, and the operating costs are normally provided on the flight leg level, while the operating revenue is normally provided in form of the flight coupon level. It is assumed that the flights in the sample network only carry passengers.

2.3.1 Measuring Airline Profitability

The literature proposed by Baldanza (1999) is addressing the measurement of the profitability of an airline its network, since it is a complicated and often misunderstood process. It is stated by Baldanza (1999) that defining which costs and which revenues to ascribe to a flight leg in a greater system is necessary to truly understand where the network is making and losing money. From this, the fundamental problem in the literature from Baldanza (1999) corresponds with the fundamental problem from Belobaba (2009a) as addressed in the previous chapter.

The profitability data from the airline should be composed in such a way that it is possible to interpret the profit contribution of a subset of the airline its network correctly and support decision making rather than financial reporting. However, it is not intuitive which revenues and costs to take into account when studying the profitability of a piece of the network, and typical accounting rules are not geared to answer such questions.

One building block of any airline profitability analysis is the measurement of the profitability of an individual flight leg in a greater system. In accordance with the method proposed by Baldanza (1999), the profitability of the flight leg A-B (see Figure 2.4) will be measured. This measurement starts with the measurement of the incremental revenues and incremental costs for that flight leg.

The incremental revenue associated with the flight leg A-B comprises two sources; the revenue from the local passengers on the flight leg A-B, and the revenue from the transferring passengers on flight leg A-B connecting in hub A to/from one of the other flight legs. The remaining part regarding the measurement of the incremental revenue has already been addressed in Subsection 2.2.2 and will not be further addressed here.

According to the cost breakdown applied by Baldanza (1999), the incremental costs for the measurement of the profitability of an individual flight leg in a greater system can be defined at three basic levels; variable flight costs only, variable flight costs plus aircraft ownership costs, and variable flight costs plus aircraft ownership costs plus overhead and non-operational costs. Using these three cost levels and the revenues described above, three basic profitability measures can be defined. In Table 2.1, these three basic profitability measures are listed.

Measurement	**Revenues Included**	**Costs Included**
Variable segment profitability	Local revenue *plus* proration of connecting itineraries	Variable flight costs
Variable plus ownership profitability	Same	Variable flight costs *plus* aircraft ownership costs
Fully allocated segment profitability	Same	Variable flight costs *plus* aircraft ownership costs *plus* overhead and non-operational costs

Table 2.1: Basic Measures of Profitability (Adapted from Baldanza, 1999, p. 151)

Each of the three basic profitability measures above can be combined with a network component to include the contribution of the network. In the network costs, a distinction can be made between real and opportunity costs. The real network costs of the flight leg A-B refer to the costs of processing connecting passenger from B at A, as well as the incremental costs of having those passengers, instead of an empty seat, on one of the connecting segments. The network opportunity costs attempts to model the revenue lost by connecting passengers in A from B in seats that could have otherwise been sold to local passengers from A or potential alternative connection points. In Table 2.2, the two possible network components are listed.

Network Component	**Revenues Included**	**Costs Included**
Basic network contribution	Remaining proration of connecting itineraries (not used above)	Variable network costs
Basic network contribution with opportunity costs	Same	Network variable costs *plus* network opportunity costs

Table 2.2: Network Connectivity Components (Adapted from Baldanza, 1999, p. 151)

In putting the basic measures of profitability and network components together, nine possible profitability measures are created by taking one of the three basic profitability measures with none, or one of the two, network components. In Appendix D, an example of these possible profitability measures is calculated numerically for the flight leg A-B. The variable segment profitability with basic network contribution is proposed to be the suitable profitability measure for short term scheduling optimization, and the variable plus ownership profitability with basic network contribution is listed to be appropriate for middle-term scheduling optimization (Baldanza, 1999, p. 152).

2.3.2 Network Profitability Analysis

The literature proposed by Frainey (1999) is addressing a range of profitability analysis issues regarding revenues, costs and profitability metrics. This source is coming immediately after the literature from Baldanza (1999), and for the sake of uniformity, these sources are presented in the identical sequence as found in the literature. As already mentioned by Baldanza (1999), the traditional profitability analysis metrics focus on the associated accounting-based revenues and costs of a particular flight leg without regard to the entire network as a whole. However, since airlines are facing increasing competition and financial pressure, airlines are constantly looking for new ways to understand and measure the profitability of a particular flight leg. Therefore, Frainey (1999) proposes more sophisticated profitability measures that also take into account the directional flow of the passengers through the network.

In terms of revenues, Frainey (1999) is addressing the passenger revenue proration and is proposing flow revenue. The proration of the passengers revenue has already been addressed in Subsection 2.2.2 and will not be further addressed here. The flow revenue is a more specific term for the incremental revenue which also provides information about the directional flow of the passengers through the network. According to Frainey (1999), this is necessary to understand the direction of the passengers its itinerary. The flow-up revenue is the revenue generated on an incoming service, whereas the incoming service considers the onward connecting service to provide flow-down revenue to it. In Table 2.3, the elements of revenue for each of the segments from Figure 2.4 are listed.

Segment	Flow-up Revenue	Local Revenue	Flow-down Revenue
A-B	C-A, F-A, E-A	A-B	n.a.
B-A	n.a.	B-A	A-C, A-F, A-D
A-C	B-A, F-A, E-A	A-C	n.a.
C-A	n.a.	C-A	A-B, A-F, A-D
A-F	B-A, C-A, E-A	A-F	F-G
F-G	A-F	F-G	n.a.
G-F	n.a.	G-F	F-A
F-A	G-F	F-A	A-B, A-C, A-D
A-D	B-A, C-A, F-A, E-A	A-D	D-E
D-E	A-D	D-E	E-A
E-A	D-E	E-A	A-B, A-C, A-F, A-D

Table 2.3: Revenues per Segment of Sample Network (see Figure 2.4)

The flow revenue brings up the issues of double counting. The principle of double counting refers to the fact that revenues are counted twice, once as local revenue and a second time as flow revenue. According to Frainey (1999), it is necessary to double count revenue in order to calculate the contribution of a flight leg in a greater system, since all the flight legs in a hub-and-spoke network support each other. In other words, double counting is necessary to properly understand the dynamics of a linked network (Frainey, 1999, p. 165). However, as this can be outdated, this research can address the feasibility to avoid the principle of the double counting in the development of a decision-making framework regarding the performance of a route considering its value in the network.

The analysis of the costs associated with a flight leg in a greater system is concerned with the pooling and allocation of costs, the subdivision of the costs among the variable and fixed costs, the identification of the incremental costs and the effects of spill. The pooling and allocation of costs, the subdivision of the costs among the variable and fixed costs, and the identification of the incremental costs have already been addressed in Subsection 2.2.2 and will not be further addressed here. The spill is the difference between the number of passengers that want to fly a specific flight leg and the number of passengers that actually fly the flight leg. The effect of spill refers to the principle of spilling passengers by accepting a seat for another passenger, or the other way around. For example, in the sample network from Figure 2.4, one connecting passenger on the itinerary B-C spills two local passengers on the itineraries B-A and A-C, while two local passengers on the itineraries B-A and A-C spill one connecting passenger on the itinerary B-C. According to Frainey (1999), the spill is an opportunity cost that arises from the airline its network, which is intended to increase as the airline increases its reliance on connections. In the case of the cancellation of the service on a particular flight leg, the effect of spill could help to replace the lost passengers on a connecting flight by passengers from other destinations (Backker, 2013, p. 43).

The six profitability metrics proposed by Frainey (1999) are the Variable Earnings (VE), the Net Earnings (NE), the Variable Earnings plus Flow contribution (VEF), and the Net Earnings plus Flow contribution (NEF). These will be elaborated below together with their applications.

The VE is defined as the local on-board revenue minus the local variable costs. This metric does not take into account aircraft ownership costs or any other fixed costs. The VE is believed not to be the best metric for measuring network profitability, since it does not capture all costs, and it forces a short-term profitability mentality rather than a long-term profitability viewpoint. Using VE is appropriate only in situations of true marginal flying (Frainey, 1999, p. 168-169). The equivalent of the VE, that also includes the flow revenues and flow passenger variable costs, is the VEF (see Equation 2.10). In this, the revenues are double counted, but so are some of the costs (Frainey, 1999, p. 169). The general principle of the VEF seems rather vague, since the VE is considered to be a monetary value, while the rest of the terms are considered to be a ratio of the revenues and the passenger variable costs. The idea is to increase the VEF in case of increasing flow-up revenues with respect to the flow-down equivalent, or to decrease the VEF in case of increasing flow-up passenger variable costs with respect to the flow-down equivalent. The rationale behind this is not intuitive and not considered to be relevant for this research. Therefore, the VEF will not be further addressed in this research.

$$\text{VEF} = \text{VE} + \frac{\text{Flow-up Revenue}}{\text{Flow-down Revenue}} - \frac{\text{Flow-up Passenger Variable Costs}}{\text{Flow-down Passenger Variable Costs}} \tag{2.10}$$

Unlike the VE, the NE includes both variable and fixed costs. This is believed to be the proper measure for understanding the true ongoing profitability of any segment, and puts each segment on an equal basis for comparison. The equivalent of the NE, that also includes the flow revenues and flow passenger variable costs, is the NEF. However, since the principle of the NEF is the same as for the VEF, the NEF will not be further addressed in this research.

Furthermore, this source is explicitly addressing the evaluation of the profitability of a tag-end service. It is stating that all the revenues, which are prorated to the main spoke segment, should be also be assigned to the segment beyond the main spoke segment. In terms of the costs, all the incremental costs incurred at the rear end airport should also be assigned to the segment beyond the main spoke segment. This seems plausible, since the revenues and costs would not be incurred if the tag-end service was not operated.

2.3.3 Relevance of Route and Network Profitability Analysis

The literature proposed by Niehaus et al. (2009) is addressing the implementation and the structure of the Route Profitability Analysis (RPA) and the Network Profitability Analysis (NPA) of passenger airlines. The RPA assumes a point-to-point network in which the route result is independent from any other route or flight leg within the network. On the other hand, the NPA examines the analyzed route as an element of a greater system, since passenger itineraries in a hub-and-spoke network often comprise multiple flight legs. The aim of the NPA is to show the network profit contribution of the flight leg, by which it also includes costs and revenues from connecting passengers in the calculation of the route network result (Niehaus et al., 2009, p. 175).

The principle of the RPA and the NPA is to allocate all revenues and costs to a single flight leg. In this allocation, several levels are used, which allows for analyzing the sources and areas of profitability in addition to the mere profitability of a flight leg. These levels are referred to as Profit Contribution (PC) levels. In Table 2.4, the interpretation of each of the PC levels is listed.

Profit Contribution Level	**Interpretation**
PC1	An indicator for the ability of a flight to cover its variable costs and contribute to the incurred fixed costs. Therefore, if PC>0, the flight is economically feasible. Consequently, PC1 indicates the absolute bottom price for a flight and determines its short-term viability assuming that capacity and other resources are fixed.
PC2	An indicator for the profitability of the aircraft being operated. Consequently, PC2 allows an analysis of the impact on cost and revenue of assigning different aircraft types and is the basis for decisions related to capacity and flight schedule.
PC3	An indicator for the profitability of the handling and station operations. Consequently, PC3 is the basis for major changes in the route structure.
PC4	An indicator for the profitability of the sales organization. However, this information bears little relation to the flight operations or the network structure as such.

Table 2.4: Interpretation of PC Levels (According to Niehaus et al., 2009, p. 177)

Subsequently, the design of the RPA and the NPA both have the same logic. In Figure 2.5, both methods are depicted. The symbol "./." is referring to minus. The starting point of both methods is the local on-board revenues. This includes the ticket revenues as well as revenues from excess baggage, on-board sales, fuel and security surcharges, belly cargo and mail (Niehaus et al., 2009, p. 176). Thereafter, in the RPA, the route result is obtained with various local costs. On the contrary, in the NPA, the network result is obtained with the allocation of various connecting revenues and costs. In terms of revenues, only the OD ticket revenues are considered, while on the cost side only the passenger variable costs of the connecting passengers are used. In the design of the NPA, as depicted in Figure 2.5, the vertical and the horizontal method can be distinguished. Both methods have the same network result. The vertical method takes into account the connecting revenues and costs after the calculation of the RPA its route result, while the horizontal method considers the connecting revenues and costs per level of the RPA. As a consequence, in the horizontal method, it is possible to consider the network-PC of each level.

After the conceptual development of the RPA and the NPA, an empirical study was also conducted by Niehaus et al. (2009) to gain an in-depth understanding of the implementation of these methods in the network management processes of an airline. In this paper, the network management processes are referring to the phases strategic network planning, operational network planning and revenue management. The empirical study consists of a questionnaire with 49 questions among the 100 largest airlines, operating a hub-and-spoke network, in terms of revenues for the fiscal year 2004. The questionnaire had a return rate of 30%, implying that 30 questionnaires were returned.

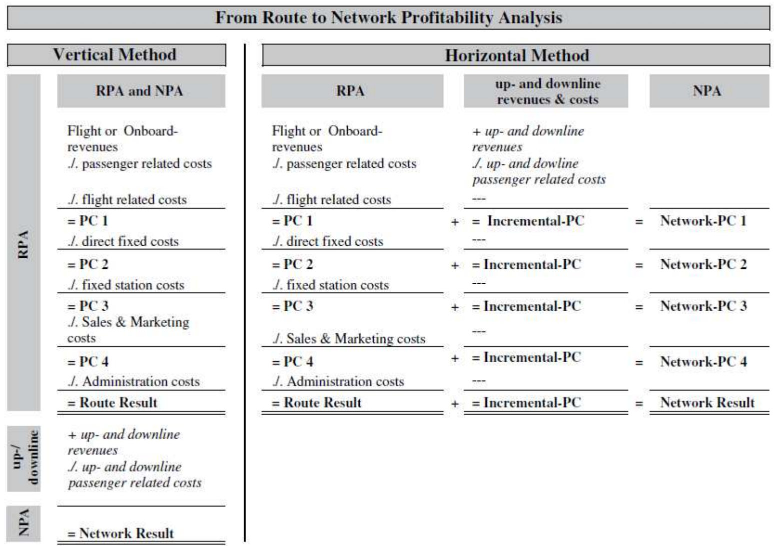

Figure 2.5: From RPA to NPA (Niehaus et al., 2009, p. 177)

In the first place, the survey reveals that 86.8% of the airlines apply a monthly analysis, while 9.9% weekly and 3.3% quarterly. Furthermore, ten of the airlines state applying a RPA, when in fact twenty also implement a NPA. In this, a positive correlation between the size of the airline by revenue and implementation of NPA was observed.

In terms of the integration of the various items of revenue and cost, the survey shows that only 30% of the airlines focus solely on operating items, while the other 70% also takes into account the non-operating revenues and costs. In Table 2.5, the used elements of revenue besides the ticket revenues are shown. This disproves the statement from Frainey (1999), that many airline fail to emphasize the importance of revenues generated from belly cargo.

Revenue	Number of Airlines	Share of Airlines
Belly Cargo	30	100%
Excess Baggage	28	93.3%
Fuel Surcharge	25	83.3%
Security Surcharges	20	66.7%
Sales On Board	14	46.7%

Table 2.5: Included Revenues by Airlines in the RPA/NPA (Adapted from Niehaus et al., 2009, p. 178)

In terms of the method used to allocate the connecting revenues and costs to a flight leg, the survey shows that 75% of the airlines use the mile-age based proration method to allocate the revenues. The rest of the airlines use the full-fare proration method for the allocation of the revenues. In Appendix E, the main drivers used for the allocation of the costs, which can not directly be assigned to a flight leg, are shown.

In terms of the use of the connecting revenues and costs, to end up with the NPA, all airlines stated to use revenues prorated with one of the methods as described earlier. On the cost side, 43.7% of the analyzed airlines indicated to only consider the passenger related costs as connecting costs, while another 43.7% additionally deducts the flight related costs and the rest of 12.6% also takes into account aircraft ownership costs. Furthermore, 30% of the airlines stated to apply the concept of network opportunity costs in the NPA.

In case of a negative PC1, all airlines stated to discontinue the route, since it not covers its variable costs. In case of a positive PC1 together with a negative PC2, airlines maintain the route, since it at least covers the variable costs and a part of the assigned direct fixed costs. As a consequence, the airline will make adjustments in aircraft type or frequency, or activities regarding marketing and pricing. In case of a negative route result, around 40% of the airlines stated to cancel the route instantly, while in fact around 60% of the airlines indicated to maintain the route due to long-term strategy to enter a market or competitive situations. On the contrary, in case of positive route result, the airlines make an assessment of introducing larger aircraft and/or increasing frequencies. The route result is used as a basis in decision making in route and company strategy. The airlines that use NPA use the same answers, but in the case the RPA indicates a negative result and the NPA a positive result, the airlines stated not to eliminate the route but to maintain it.

The airlines were also asked to identify the relevance of the RPA/NPA for the analyses in the network management processes and to give feedback on the profitability analysis methods. The most relevant use is the identification of loss generating routes. The main limitation is considered to be the correct interpretation of output information. The two strengths which are similarly relevant are the possibility for monitoring of the overall profitability of the network as well as the profit contribution of single routes. This corresponds with the expectations for this research.

2.3.4 Modelling Network Value

In the predecessor of this research (Backker, 2013), several techniques are used and or proposed to examine the performance of a route considering its value in the network. These techniques are referred to as the Network Value (NV), the Local versus Connecting (LC) passenger ratio, the Traffic Concentration (TC) index and the Feeder Concentration (FC) index. Finally, the NV and the TC index are combined in the Network Risk Matrix (NRM) to cluster routes and define their risk and according strategy.

Network Value

The first metric proposed by Backker (2013) is the NV. The principle of the NV is to sum the revenues from all ODs that make use of the Operation of Interest (OI) and subtract a fraction of the costs of all other routes in the network. In this, not only the connecting revenues are prorated, but also the connecting costs are used. In Equation 2.11, this NV is formulated. The calculation of the revenue makes use of the full fare proration method (see Subsection 2.2.2) which means that the full revenue of each OD, which also makes use of the OI, is summed. The fraction of the costs is equal to the number of passengers on the route, which also make use of the OI, over the total number of passengers on that route. In this, the fraction is zero of none of the passengers on a route also make use of the OI.

$$NV_{OI} = \sum_{OD=1}^{n} R_{OD,OI} - \sum_{route=1}^{m} \frac{pax_{route,OI}}{pax_{route}} C_{route} \tag{2.11}$$

After the calculation of the NV, also a decision making framework (see Figure 2.6) is applied by Backker (2013) to examine the maintainability of a route. The NV from Equation 2.11 is used as a starting point in this framework. In the case of a positive NV, the route should be maintained. After a negative NV, however, some strategic aspects are considered to justify the operation of the route. The strategic aspects addressed by Backker (2013) are capturing developing markets, historic and marketing reasons, corporate strategies, Joint Venture (JV) and code share agreements, maintaining flying and landing rights, possible negative operational effects, and corporate contracts. The strategic aspects to be used in the decision making framework were determined using interviews. The strategic aspects used are capturing developing markets, JV and code share agreements, and maintaining flying and landing rights. The main characteristic of these strategic aspects is that these can not be measured quantitatively and therefore an individual approach rather than a generic method is advised (Backker, 2013, p. 37-40).

In the case of the cancellation of a route, it is assumed by Backker (2013) that all the traffic on that route is lost. Although, traffic can no longer be carried on that canceled route, in some special cases it is not completely lost. These special cases refer to the principles of recapture (see Subsection 2.2.2) and spill (see Subsection 2.3.2). According to Backker (2013), however, these principles depend on specific situation for which a generic rule is not possible to define. Therefore, these principles will not be further taken into account in this research.

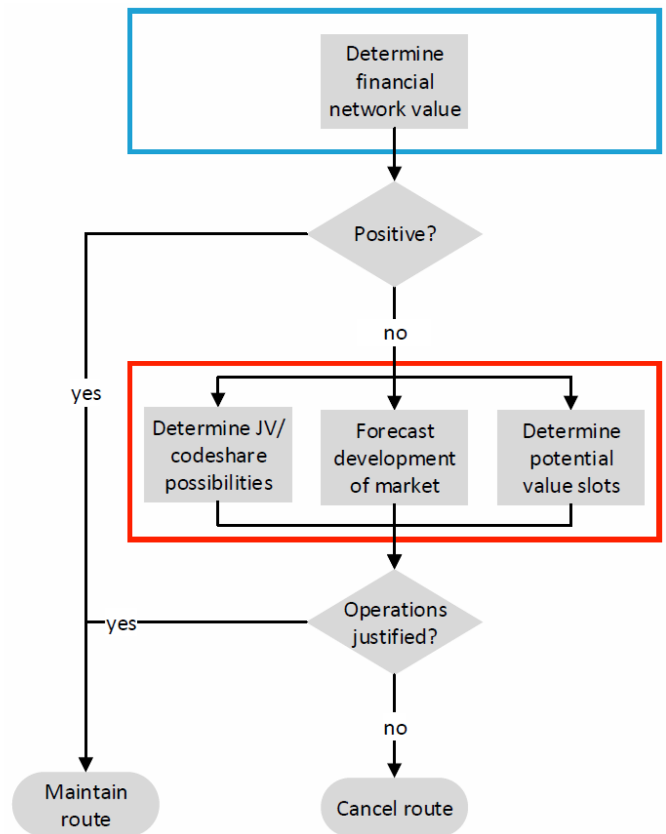

Figure 2.6: Decision Making Framework (Backker, 2013, p. 39)

Now, an example of the calculation of the NV is developed. Consider the route B-A from the sample network in Figure 2.4 over a certain period of time. In Table 2.6, the revenues of the ODs that also make use of the route B-A are listed. The sum of these revenues is equal to \$13,081,625.

OD	$R_{OD,BA}$
BA	\$ 5,590,067
BC	\$ 120,430
BF	\$ 1,234,477
BD	\$ 172,699
Other	\$ 5,964,042
Total	**\$ 13,081,625**

Table 2.6: Revenues for NV of BA

In Table 2.7, the costs of the routes in the network are listed with the total number of passengers on the route (pax_{route}) and the number of passengers on that route which also make use of the route B-A ($pax_{route,BA}$). The sum of the costs of routes in the network, which are also accountable to the route B-A, is \$13,515,654.

route	$pax_{route,BA}$	pax_{route}	C_{route}	$C_{route,BA}$
BA	21,333	21,333	\$ 11,728,506	\$ 11,728,506
AC	151	15,541	\$ 5,234,807	\$ 50,863
AF	2,641	49,180	\$ 3,933,493	\$ 211,231
AD	219	5,836	\$ 1,313,596	\$ 49,294
Other				\$ 1,475,760
Total				**\$ 13,515,654**

Table 2.7: Costs for NV of BA

In this case, the NV is equal to $\$13,081,625 - \$13,515,654 = -\$434,029$, which indicates that this route was loss-making in the period of time that is analysed. Since this NV is negative, the decision-making framework should be applied to justify the operation of the route by using strategic considerations.

Local versus Connecting passenger ratio

Another metric used by Backker (2013) is the ratio between the local and the connecting passengers on a route, the LC ratio. A high share of connecting passengers on a route indicates that this route feeds many passenger into the network, and also depends on the network for a significant share of its traffic (Backker, 2013, p. 53). No mathematical definition of this ratio is provided by Backker (2013). The ratio as a division between the number of local passengers and the number of connecting passengers on a route can have any positive real value, and will be less suitable to compare among other routes. Therefore, a ratio as the number of local passengers or connecting passengers with respect to the total number of passengers on a route could be more relevant.

Traffic Concentration index

The next metric proposed by Backker (2013) is the TC index. The TC index refers to concentration of the total traffic on a route in terms of revenues. In Equation 2.12, the TC index is formulated. The TC index of any OI is the sum of the squares of the share of revenue each OD pair, which makes use of the particular OI, has with respect to the total revenue of the OI. This total revenue of the OI also includes the connecting revenues based on the full fare proration method. The sum of the squares indicates the deviations from the average. In case any share of revenue of each of the OD pairs is relatively excessive, the TC index will increase. The value of this index ranges from 1/n to 1, in which n equals the number of OD pairs which make use of the route (Backker, 2013, p. 54).

$$TC_{OI} = \sum_{OD=1}^{n} {s_{OI_{OD}}}^2 \qquad \text{where} \qquad s_{OI_{OD}} = \frac{R_{OI_{OD}}}{R_{OI}} \tag{2.12}$$

In Figure 2.7, two examples of share of the total revenues are illustrated. On the right, the distribution of the total revenue over all OD pairs on the route NBO-JUB is illustrated. This indicates a relatively high share of local revenues. Therefore, this route has a TC index of 0.24, which is fairly high. On the left, the distribution of the total revenue over all OD pairs on the route NBO-DXB are illustrated. This indicates less dominating OD pairs, with a lower TC index of 0.07 reflecting this.

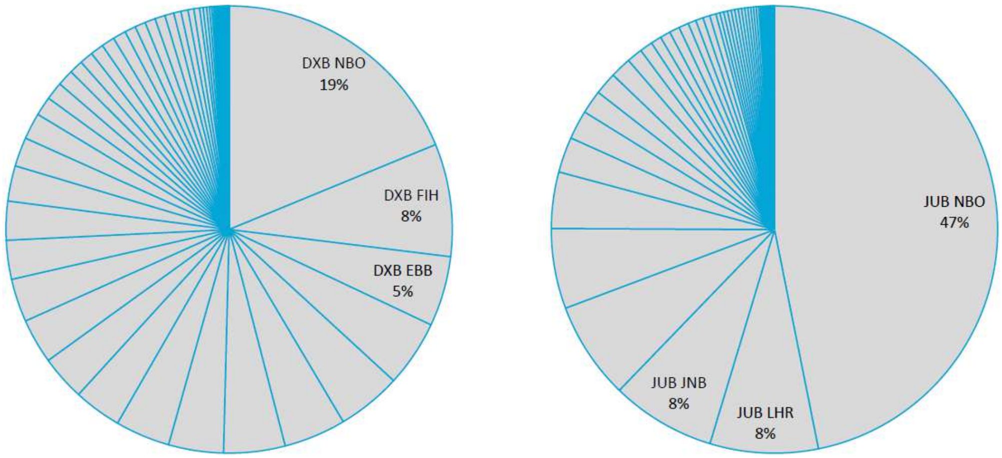

Figure 2.7: Share of Total Revenues on NBO-DXB and NBO-JUB (Backker, 2013, p. 56)

The TC index actually indicates on how many OD pairs the total revenue of the route is based. A high concentration indicates a high share of one or a few OD pairs. Therefore, if TC = 1, all the traffic on the route is on one OD pair. This does, however, not include that all the traffic is local. In this, a high TC index does not conclude a high LC ratio. On the other hand, if TC = 1/n, the traffic on the route is evenly distributed over the OD pairs which makes use of that route, including the route itself.

Feeder Concentration index

The last metric proposed by Backker (2013) is the FC index. The FC index refers to concentration of the connecting traffic on a route in terms of revenues. This index is similar to the TC index, but only based on the connecting traffic. In this index, also Equation 2.12 is used, in which only the connecting revenues are taken into account. This index should be of particular interest for a hub-and-spoke network (Backker, 2013, p. 56).

In Figure 2.8, two examples of share of the connecting revenues are illustrated. On the right, the distribution of the connecting revenue over the connecting OD pairs on the route NBO-CDG are illustrated. This indicates a fairly high share of connecting revenues to MBA, with a FC index of 0.12 reflecting this. On the left, the distribution of all OD pairs on the route NBO-JUB are illustrated. This indicates a less concentrated route with respect to connecting revenues, with a FC index of 0.09 reflecting this.

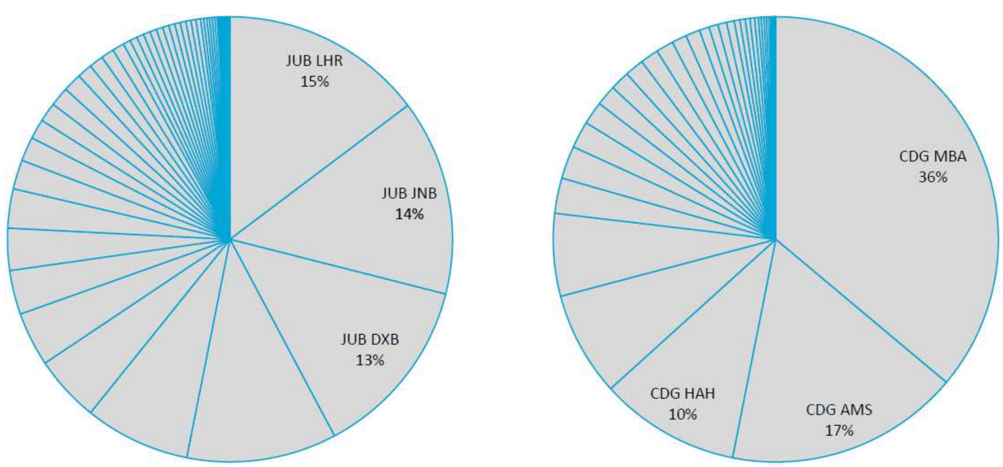

Figure 2.8: Share of Connecting Revenues on NBO-JUB and NBO-CDG (Backker, 2013, p. 56)

The FC index actually indicates on how many connecting routes the connecting revenue of the route is based. A high concentration indicates a high share of one or a few connecting routes. Therefore, if FC = 1, all the connecting passengers are connecting to one particular connecting route. On the other hand, if FC = 1/n, all the connecting passengers are evenly distributed over the connecting routes.

Network Risk Matrix

After several performance measures, Backker (2013) found a manner to indicate the risk of a route. This indication is based on the NV and the TC index and allows the development of common strategies for cluster of routes.

As explained above, the revenue of a route with a high TC index is dependent on a small number of markets. When something undesirable happens in one of these markets, this will have a significant impact on the revenue of the route. If the route at the same time has a high NV, this will indicate that a high financial value is dependent on a small number of markets. This is a situation with a high risk. Therefore, plotting the NV against the TC index can indicate the risk of a route. This plot can be divided in several areas, which clusters routes and creates a matrix. This matrix is designated as the NRM. In Figure 2.9, this matrix is depicted.

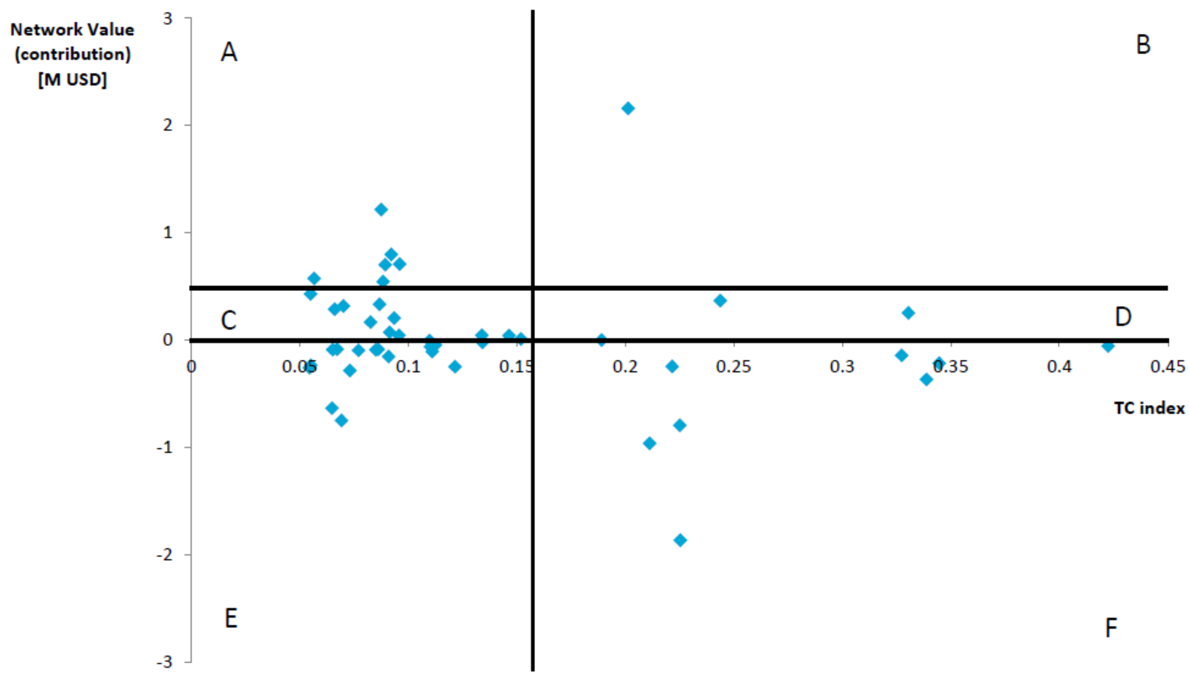

Figure 2.9: NRM (Backker, 2013, p. 57)

The NRM is subdivided into six clusters designated with the letters A to F. The thick horizontal and vertical line are drawn on the average of the positive parts of the NV respectively the TC index, such that these metrics can be distinguished among lower and higher than average with the clusters A to D. In Table 2.8, the risk and the attempt for a business strategy per cluster are listed.

Cluster	Risk	Strategy
A	medium	**Defend.** Defend routes as they generate above average value.
B	high	**Defend & Diversify.** Defend top OD pairs and give priority in scheduling. Possibly seek to improve connections and diversify OD pairs served.
C	low	**Segment.** Assess the market and segment it to optimise revenue management.
D	medium	**Segment & Diversify.** Assess the market and segment it to optimise revenue management and identify new markets.
E	n/a	**Improve.** Improve individual route and connections in general.
F	n/a	**Improve.** Improve individual route and improve connections by focusing on top OD pairs.

Table 2.8: Risk and Strategy per Cluster (Adapted from Backker, 2013, p. 58)

2.4 Conclusions Literature Review

The use of a hub-and-spoke network by an airline brings up the fundamental point that there exists a dichotomy of demand and supply, which means that there is an inherent inability to directly compare demand and supply in an individual OD market. Ultimately, this contributes to the problem that airlines operating a hub-and-spoke network are not able to fully analyze the performance of their routes considering its value in the network. Despite of that, airlines prefer to use a hub-and-spoke network due to the advantages of economies of scale, scope and density.

The operating profit is a reliable performance measure for as well the overall network as a route in that network. However, as may be clear at this point, obtaining the profit of an individual route in a greater system is a challenge in the airline industry. The profit is equal to the revenue minus the cost. The structure of operating costs is ambiguous, but to assist in the decision-making for the economic evaluation of a particular route, the preference is with the cost classification based on the degree of escapability. With respect to the revenues, it is recommended to also take the revenues from (belly) cargo into account. However, the challenge is with the proration of the revenue from the connecting passengers to split it in its components. The rest of the standard route-based could be misleading. For example, a high LF could indicate that too many passengers are paying a low price with respect to their willingness to pay. A low CASK is of little value for the airline if yield and/or LF are low as well. And a high yield could indicate that only a few passengers pay a very high price, while having a low LF which does not cover the operating costs. As a consequence, a high yield together with a high LF could gain more information with respect to the profitability. In order to also take into account non-quantitative measurable, strategic aspects, it is recommended to approach these case-by-case.

The existing network performance measures mostly apply several levels in the profitability of a flight leg in a greater system, which allows for analyzing the sources and areas of profitability in addition to the mere profitability of a flight leg. The NV of Backker (2013), however, does not apply this principle. On the other hand, the NV of Backker (2013) is double counting as well the revenues and the costs, which mitigates the problem of double counting according to Frainey (1999). Therefore, this research could apply several levels of profitability in the NV of Backker (2013). Furthermore, most of the existing network performance measures are addressing the profitability of a flight leg in a greater system, instead of the contribution of a flight leg to a greater system. For example, a positive NV could indicate an isolated point-to-point service in the hub-and-spoke network which does not contribute to the hub-and-spoke network as a whole. Therefore, this research could assess the contribution of a flight leg to a greater system in addition to the profitability in several levels.

This research will elaborate on the model and the research of Backker (2013). However, the physical model of Backker (2013) - if there is any - is not available. In the next chapter, the design of this research will be set out.

Chapter 3

Research Design

In this chapter, the research will be set up in accordance with the recommended literature Verschuren and Doorewaard (2013). In Section 3.1, the conceptual research design will be addressed containing among others the research objective and the research questions. In Section 3.2, the technical research design will be drawn containing, for example, the research material and the research planning.

3.1 Conceptual

In this section, the conceptual research design of this research will be presented. The conceptual research design determines the content of the research. It determines what, why and how much is going to be studied. It consists of four elements; the research objective, the research framework, the research questions and the research definitions.

3.1.1 Research Objective

The research objective is the goal of the research. The research objective concerns the contribution the research provides to solve a problem outside the research itself (Verschuren and Doorewaard, 2013, p. 16).

This research will contribute to the problem that airlines operating a hub-and-spoke network are not able to fully analyze the performance of their routes considering its value in the network. This will be done by the development of a Network Performance Assessment Framework (NPAF) with a graphical, analytical and interactive representation. The graphical, analytical and interactive representation will also be referred to as the Graphical User Interface (GUI) of the NPAF.

Therefore, the research objective for this research is defined as follows:

> *The research objective is to contribute to the development of a NPAF with a graphical, analytical and interactive representation by making a more comprehensive assessment of the performance of a route considering its value in the network.*

3.1.2 Research Framework

The research framework is a graphical representation of the research objective and includes the appropriate steps that need to be taken in order to achieve it (Verschuren and Doorewaard, 2013, p. 65).

In Figure 3.1, the research framework for this research is depicted. The part (a) represents the elements to produce the conceptual model in part (b). The elements to be used are the literature as proposed in the previous chapter, the consulting of experts and the data to produce the elements in the conceptual model. In part (b), the conceptual model is confronted with the research object, which leads to the NPAF with GUI in part (c). The conceptual model and the research object will be described in more detail below. Ultimately, the research contributes to the research problem by helping airlines to analyze the performance of their routes considering its value in the network.

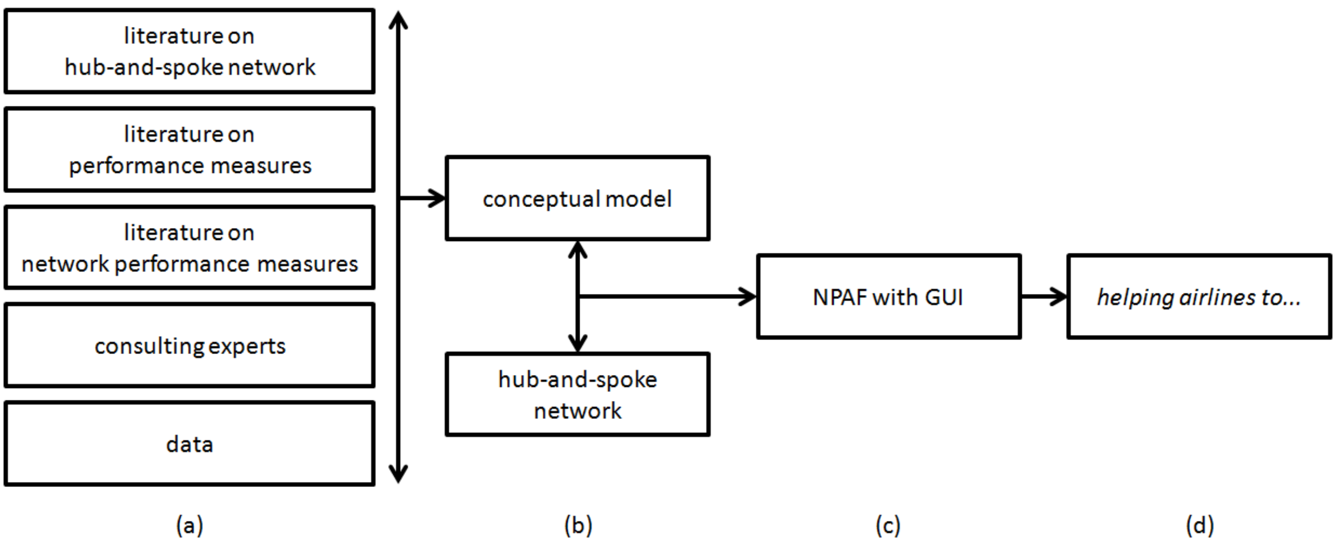

Figure 3.1: Research Framework

The conceptual model is the theoretical framework of the research project. It consists of a set of assumed relationship between the core concepts of this project (Verschuren and Doorewaard, 2013, p. 17). In Figure 3.2, the conceptual model for this research is depicted. In words, the input on the left side will be used to produce the base model. The base model consists of the network performance measures proposed by the predecessor of this research (Backker, 2013). Some elements of the input and the base model will be used to acquire the concept of the Network Contribution (NC), which was proposed in the conclusion of the previous chapter. The NC will be part of the NPAF. The dashed parts represent the elements which are not being used in the remainder of the research.

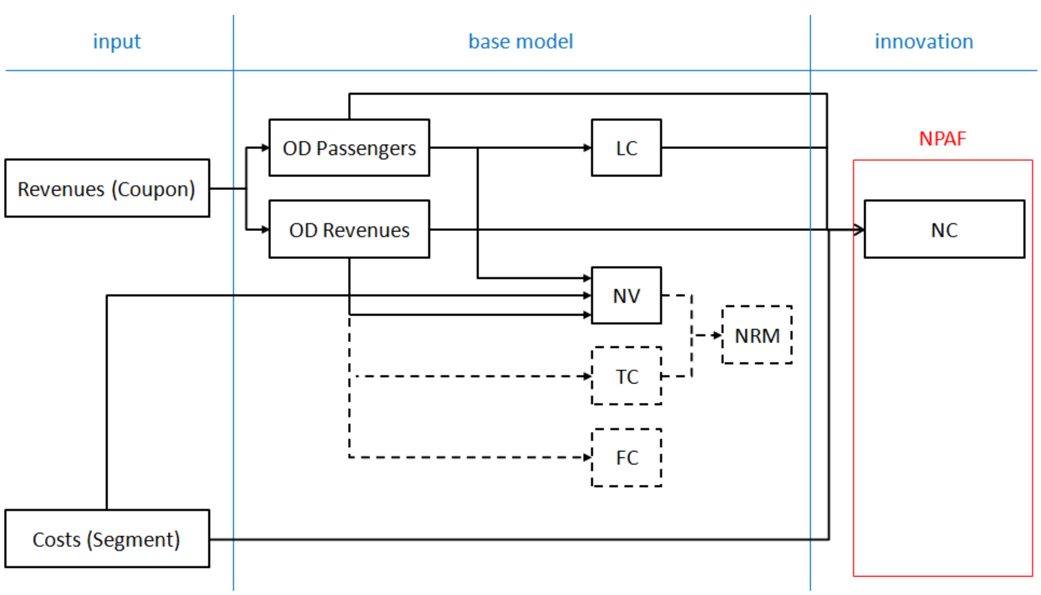

Figure 3.2: Conceptual Model

The concept of the NC is concluded from the literature review in the previous chapter. However, due to the practical background of this research, also a practical research will be conducted to obtain a counterpart from the field. This research will consists of questionnaires and interviews using the Delphi method. It will start with a questionnaire to broaden the view and an interview will follow to converge to an answer that is acceptable for all participants. As well the questionnaire as the interview will have an open structure to gain as much knowledge as possible from the participants.

The research object is the phenomenon under study about which the statements, based on the research, will be made (Verschuren and Doorewaard, 2013, p. 71). In this case, the research object is an airline its hub-and-spoke network, and especially the hub-and-spoke network of KQ. In Figure 3.3, the hub-and-spoke network of KQ is depicted. The red routes represent the route operated by KQ itself, and the blue route represent the codeshare routes. This research will be limited to the hub-and-spoke network that is operated by KQ itself.

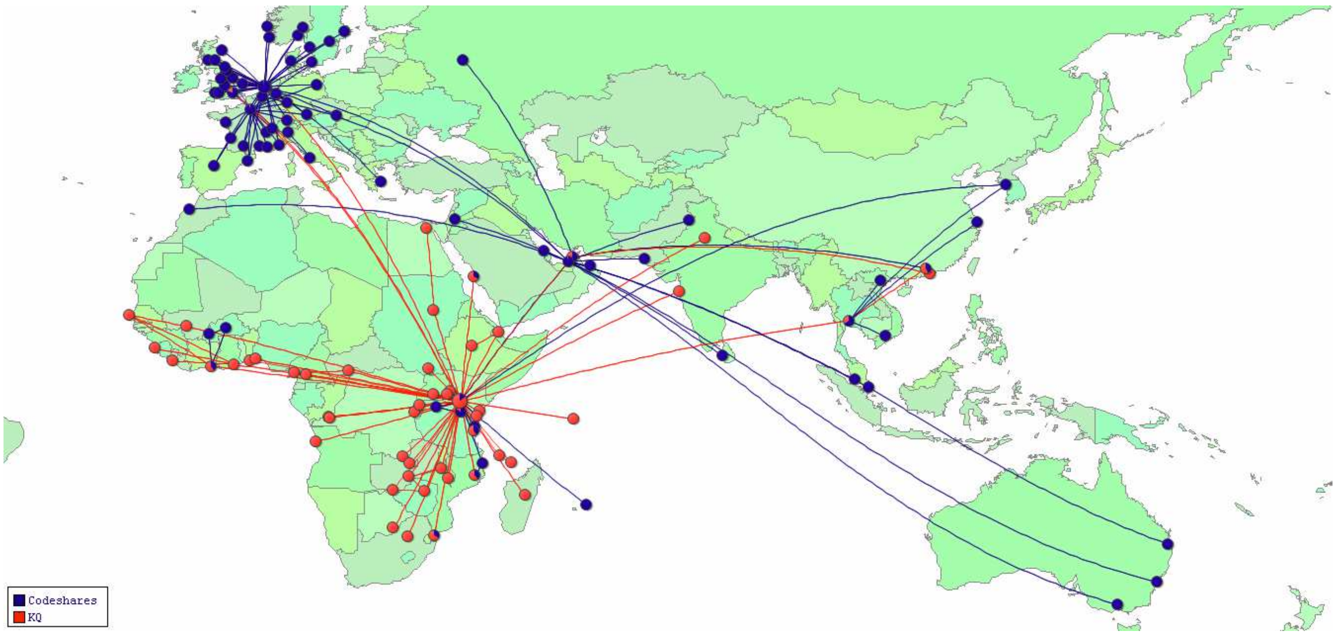

Figure 3.3: Route Network of KQ (Backker, 2013, p. 30)

3.1.3 Research Questions

The research questions are a set of questions that need to be answered during the research to acquire the information that contributes to achieving the research objective (Verschuren and Doorewaard, 2013, p. 16). One of the methods for formulating the research questions proposed by Verschuren and Doorewaard (2013) is the method of subdividing the research framework from the previous section. This method requires subdividing the research framework into certain components, after which for each of the components a research questions is formulated. In accordance with this method, the central research questions are defined as listed below.

Each of the central research questions below is accompanied with the research strategy and research material to be used to answer the question. The research strategy and research material will also be mentioned in the next paragraph on the technical research design. Furthermore, each central research question below is subdivided in sub-questions in accordance with the method of corroborative types of knowledge and the method of unravelling key concepts, both proposed by Verschuren and Doorewaard (2013).

1. **How can the base model be produced?**
The answer to this question will be based on data gathering and modelling. The data to be collected are the revenues on coupon level and the costs on segment level. The modelling will be performed using Python. The following sub-questions for this central research question are formulated:
   (a) Where can we gather the data?
   (b) What is the structure of the data?
   (c) How can we use the data to obtain the metrics in the base model?
2. **How can the performance of a route considering its value in the network be defined?**
The answer to this question will be based on literature, data gathering and modelling and practical research as discussed in the conceptual model (see Subsection 3.1.2). The data to be collected are the LF on segment level. The modelling will be performed using Python. The following sub-questions for this central research question are formulated:
   (a) How does the NC defines the performance of a route considering its value in the network?
   (b) Where can we gather the data?
   (c) What is the structure of the data?
   (d) How can we use the data, and the metrics from the base model, to obtain the NC?
3. **How can the results be presented in a graphical, analytical and interactive way?**
The answer to this question will be based on literature and modelling, and a survey if necessary. The literature will provide insight in the available methods for representing results in a graphical and analytical way. The modelling will be performed using Python due to its suitability for engineering problems. Furthermore, Excel could help for the modelling of the representation. A survey could help to gain insight in the preferences of an airline with respect to the representation. The following sub-questions for this central research question are formulated:
   (a) What are the possible methods to present results in a graphical, analytical and interactive way?
   (b) How does an airline wants to have the results presented?
4. **How can the NPAF with a graphical, analytical and interactive representation help airlines operating a hub-and-spoke network to analyse the performance of their routes considering its value in the network?**
The answer to this question will list the main innovations and limitations of this research. The answer to this question indicates how the NPAF with GUI contributes to the wider problem in the research. The following sub-questions for this central research question are formulated:
   (a) What are the innovations of the NPAF with GUI?
   (b) What are the limitations of the NPAF with GUI?

3.1.4 Research Definitions

The research definitions comprise the definition and content of the key concepts in this research (Verschuren and Doorewaard, 2013, p. 22). In this research, the following definitions are adopted. A flight leg is referring to a non-stop operation of an aircraft between two airports. A flight is referring to a serried operation of one or more flight legs by a single aircraft with a single flight code. A route is referring to a path of one or more flight legs through the network to link a pair of airports. An itinerary is referring to a path of one or more flight legs through the network chosen by a passenger to travel between a pair of airports.

The demarcation of this research will be addressed here. As already mentioned in the research framework (see Subsection 3.1.2, this research will be limited to the hub-and-spoke network that is operated by KQ itself. In other words, the code share flights of KQ will not be included in this research. Furthermore, in case of the cancellation of a flight or route, this research will assume that all the traffic on that flight or route is lost. In other words, the principles of recapture (see Subsection 2.2.2) and spill (see Subsection 2.3.2) will not be included in this research.

3.2 Technical

In this section, the technical research design of this research will be presented. The conceptual research design determines the set of activities needed to realize the content set out in the conceptual research design. It determines how, where and when is going to be done. It consists of three elements; the research strategy, the research material and the research planning.

3.2.1 Research Strategy

The research strategy is the coherent body of decisions concerning the way in which the research is to be carried out. This refers especially to gathering relevant material and processing this material into valid answers to the research question (Verschuren and Doorewaard, 2013, p. 155). The research strategies to be used in this research are a literature study, modelling using Python, questionnaires and interviews using the Delphi-method, and surveys if necessary. The way these strategies will be used in this research are already discussed in the research questions.

3.2.2 Research Material

The research material establishes the kind of material needed, and the way how and where to gather it, in order to be able to answer the research question (Verschuren and Doorewaard, 2013, p. 203). The research material to be used in this research are literature and human knowledge using the Delphi-method. The way these materials will be used in this research are already discussed in the research questions.

3.2.3 Research Planning

In contrast with the rest of the research design, the research planning is defined in accordance with the Air Transport and Operations (ATO) Thesis Procedure, provided by the section ATO of the faculty of Aerospace Engineering at the Delft University of Technology. The most important activities from this procedure are planned as listed below.

What	**When**	**Where**
Start	Mon 9 Nov 2015	n.a.
Kick-off Meeting	Fri 27 Nov 2015	Delft, the Netherlands
Mid-term Meeting	Wed 17 Feb 2016	Nairobi, Kenya
Green-light Meeting	Fri 17 Jun 2016	Delft, the Netherlands
Hand-in	Wed 27 Jul 2016	n.a.
Presentation and Defense	Thu 11 Aug 2016	Delft, the Netherlands

The period in between the kick-off meeting and the mid-term meeting will be used for the gathering of data, modelling and the organization of the practical research. The period in between the mid-term meeting and the green-light meeting will be used for further development of the NPAF with GUI and the execution and processing of the practical research.

Chapter 4

Industry Perspective

Due to the practical background of this research, also a practical research is conducted to obtain experiences and information from the field. This practical research consisted of a questionnaire and an interview using the Delphi method. The main principle of the Delphi-method is to obtain perspectives from various participants with relevant disciplines, using questionnaires and interviews, with the aim of converging to an answer that is acceptable for all participants. This method, partly using a questionnaire, is preferred due to the international set-up of this research.

The structure of this chapter is as follows. In Section 4.1, the questionnaire and interview are designed. In Section 4.2, the results from the questionnaire and interviews are presented. In Section 4.3, an evaluation of the research design of this practical research is conducted. In Section 4.4, the conclusions from the field are drawn.

4.1 Questionnaire & Interview Design

This practical research started with assembling a group of participants from all disciplines of the network management process. This group is constructed from a Business Performance Expert, a Commercial Analyst Manager, a Manager Network Strategy, a Head of Revenue Management and a Head of Network Alliances at KQ covering all the disciplines of the network management process. Furthermore, to obtain some experiences and information from a third-party, two participants from the department of Network Planning at KLM are also included in this research.

The group is informed by e-mail with a non-committal request for participation in this part of my research. This e-mail contained a brief description of the context and the design of this graduation research, and an elaboration on what contribution the participant could have in this part of the graduation research. In the conclusion of this invitation text, a link to the questionnaire was provided, accompanying a deadline on Friday 29^{th} of January and the statement that the answers will be treated as anonymous to third parties. This e-mail was sent on Friday 15^{th} of January, and a reminder was sent on Monday 25^{th} of January and on Thursday 28^{th} of January.

The questionnaire was set-up using Google Forms due to its suitability with ready-to-use formats for questionnaires and surveys. This practical part of this research mainly focuses on answering the second research question (see Subsection 3.1.3) of this research. Therefore, the questions for the questionnaire were formulated as follows:

1. **In which area of the network management process do you want to use the network performance measure? (Strategic Network Planning/Operational Network Planning/Revenue Management)**
2. **What decisions do you want to use the network performance measure for?**
3. **Which information and/or result do you need to make that decision? In case of multiple sources of information, what is the relevance of each source information?**

The rationale behind these questions was to formulate a network performance measure. In the first question, the area of the network management process in which the network performance measure will be used would be defined. This was expected to be the area of the strategic network planning. The second question of the questionnaire is determining the type of decisions for which the network performance measure will be used. In the second question, and in more detail in the third question, the analysis of the profitability of a segment or route is expected.

An analogy to the questions above is that the network performance measure is a house to be built and the answers to the third question are the stones from which the house should be built. The answers to the second question specify the functions that the house has to serve. This analogy was also used in the interviews.

In this questionnaire, no check was built-in to monitor which of the participants completed the questionnaire, due to the issue of confidentiality referred to in the invitation e-mail.

The next step in this practical research are the interviews. In the interviews, it will be find out how we can use the information from the questionnaire to make a network performance measure which can help to make the decisions from the second question of the questionnaire. The interviews will have an open structure. The method for the interviews is to identify the commonalities and deviations in the information from the questionnaire, and to discuss their suitability and importance. During the interviews, these two parts can be used in an iterative manner.

4.2 Results Questionnaire & Interviews

In this section, the results from the practical research will be discussed. The results are subdivided in the results from the questionnaire and the results from the interviews.

4.2.1 Questionnaire

The questionnaire was send among the seven participants listed above. Ultimately, five questionnaires were returned, which implies a return rate of around 70%. In Figure 4.1, the answers to the first question of the questionnaire are depicted. As expected, mostly the area of the strategic network planning is taken into consideration.

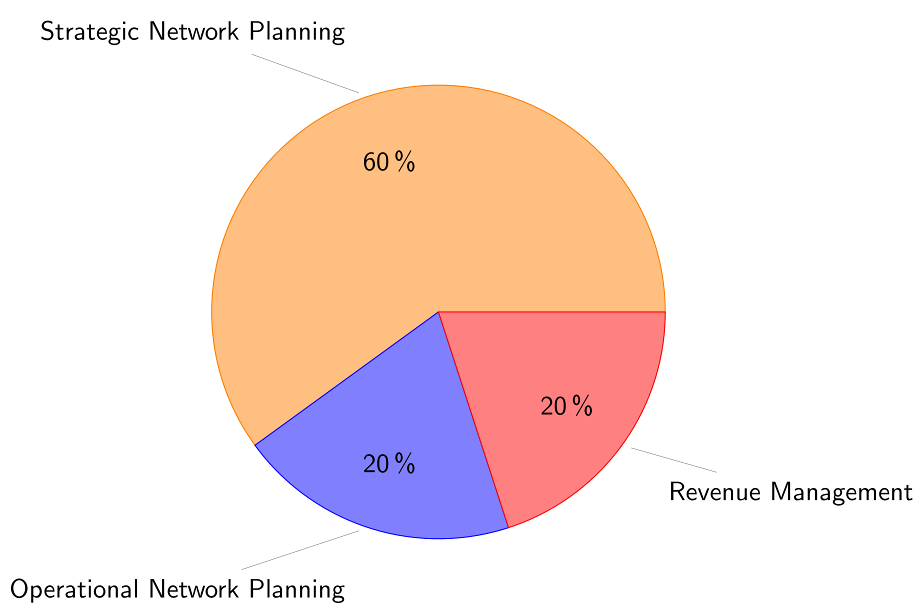

Figure 4.1: Answers Question 1

In Table 4.1, the given answers to the second question of the questionnaire are listed. The majority of these answers are referring to the strategic network planning. Some of the answers, however, are referring to the operational network planning. These comprise for example the route expansion decisions, the sensitivity of connecting time on traffic volumes, the adjustment of the capacity on a route and the impact of tactical decisions in relation to a route its contribution to the network. The latter decision seems a combination of the strategic and operational network planning. This reveals that there is a need for a network performance measure which can give support in decisions regarding adjustment of capacity on a route rather than the pure cancellation of a route. The answer on the sensitivity of price on traffic volumes seems to refer to revenue management. However, since the revenue management is a stage in which the decisions regarding the network and its routes already have been made (see Subsection 2.2.2), this research was not contributing to the revenue management process.

Decisions
Long term route evaluation to ascertain sustainability
Route contribution on enterprise profitability
Route expansion decisions
Evaluation of strategic plans (5 year to 10 year plan)
Sensitivity of price and connecting time on traffic volumes
Opening, closing or adjusting capacity on a route
Optimize the network and fleet
Evaluate the long term profitability of an operation as a stand alone route
Evaluate the long term profitability of a stand alone route and the contribution to the network
Assess the impact of tactical capacity decisions in relation to a route its contribution to the network

Table 4.1: Answers Question 2

In Table 4.2, the given answers to the third question of the questionnaire are listed. In accordance with the route-based performance measure from the literature review, these answers are subdivided into the financial, operational and other types of information. In this case, the other type of information refers to the strategic elements.

The financial part is prominent in the types of information believed to be necessary to make a network performance measure. The revenues and costs are widely mentioned, either associated with the connecting traffic or not. The connectivity of key flows seems to be part of the operational network planning area in the network management process. From this, it is decided to use primarily the revenues and costs for the network performance measure to be composed in this research. The feeder value from the financial part and the traffic stimulation bench from the operational part are not intuitive at this point and will be elaborated on in the results from the interviews. The strategic value of a route in the network was defined by Backker (2013) as the possibility for capturing developing markets, historic and marketing reasons, corporate strategies, JV and code share agreements, maintaining flying and landing rights, possible negative operational effects, and corporate contracts.

4.2.2 Interviews

The first interviews were held with the participants from the department of Network Planning at KLM on Wednesday 3^{rd} of February at the KLM Headquarter in Amstelveen, the Netherlands. As suggested by the two participants, this interview was held with the two participants at the same time. Unfortunately, the researcher was not allowed to record this interview. Instead, notes were made, which were refined and verified after the interview.

At KLM, the routes are subdivided into the intercontinental routes and the European routes. The primary principle is that the European routes feed the intercontinental routes. The performance of a route considering its value in the network is determined by the profit of the route and the so-called feeder value of the route.

Financial
Cost implication on the connecting traffic
Revenue contribution of connecting flows
Passengers revenues per flight
Cargo revenues per flight
Cost per flight, fixed and variable
Feeder value of a route to the rest of the network
Costs
Revenues
Costs at flight leg/segment level
Revenues at flight leg/segment level
Operational
Volume of connecting traffic
Connectivity of key flows
Traffic stimulation bench by regional flows
Passengers OD
Strategic
Strategic value of a route

Table 4.2: Answers Question 3

The profit and feeder value according to KLM will be explained upon a sample network (see Figure 4.2), which consists of one hub (A) with two standard spoke services (A-B-A and A-C-A). The profit and feeder value of the segment B-A are defined as follows. Assume that the itinerary B-A has one passenger with a revenue of 200 EUR and the itinerary B-C has one passengers with a revenue of 1,000 EUR, of which 100 EUR is assigned to the segment B-A by a formula which is mainly based on distance. Assume that the costs for the segment B-A are 800 EUR. The profit of the B-A segment is calculated by adding the local revenues (200 EUR) and the part of the connecting revenues which are assigned to the B-A segment (100 EUR), and subtracting the costs of the segment (800 EUR), which yields a profit of -500 EUR for the B-A segment. The feeder value is defined as the remaining part of the connecting revenues which are not assigned to the segment B-A, in this case the 900 EUR of the B-C itinerary. The feeder value represents the additional revenue that the segment is feeding into the network.

At KLM, the performance of the routes is examined on a monthly basis. At first, the profit is considered. If the profit is negative, the feeder value is taken into account. For example, a route may have a negative profit as long as it is feeding sufficient value into the network. If a route has a negative profit and is not feeding sufficient value into the network, the route will be discontinued unless there is a strategic justification to continue the route and as long an improving alternative is available. The strategic justification can be based on certain contracts regarding the route or the capturing of a developing market. The availability of an improving alternative is considered by the utilization of the aircraft, the age of the aircraft, the type of aircraft, the rest of the flight schedule, the length of the segment and the destination with its landing rights, time zones and opening hours of the airport. The point of improvement for this method is indicated to be the cost allocation of the costs to the segments.

At this point, the expectations for this practical research were adapted. It should be less desirable to converge to an answer, that is acceptable for all participants, since every participant has its own insight in the performance of a route considering its value in the network. Therefore, it is more interesting to gain inspiration for the network performance measure to be made in this research based on the ideas of the interviewees. In accordance with this adjusted aim, two additional interviews at KQ were performed.

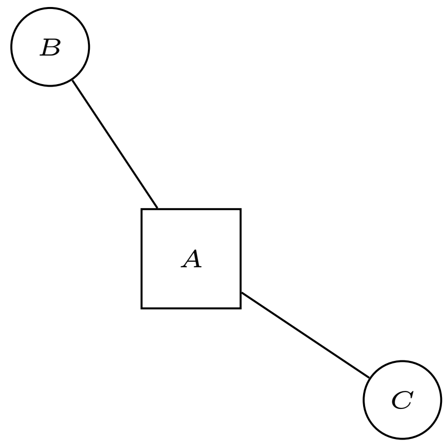

Figure 4.2: Sample Network Interview KLM

The first interview at KQ was held with the Manager Network Strategy on Thursday 11^{th} of February at the KQ Headquarter in Nairobi, Kenya. This interview was recorded, and the recording was converted into text.

During this interview, the current practice for measuring the performance of a route at KQ is discussed. In Table 4.3, this practice is listed. The Route Level is obtained by adding the local revenues and the prorated connecting revenues based on distance, and subtracting the local operating costs for the segments. This is similar to the profit used by KLM. The Network Level is obtained by adding the remaining connecting revenues which are not assigned in the previous proration. This latter is similar to the feeder value used by KLM. Subsequently, the analysis of the performance of a route takes into account the Route Level, the Network Level and the contribution of the route to the total profit of the network. For example, if the Route Level is negative and the Network Level is positive, the total profit of the network will be considered to examine the value of the route. Alternatively, in case both the Route Level and the Network Level are negative, the feasibility of the route and the availability of an improving alternative is examined based on the contribution to the total profit of the network.

-	local costs
+	local revenues
+	prorated connecting revenues*
=	**Route Level**
+	remaining connecting revenues
=	**Network Level**

Notes

* Proration based on distance

Table 4.3: Current Practice KQ

The second interview at KQ was held with the Business Performance Expert on Friday 12^{th} of February at the KQ Headquarter in Nairobi, Kenya. This interview was recorded, and the recording was converted into text.

During this interview, a brief recap of the literature study and the research design is discussed. It is doubted by the interviewee whether there is any confirmation on the contribution of the connecting revenues, making the route profitable with respect to the isolated local profit. This can be addressed in the remainder of this research.

A further elaboration on the costs per segment is also discussed. This is referring to the costs that can be assigned to each passenger, either local or connecting, on a segment. This is limited to the DOC, as the IOC are not dependent on the degree of operation. The DOC can be subdivided into fixed costs, which are not dependent on the number of passengers, and variable costs which are dependent on the number of passengers. From this, the fixed costs per passenger will decrease as the number of passengers increases and the variable costs per passenger will remain constant with a varying number of passengers. In Figure 4.3, the DOC per passenger (DOC_{pax}) is plotted versus the LF according to the discussion during this interview. In theory, in case of zero passengers, purely the fixed costs will be incurred without any variable costs. In practice, however, it will be questionable whether the segment is feasible at all. Subsequently, the minimum LF is obtained in case of one single passenger. At the minimum LF, the DOC_{pax} are maximized. This means that all the DOC of the segment are assigned to one single passenger. After the minimum LF, the DOC_{pax} will decrease exponential and approach the minimum DOC_{pax}, which is the variable cost per passenger. This means that after a certain LF, which is mostly the BELF (see Subsection 2.2.1), the incremental costs of having an additional passenger on the segment will be equal to the variable costs per passenger. In contrast to the plot, these costs are almost negligible.

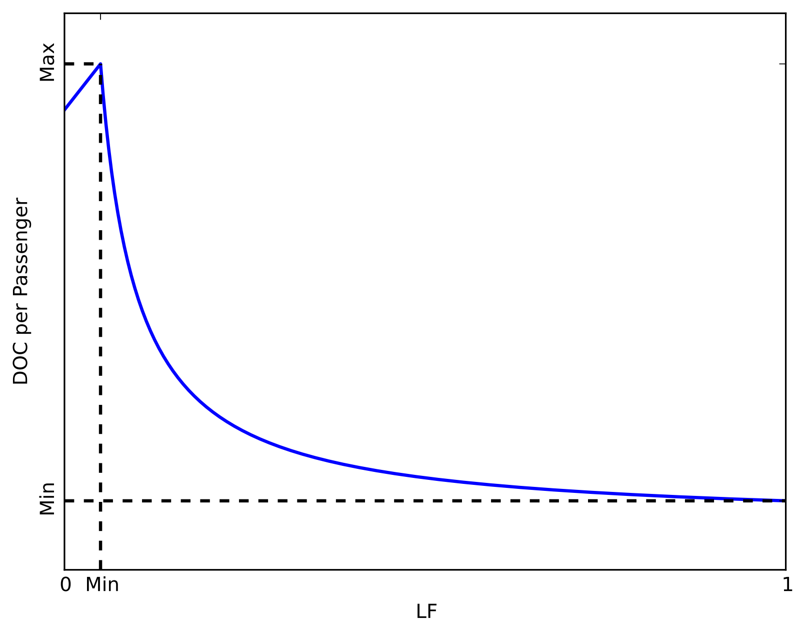

Figure 4.3: DOC per Passenger versus LF

In Equation 4.1, the DOC_{pax} as a function of LF from Figure 4.3 is formulated. This formula is dependent on the fixed costs, the capacity, the variable costs per passenger ($variable_{pax}$) and the LF of the segment.

$$DOC_{pax}(LF) = \frac{fixed}{LF \times capacity} + variable_{pax} \quad (4.1)$$

4.3 Evaluation Questionnaire & Interview Design

The first learning point from this practical research is the lack of monitoring which of the participants completed the questionnaire. This was introduced due to the issue of confidentiality. From this, at the interviews it was neither traceable which participants did fill in the questionnaire nor which answers correspond to which participant.

Afterwards, the approach for the interview at KLM was less suitable. In this interview, it was not the case to built a house from the stones from the questionnaire, according to the analogy for the questions from the questionnaire (see Section 4.1), as KLM already has a house on its own. Hereby, the expectations from this practical research were adapted to gain inspiration for the network performance measure to be made in this wider research based on the ideas of the interviewees rather than converging to one particular answer.

Despite of the description of the context and the design of the wider research in the invitation e-mail, and another introduction to the research problem during the interview, most of the information from the questionnaire and interviews did not match the current level of knowledge in this research. The invitation e-mail or the introduction in the interview could have provided a review of the literature study, which is accompanied by the challenge to retain the attention of the participant.

Furthermore, the option for revenue management was proved to be unnecessary. This option was provided for the sake of completeness, to cover all the disciplines from the network management process. However, as the revenue management was already disregarded from this research (see Subsection 2.2.2), this option should not have be considered in this practical research.

4.4 Conclusions Industry Perspective

This practical research reveals that there is a need for a network performance measure which allows for analyzing the effects of the cancellation of, and the adjustment of the capacity on, a segment or route in the strategic and operational network planning area. This network performance measure will be mainly based on the revenues and costs of the segment or route. However, as may be clear at this point, obtaining the revenues and costs of an individual segment or route in a greater system is a challenge in the airline industry.

As in the common practice from the literature, the current practice of KQ reflects the application of several levels in the profitability of a segment or route in a greater system, which allows for analyzing the sources and areas of profitability in addition to the mere profitability of a segment or route. This principle, however, is not applied in the metric of the predecessor of this research. An interview at KLM, on their common practice, revealed that some airlines using a hub-and-spoke network can have a proper understanding on the performance of their routes considering their value in the network. The point of improvement for their method is indicated to be the cost allocation of the costs to the segments.

The interviews revealed a more advanced method for determining the costs that connecting passengers are making on the connecting segments. Besides applying the multiple levels in the profitability analysis, this principle can be incorporated in the metric of the predecessor of this research.

Chapter 5

Base Model

In this chapter, the base model will be constructed, which will provide an answer to the first research question. This model is a duplicate of the model of Backker (2013), since that model - if there is any - is not available. However, that model will probably have been programmed in MATLAB, while the model in this research will be programmed using Python due to its familiarity at KQ and the researcher itself. Furthermore, some of the results from this base model will be used in the remainder of this research.

The concept of the base model is to use the revenue on coupon level and the costs on segment level to compute the number of passengers and the revenues on OD level and the LC ratio, the TC index, the FC index, the NV and the NRM as proposed by Backker (2013). In Figure 5.1, the isolated part of the conceptual model for the base model is depicted. The dashed parts represent the elements which are not being used in the remainder of the research, while the other parts will be used in the next chapter on the NC.

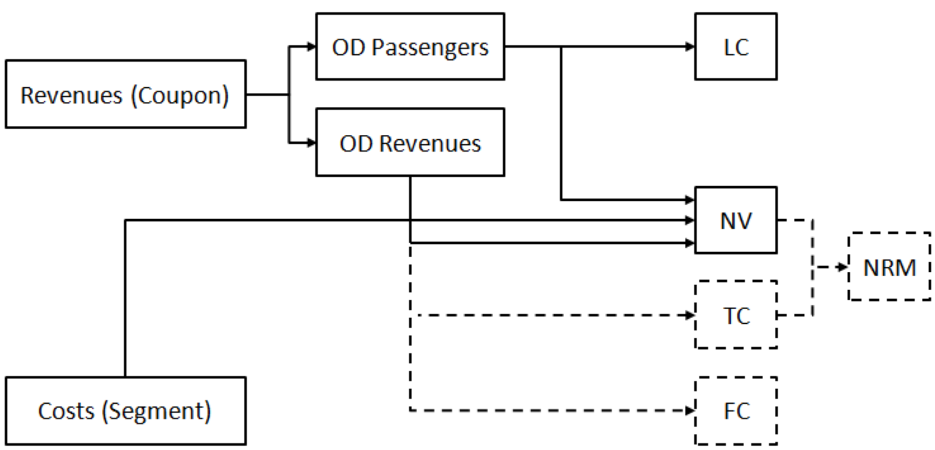

Figure 5.1: Conceptual Model of Base Model

The structure of this chapter is as follows. First, in Section 5.1, the input for the base model will be discussed. In this, the source of the input will be mentioned, together with its structure, by which the research questions 1(a) and 1(b) will be answered. In Section 5.2, the base model will be constructed using Python, by which the research question 1(c) will be answered. In Section 5.3, the conclusions from the base model so far will be drawn.

The base model will be verified upon a sample network, as depicted in Figure 5.2, which is a part of the network of KQ itself. Therefore, sample data from KQ can be used for the implementation of the base model. This sample network consists of one hub (NBO) with two spoke services (NBO-LHR-NBO and NBO-TNR-NBO), one tag-end service (NBO-BKK-HKG-BKK-NBO) and one round-robin service (NBO-LVI-HRE-NBO). It should be noticed that the round-robin service is operated counterclockwise.

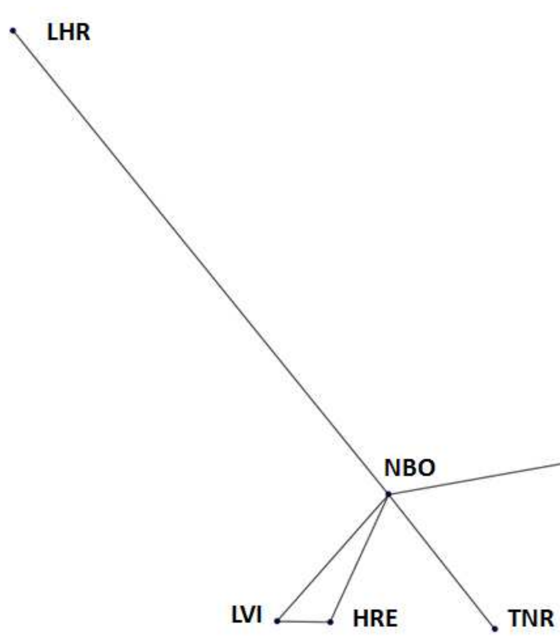

Figure 5.2: Sample Network

5.1 Input Base Model

In this section, the input for the base model will be discussed with respect to the source and structure. The two sources needed for the base model are the revenue on coupon level and the costs on segment level.

Revenues (Coupon)

At KQ, the passenger revenues on coupon level are available through KALE, which is an independent aviation consultancy company providing database services for KQ. The data is stored at the facilities of KALE and monthly reported and send to KQ. The passenger revenues are divided into passenger revenues from tickets and revenues from excess baggage, which are stored in separate databases.

In Table 5.1, a sample of the passenger revenues from tickets on coupon level as received from KALE is depicted. This data contains the flight date (Fl. Date), the document number (Doc. No.), the coupon number (Coup. No.), the flight number (Fl. No.), the route code (RC), the super route code, the origin (Ori.), the destination (Des.), the gross revenue (Gross) with the commission (Comm.), the discount (Disc.), the overhead commission (OC) and the surcharge. All the monetary values are in Kenyan Shilling (KES). In this data, one coupon corresponds to one flight and the various coupons make up the document, which corresponds to the itinerary of one passenger. From this sample, it can be noticed from document number 1930159024 that the itinerary does not have to start - or to end - on a flight of KQ itself. Furthermore, from the same document number it can be seen that the itinerary does not have to be completed on one day. It can also be noticed from document number 942499745 that the total revenue of the itinerary is prorated among its segments probably using the mile-age based proration method. The three-digit flight numbers, nor the route codes, nor the super route codes from this data correspond with the route codes used in the data from KQ itself. This is not intuitive in processing this data together with data from sources of KQ itself. The revenue to take into account is the gross revenue minus commission, discount and overhead commission, and plus the surcharge. However, as will be shown in the next section, the commissions are already incorporated in the DOC. Therefore, the commissions are not take into account in the revenues, and the revenue for the remainder of this report is the gross minus the discount plus the surcharge.

Fl. Date	Doc. No.	Coup. No.	Fl. No.	RC	Super RC	Ori.	Des.	Gross	Comm.	Disc.	OC	Surcharge
1-9-2015	942499745	3	257	175	419	TNR	NBO	19491,2	0	0	0	9168
1-9-2015	942499745	4	102	100	110	NBO	LHR	36104	0	0	0	17828,8
21-9-2015	1930159024	2	262	174	419	NBO	TNR	35194.64	1759.68	0	0	9568
24-9-2015	1930159024	3	257	175	419	TNR	NBO	35191.52	1759.68	0	0	9568
29-9-2015	2485712507	1	704	281	519	HRE	NBO	12841.92	642.1	384.59	354.46	9568
29-9-2015	2485712507	2	886	118	253	NBO	BKK	27128.61	1356.47	812.55	748.79	14040
10-9-2015	9686625596	1	861	115	251	HKG	BKK	10923.41	0	0	327.7	586.93
10-9-2015	9686625597	1	861	115	251	HKG	BKK	10923.41	0	0	327.7	586.93
23-9-2015	9693854023	1	780	641	272	NBO	LVI	31616	316.16	0	939	9568

Table 5.1: Sample Passenger Revenues Tickets from KALE

Costs (Segment)

At KQ, the costs on segment level are available through TM1, which is a database of KQ itself. In Table 5.2, the cost breakdown according to KQ is listed. It is assumed that purely the PAX Meals, PAX Costs on Ground and Commissions are dependent on the number of passengers, while the rest is allocated otherwise (see Subsection 2.3.3). As mentioned in the previous section, the commissions are incorporated in the DOC, which are not included in the calculation of the revenues. The IOC are subdivided into the overhead costs and the fleet costs. It is also assumed that all DOC are disregarded in case of the discontinuation of a segment, while the overhead costs and fleet costs remain charged. This assumption can be quite rigorous in some elements of the DOC, such as the elements for maintenance, but the majority is believed to be dependent on the degree of operations.

Direct Operating Costs	Overhead Costs	Fleet Costs
Fuel	Overheads	Engine Leases
Maintenance	Bad Debts	Component Depreciation
Maintenance Reserve	Contingency	Lease Rental
Landing		Fleet Depreciation
Handling		
Navigation		
Handling DOC		
In-Flight Entertainment		
PAX Meals		
Stores Provisioning		
PAX Costs on Ground		
Crew Route		
CRS		
Commissions		
Insurance		

Table 5.2: Cost Breakdown of KQ

In Table 5.3, the costs on segment level for the sample network is shown. This data contains the DOC, the overhead costs and the fleet costs in KES per route per segment. A quite extensive sample is shown to be able to emphasize some inconsistencies in this data. First of all, the default routes, from which the costs are not yet assigned to the other segments in the data. However, some of the segments from the default routes are not part of the sample network (see Figure 5.2), or even the complete KQ network. The costs which can not be assigned to any operated segment will be disregarded from the implementation of this model. Furthermore, the route number in this data do not correspond to the designations used by KALE in the passenger revenues on coupon level, from which it is not intuitive to process the data from different sources.

It can also be noticed from this sample of data that in the tag-end service NBO-BKK-HKG-BKK-NBO all possible segments to be offered as passenger itineraries are mentioned, while some are not operated directly. This comprises the NBO-HKG and the HKG-NBO segments. In these segments, purely some DOC are incurred, which represent the commissions for the passengers with an itinerary covering that segment. These costs will be evenly distributed over the segments of that route which are being operated directly.

The same phenomenon was expected in the round-robin service NBO-LVI-HRE-NBO, which should have contained the segments NBO-HRE and LVI-NBO, but which is not the case. Instead, the segments LUN-NBO and LVI-LUN are listed, while these are not part of this route. As in the standard spoke services, the costs which can not be assigned to any operated segment will be disregarded from this research.

Route	Segment	Direct Operating Costs	Overhead Costs	Fleet Costs
Default Route	HRE - LLW	5,713,947.04	943,461.79	1,159,424.99
Default Route	HRE - LUN	395,858.02	-12,765.32	0.00
Default Route	NBO - HRE	12,158,972.01	3,932,606.80	3,048,509.54
200 - NBO LHR	LHR - NBO	160,131,124.55	77,750,957.88	-5,718,555.24
200 - NBO LHR	NBO - LHR	240,043,845.41	81,135,322.83	-5,857,518.36
217 - NBO BKK HKG	BKK - NBO	58,649,395.44	31,013,419.46	-2,766,703.06
217 - NBO BKK HKG	HKG - BKK	26,892,215.04	8,262,111.63	-857,682.00
217 - NBO BKK HKG	HKG - NBO	1,350,478.89	0.00	0.00
217 - NBO BKK HKG	NBO - HKG	1,229,065.00	0.00	0.00
217 - NBO BKK HKG	NBO - BKK	70,286,262.04	32,066,840.50	-2,973,324.61
217 - NBO BKK HKG	BKK - HKG	30,024,150.78	8,259,563.77	-885,231.54
287 - NBO TNR	NBO - TNR	43,283,432.83	13,973,930.68	10,923,267.36
287 - NBO TNR	TNR - NBO	42,550,011.15	14,230,957.59	11,386,487.11
272 - NBO LVI HRE	HRE - NBO	10,378,571.64	3,107,073.00	2,570,009.07
272 - NBO LVI HRE	LUN - NBO	475,331.98	-15,328.13	0.00
272 - NBO LVI HRE	NBO - LVI	11,786,950.66	3,828,136.18	3,123,200.24
272 - NBO LVI HRE	LVI - HRE	5,388,337.68	889,382.05	1,040,668.48
272 - NBO LVI HRE	LVI - LUN	527,117.98	-6,600.78	148,154.87

Table 5.3: Sample Costs from TM1

It can be noticed that some of the overhead and fleet costs are negative. In case of the sample above, the negativity of the overhead costs is attributable to the contingency (see Table 5.2), while the fleet depreciation (see Table 5.2) is the reason for the negativity of the fleet costs. Despite of some intensive research,a more elaborative motive behind these negative costs has not been found.

5.2 Implementation & Results Base Model

In this section, the actual implementation of the base model in Python will be discussed. This implementation is divided into two parts; the implementation of the number of passengers and the revenues per OD pair and the implementation of the network performance measures of Backker (2013). Prior to the actual implementation in Python, the metrics are manually calculated in Excel with the aim of the verification of the implementation.

At first, the segments being operated have to be determined from the routes and the accompanying type. In Table 5.4, the routes and accompanying types from the sample network are listed. The S represents a standard spoke service, while the R represents a round-robin service and the T a tag-end service. In obtaining the operated segments during modelling, segments from the standard spoke service and the tag-end service should also be joined with the order reversed, while the round-robin service should be appended with the airport at which it started, which is assumed to be the hub. At the end, it is recommended to check for unique segments. From this, this model is examining a segment rather than an individual route or flight on that segment. Therefore, it is not possible to incorporate the sensitivity of connecting times (see Table 4.2) in this research. In case of the sample network from Figure 5.2, there are eleven unique segments being operated. The plotting of the airports and the segments being operated yields the sample network from Figure 5.2 in a Mercator projection.

Route	Type
NBO-LHR	S
NBO-TNR	S
NBO-LVI-HRE	R
NBO-BKK-HKG	T

Table 5.4: Routes Sample Network (see Figure 5.2)

OD Passenger & Revenues

In obtaining the number of passengers and revenues per OD pair, from the revenues on coupon level, it is recommended to start sorting the coupon level data by document number. Subsequently, the coupons per document can be grouped by starting with the first document number and checking whether the following document number is the same. After sorting the data per document number by coupon number, the itinerary and revenue per passenger per day can be obtained by checking which coupons are operated on the same flight date. In this, a coupon one day later is also accepted, since some flights may arrive one day later. In all cases, it is checked whether the following coupon is not the previous coupon with the order reversed, since some passenger may return on the same day or one day later. After merging the itinerary and revenue per passenger per day, it is possible to count the number of passengers and revenues per OD pair. In Table 5.5, the number of passengers per OD pair from the sample network for a certain period of time are listed. A similar table is obtained for the revenues per OD pair.

Despite of the check for an identical coupon with the order reversed, some itineraries start and end at the same airport, which can be noticed from the diagonal. The cause of this error is not clear. This yields an error of 71 passengers, equivalent to 0.48%, in case of this sample of revenue coupon level data. It is not clear whether this error decreases as the sample of revenue coupon level data increases.

	BKK	**HKG**	**HRE**	**LHR**	**LVI**	**NBO**	**TNR**
BKK	0	289	27	0	6	792	55
HKG	595	0	16	0	0	313	46
HRE	19	10	1	339	0	1113	6
LHR	0	0	251	0	51	2672	87
LVI	1	0	0	27	0	191	0
NBO	957	218	951	3452	260	70	744
TNR	72	41	4	76	0	814	0

Table 5.5: OD Passengers Sample Network (see Figure 5.2) September 2015

LC ratio, TC index, FC index & NV

Since the LC ratio does not has a mathematical description (see Subsection 2.3.4), the implementation of this metric will yield a list with the total number of passengers per segment subdivided into local passengers and connecting passengers. Therefore, it is necessary to identify the total number of passengers per segment. In Table 5.6, the total number of passengers per segment from the sample network are listed. The local passengers are the passengers which are purely carried on the particular segment. The connecting passengers are the passengers which also make use of another segment in the network. The total number of passengers, in accordance with Table 5.6, is the sum of the two latter. The local, connecting and total revenues per segment can be obtained in a similar manner.

Segment	Passengers
NBO-LHR	all passengers to LHR
LHR-NBO	all passengers from LHR
NBO-TNR	all passengers to TNR
TNR-NBO	all passengers from TNR
NBO-BKK	all passengers to BKK (except from HKG), and to HKG (except from BKK)
BKK-HKG	all passengers to HKG
HKG-BKK	all passengers from HKG
BKK-NBO	all passengers from BKK (except to HKG), and from HKG (except to BKK)
NBO-LVI	all passengers to LVI, and to HRE (except from LVI)
LVI-HRE	all passengers to HRE, and from LVI
HRE-NBO	all passengers from HRE, and from LVI (except to HRE)

Table 5.6: Passengers per Segment (see Figure 5.2)

It should be noted that these are the passengers purely carried on that segment. Therefore, this analysis is examining a segment rather than a route. In order to obtain the passengers on a standard spoke route, the passengers of the two opposite segments should be added, while for the tag-end route and the round-robin route another approach is needed. In case of a tag-end route (NBO-BKK-HKG-BKK-NBO), the total passengers of the two opposite inner segments (NBO-BKK and BKK-NBO) should be added, together with the local passengers of the two opposite outer segments (BKK-HKG and HKG-BKK), since the connecting passengers to/from HKG are already incorporated in the inner segments. In case of a round-robin route (NBO-LVI-HRE-NBO), the total passengers of the two outer segments (NBO-LVI and HRE-NBO) should be added, together with the local passengers of the middle segment (LVI-HRE), since the connecting passengers to HRE and from LVI are already incorporated in the outer segments.

The implementation of the LC ratio is executed in three phases; the segments which start at the hub, the segments which end at the hub and the segments which neither start nor end at the hub. In the segments which start at the hub, the inner outbound segment of the tag-end service (NBO-BKK) is distinguished by the fact that it has a follow-up segment which is also operated with the order reversed, while the first outbound segment of the round-robin service (NBO-LVI) does not has this property. The other segments, which start at the hub, are the outbound segments of the standard spoke services (NBO-TNR and NBO-LHR). A similar manner is used for the segments which end at the hub. In case of the segments which neither start nor end at the hub, the second segment of the tag-end service is distinguished by the fact that it is also operated with the order reversed, in which the distinction between the outbound (BKK-HKG) and inbound (HKG-BKK) version is made by checking which of the two airports of the segment is connected directly to the hub. The other segment, which neither starts nor ends at the hub, is the middle segment of the round-robin service (LVI-HRE). This method for implementation yields nine possible segments in case of the sample network, in which the number of passengers and revenues per segment are determined for each possible segment. Furthermore, due to this method, this implementation is adjusted to the standard spoke, tag-end and round-robin routes as these are presented in the sample network.

The segment NBO-LHR from the sample network is used as an example to elaborate on the calculations of the necessary metrics in this model. The implementation for the calculation of the LC ratio for the segment NBO-LHR examines how many passengers are terminating at LHR from each possible origin using the number of passenger per OD pair from the previous section. In Table 5.7, the total number of passengers for the segment NBO-LHR is calculated. The number of local passengers is equal to $3,452$, while there are 442 connecting passengers on this segment, which yield a total number of $3,894$ passengers. In a similar manner, the total revenue for this segment is $218,352,842.30$ KES, from which $192,572,123.17$ KES are local and $25,780,719.13$ KES are connecting revenues.

OD	**Passengers**
BKK-LHR	0
HKG-LHR	0
HRE-LHR	339
LHR-LHR	0
LVI-LHR	27
NBO-LHR	3,452
TNR-LHR	76
Total	**3,894**

Table 5.7: LC ratio of NBO-LHR (see Figure 5.2) September 2015

The implementation of the TC index and FC index is set up in a similar manner as for the LC ratio. In this implementation, however, the total and connecting revenues per segment are needed, from which a separate iteration has to be introduced in the implementation to obtain the TC index and FC index with respect to the calculation of the LC ratio. In Table 5.8, the TC index and FC index for the segment NBO-LHR are calculated. The calculations yield a TC index of 0.79 and a FC index of 0.60 for this segment.

OD	$s_{NBOLHR_{OD}}$	${s_{NBOLHR_{OD}}}^2$	$s_{NBOLHR_{OD}}$	${s_{NBOLHR_{OD}}}^2$
BKK-LHR	0	0	0	0
HKG-LHR	0	0	0	0
HRE-LHR	0.088	0.008	0.743	0.552
LHR-LHR	0	0	0	0
LVI-LHR	0.006	0	0.051	0.003
NBO-LHR	0.882	0.778		
TNR-LHR	0.024	0.001	0.206	0.043
Total		**0.79**		**0.60**

Table 5.8: TC index & FC index of NBO-LHR (see Figure 5.2) September 2015

The implementation of the NV is set up in an alternative manner, since also the costs on segment level should be incorporated, while in the previous metrics only input on OD level was taken into account. At first, the nine possible segments in the sample network were distinguished in the same manner as in the implementation of the previous metrics. The total revenues per segment are already calculated using the same approach as for the LC ratio. On the side of the costs for the NV, it should be calculated how many passengers on any potential segment in the network are also travelling on the segment in consideration. In this, each of the nine possible segments has its own method to examine the potentiality of the other segments in the network. For example, if the segment NBO-LHR is taken into consideration, all inbound segments of as well the standard spoke services (TNR-NBO) as the tag-end service (HKG-BKK and BKK-NBO), and the second (LVI-HRE) and third segment (HRE-NBO) of the round-robin services, are potential segments since these could have passengers which are also travelling on the NBO-LHR segment. In this implementation, the correct segment from the intermediate airport of the tag-end service is distinguished by selecting the segment from the intermediate airport of the tag-end service and the hub. In this case, the BKK-NBO segment is considered rather than the NBO-BKK segment. The other segments are distinguished by selecting all the segments which are not originating at the hub nor the intermediate airport of the tag-end service. Subsequently, a fictitious OD pair is generated from the outer airport of the segment in consideration and the outer airport of the potential segment. The number of passengers on that OD pair (see Table 5.5) is equal to the number of passengers on the potential segment that are also travelling on the segment in consideration. The total number of passengers and the costs of the potential segment are straightforward and already calculated. At this point, Equation 2.11 can be applied to obtain the NV of the segment in consideration.

In Table 5.9, the costs for the NV of the segment NBO-LHR are calculated. In the case of this outbound segment of a standard spoke service, the potentiality of the other segments in the network is examined by checking whether the other segment is not starting at NBO and LHR, while the correct segment from BKK is selected as the segment to NBO after BKK is distinguished as the intermediate airport of a tag-end service by the fact that it has more than one segment originating at that airport. The latter yields the same limitation as mentioned in the implementation of the previous metrics. The costs per segment are obtained from Table 5.3 by summing the DOC, overhead costs and fleet costs. The total revenue for this segment was calculated to be $218,352,842.30$, which yields a NV of $218,352,842.30 - 323,791,391.95 = -105,438,549.65$ for this sample network for this period of time. All monetary values are in KES. This NV seems quite low, since the revenues purely take into account the revenues from the segments in the sample network, while the costs are for the complete KQ network.

Segment	$pax_{segment,NBOLHR}$	$pax_{segment}$	$C_{segment}$	$C_{segment,NBOLHR}$
BKK-NBO	0	1,255	86,896,111.84	0.00
HKG-BKK	0	970	34,296,644.67	0.00
TNR-NBO	76	1,007	68,167,455.85	5,144,713.65
HRE-NBO	339	1,706	16,055,653.71	3,190,425.91
LVI-HRE	27	1,468	7,318,388.21	134,602.51
NBO-LHR	3,894	3,894	315,321,649.88	315,321,649.88
Total				**323,791,391.95**

Table 5.9: Costs for NV of NBO-LHR (see Figure 5.2) September 2015

In Table 5.10, the results from the base model for the sample network in Figure 5.2 are depicted. This results contain the total revenues (Rev. Tot.), the local revenues (Rev. Loc.), the TC index, the FC index, the total number of passengers (Pax. Tot.), the local number of passengers (Pax. Loc.), the costs and NV per segment. All monetary values are in KES. It should be noted that these are the results for the sample network, where the costs are indirectly covering the total network of KQ, while the revenues are purely taking into account the sample network. Therefore, the NVs are out of proportion, and no conclusions from these results can be drawn.

Segment	**Rev. Tot.**	**Rev. Loc.**	**TC**	**FC**	**Pax. Tot.**	**Pax. Loc.**	**Costs**	**NV**
BKK-HKG	29,598,320.66	6,097,823.33	0.51	0.74	970	595	37,398,483.01	-32,647,084.25
BKK-NBO	76,320,658.57	47,133,017.09	0.45	0.50	1437	957	86,896,111.84	-31,918,492.37
HKG-BKK	29,598,320.66	6,097,823.33	0.51	0.74	970	595	34,296,644.67	-26,749,813.17
HRE-NBO	74,286,631.18	38,842,802.73	0.36	0.38	1818	1113	16,055,653.71	22,357,267.04
LHR-NBO	220,648,502.93	192,572,123.17	0.77	0.52	3929	3452	232,163,527.19	-19,192,374.64
LVI-HRE	74,286,631.18	0.00	0.36	0.36	1818	0	7,318,388.21	26,063,449.56
NBO-BKK	76,320,658.57	47,133,017.09	0.45	0.50	1437	957	99,379,777.93	-45,768,773.59
NBO-LHR	220,648,502.93	192,572,123.17	0.77	0.52	3929	3452	315,321,649.88	-103,658,244.93
NBO-LVI	74,286,631.18	10,184,115.54	0.36	0.46	1818	260	18,738,287.08	23,500,778.53
NBO-TNR	47,624,132.73	34,921,497.36	0.56	0.35	1025	814	68,180,630.87	-31,730,608.11
TNR-NBO	47,624,132.73	34,921,497.36	0.56	0.35	1025	814	68,167,455.85	-34,302,554.66

Table 5.10: Results Base Model Sample Network (see Figure 5.2) September 2015

It should be noted that these are the NV of each segment separate, purely incorporating the passenger flows as specified in Table 5.6, rather than a route. In order to obtain the NV of a standard spoke route, the NV of the two separate segments should be added, while for the tag-end route and the round-robin route another approach is needed. In case of a tag-end route (NBO-BKK-HKG-BKK-NBO), the NV of the two opposite inner segments (NBO-BKK and BKK-NBO) should be added, after which the local revenues of the two opposite outer segments (BKK-HKG and HKG-BKK) should be added and the local costs of these segments should be subtracted, since the connecting passengers to/from HKG are already incorporated in the inner segments. In case of a round-robin route (NBO-LVI-HRE-NBO) the NV of the two outer segments (NBO-LVI and HRE-NBO) should be added, after which the local revenues of the middle segment (LVI-HRE) should be added and the local costs of that segment should be subtracted, since the connecting passengers to HRE and from LVI are already incorporated in the outer segments.

5.3 Conclusions Base Model

In this chapter, the base model has been constructed, and thereby the first research question is answered. This model is a duplicate of the model of Backker (2013), since that model - if there is any - is not available.

The input for the base model are the revenues on coupon level and the costs on segment level. At KQ, the revenues on coupon level are gathered through KALE, an independent aviation consultancy company providing database services for KQ, and the costs on segment level are gathered through TM1, a database of KQ itself. In this input data some inconsistencies have been encountered. For example, the flight numbers nor the routes codes in the revenue data on coupon level do not correspond with the route codes used in the data from KQ itself. This is not intuitive in processing this data together with data from sources of KQ itself. Furthermore, in the cost data on segment level, some elements were not yet properly assigned. The costs which could not be assigned to any operated segment were disregarded from the implementation of this model. An issue on negative costs remained unsolved in this research.

In the base model, three type of routes (i.e. standard spoke, tag-end and round-robin) have been distinguished. In the implementation of this model, it was not completely intuitive how to obtain the various metrics, especially for the tag-end and round-robin routes. It is not clear whether Backker (2013) distinguished these two type of routes. These two types of routes influence the passenger flow through a hub-and-spoke network drastically. In order to cope with the different type of routes, the implementation has been performed on a segment basis rather than a route or flight basis. In this, the various metrics are obtained for each segment separate. From these segment-based results it is possible to obtain the route-based result without losing sight of the contribution of the various segments of a route. It is not clear whether Backker (2013) used this approach. The major drawback of this method is that it is not possible to distinguish for an individual route or flight on a segment. Due to the segment-based approach, it is not possible to incorporate the sensitivity of connecting times (see Table 4.2) in this research.

Despite of the fact that this implementation is hardly contributing to the innovation of this graduation research, it is highly contributing to the practical relevance of this research, since the various metrics from this implementation are useful for the future model and implementations in this research.

Chapter 6

Network Contribution

As concluded from the literature review (see Section 2.4), the common practice in the literature is to apply several levels in the profitability of a segment or route in a greater system, which allows for analyzing the sources and areas of profitability in addition to the mere profitability of a segment or route. This is confirmed in the practical research (see Section 4.4), accompanied by the ambition to obtain the contribution of the connecting revenues to the profitability of a segment. This principle, however, is not applied by the predecessor of this research (Backker, 2013). From this, it is not possible to interpret the contribution of the various elements of revenues and costs to the NV of a segment or route. Therefore, the NC will elaborate on the model of the predecessor of this research by applying multiple levels in the NV of a segment or route in order to be able to identify the sources and areas of (un)profitability. The NC will also propose an improved metric to measure the contribution of the segment or route to the greater system. This will provide an answer to the second research question. In Figure 6.1, the isolated part of the conceptual model for the NC is depicted. The number of passengers and revenues on as well OD level as segment level, together with the costs on segment level, will be used to obtain the NC.

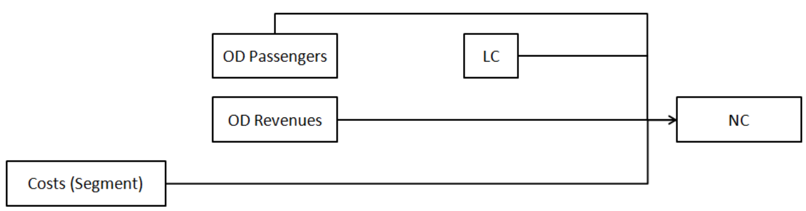

Figure 6.1: Conceptual Model of NC

The structure of this chapter is as follows. In Section 6.1, the concept of the NC will be further elaborated on, by which the research question 2(a) will be answered. In Section 6.2, the input for the NC which was not already used in the base model will be addressed, by which the research question 2(b) and 2(c) will be answered. In Section 6.3, the model for the NC will be constructed using Python, by which the research question 2(d) will be answered. In Section 6.4, the conclusions from the NC so far will be drawn.

6.1 Concept Network Contribution

The concept for the NC is subdivided into two parts. The first part is the analysis of the NV from Backker (2013) by applying multiple levels in its calculations as well an elaboration on the assumptions and drawbacks of this previously proposed metric. Subsequently, in the following part of the NC, an improved metric is presented to measure the performance of a segment or route considering its value in the network.

Network Value Analysis

The main principle of the Network Value Analysis is to apply multiple levels in the NV of Backker (2013) to be able to identify the contribution of the various elements of revenues and costs. In Table 6.1, the setup of these multiple levels is depicted. The overview starts with the IOC of the segment, since these costs are incurred prior to the operation itself. After adding the local revenues and subtracting the local DOC, the Route Result is obtained, which indicates the profit that the route is making on itself without any contribution of other segments in the network. Subsequently, the Network Result is obtained by prorating a part of the connecting revenues to the segment in consideration, based on DOC, which will be elaborated in more detail below. The Network Result indicates the profit that the flight leg is making by taking into account a part of the revenues that the connecting passengers on the segment in consideration are generating in the complete network. The NV of Backker (2013) is obtained by adding the remaining part of the connecting revenues and subtracting the connecting DOC and IOC based on the number of passengers. The NV is indicating the monetary value that is incurred by operating the segment in consideration by also taking into account the costs that the connecting passengers on that segment are incurring on other flight legs in the network.

-	local IOC
+	local revenues
-	local DOC
=	**Route Result**
+	prorated connecting revenues*
=	**Network Result**
+	remaining connecting revenues
-	prorated connecting DOC**
-	prorated connecting IOC**
=	**Network Value (NV)**

Notes

* Proration based on DOC

** Proration based on number of passengers

Table 6.1: Network Value Analysis

In reverse, the NV of Backker (2013) should indicate the monetary value which is at risk in case of cancellation of the flight leg. As assumed in the Section 5.1, however, the local IOC are not dependent on the degree of operation and will not be avoided in case of the discontinuation of the flight leg. Furthermore, the proration of the connecting DOC and IOC is dubious. First of all, the connecting IOC are also not avoided in case of the discontinuation of another flight leg. Secondly, this method is disregarding the principle of the DOC_{pax} as a function of LF from the practical research, which indicates that the incremental DOC of having an additional passenger on the segment will decrease as the LF increases. Instead, the proration of the connecting DOC is assigning every passenger an equal share of the DOC of the other segment without regard of the LF on that other segment. The DOC on a segment can namely be already covered by the current number of passengers on that segment, after which the DOC of the additional passengers are negligible.

The segment NBO-LHR from the sample network (see Figure 5.2) will be used as an example to elaborate on the concept described above. All monetary values are in KES. The local revenues for the NBO-LHR segment are 192.572.123, 17, as obtained from the base model. The local costs for the NBO-LHR segment are 315.321.649, 88, from which 75.277.804, 47 are IOC and 240.043.845, 41 are DOC, according to the cost breakdown of KQ (see Table 5.2). The connecting revenues are prorated based on DOC, instead of the full-fare or mileage based proration, in order to force the prorated connecting revenues and the Route Result on a related scale. Using this proration method, the prorated connecting revenues will be linked to the cost allocation of the DOC itself, which shares the point of improvement of KLM from the practical research. In Table 6.2, the proration of the connecting revenues for the segment NBO-LHR is worked out. In this, each OD pair that makes use of the segment NBO-LHR is listed with the total DOC and the total revenue of that OD pair. The prorated connecting revenues (Pro Con Rev) is obtained by taking the share of the total revenue equivalent to the share of the DOC of NBO-LHR with respect to the total DOC of the OD pair. For example, the OD pair HRE-LHR has a total DOC of 250, 422, 417.05 in which the segment NBO-LHR has a share of around 95%, by which an equivalent share of the total revenues of the OD pair HRE-LHR is prorated to the NBO-LHR segment. This yields that a revenue equal to 18, 354, 644.38 of the OD pair HRE-LHR is prorated to the NBO-LHR segment.

OD	DOC OD	Rev OD	Pro Con Rev
BKK-LHR	298,693,240.85	0.00	0.00
HKG-LHR	325,585,455.89	0.00	0.00
HRE-LHR	250,422,417.05	19,148,228.53	18,354,644.38
LVI-LHR	255,810,754.73	1,314,113.60	1,233,118.14
TNR-LHR	282,593,856.56	5,318,377.00	4,517,591.72
Total			**24,105,354.24**

Table 6.2: Proration Connecting Revenues by DOC for NBO-LHR (see Figure 5.2) September 2015

The remaining connecting revenues of NBO-LHR can be obtained by taking the total connecting revenues and subtract the prorated connecting revenues from the method above. Since the total connecting revenues of NBO-LHR are 25, 780, 719.13, this yields the remaining connecting revenues to be 1, 675, 364.89. The connecting DOC and IOC are prorated based on the number of passengers (see Equation 2.11), similar to the method in the base model (see Table 5.9). In this, however, the costs are split in the DOC and the IOC. This yields a prorated connecting DOC of 5, 372, 756.37 and a prorated connecting IOC of 3, 096, 985.70. In Table 6.3, an overview of this Network Value Analysis of the NBO-LHR segment is depicted. All monetary values are in KES.

-	local IOC	75,277,804.47
+	local revenues	192,572,123.17
-	local DOC	240,043,845.41
=	**Route Result**	**-122,749,526.71**
+	prorated connecting revenues	24,105,354.24
=	**Network Result**	**-98,644,172.47**
+	remaining connecting revenues	1,675,364.89
-	prorated connecting DOC	5,372,756.37
-	prorated connecting IOC	3,096,985.70
=	**Network Value**	**-105,438,549.65**

Table 6.3: Network Value Analysis of NBO-LHR (see Figure 5.2) September 2015

The relation among the Route Result and the Network Result, or the local revenues and the (prorated) connecting revenues, can be used to obtain contribution of the segment to the network. For example, a flight leg which is gaining sufficient profit, but which is mainly based on local passengers, can be a questionable contributor to the hub-and-spoke network. As an analogy, a football player which is generating a lot of goals, but which is not passing any balls to its team members, can be a questionable contributor to the football team. Therefore, in this part of the research, some additional literature study has been consulted regarding the determination of the transfer fee of a football player and the performance analysis of a football player in a team, in order to explore commonalities in assigning a monetary value to an element in a greater system or analysing its performance as part of a greater system. The transfer fee of a football player is based on the personal characteristics of the player and the characteristics of the buying and selling club (Haverkamp, 2010; Trequattrini et al., 2012; Ignacio et al., 2007), which is not applicable for assigning a monetary value to a flight leg in a hub-and-spoke network, since it is not taking into account the interdependencies among the elements of the greater system. On the other hand, the analysis of the performance of a football player in a team (Footballscience.net) addresses as well the goals as the passes as prominent technical parameters. In this, a football player which is generating goals as well as passing balls to its team member could be defined as a higher contributor to the team with respect to a football player which is purely generating goals. An attempt to combine this principle with the network performance measure to be made in this research failed.

Network Contribution Value & Network Contribution Value Analysis

The NC is elaborating on the calculation of the NV with respect to the proration of the connecting costs. Therefore, the Network Contribution Value (NCV) is proposed. In this research, it is assumed that none of the IOC are discarded in case of the cancellation of a segment. Furthermore, in Section 4.2, it is discussed that as well the local passengers as the connecting passengers are incurring DOC on a segment. However, despite of the fact that the DOC of a segment are shared by as well the local passengers as the connecting passengers, the fixed costs shared by the connecting passengers are not discarded in case of the cancellation of a connecting segment. Therefore, purely the variable costs of the connecting passengers are discarded in case of the cancellation of a segment. In Section 5.1, it was assumed from the cost breakdown of KQ (see Table 5.2) that the variable costs comprise the PAX Meals, PAX Costs on Ground and Commissions. In Equation 6.1, the NCV is formulated. The part on the revenues remains unchanged with respect to the NV. On the side of the costs, all DOC of the OI are subtracted, while for the connecting segments outside the OI purely the variable costs of the spilled connecting passengers are subtracted.

$$NCV_{OI} = \sum_{OD=1}^{n} R_{OD,OI} - DOC_{OI} - \sum_{\substack{segment=1 \\ segment \notin OI}}^{m} \frac{pax_{segment,OI}}{pax_{segment}} variable_{segment} \tag{6.1}$$

The segment NBO-LHR from the sample network (see Figure 5.2) will be used as an example to elaborate on the concept described above. All monetary values are in KES. The sum of all the OD revenues that make use of the NBO-LHR segment is $218,352,842.30$, and the DOC of the NBO-LHR segment are $240,043,845.40$. These correspond to the first and second term in Equation 6.1 respectively. In Table 6.4, the latter term from Equation 6.1 is worked out. The potential connecting segments in the sample network are listed with the number of passengers on that segment which also make use of the segment NBO-LHR, the total number of passengers on that segment and the variable costs of that segment. The sum of the variable costs of the other segments in the network, which are accountable to the segment NBO-LHR, is $685,406.32$. This yields a NCV of $-22,376,409.43$.

Segment	$pax_{segment,NBOLHR}$	$pax_{segment}$	$variable_{segment}$	$variable_{segment,NBOLHR}$
BKK-NBO	0	1255	4,116,505.69	0.00
HKG-BKK	0	970	2,253,346.13	0.00
TNR-NBO	76	1007	6,276,965.50	473,733.25
HRE-NBO	339	1706	1,028,492.30	204,372.15
LVI-HRE	27	1468	396,954.17	7,300.93
Total				**685,406.32**

Table 6.4: Costs for NCV of NBO-LHR (see Figure 5.2) September 2015

This means that the NBO-LHR segment is contributing a negative value to the network. Therefore, in reverse, the network will gain a value of $22,376,409.43$ KES in case of the cancellation of this segment. Note that in this calculations purely the number of passengers and revenues in the sample network are taken into account, while the costs are still taking into account the full KQ network.

In more detail, the NCV can be worked out in multiple levels to be able to identify the contribution of the various elements of revenues and costs, as in the Network Value Analysis. In Table 6.5, the set-up of the Network Contribution Value Analysis is listed. This analysis starts with the local revenues and subtracting the local DOC of the segment. In case of the DOC, the fixed and variable costs are mentioned separate, since both have other drivers. Subsequently, a part of the connecting revenues is prorated to the segment in consideration, based on DOC, similar as in the Network Value Analysis. The NCV is obtained by also subtracting the variable costs which connecting passengers are incurring on connecting segments.

+	local revenues
-	local fixed
-	local variable
=	**Route Contribution Result**
+	prorated connecting revenues*
=	**Network Contribution Result**
+	remaining connecting revenues
-	prorated connecting variable**
=	**Network Contribution Value (NCV)**

Notes

* Proration based on DOC

** Proration based on number of passengers

Table 6.5: Network Contribution Value Analysis

In Table 6.6, the Network Contribution Value Analysis is elaborated on for the NBO-LHR segment. The calculation of the NCV has already been discussed on the previous page. The connecting revenues are prorated based on DOC (see Table 6.2), similar as in the Network Value Analysis.

+	local revenues	192,572,123.17
-	local fixed	215,070,369.49
-	local variable	24,973,475.92
=	**Route Contribution Result**	**-47,471,722.23**
+	prorated connecting revenues	24,105,354.24
=	**Network Contribution Result**	**-23,366,367.99**
+	remaining connecting revenues	1,675,364.89
-	prorated connecting variable	685,406.32
=	**Network Contribution Value**	**-22,376,409.43**

Table 6.6: Network Contribution Value Analysis of NBO-LHR (see Figure 5.2) September 2015

This NCV indicates an improved performance of the segment NBO-LHR in the sample network with respect to the NV for the same period of time. The difference between the NCV and the NV are the local IOC and the connecting IOC which are prorated to the NBO-LHR segment.

6.2 Input Network Contribution

In this section, the input for the NC will be discussed with respect to the source and structure. Most of the input for the NC is obtained from the base model. The fixed and variable costs are obtained from the DOC in accordance with the division as specified in the base model. The DOC, however, still have to be divided into the fixed and variable costs. The variable costs represent the DOC which are dependent on the number of passengers, and are assumed to contain the PAX Meals, PAX Costs on Ground and Commissions from KQ its cost breakdown (see Table 5.2), while the rest of the DOC comprise the fixed costs which are not dependent on the number of passengers.

6.3 Implementation & Results Network Contribution

In this section, the actual implementation of the NC in Python will be discussed. This implementation is divided into two parts; the implementation of the Network Value Analysis including the proration of the connecting revenues based on DOC, and the implementation of the NC including all its elements as described above. The implementation will be tested on the sample network from the previous chapter. Prior to the actual implementation in Python, the metrics are manually calculated in Excel with the aim of the verification of the implementation.

Network Value Analysis

The implementation of the Network Value Analysis is largely similar to the implementation of the NV in the base model. The local IOC, the local revenues and the local DOC are already determined in the base model. The implementation of the prorated connecting DOC and the prorated connecting IOC are the same as for the costs for the NV in the base model, besides the fact that the DOC and the IOC are considered separate.

The deviating part from the base model is the implementation of the proration of the connecting revenues by DOC. At first, the nine possible segments in the sample network were distinguished in the same manner as in the implementation of the base model. The determination of the other potential segments in the network, and the corresponding OD pairs, is similar to the method used in the implementation of the NV in the base model. Subsequently, the revenue for the OD pair can be obtained from the OD revenues. The total DOC for the OD pair, however, should be calculated. In this, each of the nine possible segments has its own method to calculate the total DOC for the OD pairs that are served by that segment. As an example, the segment NBO-LHR is taken into consideration (see Table 6.2). At first, the DOC of the NBO-LHR segment and the potential segment are added. This is sufficient for the OD pairs which consist of two segments (BKK-LHR, TNR-LHR and HRE-LHR), while in the other OD pairs the DOC of the intermediate segment(s) should be added. The concerned OD pairs (HKG-LHR and LVI-LHR) are distinguished by the fact that the potential segment (HKG-BKK and LVI-HRE) and the segment in consideration (NBO-LHR) are connected directly. Therefore, the DOC of the intermediate segment are added, in which the appropriate segment from the intermediate airport of the tag-end service is selected by checking which is connecting to the hub. From this, this model is limited to a tag-end service with two segments in both directions. The remaining connecting revenues are the connecting revenues minus the prorated connecting revenues from this implementation, in which the connecting revenues are already determined in the base model. In Table 6.7, the results from this implementation for the sample network from Figure 5.2 are depicted. It should be noted that these metrics are out of proportion, since the costs are covering the total network of KQ, while the revenues are purely taking into account the sample network.

Segment	Route Result	Network Result	Network Value
BKK-HKG	-34,903,734.38	-30,409,894.46	-38,531,803.62
BKK-NBO	-47,966,639.11	-29,147,915.66	-40,142,093.61
HKG-BKK	-28,198,821.34	-21,133,570.92	-29,793,799.50
HRE-NBO	22,787,149.02	28,309,704.73	18,705,127.18
LHR-NBO	-70,410,541.44	-51,687,793.28	-57,199,892.43
LVI-HRE	-7,318,388.21	6,453,773.85	13,452,797.56
NBO-BKK	-52,246,760.84	-38,402,786.38	-57,648,514.35
NBO-LHR	-122,749,526.70	-98,644,172.46	-105,438,549.64
NBO-LVI	-8,554,171.53	16,770,525.84	12,432,539.72
NBO-TNR	-33,533,615.65	-29,686,012.34	-33,397,165.78
TNR-NBO	-33,245,958.49	-30,202,621.81	-36,189,117.97

Table 6.7: Results Network Value Analysis Sample Network (see Figure 5.2) September 2015

It should be noted that these are the NV of each segment separate rather than a route. In order to obtain the NV for a route, a similar method as in the base model can be used. In this case, however, the levels of the Network Value Analysis can be used to obtain the NV of a route. The NV of a standard spoke route is obtained by adding the NV of the two opposite segments. The NV of a tag-end route is obtained by adding the NV of the two opposite inner segments (NBO-BKK and BKK-NBO) and the Route Result of the two opposite outer segments (BKK-HKG and HKG-BKK), since the connecting passengers to/from HKG are already incorporated in the inner segments. The NV of a round-robin route is obtained by adding the NV of the two outer segments (NBO-LVI and HRE-NBO) and the Route Result of the middle segment (LVI-HRE), since the connecting passengers to HRE and from LVI are already incorporated in the outer segments.

Network Contribution Value & Network Contribution Value Analysis

The implementation of the NCV and the Network Contribution Value Analysis is the same as for the NV and the Network Value Analysis, besides the fact that another formula is used in the prorated connecting DOC. In Table 6.8, the results from this implementation for the sample network from Figure 5.2 are depicted. It should be noted that these metrics are out of proportion, since the costs are covering the total network of KQ, while the revenues are purely taking into account the sample network.

Segment	Route Contri. Result	Network Contri. Result	Network Contri. Value
BKK-HKG	-27,529,402.15	-23,035,562.23	-12,861,264.66
BKK-NBO	-19,719,922.71	-901,199.26	7,377,576.53
HKG-BKK	-20,794,391.71	-13,729,141.29	1,346,031.71
HRE-NBO	28,464,231.09	33,986,786.80	55,189,333.95
LHR-NBO	1,621,861.20	20,344,609.36	22,256,898.75
LVI-HRE	-5,388,337.68	8,383,824.38	49,499,805.24
NBO-BKK	-23,153,244.95	-9,309,270.49	-3,810,103.58
NBO-LHR	-47,471,722.23	-23,366,367.99	-22,376,409.42
NBO-LVI	-1,602,835.12	23,721,862.25	49,559,829.06
NBO-TNR	-8,636,417.61	-4,788,814.30	2,846,720.11
TNR-NBO	-7,628,513.79	-4,585,177.11	2,968,753.27

Table 6.8: Results Network Contribution Value Analysis Sample Network (see Figure 5.2) September 2015

It should be noted that these are the NCV of each segment separate rather than a route. In order to obtain the NCV for a route, a similar method as for the NV from the previous page can be used. In this, however, the Route Result is replaced by the Route Contribution Result.

6.4 Conclusions Network Contribution

This chapter elaborated on the model of the predecessor of this research by applying multiple levels in the NV of a segment or route in order to be able to identify the sources and areas of (un)profitability, and by proposing the NCV as an improved metric to measure the contribution of a segment or route to a hub-and-spoke network. This provides an answer to the second research question.

At first, in the Network Value Analysis, several intermediate levels in the NV have been applied. In this separation, an intermediate profitability level is introduced which prorates a share of the connecting revenues based on DOC, instead of the commonly used mileage-based proration method, before applying the full-fare proration method. Using this proration method, the prorated connecting revenues will be linked to the cost allocation of the DOC itself, which shares the point of improvement of KLM from the practical research.

In this research, it is assumed that none of the IOC are discarded in case of the cancellation of a segment. The DOC can be subdivided into fixed costs, which are not dependent on the number of passengers, and variable costs which are dependent on the number of passengers. It is discussed that as well the local as the connecting passengers are incurring DOC on a segment. However, despite of the fact that the DOC of a segment are shared by as well the local as the connecting passengers, the fixed costs shared by the connecting passengers are not discarded in case of the cancellation of a connecting segment. Therefore, purely the variable costs of the connecting passengers are discarded in case of the cancellation of a segment. In this, the NCV is proposed, which indicates the monetary value which is at risk in case of the cancellation of a segment. Using the Network Contribution Value Analysis, multiple levels in the NCV have been applied, in order to be able to identify the source and areas of (un)profitability.

The input for the NC are the revenues on coupon level and the costs on segment level, which have already been discussed - and used - for the base model. The DOC, however, still had to be divided into the fixed and variable costs. The variable costs represent the DOC which are dependent on the number of passengers, and are assumed to contain the PAX Meals, PAX Costs on Ground and Commissions from KQ its cost breakdown (see Table 5.2), while the rest of the DOC comprise the fixed costs which are not dependent on the number of passengers. The implementation of the Network Value Analysis, the NCV and its Network Contribution Value Analysis are similar to the method used in the base model.

Despite of the ability to identify the sources and areas of (un)profitability, and having an improved indication of the contribution of a segment or route to a hub-and-spoke network, this analysis purely considers the cancellation of a segment or route, rather than changing the capacity without changing it to zero.

Chapter 7

Network Contribution under Changing Capacity

As concluded from the previous chapter, the NC so far purely allows for analyzing the cancellation of a segment or route. In this chapter, the NC will be analyzed under adjustments in capacity. Actually, the cancellation of a segment or route is an extraordinary case of the adjustment of the capacity. In this chapter, the effect of the change of capacity on the NC will be considered without changing the capacity to zero. The capacity will be changed by changing the frequency on a segment or route, or changing the type of aircraft operated on a segment or route.

The structure of this chapter is as follows. In Section 7.1, the concept of the NC under changing capacity will be further elaborated on. In Section 7.2, the input for the NC under changing capacity - which was not already used in the base model or the previous chapter - will be addressed. In Section 7.3, the implementation of the NC under changing capacity in Python will be discussed, together with a presentation of the results. In Section 7.4, the potential conclusions from the NC under adjustments in capacity will be drawn.

7.1 Concept Changing Capacity

Before changing the capacity on any segment or route, it is interesting to compare the actual number of passengers with the potential demand per OD pair, to be able to identify the utilisation of the potential demand per OD pair. From this, it is possible to identify the bottlenecks in the network with respect to the spilled potential demand.

The graduation research of Schot (2015) has elaborated on an airline passenger demand model based on the gravity model with an application at KQ. According to Schot (2015), a gravity model allows for producing accurate medium- to long-term demand forecasts for as well existing routes as new routes. This research, however, will not take into account new routes. In Equation 7.1, the demand model from Schot (2015) is formulated, where the $V_{ij,t}$ represents the potential passenger demand between i and j for a certain time period t. As in the research of Schot (2015), this model will be used to forecast passenger demand on country-pair level, due to data issues. Furthermore, as in the research of Schot (2015), this model assumes there is no effect of directionality.

$$\begin{aligned} V_{ij,t} = k \times (CPI_{ij,t}^{\alpha_1} \times EFF_{ij,t}^{\alpha_2} \times GDP_{ij,t}^{\alpha_3} \times POL_{ij,t}^{\alpha_4} \times POP_{ij,t}^{\alpha_5}) \times D_{ij}^{\alpha_6} \\ \times (e^{BOR_{ij}^{\alpha_7} + BTA_{ij}^{\alpha_8} + COL_{ij}^{\alpha_9} + DT_{ij,1}^{\alpha_{10}} + DT_{ij,2}^{\alpha_{11}} + LAN_{ij}^{\alpha_{12}} + LL_{ij,1}^{\alpha_{13}} + LL_{ij,2}^{\alpha_{14}}}) \end{aligned} \tag{7.1}$$

The variables in the model can be categorized into time-dependent variables ($CPI_{ij,t}$, $EFF_{ij,t}$, $GDP_{ij,t}$, $POL_{ij,t}$, $POP_{ij,t}$), constant variables (D_{ij}) and dummy variables (BOR_{ij}, BTA_{ij}, COL_{ij}, $DT_{ij,1}$, $DT_{ij,2}$, LAN_{ij}, $LL_{ij,1}$, $LL_{ij,2}$). Each variable is associated with a coefficient α, which controls the influence of each variable. The definition of each of the variables according to Schot (2015) is listed below.

- k is the regression intercept;
- $CPI_{ij,t}$ is the annual average Consumer Price Index (2010 = 100) of country i times j at time t;
- $EFF_{ij,t}$ is the index of government effectiveness of country i times j at time t. According to Schot (2015), the values range from -3 (very weak) to $+3$ (very strong);
- $GDP_{ij,t}$ is the GDP per capita of country i times j at time t;
- $POL_{ij,t}$ is the index of political stability of country i times j at time t. According to Schot (2015), the values range from -3 (very unstable) to $+3$ (very stable);
- $POP_{ij,t}$ is the mid-year population of country i times j at time t;
- D_{ij} is the great-circle distance between city in country i and city in country j in kilometers;
- BTA_{ij} is a dummy variable which indicates whether country i and j have a bilateral trade agreement or not;
- BOR_{ij} is a dummy variable which indicates whether country i and j share a common border or not;
- COL_{ij} is a dummy variable which indicates whether country i and j have had the same colonisers or not;
- $DT_{ij,1}$ and $DT_{ij,2}$ are a dummy variables which give a penalty if the distance between country i and j is less than 100 kilometers and 750 kilometers respectively;
- LAN_{ij} is a dummy variable which indicates whether country i and j have the same official language or not;
- $LL_{ij,1}$ is a dummy variable which indicates whether only one of the two countries is landlocked;
- $LL_{ij,2}$ is a dummy variable which indicates whether both countries are landlocked;

In order to find the values for the coefficients using regression, Schot (2015) log-linearized the demand formula. In Equation 7.2, the log-linearised version of Equation 7.1 from Schot (2015) is shown. According to Schot (2015), the error ϵ_{ij} is assumed to be independent and identically distributed.

$$\begin{aligned} ln(V_{ij,t}) = ln(k) &+ \alpha_1 \times ln(CPI_{ij,t}) + \alpha_2 \times ln(EFF_{ij,t}) + \alpha_3 \times ln(GDP_{ij,t}) + \alpha_4 \times ln(POL_{ij,t}) \\ &+ \alpha_5 \times ln(POP_{ij,t}) + \alpha_6 \times ln(D_{ij}) + \alpha_7 \times BOR_{ij} + \alpha_8 \times BTA_{ij} + \alpha_9 \times COL_{ij} \\ &+ \alpha_{10} \times DT_{ij,1} + \alpha_{11} \times DT_{ij,2} + \alpha_{12} \times LAN_{ij} + \alpha_{13} \times LL_{ij,1} + \alpha_{14} \times LL_{ij,2} + \epsilon_{ij} \end{aligned} \tag{7.2}$$

In this log-linearisation, however, something odd occurred. The log-linearisation of the exponential-term from Equation 7.1 is not correct. Furthermore, since the dummy variables are binary, the coefficients of the dummy variables should not be in the power, but should be multiplied with the dummy variables. This would make the log-linearised formula correct. Therefore, in Equation 7.3, the revised demand formula is formulated.

$$\begin{aligned} V_{ij,t} = k &\times (CPI_{ij,t}^{\alpha_1} \times EFF_{ij,t}^{\alpha_2} \times GDP_{ij,t}^{\alpha_3} \times POL_{ij,t}^{\alpha_4} \times POP_{ij,t}^{\alpha_5}) \times D_{ij}^{\alpha_6} \\ &\times (e^{\alpha_7 \times BOR_{ij} + \alpha_8 \times BTA_{ij} + \alpha_9 \times COL_{ij} + \alpha_{10} \times DT_{ij,1} + \alpha_{11} \times DT_{ij,2} + \alpha_{12} \times LAN_{ij} + \alpha_{13} \times LL_{ij,1} + \alpha_{14} \times LL_{ij,2}}) \end{aligned} \tag{7.3}$$

In the research of Schot (2015) the Ordinary Least Squares (OLS), Poisson Pseudo Maximum Likelihood (PPML) and Negative Binomial (NB) regression methods were compared. It is concluded that the NB regression method yields the most accurate regression result. The result was improved by clustering the predictions based on political stability ($POL_{ij,t}$) with the levels low-low, low-high/high-low and high-high. In Appendix F, the values for the coefficients for each clustering level are listed. The constant represents the term $ln(k)$ in the log-linearised demand formula. A negative coefficient indicates that the accompanying variable has a negative effect on the demand, while a positive coefficient indicates a positive effect on demand.

The segment NBO-LHR from the sample network (see Figure 5.2) will be used as an example to elaborate on the calculations described above. As in the research of Schot (2015), the $CPI_{ij,t}$, $GDP_{ij,t}$ and $POP_{ij,t}$ are taken from The World Bank; the $EFF_{ij,t}$ and $POL_{ij,t}$ are taken from Kaufmann et al. and all the dummy variables besides the BTA_{ij} are taken from Mayer and Zignago (2011). The $EFF_{ij,t}$ and $POL_{ij,t}$ turn out to range from -2.5 to +2.5, but which does not influence the demand model, since these variables are corrected to a scale from 0 to 2 for the reason that the demand model can not handle negative values. Due to the lack of data, and the low significance (see Appendix F), the dummy variable BTA_{ij} is discarded from this research. In order to be consistent, all variables with the lowest significance are discarded from this research, which is limited to the political stability $POL_{ij,t}$ in the high-high clustering level. The constant variable D_{ij} is taken from the base model. In Table 7.1, the variables for the potential demand for the country-pair Kenya United-Kingdom for a certain year are listed.

	Kenya	**United-Kingdom**
CPI	140.90	111.80
EFF	0.88	1.65
GDP	1,358.30	46,297.00
POL	0.49	1.18
POP	44,863,583	64,559,135
D	6,840.65	
BOR	0	
BTA	-	
COL	1	
DT1	0	
DT2	0	
LAN	1	
LL1	0	
LL2	0	

Table 7.1: Variables Demand from Kenya to United-Kingdom

This yields a potential demand of 120,511 passengers willing to travel from Kenya to the United-Kingdom for this particular year. The research of Schot (2015) is converting the demand per country-pair to the demand per city-pair by analyzing the history of share of passengers travelling between the two cities in the two countries. However, due to the lack of this data in this research, it is assumed that the number of passengers willing to travel between two countries is equal to the potential demand to be attracted between the two cities in the two countries. In case of the long-haul markets, the city-pairs are mostly attracting the potential demand between the two countries. In Table 7.2, the potential demand per OD pair for the sample network for this particular year is depicted. Since the effect of directionality is not taken into account in the model of Schot (2015), this matrix is symmetric. In addition to the model of Schot (2015), it is assumed that there are no restrictions with respect to Air Service Agreement (ASA)s.

	BKK	**HKG**	**HRE**	**LHR**	**LVI**	**NBO**	**TNR**
BKK	0	249,397	649	64,598	889	8,825	1,947
HKG	249,397	0	231	18,526	164	4,215	575
HRE	649	231	0	6,041	5,093	3,969	424
LHR	64,598	18,526	6,041	0	11,786	120,511	2,391
LVI	889	164	5,093	11,786	0	9,720	290
NBO	8,825	4,215	3,969	120,511	9,720	0	3,077
TNR	1,947	575	424	2,391	290	3,077	0

Table 7.2: OD Demand per Year Sample Network

The market share of an airline is defined as the proportion of the total market demand that is captured by that airline (Belobaba, 2009a, p. 68). In this research, the S-curve market share model will be used to determine the market share of the airline in the market. This method was also used by Schot (2015). The reader is referred to Belobaba (2009a, p. 69) for a graphical representation of the S-curve. In Equation 7.4, the mathematical formulation of the S-curve is depicted, where $MS(i)$ represents the market share of airline i and $FS(i)$ the non-stop frequency share of airline i. The exponent β is greater than 1.0, and generally between 1.3 and 1.7. The value of the exponent β depends on the importance of frequency in a particular market (Belobaba, 2009a, p. 70).

$$MS(A) = \frac{FS(A)^{\beta}}{FS(A)^{\beta} + FS(B)^{\beta} + FS(C)^{\beta} + ...} \tag{7.4}$$

The model of Schot (2015) assumed that β is a linear function of the route distance, where the shortest route is assigned a β of 1.7 and the longest route is assigned a β of 1.3. This method was also used by Lammens (2014). In order to be consistent among various networks with different routes, it is assumed in this research that the direct markets are associated with a β of 1.7 and that the indirect markets are associated with a β of 1.3, since the indirect markets are less sensitive to frequency due to the presence of a transfer.

The direct markets NBO-BKK-NBO, NBO-TNR-NBO and all the segments of the NBO-LVI-HRE-NBO route have no competitors, which yields a market share of 100% for these markets. In Equation 7.5, the market share for the market NBO-LHR-NBO is calculated. The frequency shares are represented in flights per week. As the sample network is actually a part of the KQ network itself, the flight schedules of KQ and its competitors have been consulted. In this market, there is one competitor with the same frequency, yielding 50% market share.

$$MS(A) = \frac{\frac{7}{14}^{1.7}}{\frac{7}{14}^{1.7} + \frac{7}{14}^{1.7}} = 50\% \tag{7.5}$$

In Equation 7.6, the market share for the market BKK-HKG-BKK is calculated. The frequency shares are represented in flights per week. As the sample network is actually a part of the KQ network itself, the flight schedules of KQ and its competitors have been consulted. This market is quite crowded with nine competitors with varying excessive frequency shares, yielding 0.29% market share.

$$MS(A) = \frac{\frac{3}{185}^{1.7}}{\frac{3}{185}^{1.7} + \frac{42}{185}^{1.7} + \frac{57}{185}^{1.7} + \frac{34}{185}^{1.7} + \frac{21}{185}^{1.7} + \frac{7}{185}^{1.7} + \frac{3}{185}^{1.7} + \frac{7}{185}^{1.7} + \frac{4}{185}^{1.7} + \frac{7}{185}^{1.7}} = 0.29\% \tag{7.6}$$

The market share for the indirect markets is assumed to be evenly distributed among the airlines that operate that market, due to presence of a transfer. In this, it is assumed that the market share of an indirect market is zero if that market is also served directly by a competitor. For example, the markets LHR-BKK-LHR and LHR-HKG-LHR are also served directly by competitors, from which is it assumed that this $MS(A)$ is zero. In Table 7.3, the market shares for the market in the sample network are presented.

	BKK	**HKG**	**HRE**	**LHR**	**LVI**	**NBO**	**TNR**
BKK	-	0.29	25.00	-	50.00	100.00	33.33
HKG	0.29	-	25.00	-	50.00	16.67	50.00
HRE	25.00	25.00	-	33.33	100.00	100.00	50.00
LHR	-	-	33.33	-	50.00	50.00	25.00
LVI	50.00	50.00	100.00	50.00	-	100.00	50.00
NBO	100.00	16.67	100.00	50.00	100.00	-	100.00
TNR	33.33	50.00	50.00	25.00	50.00	100.00	-

Table 7.3: Market Shares Sample Network

It is assumed that the market share remains constant over the year. In obtaining the monthly potential demand for this sample network, it is assumed that each month has an equal share of the yearly demand. In this, no effect of seasonality is incorporated. In Table 7.4, the potential demand per OD pair per month for the sample network is depicted. From this, the potential demand per segment can be obtained in the same manner as in the base model.

	BKK	**HKG**	**HRE**	**LHR**	**LVI**	**NBO**	**TNR**
BKK	0	60	14	0	37	735	54
HKG	60	0	5	0	7	59	24
HRE	14	5	0	168	898	331	18
LHR	0	0	168	0	491	5,021	50
LVI	37	7	898	491	0	810	12
NBO	735	59	331	5,021	810	0	256
TNR	54	24	18	50	12	256	0

Table 7.4: OD Demand per Month, including Market Share, Sample Network

At this point, it is possible to compare the actual number of passengers with the potential demand per OD pair, to be able to identify the utilisation of the potential demand per OD pair. In Table 7.5, the comparison of the monthly OD passengers (see Table 5.5) with respect to the monthly OD demand is depicted. The numbers represent the percentage of the potential demand that is served. For example, on the LVI-BKK market only 2.7% fo the potential demand is served, while the actual number of passengers on the OD pair HKG-BKK is approximately a factor 10 higher than the forecasted potetial demand.

	BKK	**HKG**	**HRE**	**LHR**	**LVI**	**NBO**	**TNR**
BKK	-	477.89	199.69	-	16.20	107.69	101.69
HKG	983.90	-	332.47	-	0.00	534.66	192.00
HRE	140.52	207.79	-	202.02	0.00	336.51	33.96
LHR	-	-	149.58	-	10.39	53.21	174.65
LVI	2.70	0.00	0.00	5.50	-	23.58	0.00
NBO	130.13	372.38	287.53	68.75	32.10	-	290.15
TNR	133.13	171.13	22.64	152.57	0.00	317.45	-

Table 7.5: Percentage of Potential Demand Served per Month Sample Network

It can be noticed that quite some markets are adequately served. The markets with zero percent are probably due to the lack of ASAs. The outliers for the market between BKK and HKG is probably due to the fact that the model for the potential demand from Schot (2015) has been calibrated on the African market. Furthermore, the percentages are quite high overall, probably due to the lack of seasonality effects.

In the percentages of the potential demand served, it is possible to detect bottlenecks in the network with respect to underutilized demand, which can be used as an opportunity to change capacity. In the remainder of this section, the effects of the change of frequency and the change of aircraft on a route will be elaborated on.

Change of Frequency

In Figure 7.1, the flow chart for changing the frequency of operation on a segment or route is depicted. At first, the new fixed costs can be obtained by multiplying the current fixed costs with the change of frequency.

In case the frequency changes, the market share will change according to the S-curve market share model described above. The change in market share is assumed to be linear, approximated by the derivative of Equation 7.4 with respect to $FS(A)$. In Equation 7.7, the variation of the market share is formulated.

$$\frac{dMS(A)}{dFS(A)} = \frac{\beta \times FS(A)^{(\beta-1)} \times (FS(B)^{\beta} + FS(C)^{\beta} + ...)}{(FS(A)^{\beta} + FS(B)^{\beta} + FS(C)^{\beta} + ...)^2} \tag{7.7}$$

As the current market share for the direct market NBO-LHR-NBO is 50%, and for a direct market the β is equal to 1.7, the market share will change with 4.25% if the frequency on this market is changed with 10%.

It is assumed that the competitors remain constant. From this, the market shares for the indirect markets will slightly change in case the frequency is changed. As the current market share for the indirect market LHR-TNR-LHR is 25%, and for a indirect market the β is equal to 1.3, the market share will change with 2.4375% if the frequency on this market is changed with 10%.

If the frequency is decreased, the capacity will decrease from which the LF will increase, and the market share will decrease from which the potential demand will decrease. In case the new LF is not exceeding the adjusted capacity of the segment or route, purely some passengers due to decreased market share will be spilled. If the new LF is exceeding the adjusted capacity of the segment or route, the passengers will be spilled to the new demand or 100% LF, whichever is the lowest. In this, it is checked whether the current demand is higher than the current number of passengers, otherwise the passengers will be spilled to 100% LF. In both cases, the new revenues and variable costs should be calculated according to the adjusted number of passengers.

If the frequency is increased, the capacity will increase from which the LF will decrease, and the market share will increase from which the potential demand will increase. It is assumed that if the current LF is lower than 75% the OD markets on that route are saturated. Therefore, if the current LF is lower than 75%, purely some additional passengers due to increased market share will be added. In case the current LF is higher than 75%, the OD markets on that route were not yet saturated and the unused capacity will be filled with passengers up to the old LF as long as the demand allows. The old LF is used as a reasonable limit in order to put the new to be obtained LF into perspective with respect to the old LF. In this, it is checked whether the current demand is higher than the current number of passengers, otherwise the additional capacity will be filled up to the old LF. In both cases, the new revenues and variable costs should be calculated according to the adjusted number of passengers.

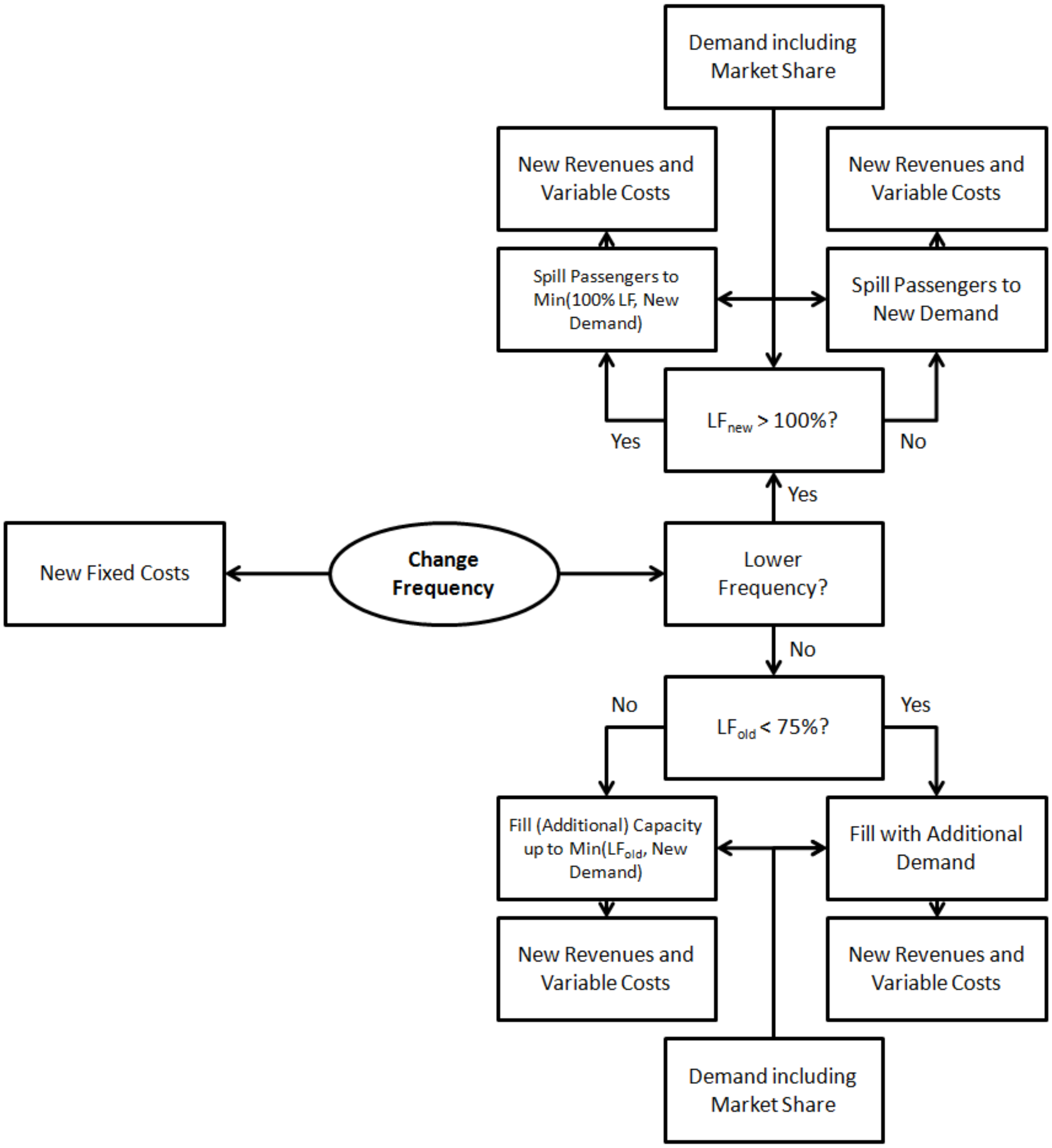

Figure 7.1: Flow Chart Change of Frequency

The route NBO-LHR-NBO from the sample network (see Figure 5.2) will be used as an example to elaborate on the method described above. Assume that, currently, seven flights each way per week are operated. The frequency on the route NBO-LHR-NBO is increased with one flight each way per week, which yields an increase of 14.3% in frequency. In Table 7.6, the Network Contribution Value Analysis for this route under this change in frequency is depicted. The fixed costs for the route will increase with 14.3%. Assume that the current LF of the segment NBO-LHR is 89% and 81% for the LHR-NBO segment, which will both initially decrease with 14.3%. The number of passengers necessary to retain the old LF with the (additional) capacity on the NBO-LHR segment is 4,451 and 3,499 on the LHR-NBO segment, while the demand - including additional demand due to increased market share - for both segments is 5,922, which means that the total number of passengers and the total revenues (i.e. local and connecting) can be increased by 14.3% to retain the old LFs on the segments. From this, the variable costs can be increased similarly. This yields a NCV of −136,600.70 KES. In this case, the absolute value of the NCV has increased by 14.3%, since the potential demand is allowing to fill-up the (additional) capacity up to the old LF.

		Current	Change	
		7 flights p/w	**8 flights p/w**	**14.3%**
+	local revenues	354,325,108.87	404,993,599.44	14.3%
-	local fixed	359,294,686.89	410,673,827.12	14.3%
-	local variable	40,880,283.07	46,726,163.55	14.3%
=	**Route Contribution Result**	**-45,849,861.03**	**-52,406,391.23**	**14.3%**
+	prorated connecting revenues	42,828,102.40	48,952,521.04	14.3%
=	**Network Contribution Result**	**-3,021,758.63**	**-3,453,870.18**	**14.3%**
+	remaining connecting revenues	4,348,611.12	4,970,462.51	14.3%
-	prorated connecting variable	1,446,363.16	1,653,193.09	14.3%
=	**Network Contribution Value**	**-119,510.67**	**-136,600.76**	**14.3%**

Table 7.6: Network Contribution Value Analysis of NBO-LHR-NBO under Changing Frequency

Another example is the NBO-TNR-NBO route. Assume that, currently, seven flights each way per week are operated. The frequency on the route NBO-TNR-NBO is decreased with one flight each way per week, which yields an decrease of 14.3% in frequency. In Table 7.7, the Network Contribution Value Analysis for this route under this change in frequency is depicted. The fixed costs for the route will decrease with 14.3%. The new LF of the segment NBO-TNR will be 69% and 68% for the TNR-NBO segment, which do not exceed the capacity. Therefore, purely some passengers will be spilled due to decreased market share. This implies that 2 out of 938 passengers on the segment NBO-TNR and 2 out of $1,007$ passengers on the TNR-NBO segment will be spilled. This yields a NCV of $16,070,474.99$ KES. In this case, the NCV has increased by 176%, since hardly some passengers due to be decreased market share were spilled while the fixed costs decrease.

	State	**Current**	**Change**	
	Frequency	**7 flights p/w**	**6 flights p/w**	**-14.3%**
+	local revenues	69,568,512.58	69,425,280.85	-0.2%
-	local fixed	72,846,086.06	62,429,095.76	-14.3%
-	local variable	12,987,357.92	12,960,583.38	-0.2%
=	**Route Contribution Result**	**-16,264,931.40**	**-5,964,398.28**	**-63.3%**
+	prorated connecting revenues	6,890,939.99	6,876,691.78	-0.2%
=	**Network Contribution Result**	**-9,373,991.41**	**912,293.50**	**-109.7%**
+	remaining connecting revenues	16,743,021.14	16,708,543.78	-0.2%
-	prorated connecting variable	1,553,556.35	1,550,362.29	-0.2%
=	**Network Contribution Value**	**5,815,473.38**	**16,070,474.99**	**176.3%**

Table 7.7: Network Contribution Value Analysis of NBO-TNR-NBO under Changing Frequency

Change of Aircraft

In Figure 7.2, the flow chart for changing the type of aircraft operated on a segment or route is depicted. At first, the new fixed costs for operating another type of aircraft on the segment or route should be calculated. The graduation research of Schot (2015) and Lammens (2014) have elaborated on calculating the operating costs per aircraft type per route. The research of Schot (2015) is used as the primary source for this method.

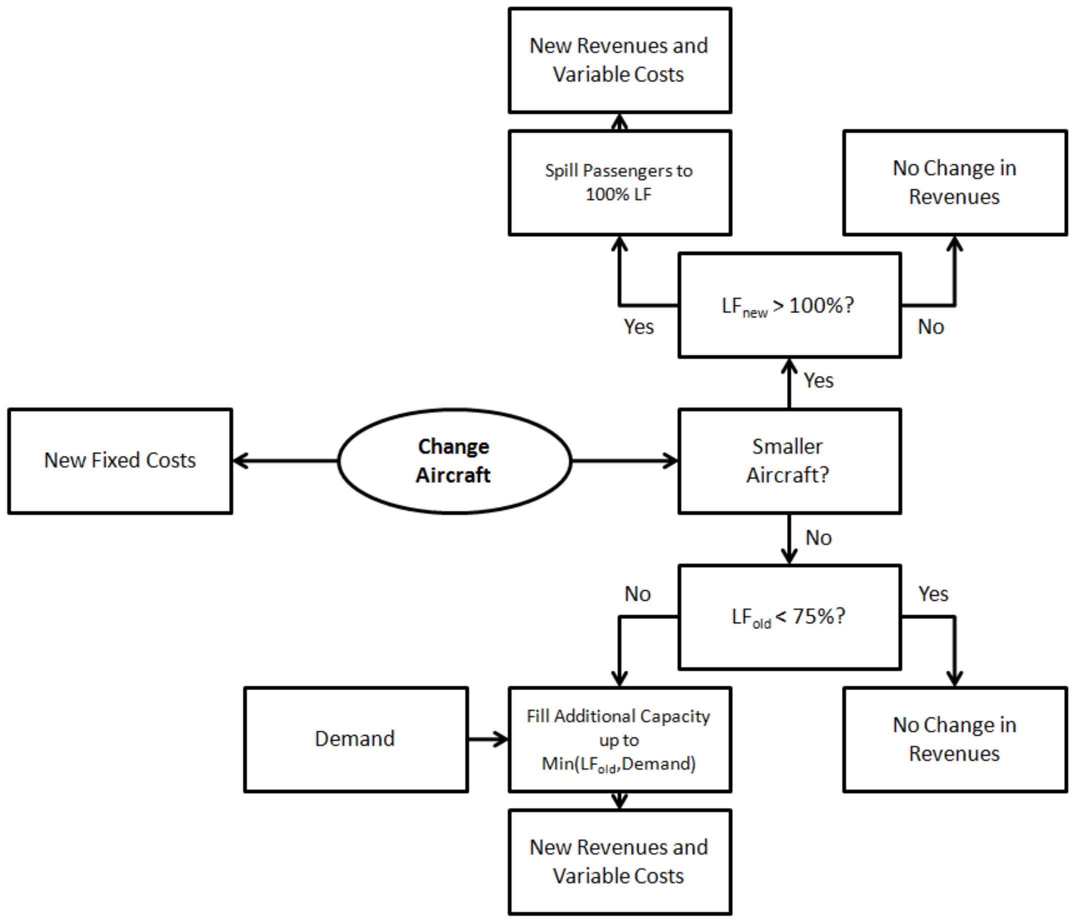

Figure 7.2: Flow Chart Change of Aircraft

In Equation 7.8, the fixed costs for a single one-way trip on any OI with a specific aircraft type according to Schot (2015) is formulated, which is the sum of the fuel costs, maintenance costs, crew costs and ownership costs.

$$fixed_{OI,AC} = costs_{fuel,OI,AC} + costs_{maintenance,OI,AC} + costs_{crew,OI,AC} \tag{7.8}$$

In Equation 7.9, the fuel costs for any OI with a specific aircraft type according to Schot (2015) is formulated, which is equal to the amount of jet fuel used by the specific aircraft type on the OI times the price of jet fuel. In this research, the jet fuel price is assumed to be 36.33 KES per liter (1.36 USD per gallon, 1 USD = 101.115 KES, 1 gallon = 3.78541178 liter) and assumed to remain constant.

$$costs_{fuel,OI,AC} = JF_{OI,AC} \times price_{JF} \tag{7.9}$$

In Equation 7.10, the amount of jet fuel used by a specific aircraft type on any OI according to Schot (2015) is formulated. The $M_{OI,AC}$ represents the fuel fraction used by the specific aircraft type on the OI specified. The latter term represents the Maximum Take Off Weight (MTOW) of the specific aircraft type.

$$JF_{OI,AC} = (1 - M_{OI,AC}) \times MTOW_{AC} \tag{7.10}$$

In Equation 7.11, the fuel fraction used by a specific aircraft type on any OI according to Schot (2015) is formulated, which is equal to the product of the fuel fractions of the different phases of a flight. According to Schot (2015), the phases of flight are engine start and warm-up, taxi, take-off, climb, cruise, descent, and landing, taxi and shutdown. The $W_{p,OI,AC}$ represents the weight at the end of phase p for the specific aircraft type on the OI specified.

$$M_{OI,AC} = \frac{W_{1,OI,AC}}{W_{TO,OI,AC}} \prod_{p=1}^{n} \frac{W_{(p+1),OI,AC}}{W_{p,OI,AC}} \tag{7.11}$$

In Table 7.8, the suggested fuel fractions for fuel un-intensive mission phases are listed.

Phase	**Fuel Fraction**
Engine Start and Warm-up	0.990
Taxi	0.990
Take-off	0.995
Climb	0.990
Descent	0.980
Landing, Taxi and Shutdown	0.992

Table 7.8: Suggested Common Fuel Fractions (Schot (2015, p. 62))

The flight phase which is the most fuel intensive is the cruise. In Equation 7.12, the fuel fraction for the cruise of a specific aircraft type on any OI is formulated. In this, the D_{OI} represents the distance of the OI in kilometers, the SFC_{AC} represents the Specific Fuel Consumption (SFC) of the aircraft type in $kg/(h * N)$, the g is the Earth its gravitation in m/s^2, the V_{AC} represents the cruise speed of the aircraft type in kilometers per hour and the L/D_{AC} is the lift to drag ratio of the aircraft type.

$$\frac{W_{5,OI,AC}}{W_{4,OI,AC}} = \frac{1}{e^{\frac{D_{OI} \times SFC_{AC} \times g}{V_{AC} \times (\frac{L}{D})_{AC}}}} \tag{7.12}$$

In Equation 7.13, the maintenance costs for any OI with a specific aircraft type according to Schot (2015) is formulated, consisting of a part dependent on the FC and a part dependent on the amount of Flight Hours (FH). The $FH_{OI,AC}$ represents the FH of the aircraft type on the OI specified in hours.

$$costs_{maintenance,OI,AC} = costs_{maintenance,FC,AC} + costs_{maintenance,FH,AC} \times FH_{OI,AC} \tag{7.13}$$

In Equation 7.14, the crew costs for any OI with a specific aircraft type according to Schot (2015) is formulated. In this, the $n_{crew,AC}$ represents the number of crew needed on the specific aircraft type and the $cost_{crew,FH}$ is the cost per crew per hour. According to Lammens (2014), the $cost_{crew,FH}$ is $2,023.31$ KES (20.01 USD, 1 USD = 101.115 KES). The $FH_{OI,AC}$ represents the FH of the aircraft type on the OI specified in hours.

$$costs_{crew,OI,AC} = n_{crew,AC} \times costs_{crew,FH} \times FH_{OI,AC} \tag{7.14}$$

In Equation 7.13 and Equation 7.14, the $FH_{OI,AC}$ is necessary. In Equation 7.15, the $FH_{OI,AC}$ according to Schot (2015) is formulated as the average flight time in hours with the cruise speed of the aircraft type in kilometers per hour and the distance of the OI in kilometers.

$$FH_{OI,AC} = \frac{D_{OI}}{V_{AC}} \tag{7.15}$$

The route NBO-LHR-NBO from the sample network (see Figure 5.2) will be used as an example to elaborate on the calculations described above. The fixed costs for operating a Boeing 777 on the route NBO-LHR-NBO will be calculated. In Table 7.9, the necessary data for these calculations is listed. The majority of this data is obtained from Lammens (2014, p. 56), while more recent predictions for maintenance costs are obtained from Schot (2015, p. 62). The cruise speed of the aircraft is expressed in the Mach-number, which represents the speed as a share of the speed of sound at that altitude. The cruise speed for Equation 7.12 and Equation 7.15 should be expressed in kilometers per hour. According to the International Standard Atmosphere (ISA), the speed of sound at the cruise altitude of the Boeing 777 is 1,061 kilometers per hour, which yields a cruise speed of 891.24 kilometers per hour.

	Unit	**Boeing 777**	**Boeing 787**	**Boeing 737**	**Embraer 190**
L/D*	n.a.	19.26	20.50	17.26	16.00
Cruise Altitude*	m	11,000	11,000	11,000	11,000
Maximum Range*	m	14,690,000	14,500,000	5,665,000	2,935,000
MTOW*	kg	299,370	227,930	79,010	51,800
OEW*	kg	167,500	118,000	41,413	28,080
Cruise Speed*	Mach	0.84	0.85	0.79	0.82
Seats*	n.a.	401	234	145	96
Crew*	n.a.	17	11	7	6
Mx Costs per Flight Hour**	KES/FH	146,617***	146,617***	72,095***	87,465***
Mx Costs per Flight Cycle**	KES/FC	637,429***	637,429***	140,247***	123,563***
SFC**	kg/h*N	?	0.0715	0.0715	0.0524

Notes

* Lammens (2014)

** Schot (2015)

*** 1 USD = 101.115 KES

Table 7.9: Characteristics of Aircraft Types in NC under Changing Aircraft

The only value that is missing is the SFC for the Boeing 777, which is necessary for Equation 7.12 in this example calculations. In Equation 7.16, the SFC for a specific aircraft type according to Lammens (2014) is formulated.

$$SFC_{AC} = \frac{V_{AC}}{g} \times \frac{1}{R_{AC}} \times \left(\frac{L}{D}\right)_{AC} \times ln\left(\frac{W_{initial,AC}}{W_{final,AC}}\right) \tag{7.16}$$

In this, the $W_{initial,AC}$ represents the initial weight of the specific aircraft type and the $W_{final,AC}$ is the final weight of the specific aircraft type. In this, it is assumed that the $W_{initial,AC}$ is equal to the MTOW of the aircraft type and the $W_{final,AC}$ is equal to the Operating Empty Weight (OEW) of the aircraft type. In accordance with the data from Table 7.9, the SFC of the Boeing 777 is equal to 0.0692 $kg/(h*N)$. Applying the equations above yields fixed costs of $5,114,321.05$ KES for operating a Boeing 777 a single one-way trip on the NBO-LHR-NBO route.

If the replacing aircraft is smaller, the capacity will decrease from which the LF will increase. In case the new LF is not exceeding the capacity of the replacing aircraft, no passengers will be spilled and the revenues and variable costs will remain constant. If the new LF is exceeding the capacity of the replacing aircraft, passengers will be spilled to 100% LF. In the latter case, the new revenues and variable costs should be calculated according to the adjusted number of passengers.

If the replacing aircraft is larger, the capacity will increase from which the LF will decrease. It is assumed that if the current LF is lower than 75% the OD markets on that route are saturated. Therefore, if the current LF is lower than 75%, no passengers will be added and the revenues and variable costs will remain constant. In case the current LF is higher than 75%, the unused capacity will be filled with passengers up to the old LF or the demand, whichever is the lowest. In this, it is checked whether the demand is higher than the current number of passengers, otherwise the additional capacity will be filled with passengers up to the old LF. In the latter case, the new revenues and variable costs should be calculated according to the adjusted number of passengers.

The route NBO-LHR-NBO from the sample network (see Figure 5.2) will be used as an example to elaborate on the method described above. It is assumed that the current - and only - aircraft operated on the NBO-LHR-NBO route is the Boeing 787. Since the distance of the NBO-LHR-NBO route is $6,840.66$ kilometers one way, the only possible replacing aircraft from Table 7.9 is the Boeing 777 with respect to the maximum range of the aircraft type. The current ASK of $54,079,940$ on the NBO-LHR segment and $51,347,940$ on the LHR-NBO segment, together with the number of seats in the Boeing 787 (see Table 7.9) and the distance of the segments, yields frequencies of 33.78 and 32.08 respectively. The sum of these frequencies times the new one-way uni-directional fixed costs yields new fixed costs of $336,829,184.50$ KES, which will replace the old fixed costs in the NCV of this route. In Table 7.10, the Network Contribution Value Analysis for this route under this change of aircraft is depicted. The old LFs of the NBO-LHR and LHR-NBO segment were 89% and 81% respectively. The number of passengers necessary to retain the old LF with the additional capacity on the NBO-LHR segment is $6,673$ and $5,245$ on the LHR-NBO segment, while the demand for both segments is $5,730$, which means that the number of passengers on the NBO-LHR segment can be increased up to the demand and on the LHR-NBO segment up to the number of passengers to retain the old LF. The same holds for the total revenues (i.e. local and connecting) and the variable costs. This yields a NCV of $232,013,672.18$ KES. In this case, the NCV has changed with a factor of around $-1,900$, which seems unrealistic. This is probably due to the new fixed costs of the replacing aircraft, as the replacing fixed costs of the Boeing 777 turn out to be lower than the current fixed costs of the Boeing 787.

	State	**Current**	**Change**	
	Aircraft	**B787**	**B777**	**+167 seats**
+	local revenues	354,325,108.87	560,560,923.05	58.2%
-	local fixed	359,294,686.89	336,829,184.50	-6.3%
-	local variable	40,880,283.07	64,007,436.28	56.6%
=	**Route Contribution Result**	**-45,849,861.03**	**159,724,302.27**	**-448.4%**
+	prorated connecting revenues	42,828,102.40	67,555,608.22	57.7%
=	**Network Contribution Result**	**-3,021,758.63**	**227,279,910.49**	**-7621.4%**
+	remaining connecting revenues	4,348,611.12	7,046,366.20	62.0%
-	prorated connecting variable	1,446,363.16	2,312,604.58	59.9%
=	**Network Contribution Value**	**-119,510.67**	**232,013,672.12**	**-194236.4%**

Table 7.10: Network Contribution Value Analysis of NBO-LHR-NBO under Changing Aircraft

Another example is the NBO-TNR-NBO route. It is assumed that the current - and only - aircraft operated on the NBO-TNR-NBO route is the Boeing 737. A smaller replacing aircraft will be considered. In accordance with the available aircraft from Table 7.9, the Embraer 190 is the only possible smaller replacing aircraft. The fixed costs for operating a Embraer 190 a single one-way trip on the NBO-TNR-NBO route is 639, 046.38 KES. The current ASK of 9, 301, 132.00 on the NBO-TNR segment and 9, 301, 132.00 on the TNR-NBO segment, together with the number of seats in the Boeing 737 and the distance of the segments, yields frequencies of 28.4 and 28.4 respectively. The sum of these frequencies times the new one-way uni-directional fixed costs yields new fixed costs of 36, 297, 834.82 KES, which will replace the old fixed costs in the NCV of this route. In Table 7.11, the Network Contribution Value Analysis for this route under this change of aircraft is depicted. The new LF of the segment NBO-TNR will be 65% and 64% for the TNR-NBO segment, which means that the number of passengers on these segments will not change. The same holds for the total revenues (i.e. local and connecting) and the variable costs. This yields a NCV of 42, 363, 724.62 KES. In this case, the NCV has changed with a factor of around 7, which seems more realistic. However, it can be noticed that this method is highly sensitive to the calculations of the replacing fixed costs of the replacing aircraft.

	State	**Current**	**Change**	
	Aircraft	**B737**	**E190**	**-49 seats**
+	local revenues	69,568,512.58	69,568,512.58	0.0%
-	local fixed	72,846,086.06	36,297,834.82	-50.2%
-	local variable	12,987,357.92	12,987,357.92	0.0%
=	**Route Contribution Result**	**-16,264,931.40**	**20,283,319.84**	**-224.7%**
+	prorated connecting revenues	6,890,939.99	6,890,939.99	0.0%
=	**Network Contribution Result**	**-9,373,991.41**	**27,174,259.83**	**-389.9%**
+	remaining connecting revenues	16,743,021.14	16,743,021.14	0.0%
-	prorated connecting variable	1,553,556.35	1,553,556.35	0.0%
=	**Network Contribution Value**	**5,815,473.38**	**42,363,724.62**	**628.5%**

Table 7.11: Network Contribution Value Analysis of NBO-TNR-NBO under Changing Aircraft

7.2 Input Changing Capacity

In this section, the input for the NC under changing capacity will be discussed with respect to the source and structure. The majority of the input can be obtained from the base model. The input that can not be obtained from the base model is the LF on segment level. At KQ, the LF on segment level are available through TM1, which is a database of KQ itself. In Table 7.12, the ASK and RPK per route per segment for the sample network are shown. This data is similar to the cost data for the base model, and it can be confirmed from the ASK and RPK that some of the segments are not being operated directly. At KQ, this data is available through TM1. This particular set of data, however, is originating from two different locations in that database. Therefore, an error is occurring, by which the ASK for the LVI-HRE segment is not specified. In the case that the ASK or RPK for a segment is not specified, the LF for that segment is assumed to be the average LF of the rest of the segments.

Route	Segment	ASK	RPK
200 - NBO LHR	LHR - NBO	51,347,940	41,799,600
200 - NBO LHR	NBO - LHR	54,079,940	48,124,180
217 - NBO BKK HKG	BKK - NBO	21,954,114	11,843,097
217 - NBO BKK HKG	HKG - BKK	5,131,854	2,134,055
217 - NBO BKK HKG	HKG - NBO	0	0
217 - NBO BKK HKG	NBO - HKG	0	0
217 - NBO BKK HKG	NBO - BKK	21,954,114	11,099,746
217 - NBO BKK HKG	BKK - HKG	5,131,854	1,336,104
287 - NBO TNR	NBO - TNR	9,301,132	5,517,201
287 - NBO TNR	TNR - NBO	9,301,132	5,424,910
272 - NBO LVI HRE	HRE - NBO	2,249,856	1,265,544
272 - NBO LVI HRE	LUN - NBO	0	0
272 - NBO LVI HRE	NBO - LVI	2,736,864	1,809,225
272 - NBO LVI HRE	LVI - HRE	0	333,723
272 - NBO LVI HRE	LVI - LUN	0	0

Table 7.12: Sample ASK and RPK from TM1

7.3 Implementation & Results Changing Capacity

In this section, the actual implementation of the NC under changing capacity in Python will be discussed, together with a presentation of the results. Prior to the actual implementation in Python, some scenarios are manually calculated in Excel (see Section 7.1) with the aim of the verification of the implementation.

At first, the routes and current type of aircraft being operated have to be determined. In Table 7.13, the routes and accompanying types and aircraft type being operated from the sample network are listed. It is assumed that each route is being operated by a single aircraft type.

Route	Type	Aircraft
NBO-LHR-NBO	S	B787
NBO-BKK-HKG-BKK-NBO	T	B787
NBO-LVI-HRE-NBO	R	E190
NBO-TNR-NBO	S	B737

Table 7.13: Routes Sample Network (see Figure 5.2)

The implementation of the NC under changing capacity basically follows the flow chart from Figure 7.1 for the change in frequency and from Figure 7.2 for the change of aircraft. In the implementation of the change in frequency, a standard change in frequency of 10% has been applied, for the sake of convenience. No feedback in the change of the number of flights per week has been provided here. From this, it is more intuitive to compare the changes in frequency among the various routes. In the implementation of the change of aircraft, the Boeing 777, Boeing 787, Boeing 737, and Embraer 190 are the types of aircraft taken into account.

In Table 7.14, each route from the sample network is listed with the FH of the route, the NCV of the route and the LF and the Potential Demand Served (PDS) per segment of that route. The LF and the PDS are listed in the order of the operation of the route. For example, the route NBO-LVI-HRE-NBO is operated in the order of NBO-LVI; LVI-HRE; HRE-NBO which yields the LF and the PDS to be notated in that same order.

Route	FH	NCV	LF	PDS
200 NBO LHR	15	-119,510.67	89%/81%	68%/53%
217 NBO BKK HKG	20	-44,756,320.91	51%/26%/42%/54%	141%/36%/626%/134%
272 NBO LVI HRE	5	99,360,825.33	66%/71%/56%	56%/4%/61%
287 NBO TNR	5	5,815,473.38	59%/58%	227%/243%

Table 7.14: FH, NCV, LF and PDS per Route Sample Network (see Figure 5.2)

It should be noted that the NCVs are out of proportion, since the costs are covering the total network of KQ, while the revenues are purely taking into account the sample network. Furthermore, it has already been noticed that the demand model from Schot (2015) has not been calibrated for outside the African market.

In Table 7.15, the results for the NC under changing frequency for the sample network are listed. The new NCVs are listed for 10% increase in frequency ($NCV + 10\%$) and for 10% decrease in frequency ($NCV - 10\%$), together with the factor that the NCV change with respect to the original.

Route	NCV +10%		NCV -10%	
NBO-LHR-NBO	-131,461.74	1.10	15,866,401.42	-132.76
NBO-BKK-HKG-BKK-NBO	-61,805,259.76	1.38	-27,707,382.06	0.62
NBO-LVI-HRE-NBO	98,543,387.66	0.99	100,178,263.00	1.01
NBO-TNR-NBO	-1,307,146.53	-0.22	12,938,093.29	2.22

Table 7.15: Results Change Frequency Sample Network (see Figure 5.2)

The increase in frequency on the route NBO-LHR-NBO and decrease in frequency on the route NBO-TNR-NBO has already been discussed. An extraordinary deviation is in the decrease in frequency on the route NBO-LHR-NBO, in which the NCV changed sign and increased drastically. This is due to the fact that the fixed costs are out of proportion with respect to the number of passengers, since in this case purely some passengers are added due to market share and in the case of this route the fixed costs are a major contributor. Another odd phenomenon occurs in the increase in route NBO-TNR-NBO, in which the NCV decreases drastically and thereby changes sign. An equivalent motivation holds as for the decrease in frequency on this route. Due to the insufficient market share, it is assumed that the markets on this route are saturated, whereby hardly some passengers due to increased market share will be added while the fixed costs increase.

In Table 7.16, the results for the NC under changing aircraft for the sample network are listed. The new NCVs are listed for each possible aircraft type from Table 7.9 respecting the maximum range of that aircraft type and the current aircraft type being operated, together with the factor that the NCV change with respect to the original.

Route	NCV B777		NCV B787		NCV B737		NCV E190	
NBO-LHR-NBO	232,013,672.18	-1,941.36	0.00	0.00	0.00	0.00	0.00	0.00
NBO-BKK-HKG-BKK-NBO	-68,663,723.65	1.53	0.00	0.00	0.00	0.00	0.00	0.00
NBO-LVI-HRE-NBO	60,062,250.22	0.60	70,265,638.87	0.71	103,621,285.98	1.04	0.00	0.00
NBO-TNR-NBO	-71,084,986.53	-12.22	-46,704,801.67	-8.03	0.00	0.00	42,363,724.62	7.28

Table 7.16: Results Change Aircraft Sample Network (see Figure 5.2)

The operation of the Boeing 777 on the route NBO-LHR-NBO and the operation of the Embraer 190 on the route NBO-TNR-NBO has already been discussed. In general, the change of aircraft follows the tendency of the change of frequency as the value of a route considering its value in the network decreases as the capacity increases, except for the operation of a Boeing 777 on the route NBO-LHR-NBO and a Boeing 737 on the NBO-LVI-HRE-NBO route. In the latter case, the positive NCV is slightly increased in case the Boeing 737 is being operated instead of the current Embraer 190 being operated. Furthermore, except for the case of the Boeing 777 on the NBO-LHR-NBO route, the calculation of the fixed costs of the replacing aircraft seems quite acceptable.

7.4 Conclusions Changing Capacity

As concluded from the previous chapter, the NC so far purely allows for analyzing the cancellation of a segment or route. In this chapter, the effect of the change of capacity on the NC is considered without changing the capacity to zero. The capacity is changed by changing the frequency (see Figure 7.1) on a segment or route, or changing the type of aircraft (see Figure 7.2) operated on a segment or route.

The model from Schot (2015) has been used for the prediction of the OD market size as a constraint for the demand in the concept of the NC under changing capacity. The S-curve market share model has been used to determine the market share of the airline in the market, with an alternative implementation with respect to Schot (2015), in order to be consistent among various networks with different routes. In case of the sample network, no effect of seasonality has been incorporated. In the concept of the change of aircraft, the model from Schot (2015) and Lammens (2014) has been used for the calculation of the replacing fixed costs for the replacing aircraft, in which Schot (2015) is used as the primary source.

The input, besides the prediction of the OD market size and the calculation of the replacing fixed costs for the replacing aircraft, which could not be obtained from the base model, is the LF on segment level. At KQ, the LF on segment level are gathered through TM1, the database of KQ itself. In the implementation of the change in frequency, a standard change in frequency of 10% has been applied, for the sake of convenience. No feedback in the change of the number of flights per week has been provided here. From this, it is more intuitive to compare the changes in frequency among the various routes. In the implementation of the change of aircraft, the Boeing 777, Boeing 787, Boeing 737, and Embraer 190 are the types of aircraft taken into account.

Chapter 8

Application & Validation

In this chapter, the model from the previous chapters - including its assumptions and limitations as mentioned - will be applied to the full KQ network. The structure of this chapter is as follows. At first, in Section 8.1, the network of KQ will be analysed. In Section 8.2, the implementation of the model will be discussed, together with the results for the full KQ network. In Section 8.3, the results for the KQ network will be presented with the help of a GUI, by which research question 4 will be answered. Thereafter, in Section 8.4, the validation will be performed based on a case-study from the KQ network. In Section 8.5, the conclusions from these results will be drawn.

8.1 Network Kenya Airways

In this section, the full network of KQ will be analysed. In Table 8.1, the routes from the KQ network are listed per region. In Appendix A, the name and location per airport is listed. The routes are accompanied by their type and the aircraft being operated. In the route types, the same notation as in the base model (see Section 5.2) is used. It is assumed that each route is operated by a single aircraft type for the sake of simplicity.

An uncommon route is the '285 - NBO ACC ROB FNA' route, which is a tag-end service with three segments in both directions. The model in this research, however, is based on a tag-end service with two segments in both directions (see Section 5.2). Despite that all the segments of the route will be taken into account in the model, it is not intuitive in what manner the calculations for the necessary metrics are performed.

Furthermore, the model in this research is not taking into account any overlap between routes, since the model is examining a segment rather than an individual route on that segment (see Section 5.2). For example, the cancellation of the '219 NBO BKK CAN' route will cancel the segments NBO-BKK and BKK-NBO, while these are also used by the '217 NBO BKK HKG' route. Therefore, the cancellation of the '219 - NBO BKK CAN' route will also make the '217 - NBO BKK HKG' route infeasible. This is not taken into account in the model in this research.

Region	Route	Type	Aircraft
Europe	200 - NBO LHR	S	B787
	204 - NBO CDG	S	B787
	207 - NBO AMS	S	B787
Middle East	212 - NBO DXB	S	B787
	905 - NBO JED	S	E190
China	219 - NBO BKK CAN	T	B787
	217 - NBO BKK HKG	T	B787
	925 - NBO HAN CAN	T	B787
India	210 - NBO BOM	S	B787
East Africa	221 - NBO EBB	S	E190
	225 - NBO SEZ	S	E190
	228 - NBO BJM KGL	R	E190
	230 - NBO KGL	S	E190
	231 - NBO DAR	S	E190
	232 - NBO ZNZ	S	E190
	280 - NBO DZA HAH	R	B737
	287 - NBO TNR	S	E190
	918 - NBO HAH	S	E190
	919 - NBO DZA	S	B737
	938 - NBO JRO	S	E190
Northern Africa	245 - NBO KRT	S	E190
	277 - NBO ADD JIB	T	E190
	903 - NBO JUB	S	E190
	915 - NBO JIB ADD	R	E190
Southern Africa	222 - NBO LLW	S	E190
	223 - NBO LUN LLW	R	E190
	235 - NBO LLW BLZ	R	E190
	226 - NBO LUN	S	E190
	227 - NBO JNB	S	B787
	281 - NBO LUN HRE	R	E190
	242 - NBO MPM	S	E190
	902 - NBO LAD	S	E190
	913 - NBO GBE	S	E190
	941 - NBO APL	S	E190
	272 - NBO LVI HRE	R	E190
Central Africa	283 - NBO NSI DLA	R	B737
	609 - NBO FIH BZV	R	E190
	524 - NBO NLA FBM	R	E190
	236 - NBO FIH	S	E190
West Africa	234 - NBO LOS	S	B737
	247 - NBO BKO DKR	T	B737
	627 - NBO ABJ DKR	T	B737
	626 - NBO LOS COO	R	B737
	285 - NBO ACC ROB FNA	T	B737
	924 - NBO ABV	S	E190
Domestic	240 - NBO MBA	S	E190
	266 - NBO MYD	S	E190
	267 - NBO KIS	S	E190

Table 8.1: Routes KQ Network

8.2 Implementation & Results Kenya Airways

The model from the previous chapters will be applied to the full KQ network for the year 2015 for each month separate. The necessary data for the demand model (see Section 7.1) for the year 2015 is incomplete. Therefore, the potential demand for the separate years 2012 up to and including 2014 has been determined according to the method from Schot (2015) as described in Section 7.1, after which a least-squares approximation (Klees and Dwight, 2012, p. 65-66) is used to determine the potential demand for the year 2015 based on the potential demand for the previous three years. In Equation 8.1, the equation used to extrapolate the demand for the previous three years to the demand for the year 2015 is formulated, where the $V_{ij,t}$ represents the potential passenger demand between i and j for a certain time period t. If the resulting potential demand for the year 2015 turned out to be negative, it is assumed to be zero, as the overall potential demand for the previous three years was declining.

$$V_{ij,2015} = \frac{3\sum_{t=2012}^{2014} t \cdot V_{ij,t} - \sum_{t=2012}^{2014} t \sum_{t=2012}^{2014} V_{ij,t}}{3\sum_{t=2012}^{2014} t^2 - \sum_{t=2012}^{2014} t \sum_{t=2012}^{2014} t} \times 2015 + \frac{\sum_{t=2012}^{2014} t^2 \sum_{t=2012}^{2014} V_{ij,t} - \sum_{t=2012}^{2014} t \sum_{t=2012}^{2014} t \cdot V_{ij,t}}{3\sum_{t=2012}^{2014} t^2 - \sum_{t=2012}^{2014} t \sum_{t=2012}^{2014} t} \tag{8.1}$$

The market shares for the full KQ network is assumed to be the average of the sample network from the previous chapter, separate for the direct and indirect markets, for the sake of simplicity in calculations and obtaining information. This yields a market share of 78.6% for the direct markets and a market share of 32.7% for the indirect markets. In accordance with Equation 7.7, the direct market shares will change with 0.056% and the indirect market shares will change with 0.033% in case of a change of 10% in frequency on a route.

While there were no seasonality effects incorporated for the sample network (see Section 7.1), a simple reflection of seasonality will be applied in this application. The peak season for KQ is June, July, August and September. It is assumed, that in these months the half of the yearly passengers are served, in which each month has an equal share. Therefore, it is assumed that 12.5% of the yearly demand is attracted in September.

The aircraft types taken into account are the Boeing 777, Boeing 787, Boeing 737 and Embraer 190. This set of aircraft types corresponds to KQ its fleet. In Table 7.9, the necessary characteristics for these aircraft types were listed. At the moment of this research, KQ is leasing out its Boeing 777s. Despite of not operating this aircraft type at the moment, it is taken into account for the case this aircraft type returns from lease out.

In Table 8.2, all routes from the KQ network are listed with their NCV and the NV for the September 2015 period. In the left the routes are sorted by NCV, and in the right the routes are sorted by NV. All values are in KES. The routes are listed ascending per value, starting in the top with the route with the lowest value. The routes with the lowest performance considering its value in the network according to the NCV are the '266 NBO MYD' and '913 NBO GBE' routes, while these are on position 16 and 6 counted from the top respectively in terms of the NV. These cases will be discussed in more detail later on. On the other hand, the routes with the highest NCV are the '281 NBO LUN HRE' and '223 NBO LUN LLW' routes, while these are on position 18 and 8 counted from the bottom respectively in terms of the NV.

Sorted by NCV		*Sorted by NV*	
Route	**NCV**	**Route**	**NV**
266 - NBO MYD	1,351,964.97	210 - NBO BOM	-222,878,686.60
913 - NBO GBE	10,689,433.15	212 - NBO DXB	-120,592,356.29
924 - NBO ABV	19,678,731.88	227 - NBO JNB	-82,869,388.61
902 - NBO LAD	24,750,485.81	277 - NBO ADD JIB	-71,931,410.35
225 - NBO SEZ	40,458,513.62	626 - NBO LOS COO	-47,264,375.79
245 - NBO KRT	42,341,809.83	913 - NBO GBE	-46,943,480.10
232 - NBO ZNZ	52,318,043.62	245 - NBO KRT	-37,374,784.50
941 - NBO APL	59,892,251.45	219 - NBO BKK CAN	-31,807,258.93
905 - NBO JED	62,188,522.38	924 - NBO ABV	-21,179,322.67
242 - NBO MPM	66,485,764.81	247 - NBO BKO DKR	-19,010,963.85
267 - NBO KIS	69,491,629.60	232 - NBO ZNZ	-17,293,854.15
919 - NBO DZA	86,899,682.38	217 - NBO BKK HKG	-17,212,648.26
938 - NBO JRO	90,846,284.89	915 - NBO JIB ADD	-15,233,056.30
277 - NBO ADD JIB	97,980,183.38	902 - NBO LAD	-14,652,500.61
903 - NBO JUB	119,126,853.31	225 - NBO SEZ	-10,876,016.50
210 - NBO BOM	136,820,851.47	266 - NBO MYD	-8,121,601.39
915 - NBO JIB ADD	137,645,963.40	925 - NBO HAN CAN	5,717,229.25
918 - NBO HAH	156,483,255.99	242 - NBO MPM	6,563,778.28
247 - NBO BKO DKR	158,022,086.22	918 - NBO HAH	9,461,200.02
524 - NBO NLA FBM	158,150,748.20	905 - NBO JED	11,002,464.87
212 - NBO DXB	158,675,206.79	627 - NBO ABJ DKR	11,773,051.99
235 - NBO LLW BLZ	165,433,772.07	280 - NBO DZA HAH	12,462,190.70
234 - NBO LOS	165,486,763.26	938 - NBO JRO	16,608,776.73
626 - NBO LOS COO	172,461,045.14	204 - NBO CDG	20,538,522.77
280 - NBO DZA HAH	174,589,063.72	941 - NBO APL	24,958,714.05
204 - NBO CDG	175,332,632.78	267 - NBO KIS	27,170,285.72
627 - NBO ABJ DKR	178,246,535.87	281 - NBO LUN HRE	29,575,418.06
283 - NBO NSI DLA	189,387,499.57	919 - NBO DZA	45,622,465.84
230 - NBO KGL	195,343,781.37	234 - NBO LOS	46,549,555.88
287 - NBO TNR	199,734,252.49	235 - NBO LLW BLZ	53,129,201.81
228 - NBO BJM KGL	246,202,437.94	272 - NBO LVI HRE	62,855,914.62
236 - NBO FIH	258,012,201.59	230 - NBO KGL	65,290,576.28
207 - NBO AMS	289,505,088.74	207 - NBO AMS	70,692,714.23
222 - NBO LLW	296,013,075.62	287 - NBO TNR	70,985,416.06
200 - NBO LHR	315,826,320.23	903 - NBO JUB	72,053,331.41
227 - NBO JNB	331,431,446.93	222 - NBO LLW	76,016,640.57
240 - NBO MBA	331,596,745.69	524 - NBO NLA FBM	76,332,617.42
285 NBO ACC ROB FNA	354,965,117.35	200 - NBO LHR	81,468,486.35
609 - NBO FIH BZV	357,644,894.75	228 - NBO BJM KGL	84,772,876.08
272 - NBO LVI HRE	359,733,690.99	283 - NBO NSI DLA	95,020,731.33
231 - NBO DAR	390,415,995.51	223 - NBO LUN LLW	100,752,705.98
925 - NBO HAN CAN	412,142,423.62	240 - NBO MBA	111,298,421.77
226 - NBO LUN	438,482,282.63	226 - NBO LUN	127,036,526.09
221 - NBO EBB	444,966,287.33	285 NBO ACC ROB FNA	141,169,570.76
219 - NBO BKK CAN	528,500,988.07	609 - NBO FIH BZV	160,475,324.56
217 - NBO BKK HKG	540,959,887.93	236 - NBO FIH	162,535,525.38
223 - NBO LUN LLW	549,514,612.72	231 - NBO DAR	187,714,998.62
281 - NBO LUN HRE	557,587,845.10	221 - NBO EBB	192,183,295.14

Table 8.2: Sorted NCV and NV per Route KQ Network September 2015

During one of the interviews in the practical research (see Section 4.2), it turned out to be doubtful whether there is any confirmation on the contribution of the connecting revenues, making a segment or route profitable with respect to the isolated local profit. Now, it can be examined whether the connecting revenues are really contributing to the profitability of a segment or route. While this analysis will be performed on a yearly basis, it is performed segment-based rather than route-based. In Table 8.3, the percentage of operated segments that would become unprofitable - in terms of the NCV - if the connecting revenues were deleted are listed per month. Besides the month December 2015, which is out of proportion and of which the cause has already been discussed, this basically reflects the essence of a hub-and-spoke network and its connecting passengers.

Jan-15	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**
84.76	76.19	74.07	77.78	75.00	78.90	85.32	79.82	81.65	77.06	76.15	38.53

Table 8.3: Percentage Unprofitable Segments Positive NCV without Connecting Revenues KQ Network 2015

In Table 8.4, each route from the KQ network for September 2015 is listed with the FH in block hours of the route, the NCV of the route and the LF and the PDS per segment of that route. The LF and the PDS are listed in the order of the operation of the route. The field for the PDS is empty if less than 1% of the potential demand is served.

Route	Time	NCV	LF	PDS
200 NBO LHR	15.00	315,826,320.23	89%/81%	%/%
204 NBO CDG	14.00	175,332,632.78	88%/59%	%/%
207 NBO AMS	15.00	289,505,088.74	85%/85%	%/%
212 NBO DXB	8.00	158,675,206.79	75%/7%	6%/6%
905 NBO JED	6.00	62,188,522.38	62%/6%	1%/1%
219 NBO BKK CAN	20.00	528,500,988.07	69%/69%/61%/65%	%/%/%/%
217 NBO BKK HKG	20.00	540,959,887.93	69%/26%/42%/65%	%/%/%/%
925 NBO HAN CAN	19.00	412,142,423.62	7%/7%/7%/7%	%/%/%/%
210 NBO BOM	10.00	136,820,851.47	59%/65%	1%/1%
221 NBO EBB	1.00	444,966,287.33	7%/7%	17%/17%
225 NBO SEZ	5.00	40,458,513.62	7%/59%	46%/37%
228 NBO BJM KGL	2.00	246,202,437.94	55%/52%/69%	3%/24%/29%
230 NBO KGL	2.00	195,343,781.37	65%/69%	22%/29%
231 NBO DAR	2.00	390,415,995.51	58%/59%	1%/1%
232 NBO ZNZ	1.00	52,318,043.62	4%/39%	%/%
280 NBO DZA HAH	4.00	174,589,063.72	43%/5%/89%	223%/26%/633%
287 NBO TNR	5.00	199,734,252.49	59%/58%	63%/63%
918 NBO HAH	3.00	156,483,255.99	23%/89%	306%/633%
919 NBO DZA	4.00	86,899,682.38	43%/94%	223%/207%
938 NBO JRO	1.00	90,846,284.89	59%/43%	%/%
245 NBO KRT	4.00	42,341,809.83	63%/52%	31%/26%
277 NBO ADD JIB	4.00	97,980,183.38	91%/41%/36%/74%	1%/72%/1%/8%
903 NBO JUB	2.00	119,126,853.31	62%/6%	257%/243%
915 NBO JIB ADD	4.00	137,645,963.40	7%/36%/74%	1%/1%/8%
222 NBO LLW	3.00	296,013,075.62	57%/88%	19%/28%
223 NBO LUN LLW	4.00	549,514,612.72	69%/7%/88%	38%/28%/28%
235 NBO LLW BLZ	4.00	165,433,772.07	57%/6%/64%	19%/19%/2%
226 NBO LUN	4.00	438,482,282.63	69%/64%	38%/27%
227 NBO JNB	6.00	331,431,446.93	76%/74%	6%/5%
281 NBO LUN HRE	5.00	557,587,845.10	69%/56%/61%	38%/37%/27%
242 NBO MPM	6.00	66,485,764.81	57%/62%	3%/3%
902 NBO LAD	6.00	24,750,485.81	32%/25%	n/a%/n/a%
913 NBO GBE	7.00	10,689,433.15	42%/46%	1%/1%
941 NBO APL	4.00	59,892,251.45	53%/55%	2%/3%
272 NBO LVI HRE	5.00	359,733,690.99	66%/7%/61%	24%/22%/27%
283 NBO NSI DLA	7.00	189,387,499.57	62%/61%/71%	4%/2%/4%
609 NBO FIH BZV	6.00	357,644,894.75	54%/109%/7%	5%/1%/6%
524 NBO NLA FBM	4.00	158,150,748.20	56%/58%/55%	8%/7%/8%
236 NBO FIH	6.00	258,012,201.59	54%/64%	5%/2%
234 NBO LOS	9.00	165,486,763.26	78%/75%	2%/1%
247 NBO BKO DKR	15.00	158,022,086.22	59%/63%/72%/55%	17%/21%/2%/15%
627 NBO ABJ DKR	15.00	178,246,535.87	64%/85%/75%/72%	7%/21%/2%/7%
626 NBO LOS COO	9.00	172,461,045.14	78%/73%/69%	2%/1%/2%
285 NBO ACC ROB FNA	14.00	354,965,117.35	66%/8%/68%/7%/83%/73%	7%/132%/126%/34%/126%/7%
924 NBO ABV	8.00	19,678,731.88	52%/46%	1%/1%
240 NBO MBA	1.00	331,596,745.69	67%/71%	5%/5%
266 NBO MYD	1.00	1,351,964.97	142%/143%	%/%
267 NBO KIS	1.00	69,491,629.60	88%/88%	4%/4%

Table 8.4: FH, NCV, LF and PDS per Route KQ Network September 2015

In Table 8.5, the results for the NC under changing frequency for the KQ network for September 2015 are listed. The new NCVs are listed for 10% increase in frequency ($NCV + 10\%$) and for 10% decrease in frequency ($NCV - 10\%$), together with the factor that the NCV change with respect to the original. It can be noted from these results that the routes '219 NBO BKK CAN', '217 NBO BKK HKG' and '925 NBO HAN CAN' are most beneficial to increase in frequency. In reverse, these are the least beneficial routes to decrease in frequency. The least beneficial routes to increase frequency, and in reverse the most beneficial routes to decrease frequency, are the '210 NBO BOM', '913 NBO GBE' and '924 NBO ABV' routes. These latter two routes will be discussed in more detail later on.

Route	**NCV +10%**		**NCV -10%**	
200 NBO LHR	347,408,952.25	1.10	331,313,186.11	1.05
204 NBO CDG	184,060,175.97	1.05	187,457,832.46	1.07
207 NBO AMS	318,455,597.61	1.10	314,809,170.10	1.09
212 NBO DXB	155,572,160.76	0.98	181,921,092.13	1.15
905 NBO JED	58,712,718.59	0.94	65,664,326.17	1.06
219 NBO BKK CAN	1,389,250,230.48	2.63	-332,248,254.34	-0.63
217 NBO BKK HKG	1,289,534,793.36	2.38	-207,615,017.50	-0.38
925 NBO HAN CAN	990,909,188.33	2.40	-166,624,341.09	-0.40
210 NBO BOM	107,854,905.12	0.79	165,786,797.82	1.21
221 NBO EBB	432,351,223.53	0.97	457,581,351.13	1.03
225 NBO SEZ	37,617,509.51	0.93	43,299,517.73	1.07
228 NBO BJM KGL	240,406,739.24	0.98	251,998,136.64	1.02
230 NBO KGL	191,149,954.03	0.98	199,537,608.71	1.02
231 NBO DAR	380,830,283.83	0.98	400,001,707.19	1.02
232 NBO ZNZ	49,328,811.83	0.94	55,307,275.41	1.06
280 NBO DZA HAH	185,463,327.12	1.06	178,506,075.60	1.02
287 NBO TNR	192,449,643.88	0.96	207,018,861.10	1.04
918 NBO HAH	167,151,553.87	1.07	160,606,233.40	1.03
919 NBO DZA	88,991,157.00	1.02	56,324,778.13	0.65
938 NBO JRO	90,146,143.30	0.99	91,546,426.48	1.01
245 NBO KRT	36,192,575.68	0.85	48,491,043.99	1.15
277 NBO ADD JIB	99,689,565.24	1.02	20,111,060.30	0.21
903 NBO JUB	114,165,650.77	0.96	124,088,055.86	1.04
915 NBO JIB ADD	135,061,751.71	0.98	140,230,175.09	1.02
222 NBO LLW	314,764,117.90	1.06	300,716,852.67	1.02
223 NBO LUN LLW	567,583,835.40	1.03	554,900,209.37	1.01
235 NBO LLW BLZ	160,875,930.12	0.97	169,991,614.02	1.03
226 NBO LUN	429,993,293.61	0.98	446,971,271.65	1.02
227 NBO JNB	336,243,612.84	1.01	356,159,543.61	1.07
281 NBO LUN HRE	548,511,668.02	0.98	566,664,022.18	1.02
242 NBO MPM	62,579,092.72	0.94	70,392,436.90	1.06
902 NBO LAD	21,327,157.23	0.86	28,173,814.39	1.14
913 NBO GBE	5,917,078.57	0.55	15,461,787.73	1.45
941 NBO APL	58,209,227.32	0.97	61,575,275.58	1.03
272 NBO LVI HRE	354,395,914.23	0.99	365,071,467.75	1.01
283 NBO NSI DLA	184,732,692.17	0.98	194,042,306.97	1.02
609 NBO FIH BZV	374,981,924.53	1.05	152,656,284.15	0.43
524 NBO NLA FBM	155,865,861.77	0.99	160,435,634.63	1.01
236 NBO FIH	250,502,254.40	0.97	265,522,148.79	1.03
234 NBO LOS	182,035,439.59	1.10	174,037,662.13	1.05
247 NBO BKO DKR	150,989,656.79	0.96	165,054,515.65	1.04
627 NBO ABJ DKR	187,521,549.98	1.05	186,265,749.48	1.04
626 NBO LOS COO	177,600,440.49	1.03	180,951,605.64	1.05
285 NBO ACC ROB FNA	358,605,594.50	1.01	374,791,129.42	1.06
924 NBO ABV	16,600,790.46	0.84	22,756,673.30	1.16
240 NBO MBA	315,705,089.76	0.95	347,488,401.62	1.05
266 NBO MYD	1,487,161.47	1.10	-14,456,322.84	-10.69
267 NBO KIS	76,440,792.56	1.10	76,250,575.43	1.10

Table 8.5: Results Change Frequency KQ Network September 2015

In Table 8.6, the results for the NC under changing aircraft for the KQ network for September 2015 are listed. The new NCVs are listed for each possible aircraft type from Table 7.9 respecting the maximum range of that aircraft type and the current aircraft type being operated, together with the factor that the NCV change with respect to the original. It can be noted from these results that the European routes are most beneficial to replace the Boeing 787 by a Boeing 777 aircraft. The routes '210 NBO BOM' and '227 NBO JNB' are most beneficial to replace the Boeing 787 by a Boeing 737, while it can even be beneficial to operate the latter route by a Embraer 190 aircraft, in which it can be questionable whether this route is really currently operated by a Boeing 787 aircraft. The most beneficial routes to replace the Boeing 737 by a Embraer 190 are the '280 NBO DZA HAH' and '919 NBO DZA' routes.

Route	NCV B777		NCV B787		NCV B737		NCV E190	
200 NBO LHR	820,108,951.59	2.60	0.00	0.00	0.00	0.00	0.00	0.00
204 NBO CDG	421,206,617.11	2.40	0.00	0.00	0.00	0.00	0.00	0.00
207 NBO AMS	704,177,881.42	2.43	0.00	0.00	0.00	0.00	0.00	0.00
212 NBO DXB	111,735,480.18	0.70	0.00	0.00	300,593,406.79	1.89	0.00	0.00
905 NBO JED	-20,129,792.52	-0.32	-253,375.30	0.00	61,897,325.38	1.00	0.00	0.00
219 NBO BKK CAN	489,941,304.64	0.93	0.00	0.00	0.00	0.00	0.00	0.00
217 NBO BKK HKG	501,926,089.56	0.93	0.00	0.00	0.00	0.00	0.00	0.00
925 NBO HAN CAN	633,565,500.82	1.54	0.00	0.00	0.00	0.00	0.00	0.00
210 NBO BOM	58,383,355.91	0.43	0.00	0.00	313,403,768.95	2.29	0.00	0.00
221 NBO EBB	16,356,615.15	0.04	93,141,276.87	0.21	422,033,637.38	0.95	0.00	0.00
225 NBO SEZ	-23,010,430.71	-0.57	-8,176,484.96	-0.20	40,233,690.97	0.99	0.00	0.00
228 NBO BJM KGL	82,141,496.61	0.33	113,269,463.28	0.46	243,393,868.07	0.99	0.00	0.00
230 NBO KGL	80,585,856.03	0.41	103,062,680.28	0.53	193,519,644.64	0.99	0.00	0.00
231 NBO DAR	12,098,370.97	0.03	81,291,973.72	0.21	366,096,510.64	0.94	0.00	0.00
232 NBO ZNZ	-96,044,460.63	-1.84	-69,477,977.27	-1.33	41,783,763.66	0.80	0.00	0.00
280 NBO DZA HAH	377,408,048.38	2.16	221,784,412.02	1.27	0.00	0.00	191,902,649.01	1.10
287 NBO TNR	46,378,689.88	0.23	83,206,504.33	0.42	201,504,441.88	1.01	0.00	0.00
918 NBO HAH	514,308,606.13	3.29	280,473,469.11	1.79	227,771,517.66	1.46	0.00	0.00
919 NBO DZA	127,569,204.47	1.47	94,896,342.86	1.09	0.00	0.00	91,761,224.57	1.06
938 NBO JRO	-2,998,202.51	-0.03	12,424,365.00	0.14	85,031,737.71	0.94	0.00	0.00
245 NBO KRT	-46,397,870.40	-1.10	-22,357,314.88	-0.53	57,412,750.82	1.36	0.00	0.00
277 NBO ADD JIB	192,488,981.25	1.96	79,267,905.13	0.81	140,645,434.72	1.44	0.00	0.00
903 NBO JUB	19,283,521.76	0.16	41,150,429.81	0.35	126,245,859.64	1.06	0.00	0.00
915 NBO JIB ADD	61,394,735.24	0.45	76,235,665.46	0.55	134,624,294.40	0.98	0.00	0.00
222 NBO LLW	804,569,705.03	2.72	569,260,940.30	1.92	423,595,505.70	1.43	0.00	0.00
223 NBO LUN LLW	1,043,872,867.17	1.90	812,321,632.29	1.48	676,703,654.02	1.23	0.00	0.00
235 NBO LLW BLZ	63,534,685.50	0.38	85,890,059.26	0.52	167,680,848.13	1.01	0.00	0.00
226 NBO LUN	273,297,554.21	0.62	313,001,241.88	0.71	446,679,656.24	1.02	0.00	0.00
227 NBO JNB	453,247,576.91	1.37	0.00	0.00	472,160,065.66	1.42	496,929,895.44	1.50
281 NBO LUN HRE	354,965,574.15	0.64	400,356,642.30	0.72	560,467,070.11	1.01	0.00	0.00
242 NBO MPM	-16,049,394.39	-0.24	4,340,334.27	0.07	67,087,758.22	1.01	0.00	0.00
902 NBO LAD	-34,367,392.55	-1.39	-18,840,998.44	-0.76	29,021,146.91	1.17	0.00	0.00
913 NBO GBE	-63,775,825.71	-5.97	-43,055,196.65	-4.03	20,406,461.51	1.91	0.00	0.00
941 NBO APL	18,793,458.42	0.31	27,823,737.94	0.46	59,262,013.85	0.99	0.00	0.00
272 NBO LVI HRE	258,864,589.44	0.72	283,638,416.77	0.79	365,279,974.90	1.02	0.00	0.00
283 NBO NSI DLA	141,763,528.03	0.75	157,284,098.96	0.83	0.00	0.00	0.00	0.00
609 NBO FIH BZV	967,020,598.30	2.70	616,746,947.27	1.72	473,451,970.44	1.32	0.00	0.00
524 NBO NLA FBM	101,195,428.88	0.64	113,111,817.41	0.72	157,864,027.46	1.00	0.00	0.00
236 NBO FIH	81,958,640.66	0.32	124,063,489.58	0.48	257,472,416.69	1.00	0.00	0.00
234 NBO LOS	332,895,076.05	2.01	202,632,891.03	1.22	0.00	0.00	0.00	0.00
247 NBO BKO DKR	97,851,467.73	0.62	119,643,063.69	0.76	0.00	0.00	0.00	0.00
627 NBO ABJ DKR	267,179,441.59	1.50	189,875,422.62	1.07	0.00	0.00	0.00	0.00
626 NBO LOS COO	339,951,529.48	1.97	209,795,549.08	1.22	0.00	0.00	0.00	0.00
285 NBO ACC ROB FNA	641,252,391.71	1.81	425,207,787.40	1.20	0.00	0.00	0.00	0.00
924 NBO ABV	-34,368,974.96	-1.75	-19,646,207.88	-1.00	23,704,106.91	1.20	0.00	0.00
240 NBO MBA	-230,269,012.57	-0.69	-131,961,017.80	-0.40	301,690,442.76	0.91	0.00	0.00
266 NBO MYD	11,120,354.82	8.23	-10,992,557.62	-8.13	10,013,516.84	7.41	0.00	0.00
267 NBO KIS	241,295,675.53	3.47	44,485,421.73	0.64	122,017,993.74	1.76	0.00	0.00

Table 8.6: Results Change Aircraft KQ Network September 2015

It can be noted that the results for the change of aircraft are sensitive to the potential demand and the replacing fixed costs for operating the replacing aircraft. For example, some routes which were considered to be beneficial from to decrease frequency, are in this case beneficial to be operated by a larger aircraft type. The results from the change in frequency are considered to be leading with respect to the change in capacity on a route.

8.3 Graphical User Interface

In this section, the GUI is presented. This GUI incorporates information on the number of passengers, costs, revenues, NV (including Network Value Analysis) and NCV (including Network Contribution Value Analysis) per route per segment for the year 2015 for each month separate.

In Figure 8.1, an overview of the GUI is depicted. In part A, the route and the month of interest are selected, and a confirmation with the type of route and the segments of the route is listed. In part B, the information on the number of passengers, costs, and revenues per segment for the selected route and month is presented. In part C, the share of revenues per OD pair on the selected route for the selected month are presented in a pie chart with a list of the top-20 OD pairs in terms of share of revenue. In part D, the Network Value Analysis' for each segment separate and the complete route for the selected route and month are presented. In part E, the Network Contribution Value Analysis' for each segment separate and the complete route for the selected route and month are presented. As discussed in the previous chapters, each type of route (i.e. standard spoke, tag-end, round-robin) has its own method for determining the total number of passengers and revenues (i.e. local and connecting), and the NV and NCV for the complete route. This has been incorporated in this GUI. In part F, a bar chart is given with the NCV per month for the year 2015 for the selected route for each month separate. In part G, each route is listed with its type and NCV according to the regions and aircraft types of the full KQ network (see Table 8.1) for the selected month. The parts B, D, E and F of this GUI will be discussed in more detail below.

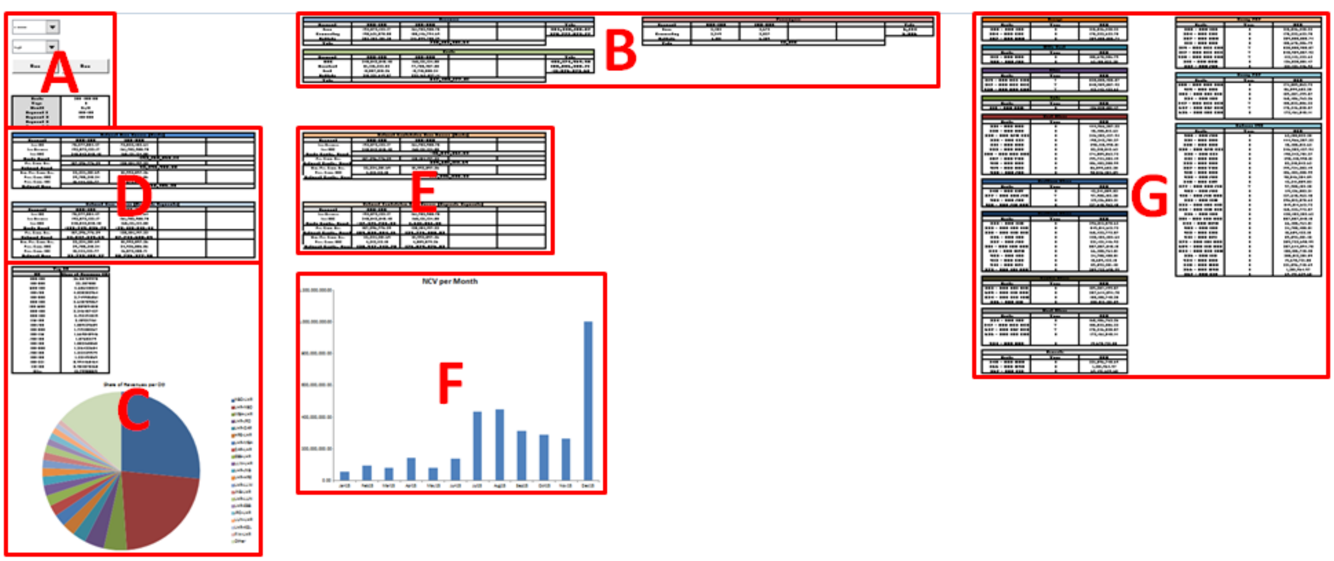

Figure 8.1: Overview of Graphical User Interface

In Figure 8.2, a close-up of part B of the GUI is depicted. In the blue area the revenues (including local and connecting) are presented, while in the green area the costs (including DOC, overhead and fleet) and in the red area the number of passengers (including local and connecting) are presented for the selected route for the selected month. In all cases, each segment is considered separate, and a subtotal per segment and per sub-part, and the total per route are provided.

Revenues					
Segment	NBO-LHR	LHR-NBO			Total
Local	192,572,123.17	161,752,985.70			**354,325,108.87**
Connecting	190,631,078.08	180,146,794.69			**370,777,872.77**
Subtotal	383,203,201.25	341,899,780.39			
Total	**725,102,981.64**				

Costs					
Segment	NBO-LHR	LHR-NBO			Total
DOC	240,043,845.40	160,131,124.50			**400,174,969.90**
Overhead	81,135,322.83	77,750,957.88			**158,886,280.71**
Fleet	-5,857,518.36	-5,718,555.24			**-11,576,073.60**
Subtotal	315,321,649.87	232,163,527.14			
Total	**547,485,177.01**				

Passengers					
Segment	NBO-LHR	LHR-NBO			Total
Local	3,452	2,672			**6,124**
Connecting	3,349	3,537			**6,886**
Subtotal	6,801	6,209			
Total	**13,010**				

Figure 8.2: Part B of Graphical User Interface (see Figure 8.1)

In Figure 8.3, a close-up of part D of the GUI is depicted. This part presents the NV - including its Network Value Analysis (see Table 6.1) - for each segment separate (light blue) and the complete route (dark blue) for the selected route for the selected month.

Network Value Analysis (Route)				
Segment	**NBO-LHR**	**LHR-NBO**		
Local IOC	75,277,804.47	72,032,402.64		
Local Revenues	192,572,123.17	161,752,985.70		
Local DOC	240,043,845.40	160,131,124.50		
Route Result	**-193,160,068.14**			
Pro. Conn. Rev.	157,296,776.39	128,154,197.33		
Network Result	**92,290,905.58**			
Rem. Pro. Conn. Rev.	33,334,301.69	51,992,597.36		
Pror. Conn. DOC	29,705,310.24	34,926,586.56		
Pror. Conn. IOC	15,444,132.77	16,073,288.71		
Network Value	**81,468,486.35**			

Network Value Analysis (Separate Segments)				
Segment	**NBO-LHR**	**LHR-NBO**		
Local IOC	75,277,804.47	72,032,402.64		
Local Revenues	192,572,123.17	161,752,985.70		
Local DOC	240,043,845.40	160,131,124.50		
Route Result	**-122,749,526.70**	**-70,410,541.44**		
Pro. Conn. Rev.	157,296,776.39	128,154,197.33		
Network Result	**34,547,249.69**	**57,743,655.89**		
Rem. Pro. Conn. Rev.	33,334,301.69	51,992,597.36		
Pror. Conn. DOC	29,705,310.24	34,926,586.56		
Pror. Conn. IOC	15,444,132.77	16,073,288.71		
Network Value	**22,732,108.37**	**58,736,377.98**		

Figure 8.3: Part D of Graphical User Interface (see Figure 8.1)

In Figure 8.4, a close-up of part D of the GUI is depicted. This part presents the NCV - including its Network Contribution Value Analysis (see Table 6.5) - for each segment separate (light orange) and the complete route (dark orange) for the selected route for the selected month.

Network Contribution Value Analysis (Route)				
Segment	NBO-LHR	LHR-NBO		
Local Revenues	192,572,123.17	161,752,985.70		
Local DOC	240,043,845.40	160,131,124.50		
Route Contri. Result	**-45,849,861.03**			
Pro. Conn. Rev.	157,296,776.39	128,154,197.33		
Network Contri. Result	**239,601,112.69**			
Rem. Pro. Conn. Rev.	33,334,301.69	51,992,597.36		
Pror. Conn. DOC	4,212,112.15	4,889,579.36		
Network Contri. Value	**315,826,320.23**			

Network Contribution Value Analysis (Separate Segments)				
Segment	NBO-LHR	LHR-NBO		
Local Revenues	192,572,123.17	161,752,985.70		
Local DOC	240,043,845.40	160,131,124.50		
Route Contri. Result	**-47,471,722.23**	**1,621,861.20**		
Pro. Conn. Rev.	157,296,776.39	128,154,197.33		
Network Contri. Result	**109,825,054.16**	**129,776,058.53**		
Rem. Pro. Conn. Rev.	33,334,301.69	51,992,597.36		
Pror. Conn. DOC	4,212,112.15	4,889,579.36		
Network Contri. Value	**138,947,243.70**	**176,879,076.53**		

Figure 8.4: Part E of Graphical User Interface (see Figure 8.1)

In Figure 8.5, a close-up of part F of the GUI is depicted. This bar chart presents the NCV per month for the year 2015 for each month separate for the route selected. It can be noticed that the result for December 2015 is quite high with respect to the rest. The input data, as well as the implementation in Python, have been consulted and nothing odd has been found. Since the revenues are based on flight date (see Table 5.1), the end-of-the-year traffic can be the cause of this peak. Furthermore, a world-trade ministerial conference held in Nairobi from 15 to 19 December 2015, for which KQ spread a promotional booking code, can also be part of this matter.

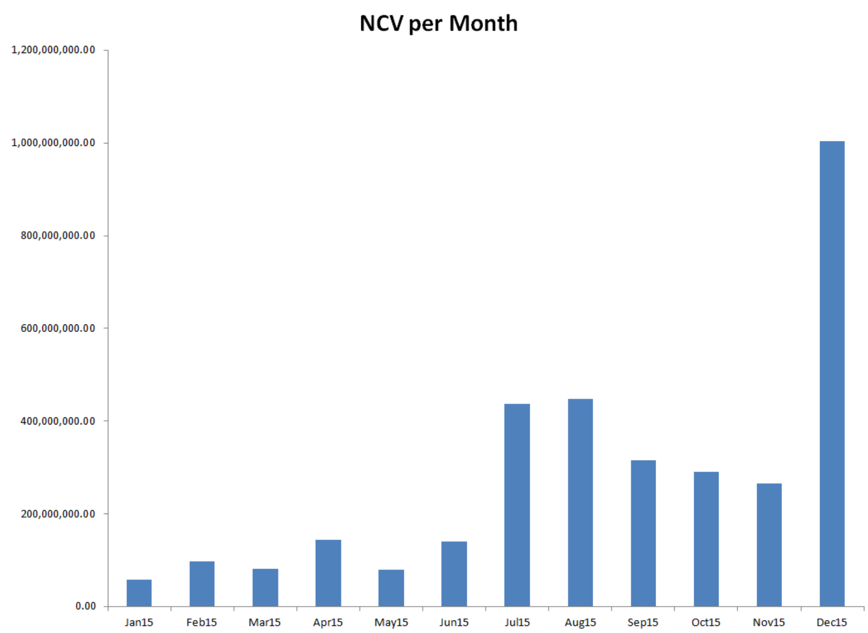

Figure 8.5: Part F of Graphical User Interface (see Figure 8.1)

Despite of the fact that this GUI is hardly contributing to the innovation of this graduation research, it is highly contributing to the practical relevance of this research, since this GUI is an efficient manner to present the results for the full KQ network. The concept of the NC under changing capacity has not been incorporated in the GUI. Despite of the fact that it has not been mentioned in every case separate, this GUI has been frequently used to obtain the result to be presented.

8.4 Validation Kenya Airways

In this section, some cases from the KQ network will be discussed. As indicated by the people at KQ, a case-study will be conducted on the hypothetical cancellation of the '924 NBO ABV' route, since KQ is considering cancelling this route. Furthermore, two case-studies will be performed on the routes '287 NBO TNR' and '234 NBO LOS', for the sake of the validation of the NC under changing capacity, since recently their frequencies has changed.

Cancel Route '924 NBO ABV'

In this case-study, the hypothetical cancellation of the route '924 NBO ABV' will be discussed. This route is a standard spoke route, hence the cancellation will yield the cancellation of the segments NBO-ABV and ABV-NBO.

In Figure 8.6, the shares of revenues per OD pair on the '924 NBO ABV' for September 2015 are listed. The numbers accompanying the pie chart represent the percentage of share of total revenues of that OD pair. From these results, it can be noticed that the local passengers are contributing around 40% to the total revenues on this route, while the connecting passengers are mostly going to/coming from DXB, BOM, CAN, EBB and LHR in the order of share of total connecting revenues.

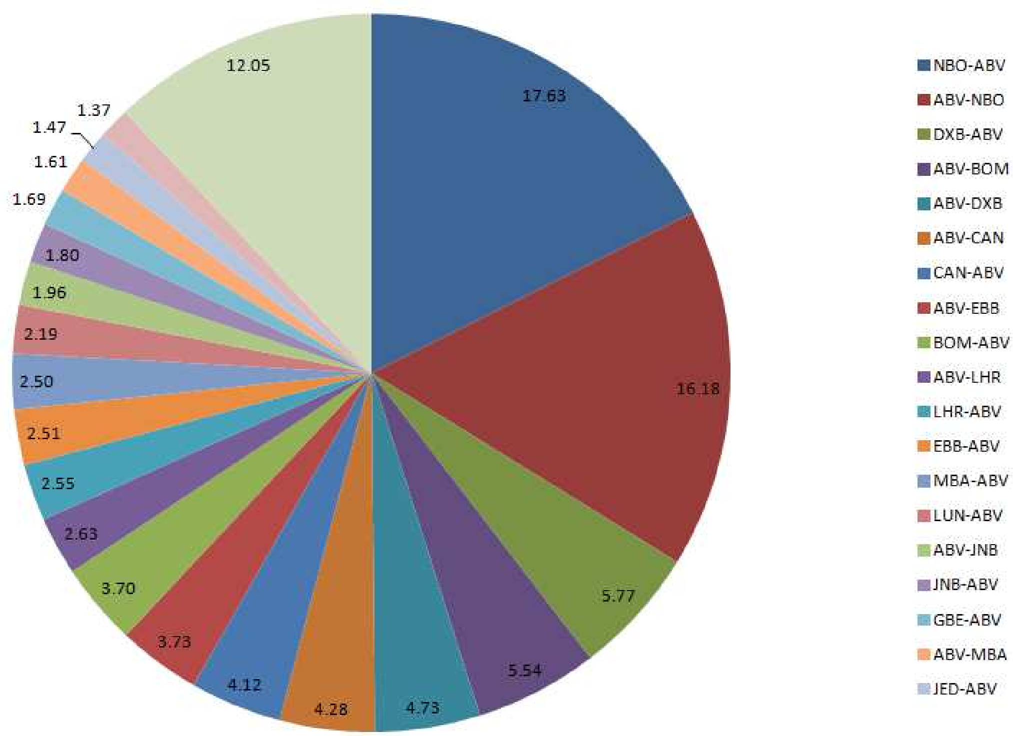

Figure 8.6: Share of Revenues '924 NBO ABV' September 2015

In Figure 8.7, the NCVs for route '924 NBO ABV' for the year 2015 for each month separate is listed. As discussed in the previous section, the extraordinary peak in the month December 2015 is probably due to end-of-the-year traffic and a world trade ministerial conference held in Nairobi in December 2015 for which KQ spread a promotional booking code. These results reveal that this route is overall positively contributing to the KQ network.

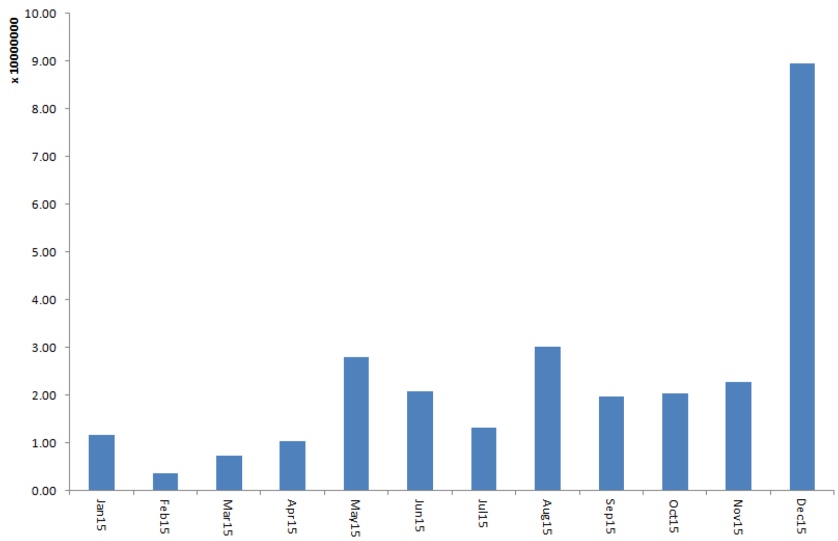

Figure 8.7: Monthly NCV '924 NBO ABV' 2015

The route '924 NBO ABV' should be put into perspective with the other routes in the network for a similar period of time to be able to compare its performance. In Figure 8.8, the NCVs for all the routes from the KQ network in the West-Africa region (see Table 8.1) for September 2015 are depicted, in order to put the route '924 NBO ABV' into perspective with respect to the rest of routes from the KQ network in the West-Africa region. These results reveal that the route '924 NBO ABV' is the least performing route for this time in this region.

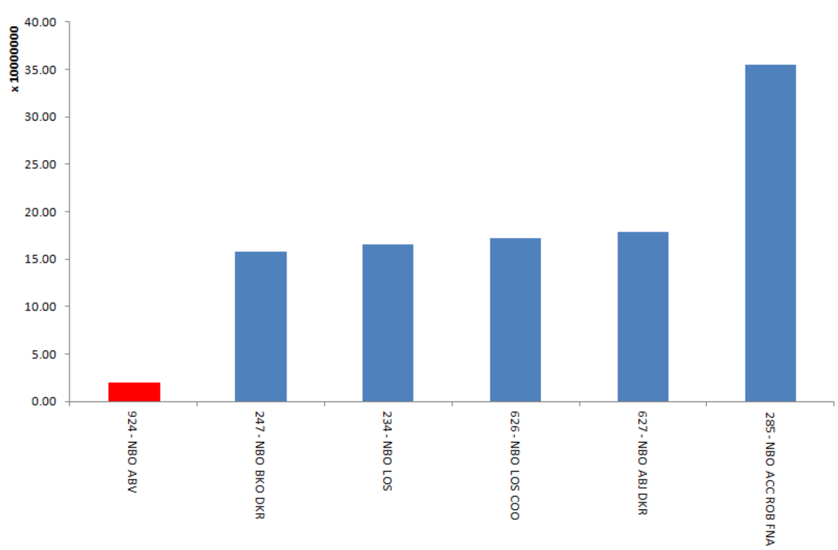

Figure 8.8: NCV West-Africa September 2015

In Figure 8.9, the NCVs for all the routes from the KQ network operated by the Embraer 190 (see Table 8.1) for September 2015 are depicted, in order to put the route '924 NBO ABV' into perspective with respect to the rest of routes from the KQ network operated by the Embraer 190 aircraft. These results reveal that the route '924 NBO ABV' is one of the least performing routes for this period of time for the Embraer 190 aircraft. In this case, the '266 NBO MYD' and '913 NBO GBE' routes are performing less than the '924 NBO ABV' route.

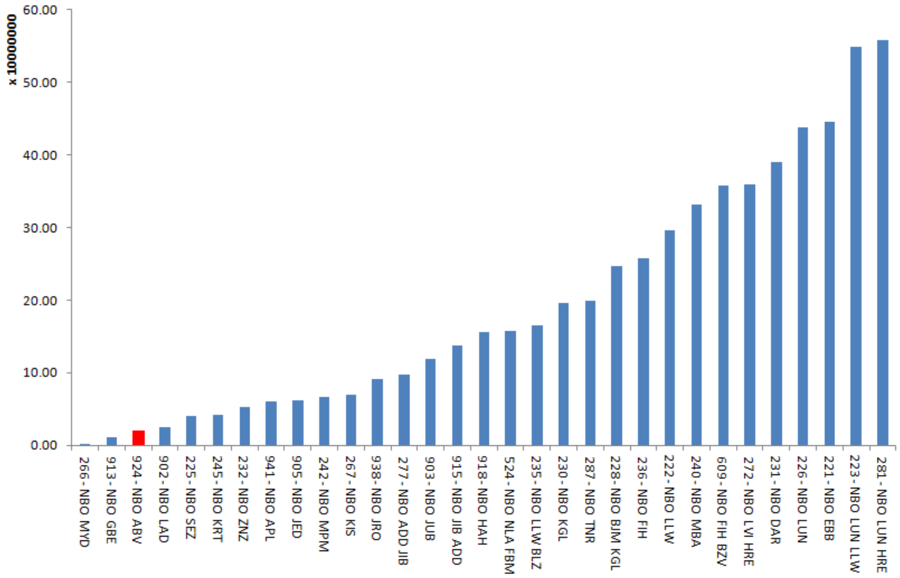

Figure 8.9: NCV Embraer 190 September 2015

This analysis validates the consideration of KQ for the cancellation of this '924 NBO ABV' route. Namely, it is the most beneficial route to cancel in terms of the NCV in the West Africa region. In relation to the routes operated by the Embraer 190 aircraft, however, it is not the most beneficial route to cancel. It is indicated by the people at KQ that the two less performing routes for the Embraer 190, the '266 NBO MYD' and '913 NBO GBE' routes, each have their own separate approach for improvement. In case of the cancellation of the '924 NBO ABV' route mostly connecting passengers to/from DXB, BOM, CAN, EBB and LHR will be spilled.

An equivalent analysis can be conducted based on the NV, whether the metric from the predecessor of this research shares the same conclusion on the hypothetical cancellation of the '924 NBO ABV' route. In Figure 8.10, the NVs for route '924 NBO ABV' for the year 2015 for each month separate is listed. In case of each month, except for December 2015, the IOC assigned to this route are sufficient to make the NV negative. An increase in performance can be noticed in May 2015 and August 2015, which was also noticeable in the NCV of these months.

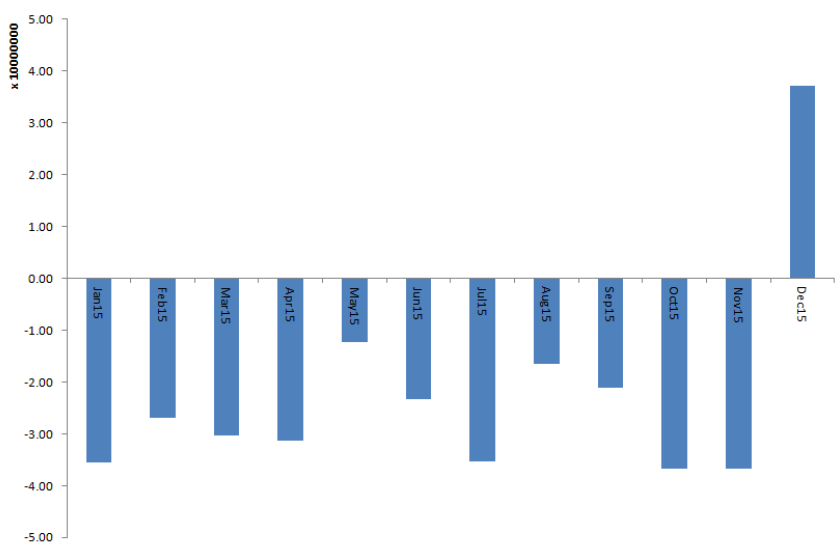

Figure 8.10: Monthly NV '924 NBO ABV' 2015

In Figure 8.11, the NVs for all the routes from the KQ network in the West-Africa region (see Table 8.1) for September 2015 are depicted, in order to put the route '924 NBO ABV' into perspective with respect to the rest of routes from the KQ network in the West-Africa region. This overview does not share the same conclusion on the performance of the route '924 NBO ABV' for this time in this region. On the contrary, one of the most profitable routes in terms of NCV is the least performing route in terms of NV, which invalidates the latter metric.

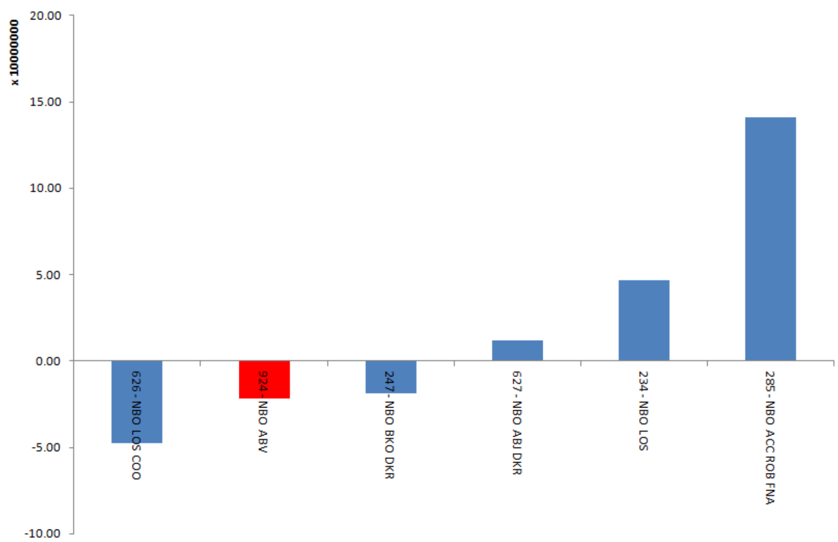

Figure 8.11: NV West-Africa September 2015

In Figure 8.12, the NVs for all the routes from the KQ network operated by the Embraer 190 (see Table 8.1) for September 2015 are depicted, in order to put the route '924 NBO ABV' into perspective with respect to the rest of routes from the KQ network operated by the Embraer 190 aircraft. Again, this overview does not share the same conclusion on the performance of the route '924 NBO ABV' for this time with this aircraft type. Furthermore, the NV of the least performing route is not even close to its corresponding NCV, which confirms the invalidation.

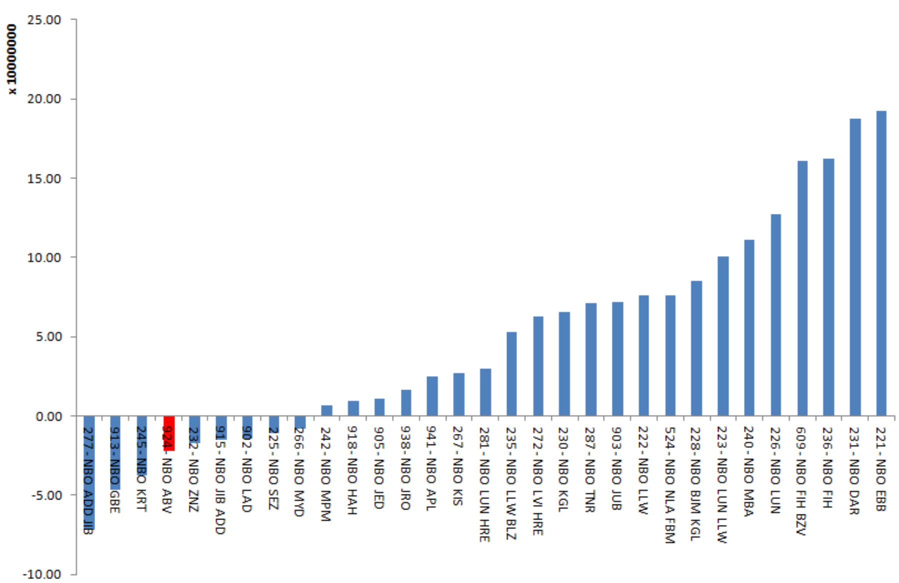

Figure 8.12: NV Embraer 190 September 2015

Change Frequency Route '287 NBO TNR'

Around mid June 2015, the frequency on route '287 NBO TNR' changed from around seven flights per week to around twelve flights per week. This implies roughly a doubling in frequency. In this case-study, the method from Section 7.1 will be applied to predict the NCV for April 2016 with respect to April 2015, after which it can be compared with the actual value. In Table 8.7, the information necessary to obtain the change in frequency and the NCV, together with the NCV itself, for the segments from route '287 NBO TNR' for April 2015 and April 2016 is presented. An odd phenomenon occurs in the variable costs for April 2016, which turn out to be negative. The implementation in Python has been consulted and nothing odd has been found. An earlier issue on negative costs (see Section 5.1) probably arises, and still remains unsolved in this research. According to the ASKs, the capacity in April 2016 doubled with respect to the same period as the year before. It is assumed that this change in capacity is purely caused by change in frequency, hence the frequency in April 2016 doubled with respect to the same period as the year before.

Period	**April 2015**		**April 2016**	
Segment	**NBO-TNR**	**TNR-NBO**	**NBO-TNR**	**TNR-NBO**
ASK	5,575,727	5,575,727	11,241,494	11,563,387
RPK	3,745,664	3,716,401	7,516,089	7,198,698
LF	67.18	66.65	66.86	62.25
Local Revenues	18,317,358.19	19,667,516.81	30,916,884.09	31,662,221.63
Connecting Revenues	57,934,539.72	56,292,051.12	161,035,208.14	133,779,184.45
Local Passengers	511	634	783	905
Connecting Passengers	1,146	1,003	2,602	2,201
Local Fixed	20,467,012.46	19,020,064.56	40,769,158.03	34,234,062.12
Local Variable	3,929,569.66	3,737,798.70	-2,812,037.71	-3,256,447.66
NCV	49,384,662.87	51,372,605.08	154,286,548.54	135,269,279.78

Table 8.7: Results '287 NBO TNR' April 2015 & April 2016

The potential demand for the year 2016 is determined using the least-squares approximation method, as previously discussed (see Section 8.2), based on the potential demand for the separate years 2012 up to and including 2014. It is assumed that the other routes in the KQ network remain constant. In accordance with the effect of seasonality, as previously discussed, it is assumed that in April a share of 6.25% of the yearly demand is attracted. As an indication, in Table 8.8, the total (i.e. local and connecting) number of passengers (Tot Pax) on route '287 NBO TNR' in both directions for the year 2015, together with the share of passengers with respect to the yearly total number of passengers (Share Yrly Tot Pax), per each month separate are listed. From this, the month April is attracting 5.72% of this yearly number of passengers. This is purely an indication, for a rough validation of the incorporated seasonality, and will not be corrected in the performance of this case-study for the sake of consistency.

Period	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**
Tot Pax	3,253	3,582	3,822	3,294	3,380	4,170	6,686	7,128	4,879	5,910	6,421	5,036
Share Yrly Tot Pax	5.65%	6.22%	6.64%	5.72%	5.87%	7.24%	11.62%	12.38%	8.48%	10.27%	11.16%	8.75%

Table 8.8: Monthly Number and Share of Passengers '287 NBO TNR' 2015

In Table 8.9, the Network Contribution Value Analysis for this route under this change in frequency according to Figure 7.1 is depicted. In accordance with the method from Section 7.1, the fixed costs for this route will double. Since the current LFs are lower than 75%, it was assumed that the OD markets on the route are saturated. Therefore, purely some additional passengers due to increased market share will be added. In this case, no passengers are added. The same holds for the revenues and the variable costs. This yields a new NCV of $61,270,190.93$ KES. An error of 373% occurs with respect to the actual value.

	Period	April 2015	April 2016			
	Frequency	**7 flights p/w**	**12 flights p/w**			
	State	**Actual**	**Forecast**	**Change**	**Actual**	**Absolute Error**
+	local revenues	37,984,875.00	37,984,875.00	0.0%	62,579,105.72	64.7%
-	local fixed	39,487,077.02	78,974,154.04	100.0%	75,003,220.15	5.0%
-	local variable	7,667,368.36	7,667,368.36	0.0%	-6,068,485.37	179.1%
=	**Route Contribution Result**	**-9,169,570.39**	**-48,656,647.40**	**430.6%**	**-6,355,629.06**	**86.9%**
+	prorated connecting revenues	27,370,373.56	27,370,373.56	0.0%	95,200,892.24	247.8%
=	**Network Contribution Result**	**18,200,803.17**	**-21,286,273.84**	**-217.0%**	**88,845,263.18**	**517.4%**
+	remaining connecting revenues	86,856,217.28	86,856,217.28	0.0%	199,613,500.35	129.8%
-	prorated connecting variable	4,299,752.50	4,299,752.50	0.0%	-1,097,064.79	125.5%
=	**Network Contribution Value**	**100,757,267.95**	**61,270,190.94**	**-39.2%**	**289,555,828.32**	**372.6%**

Table 8.9: Network Contribution Value Analysis of '287 NBO TNR' under Changing Frequency in accordance with Figure 7.1

It can be noticed from the actual results in Table 8.7 that, despite of the low LFs, the LFs remain quite constant in case of increase in capacity. Apparently, despite of the current LFs lower than 75%, the OD markets on the route were not yet saturated. Therefore, the saturation LF in Figure 7.1 is lowered to 50% and the framework has been applied again. In Table 8.10, the Network Contribution Value Analysis for this route under this change in frequency according to Figure 7.1 with a lowered saturation LF is depicted. In this case, the unused capacity will be filled with passengers up to the old LF as long as the potential demand allows. Since there are $3,314$ passengers needed on the segment NBO-TNR and $3,274$ passengers needed on the TNR-NBO segment to retain the old LFs, and the demand for April 2016 is $1,719$ and $1,682$ respectively, the unused capacity will be filled with passengers up to the demand. This implies that the total number of passengers (i.e. local and connecting) on this route will increase with about 3%, which also holds for the total revenues (i.e. local and connecting) and the variable costs. This yields a new NCV of $65,818,878.28$ KES. Now, an error of 340% occurs with respect to the actual value.

	Period	April 2015	April 2016			
	Frequency	**7 flights p/w**	**12 flights p/w**			
	State	**Actual**	**Forecast**	**Change**	**Actual**	**Absolute Error**
+	local revenues	37,984,875.00	39,210,902.39	3.2%	62,579,105.72	59.6%
-	local DOC	47,154,445.39	86,891,304.69	84.3%	68,934,734.78	20.7%
-	local fixed	39,487,077.02	78,974,154.04	100.0%	75,003,220.15	5.0%
-	local variable	7,667,368.36	7,917,150.65	3.3%	-6,068,485.37	176.6%
=	**Route Contribution Result**	**-9,169,570.39**	**-47,680,402.29**	**420.0%**	**-6,355,629.06**	**86.7%**
+	prorated connecting revenues	27,370,373.56	28,275,567.02	3.3%	95,200,892.24	236.7%
=	**Network Contribution Result**	**18,200,803.17**	**-19,404,835.27**	**-206.6%**	**88,845,263.18**	**557.9%**
+	remaining connecting revenues	86,856,217.28	89,666,191.20	3.2%	199,613,500.35	122.6%
-	prorated connecting variable	4,299,752.50	4,442,477.65	3.3%	-1,097,064.79	124.7%
=	**Network Contribution Value**	**100,757,267.95**	**65,818,878.28**	**-34.7%**	**289,555,828.32**	**339.9%**

Table 8.10: Network Contribution Value Analysis of '287 NBO TNR' under Changing Frequency in accordance with Figure 7.1 with $LF_{SAT} = 50\%$

Now, it can be noticed from the actual results in Table 8.7 that the actual number of passengers in April 2016 is higher than the estimated potential demand. Therefore, yet another approach is used, in which the constraint of the demand is deleted and the unused capacity is filled with passengers up to the old LF. The same holds for the revenues and the variable costs. In Table 8.11, the Network Contribution Value Analysis for this route under this change in frequency according to Figure 7.1 with a lowered saturation LF and unconstrained demand is depicted. This yields a new NCV of $201,514,535.92$ KES. Now, an error of 44% occurs with respect to the actual value.

	Period	April 2015	April 2016			
	Frequency	7 flights p/w	12 flights p/w			
	State	Actual	Forecast	Change	Actual	Absolute Error
+	local revenues	37,984,875.00	75,969,750.00	100.0%	62,579,105.72	17.6%
-	local fixed	39,487,077.02	78,974,154.04	100.0%	75,003,220.15	5.0%
-	local variable	7,667,368.36	15,334,736.72	100.0%	-6,068,485.37	139.6%
=	**Route Contribution Result**	**-9,169,570.39**	**-18,339,140.76**	**100.0%**	**-6,355,629.06**	**65.3%**
+	prorated connecting revenues	27,370,373.56	54,740,747.12	100.0%	95,200,892.24	73.9%
=	**Network Contribution Result**	**18,200,803.17**	**36,401,606.36**	**100.0%**	**88,845,263.18**	**144.1%**
+	remaining connecting revenues	86,856,217.28	173,712,434.56	100.0%	199,613,500.35	14.9%
-	prorated connecting variable	4,299,752.50	8,599,505.00	100.0%	-1,097,064.79	112.8%
=	**Network Contribution Value**	**100,757,267.95**	**201,514,535.92**	**100.0%**	**289,555,828.32**	**43.7%**

Table 8.11: Network Contribution Value Analysis of '287 NBO TNR' under Changing Frequency in accordance with Figure 7.1 with $LF_{SAT} = 50\%$ and unconstrained demand

This error is considered to be sufficiently improved. This application revealed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. An improved prediction of the OD market size could give an adjusted saturation LF to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The odd occurrence of negativity is observable in the variable costs, which yields the corresponding errors to be prominent.

Change Frequency Route '234 NBO LOS'

Around mid November 2015, the frequency on route '234 NBO LOS' changed from around four flights per week to a daily flight. The frequency on the round-robin route '626 NBO LOS COO', which also makes use of the segments NBO-LOS and LOS-NBO, did not changed. Therefore, the change in the NCV can be fully contributed to the '234 NBO LOS' route. In this case-study, the method from Section 7.1 will be applied to predict the NCV for April 2016 with respect to April 2015, after which it can be compared with the actual value. In Table 8.12, the information necessary to obtain the change in frequency and the NCV, together with the NCV itself, for the segments from route '234 NBO LOS' for April 2015 and April 2016 is presented. The same odd phenomenon occurs in the variable costs of April 2016 as in the previous case-study, and the same motivation holds. According to the ASKs, the capacity in April 2016 increased with around 40% with respect to the same period as the year before. It is assumed that this change in capacity is purely caused by change in frequency, hence the frequency in April 2016 increased with 40% with respect to the same period as the year before. It can also be noticed that the ASKs of the two opposite segments differ, in which that of the NBO-LOS segment is higher, since this segment is also served in one direction by the '626 NBO LOS COO' route.

Period	April 2015		April 2016	
Segment	**NBO-LOS**	**LOS-NBO**	**NBO-LOS**	**LOS-NBO**
ASK	17,472,980.00	11,465,804.00	24,362,436.00	16,575,356.00
RPK	11,849,404.00	7,407,316.00	13,564,096.00	10,502,968.00
LF	67.82	64.60	55.68	63.36
Local Revenues	42,117,785.29	39,643,925.88	58,233,022.27	63,372,197.54
Connecting Revenues	73,932,977.37	46,504,940.55	81,076,233.44	82,184,533.82
Local Passengers	1,129	1,135	1,164	1,390
Connecting Passengers	2,070	1,501	2,321	2,405
Local Fixed	57,701,743.05	33,283,043.00	70,102,793.98	39,498,593.53
Local Variable	7,318,733.96	6,035,655.36	-1,974,374.93	-2,622,365.74
NCV	46,997,617.27	46,830,168.07	71,910,044.91	108,680,503.56

Table 8.12: Results '234 NBO LOS' April 2015 & April 2016

The potential demand for the year 2016 is determined using the least-squares approximation method, as previously discussed (see Section 8.2), based on the potential demand for the separate years 2012 up to and including 2014. It is assumed that the other routes in the KQ network remain constant. In accordance with the effect of seasonality, as previously discussed, it is assumed that in April a share of 6.25% of the yearly demand is attracted. As an indication, in Table 8.13, the total (i.e. local and connecting) number of passengers (Tot Pax) on route '287 NBO LOS' in both directions for the year 2015, together with the share of passengers with respect to the yearly total number of passengers (Share Yrly Tot Pax), per each month separate are listed. From this, the month April is attracting 7.96% of this yearly number of passengers. This is purely an indication, for a rough validation of the incorporated seasonality, and will not be corrected in the performance of this case-study for the sake of consistency.

Period	**Jan-15**	**Feb-15**	**Mar-15**	**Apr-15**	**May-15**	**Jun-15**	**Jul-15**	**Aug-15**	**Sep-15**	**Oct-15**	**Nov-15**	**Dec-15**
Pax.	5,651	4,781	4,968	5,835	5,700	6,244	6,181	6,351	6,414	6,019	7,054	8,097
Share Tot. Pax.	7.71%	6.52%	6.78%	7.96%	7.78%	8.52%	8.43%	8.66%	8.75%	8.21%	9.62%	11.05%

Table 8.13: Monthly Number and Share of Passengers '234 NBO LOS' 2015

In Table 8.14, the Network Contribution Value Analysis for this route under this change in frequency according to Figure 7.1 is depicted. In accordance with the method from Section 7.1, the fixed costs for this route will increase with 40%. Since the current LF are lower than 75%, it was assumed that the OD markets on the route are saturated. Therefore, purely some additional passengers due to increased market share will be added. The same holds for the revenues and the variable costs. This yields a new NCV of 58, 621, 467.54 KES. An error of 208% occurs with respect to the actual value.

	Period	**April 2015**	**April 2016**			
	Frequency	**4 flights p/w**	**7 flights p/w**			
	State	**Actual**	**Forecast**	**Change**	**Actual**	**Absolute Error**
+	local revenues	81,761,711.17	82,267,585.33	0.6%	121,605,219.81	47.8%
-	local DOC	104,339,175.37	140,817,757.93	35.0%	105,004,646.84	25.4%
-	local fixed	90,984,786.05	127,378,700.47	40.0%	109,601,387.51	14.0%
-	local variable	13,354,389.32	13,439,057.46	0.6%	-4,596,740.67	134.2%
=	**Route Contribution Result**	**-22,577,464.20**	**-58,550,172.61**	**159.3%**	**16,600,572.97**	**128.4%**
+	prorated connecting revenues	40,312,785.59	40,653,031.05	0.8%	40,600,537.78	0.1%
=	**Network Contribution Result**	**17,735,321.39**	**-17,897,141.56**	**-200.9%**	**57,201,110.75**	**419.6%**
+	remaining connecting revenues	80,125,132.33	80,585,313.76	0.6%	122,660,229.48	52.2%
-	prorated connecting variable	4,032,668.38	4,066,704.66	0.8%	-729,208.24	117.9%
=	**Network Contribution Value**	**93,827,785.34**	**58,621,467.54**	**-37.5%**	**180,590,548.47**	**208.1%**

Table 8.14: Network Contribution Value Analysis of '234 NBO LOS' under Changing Frequency in accordance with Figure 7.1

Again, it can be noticed that – despite of the low LFs – the OD markets on this route were not yet saturated. Therefore, the saturation LF in Figure 7.1 is lowered to 50% and the framework has been applied again. In Table 8.15, the Network Contribution Value Analysis for this route under this change in frequency according to Figure 7.1 with a lowered saturation LF is depicted. In this case, the unused capacity will be filled with passengers up to the old LF as long as the potential demand allows. Since there are 4, 479 passengers needed on the segment NBO-LOS and 3, 690 passengers needed on the LOS-NBO segment to retain the old LFs, and the demand for April 2016 is 93, 367 and 65, 150 respectively, the unused capacity will be filled with passengers up to the old LFs. The same holds for the revenues and the variable costs. It should be noted that this demand is the demand between Kenya and Nigeria, as no conversion from country-pair to city-pair was included in the demand model used for this research (see Section 7.1) due to the lack of data. However, in case it is assumed that all KQ routes to/through Nigeria ('924 NBO ABV', '234 NBO LOS', and '626 NBO LOS COO') have an equal share of this demand, the demand is still sufficient. This yields a new NCV of 131, 358, 899.48 KES. Now, an error of 38% occurs with respect to the actual value.

	Period	April 2015	April 2016			
	Frequency	4 flights p/w	7 flights p/w			
	State	Actual	Forecast	Change	Actual	Absolute Error
+	local revenues	81,761,711.17	114,466,395.64	40.0%	121,605,219.81	6.2%
-	local fixed	90,984,786.05	127,378,700.47	40.0%	109,601,387.51	14.0%
-	local variable	13,354,389.32	18,696,145.05	40.0%	-4,596,740.67	124.6%
=	**Route Contribution Result**	**-22,577,464.20**	**-31,608,449.88**	**40.0%**	**16,600,572.97**	**152.5%**
+	prorated connecting revenues	40,312,785.59	56,437,899.83	40.0%	40,600,537.78	28.1%
=	**Network Contribution Result**	**17,735,321.39**	**24,829,449.95**	**40.0%**	**57,201,110.75**	**130.4%**
+	remaining connecting revenues	80,125,132.33	112,175,185.26	40.0%	122,660,229.48	9.3%
-	prorated connecting variable	4,032,668.38	5,645,735.73	40.0%	-729,208.24	112.9%
=	**Network Contribution Value**	**93,827,785.34**	**131,358,899.48**	**40.0%**	**180,590,548.47**	**37.5%**

Table 8.15: Network Contribution Value Analysis of '234 NBO LOS' under Changing Frequency in accordance with Figure 7.1 with $LF_{SAT} = 50\%$

This application confirmed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. In this case, the recommendation for improvement of the prediction of the OD market size has not been detected, since the potential demand was too high to affect the number of passengers to be added. The odd occurrence of negativity is observable in the variable costs, which yields the corresponding errors to be prominent.

8.5 Conclusions Application & Validation

In this chapter, the model from the previous chapters - including its assumptions and limitations as mentioned - is applied to the full KQ network. The model is applied to the full KQ network for the year 2015 for each month separate. Due to the type of routes taken into account, a tag-end route with three segments in both directions is not explicitly taken into account in the model. Furthermore, due to the segment-based approach, any overlap between routes is also not taken into account. In the implementation, a least-square approximation method has been used to determine the potential demand for the year 2015 based on the potential demand for the separate years 2012 up to and including 2014 due to the lack of data. A simple reflection of market share and seasonality have been incorporated for the sake of simplicity in calculations and obtaining information.

The comparison of the results for the NV and the NCV per route revealed that these metrics do not share the same opinion on the performance of a route considering its value in the network. A further analysis of the NCV revealed that the majority of the routes with initially a positive NCV will become unprofitable if the connecting segments were deleted. This basically reflects the essence of a hub-and-spoke network and its connecting passengers. A case-study on a hypothetical cancellation of the standard spoke route on ABV (Abuja, Nigeria) confirmed the consideration of KQ to cancel that route. This analysis, however, also indicated that some other routes may need more attention. An equivalent analysis based on the NV invalidates the metric from the predecessor of this research.

In general, the results for the change of aircraft are sensitive to the potential demand and the replacing fixed costs for operating the replacing aircraft. Therefore, it has been assumed that the results from the change in frequency are leading with respect to the change in capacity on a route.

A case-study on recent change of frequency on standard spoke routes on TNR (Antananarivo, Madagascar) and LOS (Lagos, Nigeria) revealed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The occurrence of negativity is observed in the variable costs, which yields the corresponding errors to be prominent.

Chapter 9

Conclusions & Recommendations

In this chapter, the conclusions and recommendations from this research will be discussed. In Section 9.1, the answers to the research questions will be presented. In Section 9.2, the main conclusions from the application to the full KQ are listed. In Section 9.3, the recommendations and suggestions for future work are listed.

9.1 Answers Research Questions

1. **How can the base model be produced?**
   The input for the base model are the revenues on coupon level and the costs on segment level. At KQ, the revenues on coupon level are gathered through KALE, an independent aviation consultancy company providing database services for KQ, and the costs on segment level are gathered through TM1, a database of KQ itself. In this input data some inconsistencies have been encountered. For example, the flight numbers nor the routes codes in the revenue data on coupon level do not correspond with the route codes used in the data from KQ itself. This is not intuitive in processing this data together with data from sources of KQ itself. Furthermore, in the cost data on segment level, some elements were not yet properly assigned. The costs which could not be assigned to any operated segment were disregarded from the implementation of this model. An issue on negative costs remained unsolved in this research.

   In the base model, three type of routes (i.e. standard spoke, tag-end and round-robin) have been distinguished. In the implementation of this model, it was not completely intuitive how to obtain the various metrics, especially for the tag-end and round-robin routes. It is not clear whether Backker (2013) distinguished these two type of routes. These two types of routes influence the passenger flow through a hub-and-spoke network drastically. In order to cope with the different type of routes, the implementation has been performed on a segment basis rather than a route or flight basis. In this, the various metrics are obtained for each segment separate. From these segment-based results it is possible to obtain the route-based result without losing sight of the contribution of the various segments of a route. It is not clear whether Backker (2013) used this approach. The major drawback of this method is that it is not possible to distinguish for an individual route or flight on a segment. Due to the segment-based approach, it is not possible to incorporate the sensitivity of connecting times (see Table 4.2) in this research.

2. **How can the performance of a route considering its value in the network be defined?**
   At first, in the Network Value Analysis, several intermediate levels in the NV have been applied. In this separation, an intermediate profitability level is introduced which prorates a share of the connecting revenues based on DOC, instead of the commonly used mileage-based proration method, before applying the full-fare proration method. Using this proration method, the prorated connecting revenues will be linked to the cost allocation of the DOC itself, which shares the point of improvement of KLM from the practical research.

In this research, it is assumed that none of the IOC are discarded in case of the cancellation of a segment. The DOC can be subdivided into fixed costs, which are not dependent on the number of passengers, and variable costs which are dependent on the number of passengers. It is discussed that as well the local as the connecting passengers are incurring DOC on a segment. However, despite of the fact that the DOC of a segment are shared by as well the local as the connecting passengers, the fixed costs shared by the connecting passengers are not discarded in case of the cancellation of a connecting segment. Therefore, purely the variable costs of the connecting passengers are discarded in case of the cancellation of a segment. In this, the NCV is proposed, which indicates the monetary value which is at risk in case of the cancellation of a segment. Using the Network Contribution Value Analysis, multiple levels in the NCV have been applied, in order to be able to identify the source and areas of (un)profitability.

The input for the NC are the revenues on coupon level and the costs on segment level, which have already been discussed - and used - for the base model. The DOC, however, still had to be divided into the fixed and variable costs. The variable costs represent the DOC which are dependent on the number of passengers, and are assumed to contain the PAX Meals, PAX Costs on Ground and Commissions from KQ its cost breakdown (see Table 5.2), while the rest of the DOC comprise the fixed costs which are not dependent on the number of passengers. The implementation of the Network Value Analysis, the NCV and its Network Contribution Value Analysis are similar to the method used in the base model.

Despite of the ability to identify the sources and areas of (un)profitability, and having an improved indication of the contribution of a segment or route to a hub-and-spoke network, this analysis purely considers the cancellation of a segment or route, rather than changing the capacity. Therefore, the effect of the change of capacity on the NC is considered without changing it to zero. The capacity is changed by changing the frequency on a segment or route, or changing the type of aircraft operated on a segment or route. The model from Schot (2015) has been used for the prediction of the OD market size as a constraint for the demand in the concept of the NC under changing capacity. The S-curve market share model has been used to determine the market share of the airline in the market, with an alternative implementation with respect to Schot (2015), in order to be consistent among various networks with different routes. In case of the sample network, no effect of seasonality has been incorporated. In the concept of the change of aircraft, the model from Schot (2015) and Lammens (2014) has been used for the calculation of the replacing fixed costs for the replacing aircraft, in which Schot (2015) is used as the primary source. The input, besides the prediction of the OD market size and the calculation of the replacing fixed costs for the replacing aircraft, which could not be obtained from the base model, is the LF on segment level. At KQ, the LF on segment level are gathered through TM1, the database of KQ itself. In the implementation of the change in frequency, a standard change in frequency of 10% has been applied, for the sake of convenience. No feedback in the change of the number of flights per week has been provided here. From this, it is more intuitive to compare the changes in frequency among the various routes. In the implementation of the change of aircraft, the Boeing 777, Boeing 787, Boeing 737, and Embraer 190 are the types of aircraft taken into account.

3. **How can the results be presented in a graphical, analytical and interactive way?**
This GUI incorporates information on the number of passengers, costs, revenues, NV (including Network Value Analysis) and NCV (including Network Contribution Value Analysis) per route per segment for the year 2015 for each month separate. Despite of the fact that this GUI is hardly contributing to the innovation of this graduation research, it is highly contributing to the practical relevance of this research, since this GUI is an efficient manner to present the results for the full KQ network. The concept of the NC under changing capacity has not been incorporated in the GUI. Despite of the fact that it has not been mentioned in every case separate, this GUI has been frequently used to obtain the result to be presented.

4. **How can the NPAF with a graphical, analytical and interactive representation help airlines operating a hub-and-spoke network to analyse the performance of their routes considering its value in the network?**
In the answer to this question, the main innovations and limitations of this research will be listed. The innovations and limitations are listed in the order as obtained from the research.

The main innovations of this research is in the NC under changing capacity. Despite of the fact that the NCV improved indication of the contribution of a segment or route to a hub-and-spoke network, this analysis purely considers the cancellation of a segment or route, rather than changing the capacity. Therefore, the effect of the change of capacity on the NC is considered without changing it to zero. The capacity is changed by changing the frequency on a segment or route, or changing the type of aircraft operated on a segment or route.

The main limitations of the model in this research is that it is examining a segment rather than an individual route or flight on that segment. In this, the various metrics are obtained for each segment separate. From these segment-based results it is possible to obtain the route-based result without losing sight of the contribution of the various segments of a route. Due to the segment-based approach, it is not possible to incorporate the sensitivity of connecting times in this research.

The NC, together with the concept of changing capacity, is examining the cancellation of a segment or route and changing the capacity on a segment or route in terms of the frequency or the type of aircraft operated. The opening of a new segment or route is not taken into account in this research. In the concept of changing capacity, it is assumed that the rest of the network remains constant.

9.2 Application & Validation

The model is applied to the full KQ network for the year 2015 for each month separate. Due to the type of routes taken into account, a tag-end route with three segments in both directions is not explicitly taken into account in the model. Furthermore, due to the segment-based approach, any overlap between routes is also not taken into account. In the implementation, a least-square approximation method has been used to determine the potential demand for the year 2015 based on the potential demand for the separate years 2012 up to and including 2014 due to the lack of data. A simple reflection of market share and seasonality have been incorporated for the sake of simplicity in calculations and obtaining information.

A case-study on a hypothetical cancellation of the standard spoke route on ABV (Abuja, Nigeria) confirmed the consideration of KQ to cancel that route. This analysis, however, also indicated that some other routes may need more attention. An equivalent analysis based on the NV invalidates the metric from the predecessor of this research.

A case-study on recent change of frequency on standard spoke routes on TNR (Antananarivo, Madagascar) and LOS (Lagos, Nigeria) revealed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The occurrence of negativity is observed in the variable costs, which yields the corresponding errors to be prominent.

9.3 Recommendations & Future Work

In this section, the recommendations and suggestions for future work are listed. The recommendations and suggestions for future work are listed in the order as obtained from the research.

In the input data for the model in this research some inconsistencies have been encountered. An issue on negative costs remained unsolved in this research. This issue has also been observed in the application, which yields the corresponding errors to be prominent. It is recommended to KQ to solve this internal issue, and thereby improve the results from the model in this research.

In the Network Contribution Value Analysis, several intermediate levels in the NCV have been applied. In this separation, an intermediate profitability level is introduced which prorates a share of the connecting revenues based on DOC, instead of the commonly used mileage-based proration method, before applying the full-fare proration method. This method, however, has not been adequately validated in this research. Therefore, a suggestion for future work is the proper validation of this method.

An application of the NC under changing capacity revealed that the saturation LF of 75% is quite high and should be adjusted to the specific airline and corresponding markets. An improved prediction of the OD market size could give an adjusted saturation LF to the specific airline and corresponding markets. Furthermore, the prediction of the potential demand was too low and did put a too high restriction on the number of passengers to be added. An improved prediction of the OD market size could also give a more realistic constraint to the number of passengers to be added in case of the increase in frequency. The model for the prediction of the OD market size could be improved in terms of competitive and schedule related variables, such as average ticket price and sensitivity of connecting times respectively. For example, in case of a drastic increase in frequency, the average ticket price could be lowered due to economies of scale. In considering the schedule related variables, the potential demand for a route can be boosted in case the connecting times with some prominent connecting routes is optimized, and the overlap of another route in the network, which influences the flow of passengers significantly.

At least, the model in this research could be improved by incorporating a route-based or flight-based approach rather than a segment-based approach. In these cases, it is possible to identify the contribution of an individual route or flight on a segment respectively. In case of a flight-based approach, it is also possible to incorporate the sensitivity of connecting times. For example, the potential demand for a flight can be boosted in case the connecting times with some prominent connecting flights is optimized.

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Appendix A

List of Airports

In this appendix, the airpors from the full KQ network are listed with their code from the International Air Transport Association (IATA) and their location in terms of city and country.

Code (IATA)	City	Country	Code (IATA)	City	Country
ABJ	Abidjan	Cote d'Ivoire	**HKG**	Hong Kong	Hong Kong
ABV	Abuja	Nigeria	**HRE**	Harare	Zimbabwe
ACC	Accra	Ghana	**JED**	Jeddah	Saudi Arabia
ADD	Addis Ababa	Ethiopia	**JIB**	Djibouti	Djibouti
AMS	Amsterdam	Netherlands	**JNB**	Johannesburg	South Africa
APL	Nampula	Mozambique	**JRO**	Kilimanjaro	Tanzania
BJM	Bujumbura	Burundi	**JUB**	Juba	South Sudan
BKK	Bangkok	Thailand	**KGL**	Kigali	Rwanda
BKO	Bamako	Mali	**KIS**	Kisumu	Kenya
BLZ	Blantyre	Malawi	**KRT**	Khartoum	Sudan
BOM	Mumbai	India	**LAD**	Luanda	Angola
BZV	Brazzaville	Congo (Brazzaville)	**LHR**	London	United Kingdom
CAN	Guangzhou	China	**LLW**	Lilongwe	Malawi
CDG	Paris	France	**LOS**	Lagos	Nigeria
COO	Cotonou	Benin	**LUN**	Lusaka	Zambia
DAR	Dar Es Salaam	Tanzania	**LVI**	Livingstone	Zambia
DKR	Dakar	Senegal	**MBA**	Mombasa	Kenya
DLA	Douala	Cameroon	**MPM**	Maputo	Mozambique
DXB	Dubai	United Arab Emirates	**MYD**	Malindi	Kenya
DZA	Dzaoudzi	Mayotte	**NBO**	Nairobi	Kenya
EBB	Entebbe	Uganda	**NLA**	Ndola	Zambia
FBM	Lubumashi	Congo (Kinshasa)	**NSI**	Yaounde	Cameroon
FIH	Kinshasa	Congo (Kinshasa)	**ROB**	Monrovia	Liberia
FNA	Freetown	Sierra Leone	**SEZ**	Mahe	Seychelles
GBE	Gaberone	Botswana	**TNR**	Antananarivo	Madagascar
HAH	Moroni	Comoros	**ZNZ**	Zanzibar	Tanzania
HAN	Hanoi	Vietnam			

Appendix B

Direct & Indirect Operating Costs

In Table B.1, the more detailed division of the DOC and the IOC, in accordance with the traditional approach from the ICAO, is listed.

Direct Operating Costs

1. Flight operations
   - Flight crew salaries and expenses
   - Fuel and oil
   - Airport and en-route charges (could be IOC)
   - Aircraft insurance
   - Rental/lease of flight equipment/crews
2. Maintenance and overhaul
   - Engineering staff costs
   - Spare parts consumed
   - Maintenance administration (could be IOC)
3. Depreciation and amortisation
   - Flight equipment
   - Ground equipment and property (could be IOC)
   - Extra depreciation (in excess of historic cost depreciation)
   - Amortisation of development cost and crew training

Indirect Operating Costs

1. Station and ground expenses
   - Ground staff
   - Buildings, equipment, transport
   - Handling fees paid to others
2. Passenger services
   - Cabin crew salaries and expenses (could be DOC)
   - Other passenger service costs
   - Passenger insurance
3. Ticketing, sales and promotion
   - General and administration
4. Other operating costs

Table B.1: Direct & Indirect Operating Costs (Adapted from Doganis, 2010, p. 67)

Appendix C

Variable & Fixed Operating Costs

In this appendix, one possible method for allocating the DOC and the IOC to the variable and fixed operating costs is explained. The variable costs includes for example the fuel costs, landing charges and passenger services costs. Furthermore, the variable costs can also contain certain crew and maintenance costs which are dependent on the amount of flying. On the other hand, the fixed costs includes among others depreciation or lease charges and insurance. Despite of the fact that most of the IOC are fixed costs, due to the independence on the amount of flying, some will vary with the operating of particular flight (Doganis, 2010, p. 79). In Table C.1, the more detailed division of this allocation method is listed.

Variable Direct Operating Costs	**Fixed Direct Operating Costs**
1. Fuel costs	1. Aircraft standing charges
• Flight crew salaries and expenses	• Depreciation of lease rentals
• Fuel and oil	• Aircraft insurance
2. Variable flight crew costs*	2. Annual flight crew costs*
• Flight crew subsistence and bonuses	• Fixed salaries and other expenses**
3. Variable cabin crew costs	• Flight crew administration
• Cabin crew subsistence and bonuses	3. Annual cabin crew costs
4. Direct engineering costs	• Fixed salaries and other expenses**
• Related to number of flight cycles	• Flight crew administration
• Aircraft utilisation	4. Engineering overheads
5. Airport and en-route charges	• Fixed engineering staff costs**
• Landing fees and other airport charges	• Maintenance administration and other overheads
• En-route navigation charges	
6. Passenger service costs*	
• Passenger meals/hotel expenses	
• Handling fees paid to others	

Notes
* Previously categorised as IOC (see appendix B)
** Unrelated to amount of flying

Table C.1: Variable & Fixed Direct Operating Costs (Adapted from Doganis, 2010, p. 81)

As can be noticed from the table on the previous page, some of the costs which are previously categorised as IOC, are in this method redefined as variable or fixed DOC. This is especially true for some of the flight crew costs and passenger service costs (Doganis, 2010, p. 79-80). In Table C.2, the costs which remain as IOC in accordance with this method are listed.

Indirect Operating Costs
1. Station and ground expenses
2. Passenger services
• Passenger service staff
• Passenger insurance
3. Ticketing, sales and promotion
4. General and administrative

Table C.2: Indirect Operating Costs (Adapted from Doganis, 2010, p. 81)

Appendix D

Profitability Measures for A-B

In this appendix, an example of the possible profitability measures of the flight leg A-B in accordance with Baldanza (1999) is calculated numerically. Consider the following revenue and costs data for the flight leg A-B during a given time period:

1. Local revenue	$6,000
2. Proration of connecting itineraries	$1,500
3. Remaining proration of connecting itineraries	$4,000
4. Variable flight costs	$4,500
5. Aircraft ownership costs	$2,000
6. Overhead and non-operational costs	$1,500
7. Network variable costs	$700
8. Network opportunity costs	$500

In accordance with Subsection 2.3.1, the nine possible profitability measures are listed below. In this, the numbers refer to the numbered data above. Each of the three basic profitability measures from Table 2.1 is combined with none, or one of the two, network components from Table 2.2.

Variable segment profitability	$((1+2)-4)$	$3,000
+ Basic network contribution, *or*	$((1+2+3)-(4+7))$	$6,300
+ Basic network contribution with opportunity costs	$((1+2+3)-(4+7+8))$	$5,800
Variable plus ownership profitability	$((1+2)-(4+5))$	$1,000
+ Basic network contribution, *or*	$((1+2+3)-(4+5+7))$	$4,300
+ Basic network contribution with opportunity costs	$((1+2+3)-(4+5+7+8))$	$3,800
Fully allocated segment profitability	$((1+2)-(4+5+6))$	−$500
+ Basic network contribution, *or*	$((1+2+3)-(4+5+6+7))$	$2,800
+ Basic network contribution with opportunity costs	$((1+2+3)-(4+5+6+7+8))$	$2,300

Appendix E

Allocation of Costs

In Table E.1, the main drivers for the allocation of the costs to a single flight leg are shown. In this, primarily the allocation drivers which are used by at least a quarter of the airlines are shown. If this is not possible, the first highest driver is listed. The reader is referred to the original table in the paper of Niehaus et al. (2009) for all the cost drivers and accompanying percentages of use.

Item	**Main Drivers**
Direct variable costs	
Passenger insurance	Passengers, RPK
Reservation	Passengers
Catering	Passengers
Credit card	% of Revenues, Passengers
Fuel	Block Hour
Landing fees	Landing
Aircraft parking fees	Landing, Flight
Ground handling	Landing
Air Traffic Control	Flight
Crew travel	Block Hour
Variable maintenance	Block Hour, Flight Hour
Cargo costs	Passengers
Direct fixed costs	
Aircraft insurance	Block Hour, ASK
Ownership costs	Block Hour
Crew salaries	Block Hour
Fixed maintenance	Block Hour, Flight Hour
Indirect fixed costs	
Station costs	ASK
Sales organization	ASK, % of Revenues
Marketing	% of Revenues, ASK
Administration	ASK, % of Revenues

Table E.1: Allocation of Costs (Adapted from Niehaus et al., 2009, p. 179)

Appendix F

Coefficients Demand Model

Variable	**Coefficient**	**Level**		
		Low - Low	*Low - High*	*High - High*
Constant		$-12.01****$	$-8.24****$	$15.47**$
$CPI_{ij,t}$	α_1	–	–	$-1.88***$
$EFF_{ij,t}$	α_2	$1.52****$	$1.94****$	$2.71****$
$GDP_{ij,t}$	α_3	$0.26****$	$0.38****$	$0.32****$
$POL_{ij,t}$	α_4	$0.32***$	–	$-2.17*$
$POP_{ij,t}$	α_5	$0.86****$	$0.72****$	$0.62****$
D_{ij}	α_6	$-1.50****$	$-1.66****$	$-1.88****$
BOR_{ij}	α_7	$0.73****$	$0.75***$	–
BTA_{ij}	α_8	–	–	$0.61*$
COL_{ij}	α_9	$0.59****$	–	$0.93****$
DT_{ij1}	α_{10}	$-10.24****$	–	–
$DT_{ij,2}$	α_{11}	$-0.96***$	$-0.88***$	$-2.25****$
LAN_{ij}	α_{12}	$0.83****$	$1.42****$	$1.01****$
$LL_{ij,1}$	α_{13}	$-0.71****$	$-0.76****$	$-0.59***$
$LL_{ij,2}$	α_{14}	$-1.07****$	$-1.77****$	$-2.25****$

Significance Codes

- Not Significant

* < 0.1

** < 0.05

*** < 0.01

**** < 0.001