Master Thesis

Modelling Consumer Behaviour in Airport Selection
The case of "ticket tax" in The Netherlands

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Before you lies the final result of an interesting class I took on Tuesday the 24th of November 2009. The professor for that day was Dr. Odette van de Riet. The topic of that class was on "Policy Analysis in Multi-ACTOR Policy Settings", which is also the title of her PhD research. I remember that I got interested by the description of Odette of The Netherlands Institute for Transport Policy Analysis (KiM), the organisation she was working in. I decided to approach and indicate my wish to do my master thesis in transportation, preferably something related to aviation and if I would get really lucky also related to system dynamics. I presume that the interest was mutual because two months later, I left the office of KiM on the Jan van Nassaustraat in Den Haag, in full suit and with a happy face. KiM was able to make three wishes come true, 1. I could do a master thesis, 2. in aviation, and 3. using system dynamics. The last wish that I had explicitly stated in my application letter was that I wished to work in an inspiring and accessible environment with plenty of opportunity to interact. I now know that also this wish has come true. I therefore want to use the space I have reserved in this part of the thesis to show my gratitude to all that have been important to me and that make me realise that this thesis is definitely not an individual product.

First of all I want to dedicate some words to the two persons that have supported me on an almost daily basis. Hugo Gordijn and Joost Kolkman, both researchers at KiM, have literally guided me through the process by the numerous discussions we have had, the (difficult) questions they have asked and the valuable comments they gave on my writings.

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...

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Summary

Introduction  On July the first 2008 the Dutch government introduced a tax on all origin and destination flights departing from Dutch airports. The aim of this “ticket tax” was to (partially) internalise the negative externalities associated with air travel and to compensate for the exemption of duty on fuel and the zero tariff for VAT. The introduction of the tax was accompanied by fierce resistance of the air transport sector, claiming that the tax would severely harm the competitive position of Dutch airports. This resistance and the upcoming economic downturn finally led to the nullification of the ticket tax on July the first 2009.

As a result of the increased prices on the Dutch airports, Dutch air passengers decided to depart from airports just across the borders with Germany and Belgium. The Netherlands Institute for Transport Policy Analysis (KiM) is interested to know how the ticket tax has influenced the choice of passengers and if the altered choice persists after the nullification of the tax. Moreover, KiM is interested to know if and how this choice can be influenced. These insights will be useful in future policy decisions. For example in reaction on the planned taxation on airline tickets in Germany in 2011.

The goal of the research is to answer four questions:

- Which modelling method could be used to model how passengers decide about which airport to depart from over time?
- How do passengers decide about which airport to depart from?
- Did the ticket tax have a structural effect on the decisions of passengers?
- Which policies can be used to influence the decision of passengers?

System dynamics  Literature suggests that people are not always able of making rational decisions because they lack complete information, or simply ignore viable alternatives because of habitual behaviour. Current models of airport choice are good at predicting future passenger numbers but do not incorporate the notion of bounded rationality. This thesis shows that system dynamics is a suitable tool to complement the traditional choice models by explicitly modelling bounded rationality. System dynamics is used to model the behaviour of complex systems over time whereas traditional choice models focus on accuracy of output.

Airport choice  The literature reveals that three sorts of information are required to make a decision about the departure airport. This information comprises of:

- The set of airports that are available to the passenger
- The properties of these airports
The passengers’ own preferences

The airport properties (choice factors) that consumers consider most important are:

- Price
- Number of destinations and flights
- Access time to the airport

Before passengers can choose for an airport they first should be aware of the existence of the airport itself. People get aware of the existence of an airport by talking to friends or relatives or because they see advertisements. People that repeatedly choose the same airport tend to slowly ignore the other airports. Next to this, people tend to forget about an airport if they do not receive enough information about that airport for a longer period of time.

The information about airport properties can be obtained from three sources. The first and most trusted source is by direct experience with the airport. The second source is by word-of-mouth communication with friends, neighbours and relatives. The third and least trusted source is by marketing conducted by commercial organisations such as airports or airlines.

The passengers own preferences determine which of the choice factors is considered most important. If for example price is considered most important, passengers will assign the most weight to price. The weight for each individual factor is different for different groups of passengers (business passengers, leisure passengers etc.). The total usefulness (utility) of an airport for a group of passengers is determined by the weighted sum of the three airport choice factors.

Simulation model

The developed simulation model simulates the transfer of information about airports and airport properties among passengers over time. Furthermore it determines the departure airport based on the information collected by the passengers over time using a standard multinomial logit function. An airline module is developed to match the supplied number of flights with the demanded number of flights.

Three airports are included in the model; Eindhoven (Netherlands), Weeze (Germany) and Charleroi (Belgium). The number of airports is limited to keep the model from becoming too complex. These specific airports are chosen since their catchment areas overlap, the type of services are similar and their markets are most price sensitive. To incorporate a spatial component the passengers are allocated to three regions corresponding to the countries of the airports.

Analysis

Experiments with the model showed that the ticket tax could have a structural effect on the decisions of passengers under two conditions. First, media attention should be sufficiently intensive. Second, airlines should be able to quickly schedule additional flights if demand increases.

From the experimentation with the model it is also deduced that in reality three components must contribute to airport growth. The first and most fundamental component is based on GDP growth and captures the overall increasing propensity to fly. The second component is based on the development of new routes and more frequent flights that create additional demand. The third component is based on awareness of an airport and mainly plays a role in the development of relatively new airports.
At the moment of writing, the German government has announced that research is conducted on a German version of the ticket tax. In order for the Dutch airports to benefit optimally from such a tax, marketing should be aimed at both increasing awareness of the Dutch airports in Germany and inform the Dutch passengers about the lower prices in The Netherlands. It is important that marketing is specifically aimed at communicating the choice factors on which the airport is superior. Furthermore the airports in The Netherlands should make sure that they are able to attract both passengers and airlines offering additional flights.

The role of the government in terms of influencing passenger choice is found to be limited given the chosen boundaries of the model. By reducing the access time to Eindhoven airport a small increase of passengers could be obtained in the simulations.

**Conclusions**  System dynamics proves to be a useful method to model how passengers decide, which aspects play a role and how this process can be influenced.

The decision making process of an passenger starts with the awareness of alternatives. Then information is collected about ticket price, number of flights and destinations and access time. The valuation of that information leads to airport choice.

The ticket-tax can lead to structural changes in case a formerly unknown airport has become generally known as a result of publicity. An essential precondition is that additional flights are provided to serve the raised demand. After abolishment of the ticket tax the risen awareness and supply have a structural effect.

Commercial organisations such as airlines and airports can influence the choice by focusing their marketing activities specifically on the choice factors that make them superior to the other alternatives. The provision by the (regional) government of public infrastructure appears to have a marginal effect on airport choice.

**Limitations and further research**  The developed model has several limitations. First and most important, it is assumed that the market is demand-driven. The analysis of the model however showed that the airlines and thus the supply play an important role in demand development.

The model only comprises of relatively small regional airports. The empirically observed growth rates of the three airports cannot be fully explained if only these small passenger volumes are considered. More and larger airport should be added to accommodate for this. Furthermore, a more elaborate supply-side is needed to explain the increase of flights and destinations that is not directly influenced by demand.

For future research there are at least two possible directions. If more insight is required on airport development and airport-airline-consumer interaction, the model should be simplified and complemented with an airport sub-model that controls expansion decisions and environmental constraints. The drawback of this approach is that the model could become more complex and that overall insight in the system is lost due to increased complexity.

If more numerical precision is required it is suggested that the model is converted into a data-rich agent based model. The drawback of the second approach is that an extensive amount of data would be required.
Part I.

Problem Formulation and Methodology
Chapter 1.

Introduction

On the first of July 2008, the Dutch government introduced a ticket tax on all origin/destination (OD) flights from Dutch airports. Passengers flying from The Netherlands to European destinations were charged an additional €11.25. Passengers for intercontinental flights were charged €45,-. The main purpose of the tax is to (partially) internalise the negative externalities associated with air travel. The decision was also affected by the exemption of duty on kerosene and a zero tariff VAT on airline tickets ([Ministerie van Financiën](#2007)). The projected 350 million euro that the tax should generate per year ([SE0](#2007)) would be invested in sustainable forms of energy. In France and the United Kingdom similar surcharges have come into force in July 2006 and on the first of February 2007 respectively. A remarkable note is that the revenues from the French tax are invested in health-care in developing countries and not in environmental investments. At the time of writing, discussions are ongoing in Germany to introduce a similar tax.

A study by SEO on behalf of The Netherlands Board of Tourism and Conventions (NBTC) and the Dutch association of travel agents and tour operators (ANVR) shows a trend-breaking decrease in travel demand which can partially be attributed to the ticket tax. Other factors, such as high oil prices and the increased pressure on consumer confidence as a result of the latent economic downturn also play a role ([Veldhuis](#2009)). Furthermore ([Veldhuis](#2009)) indicates that the growth of Dutch airports is lagging behind that of neighbouring countries in the period that the tax is levied. Airports in Germany and Belgium, that are situated close to the Dutch borders, have profited from the tax since an estimated one million Dutch passengers have chosen to depart from an airport outside The Netherlands.

On the 25th of March it was announced that the ticket tax would be nullified on the first of July 2009 by adjusting the rates to zero euro for both intra-European and intercontinental flights. The abolishment was part of a package of crisis mitigating measures and has been the result of extensive lobbying by the airline and tourist industry against the tax. Recently, the tax has completely been abolished. The taxes in France and the UK remain intact to date.

The ticket tax measure had large economic and financial consequences. The question that arises now is how we can learn from the response of the aviation “system” in order to anticipate side-effects in consecutive policies, and in the future be able to design better and more robust policies. The Netherlands Institute for Transport Policy Analysis (KiM) initiated an investigation to gain insight in consumer, airport and airline behaviour, as these are the most influential subjects to determine the output of aeronautical policies. Even though many (econometric) models exist to present demand, consumer choice and corporate strategizing, there is a lack of applicable models that incorporate ”softer” aspects of human behaviour such as habitual or culturally induced practises. In the occasion that these models exist, an integration is missing with broader and dynamic airport and airline strategies.
This thesis is split up into four parts. In Part 1, "Problem formulation and methodology", Chapter 2 starts with exploring the problem and defining the research questions. In Chapter 3 an analysis of available modelling methods is described after which a suitable method is chosen.

The Second part, "Conceptualisation" starts with Chapter 4 in which the results of a literature study on consumer behaviour are documented. Chapter 5 covers the description of airport utility and airline strategy. In Chapter 6, 9 hypothesis are formulated based on the literature review that will form the foundations of the simulation model. Part 3 starts with Chapter 7 in which the general structure of the model and the equations on which it is build are described. Chapter 8 then tests if the model is suitable for solving the research questions.

Part 4, "Analysis of results and conclusions", concludes the thesis and starts with Chapter 9 in which the behaviour of the model under different scenarios is analysed. Chapter 10 provides a set of policy recommendations that are based on experiments that where conducted with the model. Chapter 11 concludes the thesis by summarising the most important findings from the literature and the modelling study.
Chapter 2.  

Problem Exploration

Before a detailed analysis can be conducted, it should be perfectly clear what exactly is the question that will be addressed, how this question should be addressed and why it is relevant to address it. This chapter starts with a description of the research problem in Section 2.1. Section 2.2 describes the objectives of the research. In Section 2.3 the scope of the research is determined. Finally, in Section 2.4 the research questions are stated.

2.1. Problem Description

The Netherlands Institute for Transport Policy Analysis (KiM) has launched an investigation to get insight in the effects that the “ticket tax” has had on airport choice of travellers originating from The Netherlands (KiM, 2009). The research consists of two parts of which this thesis only addresses the second one.

The first part is dedicated to collecting air travel statistics and information from the field of practitioners. Using these data it is possible to derive how airport choice of passengers, the competition between substitute airports and the decisions made by the supply-side of the market (e.g. airports and airlines) have evolved in the period before, during and after the tax. The goal of KiM with this part of the research is to accurately quantify the visible effects of the tax.

The second part of the research is aimed at understanding which mechanisms have contributed to the formation of the observed data and behaviours. A strong belief exists that the taxation and the media attention that surrounded the implementation has increased the awareness by Dutch travellers of other foreign airports. This might have resulted in structural changes in the market. However, it is impossible to measure ex-post how this awareness has evolved over time and moreover, to identify which other unmeasured factors have played a role.

2.2. Research Objectives

The objective of this research is to gain deeper insight in the factors and mechanisms that contributed to the airport choice of air travellers before, during and after the ticket tax. The final aim is to develop effective policy options that can be used in order to influence passenger choice. It is of special interest to analyse the effects of bounded rationality (incomplete information, habitual behaviour) and actor interaction since these are only sparsely covered in existing literature on airport choice (see for example Basar & Bhat (2004); Chorus & Dellaert (2009); Hansen (1995)).
The insights that result from the analysis should complement the explanatory value of the collected data and of existing airport demand models. This can be achieved by acquiring a deeper theoretical understanding of consumer behaviour, that is not only focused on full rationality, but also incorporates insights from psychology and multi-disciplinary fields such as behavioural economics. The knowledge should lead to the identification of a number of factors and mechanisms that could be used by either governmental (public) or corporate (private) entities to effectively influence passenger choice.

2.3. Scope of the Research

The scope can be subdivided into four separate parts based on fields of research. Human behaviour and choice modelling will form the theoretical backbone of the research. Once it is known which basic elements are relevant in human decision-making the airport characteristics that contribute are analysed. There is extensive (statistical) research on airport choice that can provide an initial list of common factors of airport attractiveness. When airport attractiveness/quality is defined, airlines strategy is analysed to determine which tactics are used in order to improve attractiveness or to be more precise, increase their market shares and revenues. Finally all aspects are integrated into a set of conceptual models and a simulation model that can be used to explore the dynamics of the system and test sensitivities. In Illustration 2.1 the interrelations between the scope components are graphically represented.

- Human behaviour
  - Literature study to find out how a choice is made (including decision rules, [perceived] utility, cognitive biases, etc)
  - Literature study on modelling paradigms in order to find a way how to incorporate the human behaviour into models
- Airport Attractiveness
  - Literature study to find choice factors that play a role in airport selection
- Supply-Side Strategy
  - Literature study on airline behaviour
  - Empirical analysis of airline strategies (causal relations perceived by organisations, interviews)
- Modelling
  - Develop conceptual models to illustrate mechanisms
  - Usable simulation model (including Verification & Validation)
  - Sensitivity analysis
  - Experimentation (developing policies and test these in the model)

Airport strategy will not be part of this modelling study. It was found that most decisions taken by airports have effect only on the long term. The tax has only been implemented for a year which would be too short for most strategic decisions made by airports. For example it is decided not to include terminal or runway expansion. For simulations that run over a longer period of time these mechanisms should be investigated, and the effect on the model behaviour should be analysed.
2.4 Research Questions

The research will consist of three steps. In the first step a methodology is selected that is used to model how passengers decide about which airport to depart from. In the second step literature on consumer choice and more specific mechanisms and factors play a role in airport choice is studied. In the third step of the research the possibilities to influence the consumer choice will be explored.

Each step in the research has its own central research question. The research questions have been numbered for easy reference later in the thesis.

The central question for the first step is:

(1) Which methodology is most suitable for modelling consumer behaviour and airport competition?

To answer the question the following descriptive sub questions should be answered first:

(1.1) Which are the requirements for the modelling methods?

(1.2) What are the characteristics of other methods that have been used in the past to investigate consumer behaviour and airport competition and can these methods be used in this research?

The central question for the second step of the research is:

(2) Which mechanisms influenced the redistribution of air travel demand as a result of the Dutch "ticket tax", in The Netherlands, Belgium and Germany and how can this redistribution be explained over time?

The question can be decomposed into several sub questions:

(2.1) Which information is required to make a decision and how is this information obtained?

(2.2) What are the objective and subjective attributes that determine airport attractiveness?
• (2.3) How does airline strategy influence consumer choice?
• (2.4) What are the mechanisms that influence the choice of airport by air travellers?

The central question for the third step of the research is:

• (3) Which are the factors and mechanisms that can be used by the Dutch government to effectively influence airport choice of Dutch air travellers?

The question is decomposed into:

• (3.1) Are there any structural effects of the tax that can be identified?
• (3.2) To which of the factors the system is most sensitive?
• (3.3) What are the possible side-effects of intervention in the system?
Chapter 3.

Choice of Methodology

This chapter is dedicated to the selection of the right "tool" for the . It starts with a description of the requirements of the methodology in Section 3.1. In Section 3.2 the most widely applied methodologies are described. In Section 3.3 an introduction on the characteristics and application of system dynamics is given.

3.1. Methodological requirements

Answering research question 2 and 3 from the previous chapter requires the combination of a large number of factors and mechanisms and an assessment of their contribution in the observed behaviour. The amount of complexity that a human being can deal with cognitively is however limited. modelling is used in this research as a tool to reduce the complexity of the real-world environment into a more easily and comprehensible environment in which experiments can be conducted. The elements that make up the modelled environment have been chosen explicitly by the modeller based on literature, empirical findings and intuition. Hence it should be noted that every model is an abstraction of reality and can therefore only attempt to explain a certain part of the observed behaviour.

The modelling method must meet a number of requirements in order to be useful for answering the research questions. First, in order to be able to relate the output of the model to time, a methodology should be selected that allows for time dependency (temporal). Second, because we are interested in the interaction between airlines and consumers and vice-versa (feedback), the model should be dynamic. Third, the focus of the research is on how the system works. The method should therefore be structure oriented ("white box") and not output oriented. This aspect is also desired when policy measures need to be developed and tested because it simplifies the identification of leverage points. Fourth, the model should facilitate the specification of soft variables since bounded rationality is assumed to play a role in all decision-making processes and is of specific interest in this research.

Besides the direct requirements that can be derived from the research questions there are other constraints that limit the number of applicable methods. Data availability is one of these constraints. The data that is available for this research is limited due to the high costs associated with the collection and due to sensitivity of certain data to competition. The second major constraint is the amount and the level of detail of accessible knowledge of the system. The fewer data and the less knowledge about the system, the more aggregate the resulting model will be.
3.2. Overview of common methods

3.2.1. Cross-sectional regression analysis

In cross-sectional regression analysis, a regression model is estimated based on observations at one specific point in time. Cross-sectional regression models are used in consumer behaviour/market analysis to estimate the relative importance consumers associate to the attributes of a choice alternative. These weights can then be used to determine elasticities. A large field of research exists in which regression models are estimated to define which attributes of an airport are most significant for consumer choice. The general type of regression model that is used is the logit model (McFadden, 1986). Logit models exist in different forms ranging from binary forms in which just two alternatives are considered, to complex nested logit models in which several choices (e.g. access mode and airport) are modelled subsequently.

The advantage of a cross-sectional regression analysis is that models can easily be validated based on observed data. The downside however is that sufficiently detailed data should be available in an amount that can produce statistically significant results. These data have to be collected through passenger surveys that are costly to undertake and of which the results are highly sensitive to competition. Another means of obtaining the data is trough stated preference research. This research is conducted by asking participants to make hypothetical decisions about travel options (see for example Hess et al. (2007) for a brief discussion about stated preference research or Hess (2005) for a more elaborate description).

Another disadvantage of logit models is that they assume that attributes are valued equally by each member of the population and that the values are perceived identically (Alamdari & Black, 1992). Furthermore, it is assumed that all individuals in the model are perfectly aware of the different alternatives that are offered. To conclude, the models assume full rationality while it is widely recognised that humans are sometimes not capable of behaving rationally, according to its pure definition (Kahneman, 2003; Tiemeijer et al., 2009, pp. 41-42).

3.2.2. Trend projection

Trend projection is used to create short term forecasts. The method implies the use of historical data in order to derive a trend. To make predictions about the future, the trend is then continued with the assumption that all the factors that drive the trend remain constant. Trend projection is a simple way to obtain forecasts however, it does not take into account which factors and how these factors drive the trend (Profillidis, 2000).

3.2.3. Econometric simulations

Econometric simulations are an expansion of the cross-sectional regression models. Besides collecting data on the attribute values, econometric models assume a relationship between the size of the market and socio-demographic and financial data. Econometric models can range from aggregate to disaggregate models that have a spatial component. A logit model is used at the core to determine market shares. The econometric simulations are aimed at providing medium to long term forecasts. The advantage of using an econometric models is that they are widely accepted and supported. However, these models are also assuming full rationality and thus perfect information.
The econometric models do not incorporate the way information about alternatives is acquired and perceived by a traveller. Consider a traveller deciding which airport to depart from. After recognising the decision problem, she or he will actively or passively acquire information from a diverse set of sources. Sources that allow for passive acquisition are for example marketing, comments from friends and relatives about their experience. Sources for active acquisition can be websites, travel agencies or other experienced users. The information acquisition process results in a set of airports that are known to the traveller (awareness set (Shocker et al., 1991; McFadden, 1986)) and feasible as a departure point. Furthermore the traveller will have a perception of the quality of each airport. While using the airport, a traveller also learns about the true quality and might adjust his perceptions. Information acquisition and learning (also described in Hutchinson & Meyer (1994)) bring dynamics into the decision-making process that can result in asymmetric or delayed responses to attribute changes.

3.2.4. Overview

In the previous section a number of methods that are frequently used are described. Table 3.1 summarises the descriptions of these methods and states the general purpose of each method. In the third column of the table each method is described by stating the most important characteristics.

It can be concluded that two of the three previously mentioned methods are static models, which means that the output they produce relates to a single point in time. Because the output is directly related to the input, none of the methods can be used to reveal the underlying systemic factors and mechanisms that produce the output. Put in other words, the focus is on output and accuracy of the output. The econometric simulations assume full rationality, e.g. it is assumed that travellers are aware of all airports within their reach and have perfect knowledge about the attributes of these airports. Finally, none of the methods is used to model dynamic interactions between the actors and state variables in the system.

<table>
<thead>
<tr>
<th>Method</th>
<th>Purpose</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Cross-sectional) regression analysis</td>
<td>Find significant airport choice determinants</td>
<td>Static, estimate of consumer preferences at a single point in time.</td>
</tr>
<tr>
<td>Hess et al. 2007; Pels et al. 2001</td>
<td>Filtering of data, short term demand forecasting</td>
<td>Extrapolation of data, no systemic explanation of unique events</td>
</tr>
<tr>
<td>Time series analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Econometric simulations</td>
<td>Estimate market share of an airport based on current or future utility</td>
<td>Static equilibrium models, full rationality, black box, no dynamics</td>
</tr>
<tr>
<td>(Ashley et al., 1995)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

From the analysis it is derived that none of the currently applied methods is fully capable of generating the desired insight in the mechanisms of the system. A range of other models from qualitative to quantitative exist to model the different concepts mentioned in the previous paragraphs and the desired concepts of bounded rationality and actor interaction. Choice set generation is often modelled with the use of a logit function as well, attaching a probability to the occurrence of an alternative in the choice set (Basar & Bhat 2004). Information
acquisition is modelled in different ways using for example optimisation to determine optimal information search (Nelson, 1970; Meyer, 1982) or dynamic diffusion models such as the Bass model which incorporates word-of-mouth and marketing mechanisms to model the influence of social exposure to new innovations on the diffusion process (Bass, 1969). Learning can be modelled, among others, mathematically using the principles of Bayesian learning (Chorus & Dellaert, 2009) or by applying concepts from behavioural economics (Hopkins, 2007).

The present study requires a combination of the capabilities of all methods described above. The level of detail should however be limited in order to prevent the model from becoming overly complex. System dynamics is found to be a good match given the methodological requirements and the purpose of the research. In Table 3.2 the requirements imposed by the research issue and purpose are contrasted with the 'summarised' characteristics of the current research methods and with the characteristics of system dynamics.

<table>
<thead>
<tr>
<th>Required</th>
<th>Current methods</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>System output over time</td>
<td>temporal, cross-sectional</td>
<td>temporal</td>
</tr>
<tr>
<td>Understanding of system</td>
<td>‘black box’/output oriented</td>
<td>‘white box’/system oriented</td>
</tr>
<tr>
<td>Dynamic interaction</td>
<td>static (no feedback)</td>
<td>dynamic (feedback)</td>
</tr>
<tr>
<td>‘soft’ factors</td>
<td>numerical accuracy</td>
<td>general tendency</td>
</tr>
</tbody>
</table>

### 3.3. System Dynamics

System dynamics is a modelling methodology that is intended to model complex systems at an aggregate/systems level. The methodology was developed around the philosophy that the behaviour of a system over time is driven by its structure (Meadows & Robinson, 1985). The system comprises of a collection of elements that continuously interact over time. The structure of the system is defined as the underlying relationships and connections between the elements within the system. The behaviour of a system is determined by the way the elements of the system vary over time (Martin, 1997). System dynamics is widely used to model complex (social, socio-economic and physical) systems over time (Sterman, 2000).

System dynamics is a so-called "white box" modelling method. This means that the elements connecting the input and output variables and form the structure of the system are explicitly modelled. The focus of the model is therefore diverted from the inputs and outputs to the system itself. Elements in the system can be dependent on their own past value. In this case the system is called dynamic and contains feedback loops. The Deming cycle is probably the most well know example of a feedback loop in management science. After the plan is executed, its effects are monitored. If these effects differ from the desired effects, action is take to correct. The loop continuously adjusts the actions based on the desired outcome.

The modelling of the elements and structure of the system is done visually by means of two types of diagrams:

1. Causal loop diagram
2. Stock-flow diagram

The first and most basic diagram is the so-called causal loop diagram. This diagram is used to describe perceived causal relations and is often applied in the conceptualisation stage of
model development. Since the creation of the diagram does not require any parameters to be specified, the diagram can only be used for qualitative analysis of the system and as a blueprint for simulation models. In Figure 3.1 an example of a causal diagram is depicted. The figure shows the two types of the core structural element of all system dynamics models namely feedback loops. The arrows indicate perceived causal relations between factors, that can be positive (+) or negative (-). A relation is called positive when an increase in the first factor causes an change of the other factor in the same direction. A relation is called negative when a change in the first factor causes an opposite change in the second factor. An example of a positive relation is between population and births. The arrow is read as, the larger the population, all other things being equal, the larger the number of births. An example of a negative relation is between deaths and population. The larger the number of deaths, all other things equal, the smaller the population.

If the arrows departing from a factor connect back to that same factor through one or more other factors a feedback loop is created. When all the perceived relations in such a feedback loop are positive or when there is an even number of negative relations, the loop is called a reinforcing or positive feedback loop and is indicated with a $\bigodot$ with a + inside. If there is an uneven number of negative relations, the loop is called a balancing or negative feedback loop and is indicated with a $\bigodot$ symbol with a - inside. The birth loop in Figure 3.1 is an example of a positive feedback loop. On its own the loop causes exponential growth of the population. The mortality loop has a negative effect on the population and therefore counteracts the exponential growth.

![Causal Diagram](image)

The second type of diagram used in system dynamics is the stock-flow diagram. This diagram is the basis for simulation models and has four basic elements. Figure 3.2 shows an example of a stock-flow diagram inspired by the causal diagram in Figure 3.1. The factor enclosed in the box is represents a level of stock variable. A stock is one of the four elements and can be seen as an accumulation or memory of, in this case, the population. The level is increased by an inflow, which is indicated with the valve symbol and an ingoing arrow. The inflow in the example is indicated with the name "Births" and has the units of the level divided by the unit of time. If the population has units [people] and the time unit in the model is [month] than the inflow has units [people/month]. The inflow represents the number of people per month that is added to the population. The valve symbol indicated with "Deaths" is the outflow of the level. It has the same units as the inflow and represents the number of people that are subtracted from the population per month. The third element that is represented in the example are the constants "Birth rate" and "Average lifetime". A fourth element is not shown in the example are the auxiliaries which are variables that do not directly influence levels.
In order to be able to run the model, all factors must be specified. The level “Population” in this case needs to have an initial value. The ”Birth rate” and ”Average lifetime” have to be determined preferably empirically. The formulation of the flows is then evident. The inflow will be specified as Population * Birth rate. The outflow is specified as Population / Average lifetime. If these two flows are combined, the change of the population becomes:

\[
\frac{d\text{Population}}{dt} = \text{Population} \times \text{Birth rate} - \frac{\text{Population}}{\text{Average lifetime}}
\] (3.1)

For the interested reader a more elaborate description of system dynamics and its use can be found in Forrester (1993) and for a complete overview of the methodology please refer to Sterman (2000).

In the next part of this thesis, the fundamental mechanisms that form the basis of the system dynamics model to be developed will be derived from the literature. A set of causal loop diagrams that can be used as a basis for the specification of the model will be the end result.
Part II.

Conceptualisation
Chapter 4.

Consumer behaviour

Research on consumer behaviour is concerned with the study of, among others, decision processes that precede and follow the action of purchase a product or service (Blackwell et al., 2005). These decision processes can be viewed from the perspective of a single individual or more generally for a group of individuals (e.g. the group of leisure airport users) or a society as a whole. The concepts of consumer behaviour are used to describe the process of decision-making for the selection of a departure airport and synthesise these concepts into a series of conceptual models that capture the mechanisms of learning, information acquisition, repeated use and habitual behaviour. The structure of this chapter is based on the cognitive decision sequence, a widely accepted framework in the field of consumer sciences (Erasmus et al., 2001), as it provides a framework to allocate and support the different theoretical concepts that are explored.

In this chapter the focus will first be on the cognitive decision sequence (Section 4.1). In the subsequent sections the steps of information acquisition (Section 4.2), evaluation of alternatives (Section 4.3) and outcome evaluation (Section 4.4) will be described. The focus is on decision sequence of an individual decision-maker. The reason for this is that individual decision making must be understood in order to be able to deduce the more aggregate and abstract decision making processes at a society level.

4.1. The Cognitive Decision Sequence

The cognitive decision sequence (Figure 4.1) is the traditional five step approach to capture the steps of consumer decision-making (Erasmus et al., 2001). The process consists of five distinct steps, starting with problem recognition. For example, it must be clear that a problem exists that requires a decision to be taken. In the second step information is acquired about the alternatives, there must be more than one option otherwise there is no need to choose. This information is then used in the third step to compare the alternatives with each other or with a reference value. In the fourth step the alternative that is considered most appropriate at that specific moment is chosen. In the last step the newly acquired knowledge that is obtained by using the alternative (experience) is evaluated and compared with the prior expectations. Based on the outcome of this step, a choice can be regretted or perceived as successful. Both will adjust the process of decision-making for the next decision to be taken.

1These more abstract processes are described and depicted in synthesis (Chapter 6)
4.2. Information Search

4.2.1. Need for information in decision process

According to rational choice theory, described by Simon (1955), we need at least three types of information to be able to make a decision. The first type of information is related to the existence of brands, products and services. In this sense the information creates awareness and contributes to the construction of the evoked set, which comprises the set of alternatives that are known and available to the consumer (Shocker et al., 1991). The second type of information is about the specific attributes of the alternatives in the evoked set. This information allows us to compare the different alternatives in the set. Finally the third type of information is about our own preferences. Based on these preferences the consumer decides whether she or he will consider an alternative. An alternative is considered if one or more, or all attribute values are above a consumer specific threshold level, depending on the assumption of choice heuristic (see section 4.3.2). As opposed to the theory of full rationality and the existence of an "economic man", not all these types of information are consistently available to the individual in a decision-making process.
4.2 Information Search

The need for information can be easily explained with a simple example. Consider the process of buying a car. After recognising that the current car is ready to be replaced (step 1 of the cognitive decision sequence) an information search starts to gather information about the alternatives. Not all alternatives will be available due to budget constraints, unawareness, availability on the market, etc. Now assume that after the "extensive" information search, two cars (alternatives) are in your evoked set. Both cars are identical in all attributes, except for the size of the baggage compartment. Because you go on regular camping trips, you prefer to have a big car that can fit all the camping equipment. When matching the personal preferences with the attributes of the car, it becomes clear that the larger car will be more useful, it can fit all the baggage you need for camping so there is no need for other measures to guarantee a successful trip. Without either personal preferences or information about the attributes of an alternative, a decision cannot be made (see also Figure 4.2 for a graphical representation of the interrelationships).

4.2.2. Information acquisition

There are three main ways of obtaining information about the alternatives. The first way is through direct experience with the alternative, for example by using an airport you learn about the comfort, service, waiting times and walking distances, etc (Ackerberg, 2003; Hopkins, 2007). Due to the existence of personal preferences and expectations, an experience that one considers very pleasant and positive might be considered as negative by another.

The second way to obtain information about an alternative is through social interaction. The most well known mechanism of social information diffusion is the process of word-of-mouth in which information is communicated from person to person while the receiver of the information perceives the sender as non-commercial (Arndt, 1967). With the increasing application of the Internet to share consumer experiences, word-of-mouth also has a virtual component as long as the provider of the information does not have a commercial motive. An example of a platform of virtual word-of-mouth is the website "airlinequality.com" which claims to provide the world’s largest selection of independent airline and airport reviews.

The third possibility to gather information is through efforts of marketers (Ackerberg, 2003). According to Ackerberg (2003) advertising can have two effects. The first is related to the prestige and the image of the product or service, and directly influences the amount of usefulness of the product or service to the consumer. The second effect of advertising is that it creates awareness and updates the consumers knowledge about the attributes of a product or service. Ackerberg further assumes that the more experienced the consumer is with a specific product or service, the lower the impact of advertising.

4.2.3. Human nature and the quality of information

In models of decision-making an important distinction is made between external information (stimulus-based) search and internal information (memory-based) search (see for example Bettman (1979) and Blackwell et al. (2005)). The former refers to information that is acquired by exposure to advertisements or by social interaction. The latter refers to the use of information that is stored in memory (Figure 4.3). Since the process of external information acquisition is costly (Nelson, 1970), it is assumed in this study that the memory will be used as a primary source of information. In the case that this information is not sufficient, external sources will be used. Besides being less costly, the use of information directly from the

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source: www.airlinequality.com; accessed 2nd April 2010
memory can result in having incomplete information. In this case, people tend to make inferences about the missing information that are erroneous and can lead to different decisions (Bettman et al. 1991).

The transfer of information from external sources to the mind is not free from biases. Several cognitive mechanisms can alter the scope and quality of information obtained from external sources. Based on (Howard & Sheth 1969) two mechanisms are described that influence the amount and quality of information that we store in our memory. The first mechanism is related to sensitivity to information and determines the level of attention a receiver pays to information received from a sender. By this mechanism the receiver controls the quantity and scope of information that enters her or his mind. It is argued that complex or ambiguous information is less likely to grab the attention of a receiver than information that is better formulated to match the specifics of the receiver. Furthermore too simple information may reduce attention and thus sensitivity as well (Erasmus et al. 2001).

The second mechanism is called the perceptual bias, and directly alters the quality of information. Information can be more or less distorted for several reasons. The type of information search, i.e. information obtained from an active search is less likely to be distorted than information obtained passively. The difference between the cognitive elements stored in the information and the own frame of reference of the receiver, i.e. the more different the information compared to what the receiver already knows, the more the receiver will try to match it with his own reference values. This also implies that the more the receiver knows about the subject of the information, the lower the impact of new information (diminishing sensitivity of new information to perceived knowledge). Finally information that is obtained from trustworthy or social sources is less likely to be distorted than information from commercial sources (Howard & Sheth 1969).

External sources of information can be divided into marketing and non-marketing (Middleton et al. 2009, pp. 79-86) or as Howard & Sheth (1969) put forward, in social and commercial stimuli. As we saw before, the word-of-mouth mechanism is a source of social stimuli whereas marketing is the most obvious form of commercial stimuli. Another factor influencing the sensitivity to information is the predisposition one has towards the source of information or the subject of the information. Non-marketing or social sources are less likely to induce resistance for two reasons. The first reason is that social sources are most likely people from your surrounding that you have a certain degree of confidence with (Tiemeier et al. 2009).
Therefore it is more likely that you trust the information that they present to you which positively influences the willingness to accept that information. The second reason is that information from society has already passed through personal biases that have shaped the information in such a way that it has become more easily acceptable. In other words, the information is shaped by the social environment it lives in (Bettman et al., 1991 and Howard & Sheth, 1969).

4.3. Evaluation of alternatives

4.3.1. Preferences and utility

In rational choice theory, preferences are assumed to be stable and consistent. There are several assumptions that are made about the consistency of preferences, but in this study the assumption that is most discussed namely that of transitivity (Hansson & Grüne-Yanoff, 2009) is used. Transitivity implies that when alternative A is preferred to alternative B, and B is preferred to C, A must be preferred to C as well. A preference can either be weak (\(A \geq B\)) or strong (\(A > B\)).

The notion of utility is often used in economics and game theory to organise the information about peoples preferences (Straffin, 1996). Utility can best be described as a container concept that expresses (in a single numerical value) the usefulness of an alternative to a specific entity (can be either an individual consumer or an organisation). Hence, utility is a combination of both attribute values and weights derived from preferences. Utility can be defined both on an ordinal scale (ordinal utility), the most preferred alternative receives the highest value, or on an interval scale in which the ratio’s between the values is also taken into account (cardinal utility). Comparisons of utility between individuals is not possible on either a ordinal or cardinal scale since the values are based on personal preferences that are highly subjective. Rational choice theory furthermore assumes that people maximise their utility, or in other words, they optimise a mathematical function (utility function) (Lovett, 2006).

The strict assumptions of consistent preferences and utility maximising are somewhat relaxed in the field of behavioural economics. Bettman et al. (1998) argue that preferences are usually constructed at the moment a decision has to be taken. The basis on which they are constructed might however be already in the memory in the form of criteria that are used for other type of decisions or partially constructed preferences. The actual choice that people make does not only depend on their preference at the moment of the decision, research has also indicated that the way in which the question is formulated highly influences the decision (Kahneman, 2003). Furthermore people have a tendency to choose for the alternative that can most easily be justified to others or the self (reference). Due to the limited information processing capabilities of people, optimising utility is nearly impossible and most certainly practically unfeasible. Therefore people satisfice, they stop evaluating alternatives once they have found an alternative that is good enough (Simon, 1955).

4.3.2. Cognitive architecture and heuristics

There are several ways to rank alternatives, given the preferences and attribute values. The alternative alternative that scores highest on one specific attribute, or the alternative that scores best overall can be selected for example. The basis on which we evaluate and rank
alternatives depends on the type and character of decision that has to be made (e.g. many attributes, high gains/losses) \cite{Bettman1991}, the experience that the decision-maker has with making the same or similar decisions, and the accessibility of the attributes that we are evaluating \cite{Kahneman2003}.

In a major synthesis article, \cite{Kahneman2003} distinguishes between two cognitive systems, intuition and reasoning, that are used, among other tasks, for taking decisions. The former system is characterised by fast, effortless and emotional decisions, while the latter is characterised by slow, effortful and neutral decisions. In general the higher the potential losses as a consequence of making a decision, the more the system of reasoning will be applied and consequentially the more effort it requires to take a decision. The more the decision process is standardised and simplified, for example because of experience, the more the use of intuition and the less effort is required. Decisions are not made using either the reasoning or the intuition, rather a continuum exists between reasoning and intuition and hence the speed, effort and level of emotional involvement vary on a continuous scale between the two extremes.

In both cognitive systems heuristics, or rules of thumb, can be used to simplify the evaluation process and to cope with missing or incomplete information. The big advantage of using (simple) heuristics is that it reduces the amount of effort required to make a (complex) decision. The downside however is that they can lead to systematic errors \cite{Kahneman2003} in the decision process. Table 4.1, adapted from \cite{Ben-Akiva1985} shows four categories of heuristics that can be used to rank alternatives or to select the most favourable ones. All four heuristics require careful evaluation of the alternatives and/or their attributes and require a variable but substantial amount of effort of the decision-maker.

To illustrate the use of heuristics let’s consider which one of the heuristics you would use when selecting between two brands of similar products, for example a shampoo, in a supermarket. The dominance or satisfaction heuristic could be applied if the product is totally unfamiliar. If you assume however that you are very familiar with the product, probably you will just rely on your experience and select the one that you have good experiences with. In other words you reduce the amount of reasoning and increase the amount of intuition.

\cite{Kahneman2003} and in his research history with Tversky pointed out that people tend to compare attributes on a relative scale rather than to look at the absolute values. Hence a comparison can either be based on relative attractiveness of similar products or on a reference value stored in memory that is obtained from previous experiences. The latter would be more prone to cognitive biases. The satisficing heuristic, based on Simon’s theory of bounded rationality \cite{Simon1955}, uses a predetermined cut-off value for each attribute. Whenever the value of an attribute is below the cut-off level, the alternative will not be considered. All alternatives that pass are in principle good enough.

In case of intuitive behaviour, other heuristics are more likely to be applied. The simplest and most intuitive one is maybe the selection of the alternative that was selected the previous time (habitual behaviour). This heuristic does not require any new information or evaluation of products. The downside however is that in a changing range of alternatives, you might have not selected the one that was the most attractive at the moment of the decision. Empirical research shows that the more frequently a decision is made that is similar to previous decisions (routine) the stronger the habit \cite{Tiemeier2009}. 
4.4 Outcome evaluation

Table 4.1: Types of heuristics, adopted from Ben-Akiva & Lerman (1985)

<table>
<thead>
<tr>
<th>Category</th>
<th>Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominance</td>
<td>The alternative that is at least better for one attribute and equal for</td>
</tr>
<tr>
<td></td>
<td>the other attributes is selected</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>The alternative is selected of which the attributes score above a</td>
</tr>
<tr>
<td></td>
<td>threshold level</td>
</tr>
<tr>
<td>Lexicographic</td>
<td>The attributes are ranked by their importance to the decision-maker,</td>
</tr>
<tr>
<td>rules</td>
<td>the most attractive alternative on the most important attribute is selected</td>
</tr>
<tr>
<td>Utility</td>
<td>The attractiveness of alternative is expressed in a single value based on</td>
</tr>
<tr>
<td></td>
<td>the vector of attribute values</td>
</tr>
</tbody>
</table>

4.4. Outcome evaluation

The final step in the cognitive decision sequence is the evaluation of the outcome. We have already seen in Section 4.2 that the perception people have of an alternative is adjusted once the alternative is selected and used/experienced. Howard & Sheth (1969) define a number of hypothetical learning constructs which includes the construct of satisfaction. They argue that if the actual consequences of a decision are better than the expected consequence, a consumer is satisfied and will increase the alternative’s attractiveness and hence the ranking in the evoked set. If the actual consequences are worse than expected the attractiveness decreases and in the most extreme cases the alternative might be removed from the evoked set completely (i.e. the consumer will not longer consider it in a next decision). From this hypothetical learning construct we can conclude that it is important to manage the expectations consumers have of an alternative since the consequences of extremely high expectations might render the alternative useless in the long run.
Chapter 5.

Supply-side Description

This chapter will provide an answer to the research questions (2.2), "What are the objective and subjective attributes that determine airport attractiveness?" and (2.3), "How does airline strategy influence consumer choice?" To answer the first question a literature study and interviews with the Dutch airline KLM, the airport Schiphol, and with Airport Coordination Netherlands have been conducted. This chapter is divided into two sections. In Section 5.1 the choice factors that determine airport and airline utility are described. In Section 5.2 the airline strategy is described.

5.1. Airport and Airline Utility

As described in the previous chapter, prior to taking a decision about the airport to depart from, a passenger acquires information about the options (possible airports) either by internal (memory) or external (environment) information search. Combined with the specific preferences of the passenger, a perception of the utility of each of the airports is formed. The information that has been acquired contains, among other things, characteristics of the airport that the passenger considers important in her or his decision process.

To find out what characteristics of an airport are considered important, literature on airport choice has been reviewed. Two main methodologies are applied in order to construct the utility function for air transport passengers. The first method is that of revealed preferences, in which the actual choice of a passenger is recorded, together with the attributes (characteristics) of an airport. The attribute values are obtained directly from the decision-maker or from exogenous data and represent perceived values rather than actual values (Hensher & Bradley, 1993). The method of stated preferences on the contrary employs experiments in which a group of people is asked to make choices between hypothetical alternatives. In this case the attribute values as well as the attributes themselves are chosen by the researchers and hence represent actual values (Hensher & Bradley, 1993).

In the literature two types of attributes are distinguished namely attributes that are related to characteristics of the airlines operating at the airport, and attributes that are related to the characteristics of the airports themselves (Pels et al., 2000). In various studies on both airport and airline choice (see for example Veldhuis et al. (1999); Ashley et al. (1995); Harvey (1987); Pels et al. (2001); Hess et al. (2007)), the significance of various attributes and the relative weights given implicitly to them by passengers have been investigated. Most of these studies find airfare, access time (to the airport) and frequency of service as most significant determinants of airport market share (Pels et al., 2000).

Harvey (1987) indicates that access time and frequency of direct air services explain the largest part of the variation. He also indicates that these factors have non-linear effects on
airport utility. In his study, Harvey analyses data about choice behaviour of resident-business and resident-non-business travellers in the San Francisco bay area. Harvey also describes the diminishing marginal benefits of increased frequency until at a certain point the benefits even become negative as a result of unobserved terminal congestion he argues. In a study by Ashley et al. (1995) that was at the basis of the Dutch built Airport Catchment Competition Model (ACCM) later Aeolus, the limited capacity at Schiphol airport as a result of governmental restrictions was taken into account.

de Neufville (1995) approaches airport quality from a more qualitative perspective and states that the airport should provide convenient access to desired air services (accessibility of airport and frequency of departures). Furthermore, the time between land-side arrival at the airport and the departure time plays a role (related to check-in capacity, walking distances, customs capacity, etc). He points out that the attractiveness of an airport is always defined in comparison with its competition. The competitors of an airport are located within the multi-airport system, which includes all the airports that serve a specific region.

Another aspect that is likely to have an effect on the perceived utility of an airport is the quality of service of the airlines that operate from the airport. Specifically substitution between inexpensive and very basic flight services of Ryanair and mixed carriers such as Transavia.com or EasyJet which provides a less basic service, intuitively plays a role in the passengers choice of airport. Mason (2000) found that the in-flight service provided to business passengers on short-haul flights in Europe played a significant role in selecting low-fare airlines. The study also showed that business men for smaller size companies are less willing to pay for the extra comfort than business men working in large companies. This is explained by the fact that smaller companies have tighter budgets for travelling and costs are more directly related to the individuals. In general it is not likely that the quality of service plays a significant role in the airport choice of the most price sensitive groups of travellers (own experience).

Because the perceived utility is related to both the attributes of an alternative and the preferences of the passenger, in principle the perceived utility differs for each individual. The most widely used distinction in literature is that between business and leisure passengers (Ashley et al., 1995; Veldhuis et al., 2005; Pels et al., 2001), where sometime leisure is further disaggregated into holiday and visiting friends or relatives (VFR) (For example Hess et al., 2007). Variations between leisure travellers are however considered small enough to group them.

In Table 5.1 the attributes and their relative importance are given. The relative importance is based on results from the studies discussed before and the author’s interpretation and experience. For each of the attributes the character of the relation to utility and the symbol is stated based on what is found in literature. For the relations where diminishing marginal attractiveness with increasing values is expected, a logarithmic relation is assumed. The logarithmic formulation of the frequency is among others used in Hansen (1990) and Pels et al. (2001) in order to capture the non-linear relation between market share and frequency share. The negative symbol illustrates that the higher the value of the attribute, the lower the utility and vice-versa. The last column of the table indicates if experience is required in order to obtain information about the attribute values. The rule here is that whenever the value can be determined through media or word-of-mouth (such as a fare), no experience

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\(^1\)Empirical evidence shows that the relation between frequency share and market share is non-linear. Above a frequency share of 50% the obtained market share is higher than the frequency share. Below 50% the obtained market share is lower than the frequency share.
5.1 Airport and Airline Utility

is required. Whenever there are preferences involved that bias the perception of a value, direct experience will play an important role in the perception of an attribute. Access time is a factor that sits between an experience factor and a non-experience factor. People from the same region might for example discuss about the distance to an airport and therefore learn about it. People from different regions simply do not have the same actual access time and therefore they cannot inform people about their own access time. Access time is only communicated by word-of-mouth within a geographical region in which the individuals on average have to travel for the same amount of time to the airport. Access time to airports outside the region can only be known by direct experience or through contact with someone that directly experienced it that lives in the same region.

Table 5.1.: Attributes determining airport utility

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Relative importance</th>
<th>Relation</th>
<th>Symbol</th>
<th>Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average fare at airport</td>
<td>1</td>
<td>Linear</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>Frequency of service</td>
<td>2</td>
<td>Log</td>
<td>+</td>
<td>No</td>
</tr>
<tr>
<td>Access time</td>
<td>3</td>
<td>Linear</td>
<td>-</td>
<td>Partially</td>
</tr>
</tbody>
</table>

Given these attributes and their assumed relationship with the attractiveness or utility of an airport, a utility function can be formulated for each airport \( d \) in the set of airports \( D \). Because we do not consider all existing airports and because a consumer might not be aware of an airport that technically lies within her or his reach, \( D \subseteq A \) in which \( A \) is the total set of all existing airports. The attributes described in Table 5.1 are an element of the total set of attributes for all alternatives such that \( s \in S \), in which each element depends on the specific alternative and the individual, or aggregated group. The utility function for an individual or aggregate group, adopted from McFadden (1986), is given by:

\[
U = V(s, i) + \varepsilon(s, i)
\]  

(5.1)

In which \( V(s, i) \) is the deterministic part of utility of alternative \( i \) for attributes \( s \) and \( \varepsilon(s, i) \) is the stochastic part of utility from unobserved preference variations etc. (McFadden 1986). The deterministic part of utility depends on the attributes of the alternative and is defined as:

\[
V_i = \beta_p p_i + \beta_t t_i + \beta_f \ln(f_i)
\]  

(5.2)

The beta’s correspond to each attribute and represent the relative weight given to each attribute and the symbol.

\[
p_i = \text{average fare at airport } i \quad (\text{€/ticket})
\]

\[
t_i = \text{average access time to airport } i \text{ from core of user location} \quad (\text{minutes})
\]

\[
f_i = \text{frequency of service at airport } i \quad (\text{flights/month})
\]
5.2. Airline strategy

5.2.1. Airline objectives

Airlines are the operators of aircraft with the objective to generate revenues by transporting freight, passengers or a combination of both. The number of destinations and the frequency of the flights depend on many factors among which size of the market, existing network and available aircraft fleet. In terms of ground based facilities, airlines require an airstrip of sufficient length in order to be able to get airborne and reach their destinations. Furthermore, passengers, freight, fuel and other supplies have to be able to enter the aircraft in the shortest possible time. Airlines therefore depend on airports for their daily operation.

The main objective of an airline is optimise the use of their assets (aircraft) in order to generate revenues. As a general rule it is said that aircraft only generate revenues when they are airborne. Although this is largely true, without being on the ground every once in a while, no airline would be able to generate profits. As a consequence, there should be an optimal balance between time spent on the ground (turn-around time) and time spend in the air (flight time). The turn-around time should be sufficient to transfer all the passengers, freight, fuel and other supplies. Any "unnecessary" delay decreases the maximum flight time and thus the maximum achievable revenues. For long distance flights the turn-around time is naturally a relatively small portion of the total time. In this case, reductions of the turn-around time have only minor effect on the revenues. For short-haul high frequency flights, where turn-around time is a significant share of the total time, time savings can have significant effects on revenues.

Minimising ground time is not the only prerequisite to maximise revenues. Without sufficient demand to fill the aircraft past the limit of economically viable operations an airline will still encounter losses. Airlines therefore continuously assess which routes generate sufficient demand to justify operations and if the current frequency of flights at one specific destination matches the demand. The objective here is twofold, first the loadfactor should be maximised, an aircraft flying full with paying passengers generates more than an aircraft flying half-empty. Second, by strategically adding new routes to an existing network, the value of the network can be significantly increased (network effects) and can generate additional traffic on existing routes.

Obviously there are many more aspects that play a role in the decision making of airlines. The purpose of this section however is not to provide a description of airline strategy at the detailed, daily base level. The primary reason for this is that this would be too time consuming in the context of this specific research. Furthermore, airlines are reluctant to propagate their specific strategies. The route structure offered by the airlines is assumed to be equal at all airports, and the only difference is in the number of flights per destination. In the next section the constraints which are faced by airlines in their day-to-day operations will be briefly discussed.

5.2.2. Airline constraints

Just like airports, airlines face constraints in their operations. We can distinguish three types of constraints. The first type of constraints are related to the acquisition of aircraft. Aircraft

\(^2\)Percentage of flight capacity per aircraft sold
are the main capital stock of an airline and are a basic necessity to generate revenues. Besides
the existence of financial constraints limiting the amount of aircraft that can be purchased,
delivery delays exist for the purchase of new aircraft. In other words, once an aircraft is
bought, it does not become available for operations the same day. The network planning
department of an airline has to take the availability of aircraft into account. On the other
hand, the acquisitions department has to take the demand forecasts into account.

The second type of constraint that airlines face is related to the limited capacity at some
airports. Mainly the big hub airports in Europe such as Amsterdam, London and Paris face
capacity shortages during peak-hours. The available capacity is divided into slots in order to
be able to allocate the scarce capacity among the airlines. Trading of slots between airlines
is not allowed and the basic principle of allocation is through so called grandfather rights.
This means that an airline that had a certain amount of slots in year one, will have the right
on the same amount of slots in year two. The condition however is that the airline has used
80% of the slots in its possession [Graham, 2008]. When capacity is insufficient at a specific
airport, airlines might decide to relocate part of their operations to another airport where
the capacity is sufficient. The tendency to relocate part of the operations depends on the
strength of the binding an airline has with the airport. Traditional "full-service" carriers that
are highly embedded in the airport, for example KLM at Schiphol, will not easily transfer
their operations to a different airport. Low-cost airlines on the other hand do not have such
strong relations with airports and thus are more mobile.

The third type of constraint is related to route development procedures. While the frequency
of a flight can quite easily be adjusted, adding a new route requires more effort and formalities.
First market research has to be conducted in order to develop a business plan for the new
route. Once the route proves to be economically viable on paper, a flight plan has to be
developed. The authorities of each of the countries below the flight route have to be requested
for permission to pass through their airspace. An aircraft has to become available either from
reducing the frequency on another route or by employing a newly purchased aircraft, inducing
additional delays. A rough estimate for the process of route development would lie around
two months in case the slots are available. If slots are not available the airline has to wait
until new slots are allocated at the starting of the season. Each April and each September
slots are allocated for the next winter and summer respectively.[3]

---

Chapter 6.

Synthesis

In this last conceptualisation chapter, the theory described in the previous chapters is distilled until a set of basic assumptions remain that together form the core of the dynamic behaviour of the model. In order to facilitate the specification of the model in a later stage, causal diagrams are developed based on the assumptions.

In Section 6.1 the information flows are described. Section 6.2 then briefly describes how decisions are modelled. In Section 6.3 the causal loop diagram for airline behaviour is developed.

6.1. Information flows

In this section a distinction is made between information acquisition and forgetting about alternatives.

6.1.1. Information acquisition

As described in Section 4.2.2 information is obtained in three ways. The first assumption is:

1. If people talk to other people they learn about the existence and the characteristics of an airport.

This implies that the information that the sender has is transferred during contact with the receiver. Furthermore, the probability to encounter a sender that has information from direct experience with the airport of interest determines how often information is transferred within a given time frame. Finally it is unlikely that all the information is transferred at once. There might be all sorts of barriers such as language that reduce the effectiveness of communication. The information that is transferred does not only contain the existence of an airport, but also the characteristics of the airport. This type of information transfer is often referred to as Word-of-Mouth (WoM) communication.

A concern rises here when transferring characteristics of an airport which is also described in Section 4.2.3. The information that the sender holds might not be the actual and objective information about an airport. Rather, the information is most likely biased. So instead of transferring the objective information, perceived information about the airport is transferred. The choice that the receiver finally will make is based on his own set of perceived information.

The second assumption in this section is:
2. If people choose and use an airport they learn about the characteristics of that airport.

While booking a flight on-line or at a travel agency information about the possible airports, available destinations and the average ticket price is quickly obtained. When driving to the airport, you experience how long it takes to arrive, how much congestion you have encountered on the way and the transportation costs. In case of direct personal experience, there is no party in the middle that could possibly bias the information you obtain. Learning therefore contributes to increasing the awareness of an airport and to adjusting the perceived information towards the actual information of an airport. The speed at which learning by experience occurs is determined by the number of flights a person makes per time unit. The more often someone flies, the quicker she or he will become acquainted with the actual characteristics of the airport.

The last source of information is marketing. It is assumed that:

3. If people receive information by marketing they learn about the airport and airport attributes.

Marketeers from both airlines and airports continuously try to create awareness and present their product as the best, most favourite and least expensive among all other products. In Section 4.2.3 it was described that information obtained through marketing is much harder to accepted that information obtained by direct experience or by word-of-mouth. The advantage of marketing is that is does not depend on a probability to encounter a sender with information about the airport like word-of-mouth, or on the number of trips one makes per year. Marketing is a method to spread new information in a society.

In Figure 6.1 the three information related mechanisms that are described so far are depicted. Based on the perceived information about an airport an air traveller determines how attractive she or he finds the airport. In a group of people the perceived attractiveness is the average of all individual perceived attractiveness. The more attractive the group finds the airport, the more people will start using the airport and hence the size of the group of airport users increases. When the individuals of the group of airport users comes into contact with other people that don’t use the airport, information is transferred and the perception of the group of non-users is updated. The larger the group of users in relation to the group of non-users, the higher the probability to encounter each other and the larger the total perception update. The perception update is limited by the difference between the perception of the sender and the perception of the receiver. This limitation is depicted by the negative feedback loop in the figure. The more attractive the group of non-users finds the airport, the more of them will choose it for their next trip. This cycle forms a positive feedback loop indicated by "Word-of-mouth" in the diagram.

On the right side of the diagram the loop for learning by experience is depicted. The basic concept behind the process is that the more people use an airport, the faster the perception of airport attractiveness reaches the actual airport attractiveness. Or when looking at the individual traveller, when the airport is used the perception (expectation) prior to using that alternative is updated towards the actual airport attractiveness (Shapiro, 1982). This time the update is limited by the difference between the perceived attractiveness and the actual attractiveness of the airport. The smaller the difference, the smaller the total update. This limitation is depicted by the negative feedback loop between perceived attractiveness and perception update due to experience.
The last negative feedback loop represents the information updating towards the actual airport attractiveness as a result of marketing. The amount of effort in terms of time and money a marketeer puts into a campaign influences the updating. The more effort is put, the larger will be the perception update. Again the update is limited by the difference between the actual attractiveness and the perceived attractiveness. The result is a diminishing effect of marketing with increased knowledge. The literature suggests that the greater the knowledge of the attributes of a product or service, the harder it is to acquire additional knowledge.

![Diagram of Information Acquisition](image)

Figure 6.1.: Information acquisition

### 6.1.2. Forgetting and habits

Besides information updates toward the actual attractiveness and to increase the awareness of an airport there are processes that cause that people forget about the existence of an airport. This forgetting could have two main causes. The first cause is based on the assumption that:

4. *If there is insufficient word-of-mouth and marketing, people forget about an airport.*

This is mainly true for airports that do not have a very large group of people that regularly use it. Once the updating by word-of-mouth and marketing drops, people slowly start forgetting about the airport and hence not longer consider it as an alternative. In case one would frequently encounter people that have experience with an airport, or receive advertisements, it will take much longer to forget about it.

Besides the forgetting that is related to word-of-mouth and marketing intensity, a part of forgetting will always occur once an airport is not used for a subsequent period of time. The assumption is that:

5. *If people don’t fly from an airport they tend to slowly ignore the existence of the airport.*

In Figure 6.2 the causal loop diagram of habit formation and forgetting of awareness is depicted. Two mechanisms are responsible for the behaviour. The first is represented around the “Forgetting” loop. This is the mechanism described in assumption 4. Word-of-mouth and
marketing is combined into social exposure. The higher the airport market share, the higher the social exposure, the lower the loss of awareness due to forgetting and hence the higher the awareness of the airport.

The second mechanism that is added is related to assumption 6. The loop indicated by "Habit" represents the loss of awareness over time. The time constant "Time to form habit" is a measure for how quickly alternatives are ignored in the decision process. If the time constant is long, it is unlikely that any alternative will be ignored due to the constant learning by experience and social exposure. If the constant is very short, the airport that is not frequently used is quickly forgotten.

The mechanism captures the formation of habit. The result of a habit is that one airport is repeatedly chosen because all the other airports are not considered (ignored). Due to this habitual behaviour, the possibility exists that the same airport is always chosen while there might be other airports that have better characteristics.

![Habit formation diagram]

**Figure 6.2.: Habit formation**

### 6.2. Decision making

In Section 4.1 it is described that in order to make a choice, information is needed about the personal preferences, the available alternatives and their characteristics. In Section 5.1 the three most important choice factors for decision making are stated. This leads to the assumption that:

6. People base their choice of airport on their preferences, the available airports and the characteristics of each available airport.

In the literature on choice models, the most widely used model to predict consumer choice uses the logit function in one of its forms. The inputs of the function are the characteristics of all available alternatives and a set of preference weights. The function then outputs the
probability to choose a specific alternative. The logit function will be used in the system
dynamics model to determine the market shares of each airport.

6.3. Airline representation

Three assumptions underlie the dynamics that stem from airline behaviour. These assump-
tions are highly simplified and represent only the most basic operational and economic consi-
derations. In reality many more aspects play a role in the day to day decision-making of
airlines. However, to capture all these aspects is not feasible in this modelling study. It is
assumed that the market for air transportation is demand-driven. In other words, airlines
act on demand. This is a simplification of reality in which demand and supply continuously
interact while in some cases demand might drive the market and in other cases the supply is the
most important driver.

To satisfy the demand it is assumed that:

7. If demand is high, an airline schedules additional flights, this scheduling takes time.

And:

8. If the demand is low, an airline can decide to remove flights from the schedule, this action
is not taken immediately.

Airlines can adjust the number of destinations and flights per destination according to, among
other reasons, the expected demand. As described in Section 5.2.2 there will always be a
certain delay between realising that additional supply is required and the realisation of this
additional supply. If an airline has already established an operational base at the airport,
additional supply can be realised with only a short delay. If a new base has to be set up, this
delay can be larger. The type of service and the airline business model also affects the delay
time. Network carriers will in general perform more elaborate feasibility studies in order to
analyse the effects of an additional route on their network. Low-cost carriers on the other
hand have much more freedom and flexibility to experiment and hence can achieve shorter
scheduling delays.

When demand is lower than supply, leading to low load factors, an airline may decide to
reduce the number of routes and flights per route supplied. Again for network carriers the
decision to reduce flights and especially destinations will be delayed much longer than a low-
cost carrier would do. Furthermore, the time between realising that there is too much supply
and the realisation of the new schedule does not have to be equal to the delay to schedule
additional flights.

The last assumption is based on the law of supply and demand and states that:

9. If the demand is high and the airplanes become very full the price of a ticket will rise.

The average price of an airline ticket at a specific airport is assumed to be higher when there
is a lot of demand for this ticket. This mechanism acts as a balance and matches the quantity
supplied with the quantity demanded. In case of the taxation on airline tickets, the change of
passengers from Eindhoven to other airports can lead to a price decrease at Eindhoven and
a price increase at the other airports.
In Figure 6.3, the three assumptions related to airline behaviour are depicted in a causal loop diagram. Assumption 7 and 8 are captured in the two bottom loops. The "Supply loop" is a positive feedback loop. The attractiveness of the airport influences the number of seats (airline tickets) demanded. The higher the attractiveness, the more seats demanded. The airline will analyse the number of seats demanded over time and predicts how many seats will be demanded in the future. The forecasted demand is then compared with the actual number of flights. The higher the forecasted demand, the higher the difference between actual and forecasted flights. This difference is then diminished by adding or removing flights as indicated by the negative feedback loop between the difference and actual flights. Before the flights are operational, some time will pass, this time is called the "Scheduling delay". The longer the delay, the lower the number of actual flights. The feedback loop is closed by the relation between the actual number of flights and the attractiveness of the airport.

The negative feedback loop indicated with "Price balance" realises assumption 9. Again the attractiveness of the airport influences the number of seats demanded. The more seats demanded, all other things being equal, the higher the load factor. The load factor is determined by dividing the seats demanded by the seats available. The load factor then positively influences the average ticket price. The higher the load factor, the higher the average ticket price will be. The higher the average ticket price, the lower the attractiveness of the airport.

In the next part of the thesis the nine assumptions and the causal loop diagrams will be used as a guide to construct the formal equations that are necessary to obtain a quantitative output from the model. The part will also cover the testing of validity of the model.
Part III.

Model Specification and Use
Chapter 7.

Specification of the model

In the previous chapters the conceptual composition of the model and its mechanisms is described. This has resulted in three causal loop diagrams. These diagrams give a first insight in how the different mechanisms influence each other. It is however still difficult to analyse what type of behaviours these mechanisms can generate. By specifying the equations and parameter values, the model can be used to simulate the system over time and to generate quantitative results.

This chapter describes the general setup of the simulation in Section 7.1. In Section 7.2, the geographic and demographic characteristics of the modelled system are described. The equations are derived in Section 7.3. Section 7.4 describes the data collection.

7.1. Simulation setup

The simulation runs over a period of ten years from January 2005 to January 2015. The simulation starts in 2005 to be able to compare the results to empirical data in the period prior to the ticket tax. The units of time in the model are months and a time-step is set at 0.1 month. The ticket tax is introduced as a step function in 2008. Because of the use of a step function, it is considered most safe to choose the Euler integration method. The model is programmed in Vensim DSS version 5.9e. The DSS version is required because the model extensively utilises subscripts (arrays).

7.2. Overview of the system

To keep the model from becoming too complex, a set of three airports has been chosen to be assessed. The most important criteria for selecting these three airports is that they facilitate services that are (potentially) competitive. An airport that for example only has general aviation is not likely to compete with an airport that is solely designed to facilitate the operation of a large commercial fleet. Less strong, but still relevant is the dedication of an airport to a specific group of users such as business or leisure travellers, and the function of the airport in the network, e.g. regional or hub airport.

In the context of the Dutch ticket tax, three regional airports are specifically interesting namely Eindhoven airport in the south of The Netherlands, Brussels South - Charleroi and Airport Weeze, that is located about 80 kilometres from the city of Dusseldorf (Figure 7.1). There are four reasons why these airports have been selected. The first is that since they are all regional airports and are located within 2.5 hours (by car) distance from each other, their
catchment areas overlap leading to potential competition. The second reason is that all three airports provide a very similar type of services and destinations, which mainly consists of low-cost flights to popular tourist destinations. The more similar these services are, the more perfect the substitutability between the airports. The third reason is that low-cost airlines are in general more "footloose" than traditional network and full fare carriers (Graham 2008). There are no concerns regarding the preservation of a network and low-cost airlines are not likely to have substantial sunk costs at specific airports. When a route does not prove to be financially viable, a decision can be made within a relatively short period of time to remove the route from the time tables. These airlines are thus highly capable of quickly adapting to demand. The fourth and final reason is that passengers that are attracted by low-cost airlines are in general relatively price sensitive passengers. Hence, they are more likely to react to an increase in ticket prices as a result of the Dutch imposed ticket tax.

Although they are left out of the system, larger hub airports are interesting as well. The growth on Weeze for example will partially have been at the expense of Dusseldorf airport, and most likely also at the expense of Schiphol airport. The same can be said for the development of Eindhoven and Charleroi. The low-cost services offered at these regional airports compete with the full cost services at the hub airports. Especially in times of economic downturn more people might decide to save on their travel expenses by choosing for a low-cost airline. In The Netherlands, Eindhoven airport has been growing while Schiphol saw a decline of passenger numbers. Given these observations it is likely that hub airports fulfil a donor function in terms of passengers to regional airports. A phenomenon that is not new in case the hub airport is reaching its maximum capacity and regional airports collect the overflow (de Neufville 1995). The consequence for the model is that with the small volume of modelled passengers, the explosive growth at Weeze cannot be completely reproduced.

The model is spatially distinct in three geographic regions. The reason for defining these regions is that due to the existence of national and language boundaries, communication between groups of people might be reduced. Consider for example the level of information transfer between two Dutch speaking citizens and between a Dutch and German speaking citizen. Besides the language barrier, the probability to encounter each other is simply smaller. The three regions that are specified comprise a Dutch region [1], a German region [2] and a Belgian region [3]. It is assumed that travellers originating from the same region speak the same language, which is a simplification for the Belgium region.

In Figure 7.2 the composition of user groups in one specific region is depicted. As can be noted each region has two main groups being a group of business passengers and a group of leisure passengers. Each group is then further subdivided into sub-groups according to the last used airport. passengers can only change between sub-groups. Hence it is assumed that people don’t move to another region and that a leisure/business passenger will always remain a leisure/business passenger.

Several properties have been assigned to the passengers in order to keep track of the market shares of each airport, utility perceptions and awareness. These properties are:

- last airport used
- awareness of the airports
- utility perception of the airports
- travel motive
- region of origin.
7.2 Overview of the system

As a member of a group you share the properties that the other members of the group have. When passengers change between groups, the airport related properties that they have inherited from the previous group will be taken to the next group. If the values of these properties differ, the average value of these properties in the new group will change. This construct ensures that knowledge and experience does not disappear suddenly. To clarify this transfer of knowledge and experience between user groups consider the following example:

Consider two groups of 100 passengers and two airports i and j. The first group consists of people that use airport i and have an average awareness of airport i ($\bar{A}_{ii}$) of 1 and of airport j ($\bar{A}_{ij}$) of $\frac{1}{2}$. The second group consists of people that use airport j and have an awareness of airport i ($\bar{A}_{ji}$) of $\frac{1}{2}$ and of airport j ($\bar{A}_{jj}$) of 1.

Now let’s assume that all people in group 2 decide to start using airport i, while users group 1 do nothing. Since all members of group 2 instantaneously become familiar with airport i once they have chosen it, the average awareness of airport i in group 1 ($\bar{A}_{ii}$) does not change. The awareness of airport j in the second group was higher than in the first group. The people in the second group will transfer that awareness to their new group, resulting in an increase in average awareness of airport j in the first group. The total awareness of airport j in the first group ($A_{ij}$) initially was $100 \times \frac{1}{2} = 50$ and will increase with 100 as a result of the 100 people of the second group changing to airport i. The total awareness in group 1, which now has 200 people, of airport j then becomes 150. The average awareness of airport j in group 1 will then be $\bar{A}_{ij} = \frac{A_{ij}}{PAX} = \frac{150}{100+100} = \frac{3}{4}$. 

Figure 7.1.: Map of the modelled airports
7.3. Formal specification

The simulation model comprises of three subsystems (Figure 7.3) being a subsystem for consumer behaviour, a subsystem that simulates the decisions of passengers, and a subsystem for airline strategy. Each of the subsystems is described separately below.

In order to keep the mathematical formulation of the model readable, several conventions have been used. Subscripts are used to indicate the index of the airport, the letter i, j and k.

\[ M_S = \frac{N_C}{\sum \text{Airline Strategy}} \]

\[ \text{Demand} \]

**Airline Strategy**

- Price & Supply

**Consumer Behavior**

- Utility Perception
- Awareness of Alternatives

**Decision Core**

\[ M_S = \frac{\text{Airline Strategy}}{\sum \text{Airline Strategy}} \]

Figure 7.3.: Model overview

1 A more elaborate overview of the system can be found in Appendix A.
7.3 Formal specification

have been used. There are three airports in the model \((n = 3)\), in cases where users of one airport have a perception of another airport two subscripts are added to the variable. For example, \(A_{ij}\) represents the awareness of the group of users of airport \(i\) with airport \(j\). If the value of \(A_{ij}\) would be 0.25 this would indicate that 25% of the users of airport \(i\) is aware of airport \(j\). Superscripts are used in combination with utility to indicate if the utility is actual or perceived. The formulation \(V^p_{ij}\) for example represents the perceived utility of airport \(j\) by users of airport \(i\).

Table 7.1 provides a list of most used variables and their meaning. In Table 7.2 a list of the most used constants and their values is given.

### Table 7.1.: Most used variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
<th>Units (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V^p_{ij})</td>
<td>Perceived utility of (j) by users (i)</td>
<td>dmnl</td>
</tr>
<tr>
<td>(V^a_{ij})</td>
<td>Actual utility of (j) by users (i)</td>
<td>dmnl</td>
</tr>
<tr>
<td>(A_{ij})</td>
<td>Total awareness users (i) with (j)</td>
<td>([0, 1])</td>
</tr>
<tr>
<td>(F_{ij})</td>
<td>Forgetting of (j) by users of (i)</td>
<td>dmnl/month</td>
</tr>
<tr>
<td>(E_{ij})</td>
<td>Social exposure of users (i) to (j)</td>
<td></td>
</tr>
<tr>
<td>(PAX_i)</td>
<td>Passengers last used airport (i)</td>
<td>pax</td>
</tr>
<tr>
<td>(PAX_{i→j})</td>
<td>Passengers changing from (i) to (j)</td>
<td>pax/month</td>
</tr>
<tr>
<td>(MS_i)</td>
<td>Market share of (i)</td>
<td>([0, 1])</td>
</tr>
<tr>
<td>(P(i → j))</td>
<td>Probability of users of (i) choosing (j)</td>
<td>dmnl</td>
</tr>
</tbody>
</table>

### Table 7.2.: Most used constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Meaning</th>
<th>Value [units]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tau_I)</td>
<td>Ignorance time, habit formation</td>
<td>24 [month]</td>
</tr>
<tr>
<td>(\tau_l)</td>
<td>Learning time</td>
<td>3 [flight]</td>
</tr>
<tr>
<td>(\tau_p)</td>
<td>Time horizon for forecast</td>
<td>3 [month]</td>
</tr>
<tr>
<td>(\tau_s)</td>
<td>Scheduling delay</td>
<td>2 [month]</td>
</tr>
<tr>
<td>(\alpha_i)</td>
<td>Marketing effectiveness</td>
<td>0.01 [1/year]</td>
</tr>
<tr>
<td>(c_{ij})</td>
<td>Word-of-mouth effectiveness between (i) and (j)</td>
<td>0.25 (i=j), 0.11 (i\neq j) [1/year]</td>
</tr>
<tr>
<td>(\omega)</td>
<td>Number of flights per pax</td>
<td>6 (business), 2 (leisure) [flight/(pax*year)]</td>
</tr>
<tr>
<td>(\lambda_i)</td>
<td>Autonomous growth airport (i)</td>
<td>between 0 and 0.5 [1/year]</td>
</tr>
<tr>
<td>(lf_N)</td>
<td>Normal average loadfactor</td>
<td>0.8 [dmnl]</td>
</tr>
</tbody>
</table>

7.3.1. Consumer behaviour

The subsystem consumer behaviour comprises of two parts. In the first part the awareness development is modelled. In the second part the utility perception is modelled. Because both of the parts have similar mechanisms, the awareness model is specified first, and after the difference with the utility model are described.

Awareness can be obtained in three ways. Section 7.3.1.1 covers the first two ways namely word-of-mouth and marketing. This section also covers the forgetting of airports. In Section 7.3.1.2 the third way, learning by experience, is covered. This section will also explain how
awareness is transferred between groups of people. In the last section the focus is on the nuances between the specification of awareness and utility perception (7.3.1.3).

7.3.1.1. Awareness gain and decay

This section covers the formulations that are developed to model assumptions 1, 3, 4 and 5.

1. If people talk to other people they learn about the existence and the characteristics of an airport.

3. If people receive information by marketing they learn about the airport and airport attributes.

4. If there is insufficient word-of-mouth and marketing, people forget about an airport.

5. If people don’t fly from an airport they tend to slowly ignore the existence of the airport.

The awareness is indicated by $\bar{A}_{ij}$, which, expressed in words, is the average awareness by users of airport i of airport j. The average awareness can vary between zero and one and can be interpreted as the share of users of airport i that is aware of airport j, hence a value of one means that all users of i are aware of j.

The average awareness is influenced by two factors, the first factor increases the average awareness due to social exposure of users of airport i to airport j ($E_{ij}$). The second factor decreases the average awareness in case of limited social exposure of users of airport i to airport j ($F_{ij}$), i.e. people forget when there is insufficient social exposure. However, when there is sufficient exposure, people might still lose awareness due to the formation of habitual behaviour. To account for this ignorance effect the average awareness of an airport that is not used will decay with a decay constant ($\tau_I$).

We can now compose the formal differential equation by combining social exposure and forgetting into:

$$\frac{d\bar{A}_{ij}}{dt} = E_{ij}(1 - \bar{A}_{ij}) - F_{ij}\bar{A}_{ij}$$

(7.1)

In which:

$$E_{ij} = \alpha_j + c_{ij}MS_j$$

(7.2)

Where $E_{ij}$ represents social exposure of users of airport i to airport j. Social exposure is a function of $\alpha_j$ (marketing effectiveness of airport j), the effectiveness of word-of-mouth $c_{ij}$ between users of airport i and the users of airport j and the market share $MS_j$ of airport j. The word-of-mouth effectiveness multiplied by the market share can be interpreted as a measure for the probability that a user of airport i encounters a user of airport j.

The forgetting rate is defined as:

$$F_{ij} = F_0 f(E_{ij}) + \frac{1}{\tau_I}$$

(7.3)
7.3 Formal specification

The equation combines two effects. The first term of the equation represents the forgetting effect as a result of insufficient social exposure. In which \( F_0 \) is the maximum forgetting rate and a function of social exposure is included because it is assumed that forgetting takes more time in case the social exposure is high. The second term of the equation represents the part of forgetting that is independent of social exposure and in which \( \tau_I \) is the standard ignorance time related to the formation of a habit. A large standard ignorance time will result in a very gradual formation of a habit, even if just one airport is consecutively chosen. However, when the standard ignorance time is small, a habit can quickly be formed.

A logistic relation is assumed between social exposure and awareness decay, so that awareness reduces fast when the social exposure is small (equation adapted from Struben (2006)):

\[
    f(E_{ij}) = \frac{\exp(-4\varepsilon(E_{ij} - E^*))}{1 + \exp(-4\varepsilon(E_{ij} - E^*))}
\]  

(7.4)

The factor \( \varepsilon \) gives the slope of the curve at the point where the social exposure is equal to the reference or normal value of social exposure \( E^* \). Figure depicts the logistic relation between social exposure and forgetting. It shows that when social exposure increases, forgetting approaches zero.

So far we have considered the average awareness among the users of a specific airport. We can also consider the total awareness of the group by multiplying Equation 7.1 by the total users of each airport:

\[
    a_{update}^{ij} = PAX_i \frac{d\hat{A}_{ij}}{dt}
\]  

(7.5)

Where \( a_{update}^{ij} \) is the updating of total awareness as a result of social exposure and forgetting and \( PAX_i \) is the total number of users of airport \( i \).

7.3.1.2. Learning by experience and transfer of awareness

This section covers the the formulations that are developed to realise assumption 3.

3. If people choose and use an airport they learn about the characteristics of that airport.
As can be derived from the equations in the previous section, the speed of awareness gain and decay is related to the marketing effectiveness and word-of-mouth constants, and to the forgetting time. However, in Section 4.2 we have also seen that experience with the chosen product self leads to learning of that product’s properties and hence increases awareness. It makes sense to assume that once a product, or in this case an airport is chosen, the awareness of that alternative is equal to 1. Hence, one becomes fully aware of an alternative when the choice has been made to use the airport. In order to put this in perspective we first have to consider the use of co-flows (Sterman, 2000, pp. 497-503).

Co-flows are used to model attributes of a state variable. In this case that state variable contains the number of users of airport $i$. The attribute that it tracks is the awareness of those users of their own airport and of the other airports. The use of co-flows is important to keep track of the average awareness of an airport when users of an airport change to another airport. To capture the evolution of total awareness on the population level we have to define the transfer of awareness between groups:

\[ a_{ij}^{\text{transfer}} = \bar{A}_{kj} \frac{dPAX_i}{dt} \] (7.6)

Where $a_{ij}^{\text{transfer}}$ is the change of total awareness by transfer of airport $j$ among users of airport $i$. $\bar{A}_{kj}$ is the average awareness of airport $j$ among users of airport $k$. Finally $\frac{dPAX_i}{dt}$ is the net change of users in group $i$. The change of total awareness by transfer as defined by Equation (7.6) has four components. The first component increases the total awareness of airport $i$ among users of airport $i$ if a user enters the group. The component thus captures the learning about the chosen airport within the group of airport users and is defined as:

\[ a_{ij}^{\text{learn}} = \sum_{k\neq j} PAX_{k\rightarrow i} \quad i = j \] (7.7)

Where $a_{ij}^{\text{learn}}$ captures the awareness increase of airport $j$ among users of airport $i$ due to learning and $PAX_{k\rightarrow i}$ represents the number of passengers changing from airport $k$ to airport $i$. Users that decide to start using an airport are assumed to become fully aware of that airport immediately and hence an awareness of one is added to the total awareness for each new user.

The second component of the change of total awareness by transfer increases the total awareness of airport $j$ among users of airport $i$ if a user enters the group. This is the awareness increase due to transfer of experience and knowledge and is defined as:

\[ a_{ij}^{\text{enter}} = \sum_k PAX_{k\rightarrow i} \bar{A}_{kj} \quad i \neq j \] (7.8)

Where $a_{ij}^{\text{enter}}$ captures the awareness increase of airport $j$ among users of airport $i$ due to new entrants and $PAX_{k\rightarrow i}$ captures the number of users of airport $k$ that decided to change to airport $i$ and $\bar{A}_{kj}$ is the average awareness of airport $j$ among users of airport $k$.

The third component of the change of total awareness by transfer increases the total awareness of airport $j$ among users of airport $i$ as a result of new passengers entering the market. This awareness increase due to autonomous growth is defined as:

\[ a_{ij}^{\text{growth}} = PAX_{ij} \bar{A}_{ij} \] (7.9)
Where $a_{ij}^{\text{growth}}$ represents the total increase of awareness of $j$ by users of airport $i$ as a result of autonomous growth, $PAX_{g_{ij}}$ is the number of new passengers at airport $i$ as a result of autonomous growth and $\bar{A}_{ij}$ is the average awareness of airport $j$ among users of airport $i$. Hence, new users are assumed to inherit the average awareness of the group.

The factor $PAX_{g_{ij}}$ is calculated by:

$$PAX_{g_{ij}} = PAX_i \lambda_i$$  \hspace{1cm} (7.10)

In which $\lambda_i$ is the autonomous growth rate of airport $i$.

The last component for the change of total awareness by transfer decreases the total awareness of airport $j$ among users of airport $i$ if a user leaves the group. This awareness decrease is defined as:

$$a_{ij}^{\text{leave}} = \sum_k PAX_{i\rightarrow k} \bar{A}_{ij}$$  \hspace{1cm} (7.11)

Where $a_{ij}^{\text{leave}}$ captures the awareness decrease of airport $j$ among users of airport $i$ due to people leaving the group. $PAX_{i\rightarrow k}$ represents the number of users of airport $i$ that decide to change to airport $k$ and $\bar{A}_{ij}$ is the average awareness of airport $j$ among users of airport $i$.

The complete increase of total awareness by transfer $a_{ij}^{\text{additonal}}$ can now be composed by combining equations 7.7, 7.8 and 7.9. This results in:

$$a_{ij}^{\text{additional}} = a_{ij}^{\text{growth}} + \left\{\begin{array}{ll}
a_{ij}^{\text{learn}} & i = j \\
a_{ij}^{\text{enter}} & i \neq j
\end{array}\right.$$  \hspace{1cm} (7.12)

The change of total awareness by transfer then becomes:

$$a_{ij}^{\text{transfer}} = a_{ij}^{\text{additional}} - a_{ij}^{\text{leave}}$$  \hspace{1cm} (7.13)

The complete change of total awareness $\frac{dA_{ij}}{dt}$ comprises of the total awareness updating by social exposure and forgetting derived in Equation 7.5 and the change of total awareness by transfer stated in Equation 7.13. This results in:

$$\frac{dA_{ij}}{dt} = a_{ij}^{\text{update}} + a_{ij}^{\text{transfer}}$$  \hspace{1cm} (7.14)

### 7.3.1.3. Differences with formulation of utility perception

Just like awareness, perceived utility is an attribute associated with the variable that holds the number of users per airport. The general equation for the transfer of awareness between user groups (Equation 7.6) can therefore be applied without modifications. The equations for updating and learning about utility are somewhat different. First of all, it has been decided not to include a forgetting effect as part of the utility update mechanism. The reason for this is that it cannot be defined what will happen with the value of the perceived utility when one forgets about it, i.e. it cannot be stated that perceived utility decreases or increases as
a result of time. We could however incorporate the concept of uncertainty about the utility. Intuitively we can argue that uncertainty about utility of an alternative increases when the alternative has not been chosen for an extended period of time. Including uncertainty would lead to dynamics\[^2\] equivalent to the ones created by the notion of awareness. Therefore has been decided not to include uncertainty in the current study.

Updating of utility perception by users of airport i of airport j is influenced by marketing and word-of-mouth between users of airport i and j and the difference between the perceived utility by users of airport j and users of airport i:

\[
\frac{dV_{ij}^p}{dt} = \alpha_j(V_a^j - V_{ij}^p) + c_{ij}(V_{jj}^p - V_{ij}^p)MS_j
\]  

(7.15)

It is assumed, as it was conceptualised in Section 4.2 that the contribution of marketing as well as that of word-of-mouth diminishes once one is well informed about the utility of an alternative. This effect is included by using the difference between actual utility \((V_a^j)\) and the perceived utility \((V_{ij}^p)\) in case of marketing, and the difference between the perceived utility of j by the group of users using j \((V_{jj}^p)\) and the perceived utility of j by the group of users using i \((V_{ij}^p)\). To put it in other words, with the help of marketing, the utility perception of a group will approach the actual utility. By the effect of word-of-mouth, the utility perception of a group will approach the utility perception of the other groups they are interacting with proportional to the intensity and effectiveness of communication.

The mechanism for learning also has to be slightly adapted since it cannot longer be assumed that one becomes completely informed about the airport utility after it has been used one time. The equation for learning about of utility at the population level becomes:

\[
v_{ij}^{learn} = \sum_{k \neq j} PAX_{k \rightarrow i} \frac{(V_a^j - V_{ij}^p)}{\tau_l} i = j
\]  

(7.16)

In which \(\tau_l\) is the time required for learning about the utility of an alternative.

### 7.3.2. Decision core

This section covers the formulations that are developed to realise assumption 6.

6. People base their choice of airport on their preferences, the available airports and the characteristics of each available airport.

The decision core of the model determines what share of the population considered in the model will go to each airport based on the awareness and perceived utility attributes. In Section 5.1 we have seen that the actual utility is composed of a deterministic part and a random part (Equation 5.1). We will use the common assumption that the market shares are distributed according to the relative difference between the utilities of the alternatives and the awareness of each alternative. We will also assume that the random parts of the utility for each alternative are equal and thus can be left out of the equation.

The deterministic part of utility is defined, accordingly with Equation 5.2, as:

\[^2\]These dynamics can include lock-in effects and inertia for risk averse travellers (see for example Chorus & Dellaert (2009))
Where \( V_i^a \) is the deterministic actual utility of airport \( i \), \( P_i \) is the average ticket price at airport \( i \) in euro, \( T_i \) is the access time in minutes and \( F_i \) is the number of flights per week. The beta (\( \beta \)) values in this equation are measures for the relative importance passengers give to the different attributes (preferences), that are considered stable over time. Because the beta values are multiplied with the attribute values, the absolute difference between the utilities increases or decreases. The logit function then makes sure that the larger the absolute difference in utilities, the larger the difference in market shares. A very high beta value will thus yield a market share of near to 100\% for the alternative with a slightly higher unweighted utility.

The fraction of users of airport \( i \) choosing for airport \( j \) or in other words the probability of choosing airport \( j \) for users of airport \( i \) can now be calculated by using the multinomial logit equation:

\[
P(i \to j) = \frac{C_j \bar{A}_{ij} e^{V_{ij}^p}}{\sum_{k=1}^{n} C_k \bar{A}_{ik} e^{V_{ik}^p}}
\]

In which \( C_j \) is the capacity constraint factor\(^3\) of airport \( j \), \( a_{ij} \) represents the awareness of travellers that previously used airport \( i \) with airport \( j \), \( V_{ij}^p \) is the perceived utility that users of airport \( i \) hold of airport \( j \). The perceived utility is only equal to the actual utility in case there is perfect information. Finally, \( V_{ik}^p \) is the perceived utility that users of airport \( i \) hold of airport \( k \). It can be concluded that airports of which a user is not aware of are not considered in the decision process, e.g. \( a_{ij} = 0 \) yields \( P(i \to j) = 0 \).

The capacity constraint factor restricts the number of passengers that can choose for an airport given the available number of seats. In other words, when all flights departing from an airport are completely full, no additional passengers can be transported. The capacity constraint factor is calculated by:

\[
C_j = 1 - \left( \frac{\text{seats demanded } j}{\text{seats available } j} \right)
\]

The factor thus reaches zero when the number of seats demanded is larger than the number of seats available. Before the factor reaches zero it will be successively harder to obtain the desired seat and it is assumed that the probability of choosing the airport will decrease when the number of seats demanded approaches the number of seats available.

With probability of choosing \( j \) we can then calculate the inflow of passengers for airport \( j \).

\[
PAX_{\rightarrow j} = \sum_i P(i \to j) PAX_{i \to j}
\]

Where \( PAX_{\rightarrow j} \) is the number of passengers changing to airport \( j \) and \( PAX_{i \to j} \) is the number of passengers that have used airport \( i \) and are about to make a new travelling decision.

The outflow of passengers from the stock of airport users is a function of the frequency of flight and the total number of users of that specific airport. Strictly speaking this means that

\(^3\)Captures the amount of available capacity.
passengers will remain at the last airport they have chosen until they will have their next flight. The simple equation used to control this is:

\[ PAX_{i \rightarrow} = PAX_{i \omega} \]  

(7.21)

Where \( \omega \) represents the number of flights per time unit in the model.

### 7.3.3. Airline strategy

This section covers the formulations that are developed to realise assumptions 7, 8 and 9.

7. If demand is high, an airline will schedule additional flights, this scheduling takes time.

8. If the demand is low, an airline can decide to remove flights from the schedule, this action is not taken immediately.

9. If the demand is high and the airplanes become very full the price of a ticket might rise.

After demand is generated based on the total population and the shares of passengers choosing for each airport the airlines have to make sure that there is sufficient capacity to actually facilitate the demand. The model uses a naive setup that uses the forecasted demand to determine the gap between the desired number of seats and the available number of seats. This gap is then closed by adding additional flights. The model considers just one single airline that operates on all airports. The strategy of the airline on each airport is thus identical. Transfer of flights from one airport to the other only takes place if demand at one airport decreases and increases at the other. The price of a ticket reacts on demand. When flights are above (below) the normal average load factor of 0.8\(^4\) the price will increase (decrease) according to a predefined non-linear function.

The forecasted demand is calculated by:

\[ PAX^F_i = (1 + r_i)^{\tau_p} PAX_i \]  

(7.22)

In which \( PAX^F_i \) is the forecasted number of passengers at airport \( i \), \( r_i \) is the growth rate of airport \( i \) and \( \tau_p \) is the time horizon for the forecast. The forecasted number of passengers is obtained through the use of an expectation formulation structure originally developed by Sterman [2000, pp. 631-642]. The desired number of flights can then simply be calculated by:

\[ f^d_i = \frac{PAX^F_i}{S \cdot l_{f_N}} \]  

(7.23)

Where \( f^d_i \) is the desired number of flights per time unit at airport \( i \), \( S \) is the average number of seats per aircraft and \( l_{f_N} \) is the normal average load factor. The change of flights per time unit at airport \( i \) then becomes:

\(^4\)Based on word-wide average passenger load factor, IATA
Here the distinction between capacity deficit and surplus is made to allow for policy intervention. An airline can choose not to reduce flights in times of reduced demand in order to keep the attractiveness high. In this equation $f^a_i$ represents the actual number of flights per time unit offered at airport $i$ and $\tau_s$ is the scheduling delay between realising demand and actually operating an additional flight.

The load factor is calculated by:

$$lf = \frac{PAX_i}{f^a_i S}$$

(7.25)

The price is a function of the average ticket fare ($\bar{P}_i$), the load factor and the normal average load factor:

$$P_i = \bar{P}_i f(\frac{lf}{lf_N})$$

(7.26)

The function is defined graphically and results in 1 if the current load factor is equal to the normal average load factor and runs asymptotically to 1.3 at load factors larger than the average. The load factor runs asymptotically to 0.7 for load factors smaller than the average.

### 7.4. Data collection

#### 7.4.1. Sources

System dynamics models in general do not require extensive amounts of data. For the model that has been developed two types of data have to be obtained. The first type is the data related to initial values of the major state variables in the model. These values can mostly be obtained empirically by consulting airport websites and annual reports or tourism agencies [Eindhoven Airport N.V., 2006, 2007] [Observatorium voor Toerisme te Brussel 2006]. In Table 7.3, the number of passengers per airport is reported per year and per week for the base year 2005.

The second type of data includes all the constants that are used in the model. These constants can only be partially obtained empirically due to unavailability or due to lack of time and resources. To obtain these data other studies have been consulted [Struben, 2006] [Terpstra 2009] [Gillen et al., 2003]. In Appendix B, a table is included listing all the values used as exogenous inputs to the model including the sources.

---

5 The number of flights per week is calculated by dividing average passengers per week by the capacity of an aircraft (189 for a B737-800) and the normal average load factor of 0.8
7.4.2. Parameter assumptions

Because not all data has been available some assumptions had to be made. The average ticket prices at each airport are considered equal in the reference year 2005. The reason for this is that the airlines are considered identical at each airport and thus have the same cost structure. The airport charges are expected to differ at each airport and data on the official charges is available. However, it is expected that there are various other factors unknown to the author that influence the actual tariff the airlines pay at each airport, a difference between the Dutch airport and the other airports is however assumed. The average price for a ticket is initially set at €100,- for Eindhoven and €90,- for Weeze and Charleroi. It is important that the ratio of the additional ticket tax to the average price is realistic.

The preference weights in the model are adapted from Terpstra (2009). This research comprised of the estimation of a logit model to analyse the effect of a high-speed railway connection on passenger demand at Amsterdam Airport Schiphol. The study uses the same attributes and units. A limitation is that the study provides only preference values for an aggregate travel motive. In other words, no distinction could be made between leisure and business travellers. It is assumed that the values are valid for both groups of travellers. An adjustment has been made to the weight factor for average ticket price in order to reflect an average price elasticity of -1.5 (Gillen et al., 2003).

The word-of-mouth effectiveness is assumed to be different between people that speak different languages and people that speak the same language. In the model it is assumed that within a region people speak the same language. Between two regions the effectiveness of word-of-mouth is reduced with about 60%. Between the Dutch region and the Belgium region the effectiveness is a little higher since a proportion of the people in the Belgium area speak Dutch.

The initial awareness is chosen partially based on the observed composition of travellers at the three airports as a proxy, and partially results from an internet panel questionnaire (KiM airport choice survey 2010) conducted among Dutch citizens (see Figure 7.5). Users of an airport are always assumed to be fully aware of the airport they have last used. Furthermore, users in the origin region of an airport are considered to be fully aware of that airport. For the reference case it is assumed that the perceived utility is equal to the actual utility initially. In a later stage, these initial perceptions can be changed to be higher or lower than the actual utilities.

Travel times from one region to the airport in the other region are considered to be equal to the travel time between the airports in both regions as obtained from the ANWB routeplanner. For the travel time to the airport within the region 30 minutes is assumed. Leisure travellers are assumed to travel once per year on average and business travellers are considered to travel three times per year on average.
7.4 Data collection

Figure 7.5.: Airport awareness among Dutch citizens 2010, source: KiM airport choice survey 2010

Figure 7.6.: Flight frequency Dutch travellers, source: KiM airport choice survey 2010
The initial size of the user groups in each region is derived from the actual number of passengers per airport and the probability of choosing for a specific airport. This probability is calculated using the logit function with all actual utilities and the initial awareness and preference (beta) values. Because the final number of passengers and the probability are known, a system of linear equations can be created (Equation 7.27):

\[
\begin{bmatrix}
\sum_{k=1}^{n} MS_{k \rightarrow i}^{k} Pop_{k} \\
\sum_{k=1}^{n} MS_{k \rightarrow D}^{k} Pop_{k} \\
\sum_{k=1}^{n} MS_{k \rightarrow m}^{k} Pop_{k}
\end{bmatrix}
\begin{bmatrix}
PAX_{i} \\
PAX_{D} \\
PAX_{m}
\end{bmatrix}
\]

(7.27)

In which \( MS_{k \rightarrow i}^{k} \) is the fraction of people changing to airport \( i \) from region \( k \) and \( Pop_{k} \) is the size of the population that travels by air in region \( k \).

The following steps illustrate how the initial values for the user groups are calculated. Let us start with the total number of passengers per month per airport\(^6\) and put them in a vector. The first row stands for Eindhoven, the second for Weeze, and the last row stands for Charleroi.

\[
\begin{bmatrix}
62.890 \\
25.396 \\
104.145
\end{bmatrix}
\]

(7.28)

Now the market share of each airport in each region needs to be calculated. This is done based on the initial actual utility values and the initial awareness for each region. The results of the logit function for each region are put in a matrix where the rows represent airport and the columns represent regions. Similar to the initial passengers, the first row represents Eindhoven and the third represents Charleroi. The first column represents the Dutch region, the second column represents the German region, and the third column represents the Belgian region.

\[
\begin{bmatrix}
0.805 & 0.068 & 0.005 \\
0.113 & 0.912 & 0.002 \\
0.083 & 0.019 & 0.993
\end{bmatrix}
\]

(7.29)

The system of linear equations can now be constructed with the only unknown being the number of passengers per region per month.

\[
\begin{align*}
0.805 \times Pop_{NL} + 0.068 \times Pop_{D} + 0.005 \times Pop_{Be} &= 62890 \\
0.113 \times Pop_{NL} + 0.912 \times Pop_{D} + 0.002 \times Pop_{Be} &= 25396 \\
0.083 \times Pop_{NL} + 0.019 \times Pop_{D} + 0.993 \times Pop_{Be} &= 104145
\end{align*}
\]

(7.30)

Solving system of equations yields the following number of passengers per region per month. The first column represents the Dutch region, the second column represents the German region, and the last column represents the Belgian region.

\[
\begin{bmatrix}
75.999 \\
18.259 \\
98.174
\end{bmatrix}
\]

(7.31)

\(^6\)These values differ from the values in Table 7.3 because they are corrected for seasonal influences.
The initial size of the group per travel motive per region is then calculated by multiplying the total number of passengers per month by the fraction of business/leisure passengers and by dividing by the frequency of flight.

\[
\begin{bmatrix}
379.178 \\
92.601 \\
485.179
\end{bmatrix}
\] (7.32)

These numbers indicate that in 2005 the Dutch part of the shared catchment area of Eindhoven, Weeze and Charleroi contains about 379 thousand people that fly, the German part of the shared catchment area of these three airports contains more than 92 thousand people that fly and the Belgian part contains 485 thousand people that fly.
Chapter 8.
Verification and Validation

This chapter is dedicated to describing a series of tests that are designed to reveal flaws in the structure and specification of the model and hence to build confidence in the outcomes of the model. There are two questions that always should be answered before the model can be used. The first question is: Did we build the right model? To answer this question the elements within the boundaries and the structure of the model have to be compared to the purpose of the model. The second question is: did we build the model right? For answering this question the technical specification of the model is analysed.

The first section (8.1) of this chapter deals with the more general tests that are performed continuously during the model development process. In the second section (8.2) we will zoom in onto a number of ”test cases” that we use to check whether the model produces the results that we intuitively expect. In the third section (8.3) a sensitivity analysis is performed in order to identify the (uncertain) parameters that the model is most sensitive to. In the fourth section (8.4) the results of the model are compared with data obtained from reality. The last section (8.5) concludes the verification and validation process.

8.1. General checks

There are several basic consistency checks that a modeller should perform continuously during the process of building a model. Table 8.1 is partially adapted from Sterman (2000) and gives a representation of these checks. Important to notice is that these checks do not lead to a model that closely represents reality. Rather the checks are a guidance to make sure that the model is built properly, i.e. obeys the rules of system dynamics, physics and mathematics.

8.1.1. Boundaries

Determining the boundaries of a model is one of the hardest jobs in model development. If time would be unlimited, the model would be expanded to the largest system possible and then all mechanisms and factors that do not seem to influence the core characteristics of the behaviour can be taken out one by one. Time is however never limited and thus we need to make choices before hand. In the conceptualisation phase of the research decisions about what to include and what not have already been made. Human decision making is one of the key aspects that are included in the model and thus the mechanisms of awareness and utility perception are highly represented. Airline and specifically airport strategy are less represented, or absent in case of airport strategy. This can be justified by considering the level of aggregation (one airline is considered) and the time span of ten years over which
Table 8.1.: Model checks summary

<table>
<thead>
<tr>
<th>Test</th>
<th>Purpose</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundaries</td>
<td>Are all relevant mechanisms to solve the problem enclosed within the system boundaries?</td>
<td>Given the short time-frame of the simulation and the level of aggregation it is believed that all relevant mechanisms are included.</td>
</tr>
<tr>
<td>Structure</td>
<td>Is the structure of the model a correct reflection of the known real-world structure?</td>
<td>Consistency checks with the conceptual models based on literature showed some deviations that can be explained by differences in the level of aggregation.</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Consistency of units throughout the model, no strange conversion factors.</td>
<td>Checked, but inconsistencies arise in utility functions.</td>
</tr>
<tr>
<td>Parameters</td>
<td>Parameters should have real-world meanings and values.</td>
<td>All parameters can, in theory, be found empirically.</td>
</tr>
<tr>
<td>Extreme conditions</td>
<td>Equations should function realistically in all possible states of the model.</td>
<td>Several problems found and taken care of.</td>
</tr>
<tr>
<td>Integration method</td>
<td>Integration routine and time-step should be adequate given the characteristics of the system behaviour.</td>
<td>Time-step checked and results do not vary with smaller step.</td>
</tr>
</tbody>
</table>

the simulation runs. It is assumed that no major restriction of capacity occurs that could influence the response of an airport to expand.

Keeping in mind the purpose of the model, it is believed that the most relevant mechanisms to capture the dynamics of consumer choice and shifting demand are included in the model. Furthermore, sufficient factors are included in the model that provide the opportunity to test the results of policies.

8.1.2. Structure

A potential unrealistic aspect of the model is related to the additional number of flights an airline is able to deploy within a given time interval. Due to the construction of the equation the number of additional flights can be unlimited if the difference between the desired flights and the current number of flights is unlimited. In reality this type of fleet growth at an airport is of course impossible but since in the model this situation does not occur under normal circumstances no limitation to the growth is defined.

Passengers belong to a group of airport users. The group is modelled as a level variable with an outflow that corresponds to the number of people in the group that decide to fly per month. This outflow is connected to the inflow of the same level variable through the logit function. In system dynamics, connections between outflows and inflows in principle are not applied (Pruyt et al., 2008) and thus require some extra attention because they might not always be realistic. In this case users flow from one group directly into a new group (if they alter their choice) or back into the same group if they decide to choose the same airport again. The inflow of the groups therefore directly depends on the outflow of the groups, resulting in
the conservation of the total number of passengers in the system. Similar flow to flow links have been used to incorporate the co-flows structure.

8.1.3. Dimensions

The first test that is continuously performed during model development is that of units consistency. All equations in the model must be dimensionally consistent. A difficulty arises because utility has been modelled using an array. The components that make up utility, and the array, have different dimensions. The array should thus have different units for each position. In Vensim this is not possible. A way around this would be to multiply the different components of the utility with the beta values (1/unit of utility) before creating the array. It is chosen not to do this to keep the model more transparent. Furthermore, a comparison is made between actual utility and average utility to simulate learning effects. Unless the actual utility is somehow transformed to match the units of the average utility, it will not pass the units consistency check.

8.1.4. Parameters

For most of the parameters it is obvious that there is a real-world counterpart. Some less obvious examples are marketing and word-of-mouth effectiveness, and learning and forgetting times. The parameters are chosen intuitively or are adopted from other studies. This means that the values of these parameters have to be varied extensively in order to analyse their effect on the system behaviour. In Section 8.3 the results of the sensitivity analysis in which the parameters were varied are shown.

8.1.5. Extreme conditions

Extreme conditions occur when the model operates at the boundary, or outside, of the behavioural "envelope" it was originally designed to. An extreme conditions test, in which initial values of levels were set at either zero or infinite, revealed that several equations in the model result in division by zero unless appropriate care has been taken. The cases where divide by zero errors could not be prevented otherwise are resolved by using the functions 'ZIDZ' or 'XIDZ' in Vensim. ZIDZ returns zero in case the denominator is zero, whereas XIDZ returns any specified value when the denominator is zero. One example of such a case is the average utility perception in case the number of users of an airport is zero.

8.1.6. Integration method

There have been no indications of integration errors using the Euler method and accuracy did not improve by using the Runge-Kutta 4 with automatic time-step adjustment. The time-step was changed to a factor 10 smaller which did not result in changes. A larger time-step (factor 5) resulted in a shorter simulation time but there was substantial deviation in simulation results. A time-step of 0.1 month in combination with Euler is believed to be adequate.
8.2. Test cases

The main purpose of simulating cases is to see if the model produces the behaviour that is expected. If this is not the case, we have to ask the question whether our expectations were wrong or if the model is not suitable for its purpose.

8.2.1. General structure and Key Performance Indicators

Before any test case can be simulated we need to define key performance indicators in order to monitor the behaviour of the system over time. The following four Key Performance Indicators (KPI’s) have been chosen:

- Number of passengers per airport [pax/month]
- Trend of passenger development per airport [%]
- Awareness of airports [dmnl]
- Airport choice per region [%]

The number of passengers per airport is an important indicator as it allows us to compare model results with empirical data. The trend of passenger development is the same variable that is used by airlines in the model to forecast demand. It is defined as the percentage of passenger growth per year. The awareness is defined as the average awareness within a region of each airport. The awareness is always between 0 and 1. The airport choice per region describes the fraction of people within one region that choose for a specific airport.

The relative attractiveness of an airport is used extensively in the description of the system behaviour and the analysis of policies. Relative attractiveness is defined as:

\[
RA_j = 1 - \frac{1}{n} \sum_{i=1}^{n} \frac{V_{ij}^p}{\sum_{j=1}^{n} \sum_{i=1}^{n} V_{ij}^p} \tag{8.1}
\]

The relative attractiveness of airport j \( RA_j \) describes the average attractiveness of an airport as perceived by all user groups in one region relative to the average attractiveness of all the airports as perceived by all user groups in that region. The function uses the perceived utility per group \( V_{ij}^p \) as input. An airport that has a relative attractiveness of 1 will thus have a market share of 100% in that region. Airports that develop equally in terms of price, flights and access time will remain at a constant relative attractiveness.

The structure of each test case will be kept identical. First a description is provided about the scenario of the case, including the initial conditions of the system. In the second part a dynamic hypothesis, or expectation of the behaviour will be drafted to which the outcome of the simulation can be tested. In the last part the outcome of the simulation will be described and a conclusion is drawn regarding the initial hypothesis.

1. Description of the situation and initial conditions
2. Formulation of the dynamic hypothesis complemented with references from reality
3. Description of the outcomes and conclusion
8.2.2. Case 1: Opening of a new airport

The first case we will assess is the opening of a newly built airport. The purpose of this test is to make sure the mechanisms of word-of-mouth and marketing to generate awareness are functioning properly. In this case we will monitor the first 10 years of an airport that has just opened its doors. We will consider the airport of Weeze as a base for the new airport in terms of location and average ticket price. The airport is designed to facilitate the operation of low-cost airlines that are planning to directly compete with the airports of Eindhoven and Charleroi. Because it is a new airport the initial awareness of the airport among all people will be zero. The initial market share will be zero as well. Initially there will be no airlines operating at the new airport. In this case we will monitor the development of the market share of the new airport in case of the presence of marketing and in the case where there is no marketing.

It is expected that if marketing is being conducted on behalf of the new airport, the market share will slowly start to rise until finally the awareness reaches an equilibrium value. Without marketing, the awareness should not increase even though there is word-of-mouth communication.

Figure 8.1 shows several cases where marketing is conducted:

1. No marketing

2. Normal intensity marketing

3. High intensity marketing

4. Normal marketing with supply push

As can be seen in the figure, if no marketing is conducted the awareness of the new airport remains zero. If marketing is conducted, the average awareness slowly starts to rise. In case an airline decides to push the supply of flights a little ahead of demand, the airport will eventually capture a larger market share. If a short marketing boost of 1 year is applied in combination with the supply push, the equilibrium level of awareness will be reached sooner, but the market share will not be significantly higher.

Both results are in line with the prior expectations. The graphs for the other indicators can be found in Appendix C.
8.2.3. Case 2: Over/under expectations

In this case we will test how market shares evolve if the expectations of an airport (perceived utility) are higher or lower than the actual utility of the airport. The purpose of this test is to check whether consumers are able via learning and word-of-mouth to adjust their perceptions of the utility of an airport. Furthermore, we can test if the speed at which these perceptions are adjusted is realistic given the number of visits a traveller pays to the airport. To simulate over and under expectations the perceived average price of a ticket at Weeze airport is adjusted to be 10% lower and 10% higher than the actual ticket price. All other parameters values are set according to the base case scenario (Appendix B).

It is expected that if an airport is expected to be more attractive than it actually is, initially it would get a relatively larger market share compared to the base case scenario. However, since perceptions have to be adjusted when people communicate and learn by experience, the market share will stabilise again around the base case market share. The stabilisation of the market shares is driven by the converging of the perceived utility towards the actual utility. It is expected that the speed of the adjustments is higher for frequent flier than for occasional fliers. The speed of adjustment is also expected to be higher in regions where a large share of the population chooses for the airport compared to regions where the airport has a smaller market share. Finally it is expected that the speed of adjustment will be higher with users of the airport compared to non-users of the airport.

Figure 8.2 shows the effect of a lower perceived price on the annual growth rate of the airports. The trend line of Weeze (Weeze Perceived Price -10%) clearly shows that although Weeze airport grows substantially more in the first period compared to the baseline, the growth converges towards the normal growth in the base case over time. In terms of passenger
numbers (Figure [8.3], the damage in the early stage to Eindhoven proved to be at such a level that the airport is be able to retrieve its baseline value and Weeze will have a large benefit of the over expectancy of utility. The effects are less strong when the perceived price of a ticket is increased with 10%. An explanation for this is that with an increase of 10% the average price will be almost equal to the price at Eindhoven airport, and thus smaller differences in utility exist.

The results are not completely in line with the prior expectations. It was expected that an airport would converge to its normal market share once the utility perception would have been adjusted fully. This does not seem to be the case. In hindsight it makes sense that the market share is larger because if airlines provide more flights where demand is high, in the end the number of flights provided at an airport that experienced high demand will be higher and thus the attractiveness of the airport will be higher. The model is still valid, however further research is required to see how the effect of overexpectancy holds in case the supply does not always follow demand (i.e. in a supply-driven market). More figures can be found in Appendix D.

8.2.4. Case 3: Capacity constraints

So far, capacity constraints have not been included in the model because it is assumed that the limitations did not play a role during the implementation of the tax. However, in order to judge how the modelled system reacts on such constraints we will implement an airport capacity constraint on Weeze airport. The capacity of the airport will be set at 140 flights per week, which means that the airport will reach its capacity limits in January 2010 according to the base case scenario.

It is expected that the number of passengers at Weeze grows normally before the maximum capacity is reached. Once the maximum capacity is reached the number of passengers quickly
stabilises at the maximum attainable value. The average load factor might increase a little as a result of excess demand but can never be larger than 1. The other airports will start to benefit from their saturated competitor and show increased growth rates. Because the market share of the congested airport will be declining, the awareness update as result of social exposure will decrease and the level of awareness will drop.

In Figure 8.4 and 8.5 the development of passengers and awareness with and without capacity constraint is depicted. As expected the number of passengers stabilises almost immediately after the capacity limit has been reached. Because the other airports don’t suffer from a capacity constraint the market share of the congested airport decreases. As a result the effectiveness of word-of-mouth communication decreases and the awareness of the airport is decreases as well. The load factor (Appendix E) increases until about 94% after which it stabilises. Because Figure 8.5 shows the awareness in the Dutch region [1], the majority of the passengers that normally would choose Weeze will now choose for Eindhoven. The awareness of Eindhoven therefore increases while the awareness of Charleroi remains almost unchanged.

The results of the simulation are similar to the expected results.
8.3 Sensitivity testing

8.3.1. Metrics

Besides analysing how the model performs in different predefined cases it is interesting to see how and how much the output of the model changes with variations of the input values. In order to get an overview of the sensitivity of the model to parameter changes a sensitivity analysis is conducted. In total 19 of the exogenous parameters have been varied by + and - 10%. The results have been compared with the baseline output based on the implementation of a Dutch ticket tax in 2008 of €11.25 for the duration of one year. Four metrics have been used to calculate the differences between the runs. The first metric is a simple comparison of the final values (t=1-1-2015).

\[ D_{it_f} = \frac{|x_{it_f} - \sigma_{it_f}|}{|\sigma_{it_f}|} \]  

(8.2)

In which \( x_{it_f} \) is the value of indicator \( i \) at the final time of the sensitivity run and \( \sigma_{it_f} \) is the reference value (without parameter changes) of indicator \( i \) at the final time of the baseline run. The difference is normalised in order to be able to compare the results between indicators. The second metric is the maximum normalised difference during the simulation:

\[ D_{t_0-t_f}^{max} = \max \frac{|x_i - \sigma_i|}{|\sigma_i|} \]  

(8.3)

Where \( x_i \) is the value of indicator \( i \) and \( \sigma_i \) is the reference value of indicator \( i \) at the the same time step. The third and fourth metrics are measures for the total integrated difference between the reference value and the outcome of the sensitivity run:
And the squared integrated difference:

\[ D_{i}^{\text{sqint}} = \int_{t_0}^{t_f} \frac{(x_i - \sigma_i)^2}{\sigma_i^2} \, dt \] (8.5)

Both metrics in fact calculate the surface area between the two curves. In the squared metric the larger differences are counted extra due to the power two.

The time series results of all the individual simulations are exported to excel. With the use of a macro the metrics have been calculated. For a technical specification of the sensitivity analysis please refer to Appendix F.

8.3.2. Results

A number of interesting conclusions can be drawn from the data obtained in the sensitivity analysis. Important to realise is that the goal of the sensitivity analysis is twofold. First, it is used to test the sensitivity of the key performance indicators to parameter assumptions made. The second goal is to distinguish parameters that can effectively be used to change the outcome of the system in policies. In general it is found that the model is not very sensitive to parameter changes.

The most important observation from the sensitivity analysis is that the model is highly numerically sensitive to the preference parameters (beta values) used to calculate the utility.
and thus to the frequency of flights, the access time and average ticket price. All indicators are affected by the beta value for ticket price and for access time. The model is less sensitive to the frequency of flight parameter and the passenger composition per airport is mildly affected. Besides being highly sensitive, a difference in sensitivity can be observed between the ticket price preference parameter and the access time parameter. When distance to an alternative airport is far, the model is more sensitive to the access parameter, whereas when the distance is small the price plays a more important role.

The high sensitivity of the model to these parameters means that is important in case we want to achieve numerically accurate results to correctly specify the preference parameters. Because the intention of this study is not to obtain accurate predictions and since the data required to estimate these preference parameters is not available it is decided to keep the parameters as they are.

Another parameter that the model was found to be sensitive to is the word-of-mouth effectiveness. Because the word-of-mouth effectiveness for exchange between regions differs from that within regions the passenger composition at and awareness of an airport are affected when the inter-regional constants are varied. This "cross-border information exchange" sensitivity is especially interesting for policy applications. It shows that improvements in information exchange among air travellers in general (independent from where they live) is of importance to the development of an airport. The intra-regional word-of-mouth effectiveness does not produce large changes in the outcome of the model. This is explained by the nature of information that is communicated. Because the perceived utility of an airport is communicated through word-of-mouth, the only ways to obtain the actual utility is through learning and marketing. The perceived utility will therefore be more dependent on the speed of learning and the marketing effectiveness than on the word-of-mouth effectiveness. Only when perceptions between groups differ largely and the size of the group of senders is large in comparison to the total group of users, the word-of-mouth effectiveness is more relevant.

Word-of-mouth is not effective within a region and within a group of users (users of an airport don’t learn from other users of the same airport). The reason for this is because the utility perception for each member in the group is equal. In case group members communicate with each other there is no flow of information since both perceptions are equal. This also explains why the perception update within a group does not respond to changes in intra-regional WoM effectiveness.

Another observation is that the WoM effect to update the perception of a group of users of their own airport actually works against the actual change in utility. This is because the talks to own members do not contribute significantly, but the talks to users of other airports do. If these users lag behind the actual utility, which they do since they don’t have direct learning, the impact of the WoM effect is opposite to the direction of change in utility. In Figure 8.6 marginal contribution of learning and word-of-mouth within a group of passengers is depicted. The system responds to a sudden price increase. As can be observed, the effect of learning is directly opposed to the effect of word-of-mouth. This is true in all cases where the receiving party talks to a sending party that is less well informed about the actual utility than the receiver.

The forgetting time, which is used to model habitual behaviour, plays a relatively important role in the awareness of an airport. Preventing habits to form seems therefore an interesting

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1Because the preference parameters are multiplied with the utility values, a 10% variation in the preference parameter equals a 10% variation in utility value. This means that effectively the sensitivity of the model to these utility values is tested.
policy measure which is not totally new in the field of transport research. The final parameter that the model was found sensitive to is the number of flights per passenger per month. This parameter is associated with the speed of awareness and perception update.

In Figure 8.7 the most influential parameters are summarised. The statistics that are shown are the maximum normalised difference metrics. The blue bars represent the relative contribution of each parameter change over all the others parameter changes. The factors Time to Perceive Present Condition (TPPC), Time Horizon for Reference Condition (THRC), and Time to Perceive Trend (TPT) are parameters for the trend projection mechanism that is used by airlines to forecast demand.
8.4. Empirical validation

A complete validation of a system dynamics model is never possible (Sterman, 2000). In the previous sections we have seen a series of tests that have been conducted in order to confirm that the model has been constructed according to system dynamics practises. Furthermore, the response of the model has been tested against our intuitive expectations. All these tests are designed to check if we have build the model in a right way and if we have built the right model, i.e. does it capture the mechanisms that we consider relevant. This last step of the confidence building is to see whether the mechanisms that are considered relevant to produce the observed behaviour, are actually capable of producing the observed behaviour. In order to do this, observed data is compared to the output of the model.

The model has been calibrated numerically to be able to reproduce the observed behaviour. Two parameters have been adjusted to calibrate the model:

1. The preference weights
2. The autonomous growth rates
3. A marketing pulse is assumed

The preference weight for price \( \beta_p \), which partially determines price elasticity, proved to be too low to match with the characteristics of the group of travellers included in the model. In other words, the share of passengers that altered their choice as a result of a price change was too small. To match with an average price elasticity of -1.5, which is common in the market for low-cost carriers, the preference weight has been increased. This adjustment is also described in Section 7.4.2.

The autonomous growth rates \( (\lambda_i) \) have been set using the empirically estimated growth rates derived from OAG\(^2\) data in the period 2005 until 2008. It must be said that these estimated growth rates include the effects of awareness increase and are therefore expected to be higher than the actual autonomous growth rates. The modelled growth rates will have a double growth factor resulting from awareness gain in developing airports.

It was found that without any additional marketing, the change of passengers that was empirically observed could not be modelled. In reality, the implementation of the ticket tax was accompanied by intense coverage of the media. To simulate this media attention, the marketing effectiveness \( (\alpha_i) \) in the model is increased from 1% to 25% for a duration of one year, starting six months before the implementation of the tax.

Figures 8.8, 8.9 and 8.10 show the results of this calibration. The year-on-year growth rate has been calculated based on the modelled passenger numbers and on empirical data\(^3\). A slight shift in timing has occurred at Eindhoven that is not explained by the model. The large peak at Weeze in the period before the tax was implemented was the result of a supply-side decision to double the amount of flights (OAG). At Charleroi nothing seems to happen initially, but a slight growth (empirically) can be observed later. The model was not able to reproduce this behaviour and it is expected that another mechanism was responsible for the development at Charleroi.

\(^2\)The Official Airline Guide, collects airline schedule data.
\(^3\)Passenger number at Eindhoven are collected from www.cbs.nl, Weeze statistics are collected at www.adv.aero, and the Charleroi data is collected from www.charleroi-airport.com.
Figure 8.8.: Comparison with empirical data Eindhoven - source: own calculations based on CBS and model data

Figure 8.9.: Comparison with empirical data Weeze - source: own calculations based on ADV and model data

Figure 8.10.: Comparison with empirical data Charleroi - source: own calculations based on Airport and model data
8.5 Conclusion on verification and validation

8.5.1. Did we build the right model?

The purpose of the model is to complement the explanatory value of empirical data gathered after the implementation and abolishment of the ticket tax in The Netherlands by a deeper understanding of the mechanisms and their dynamic properties that have contributed to the formation of this empirical data. These mechanisms should mainly concern the mechanisms that are related to bounded rationality in consumer behaviour as this is the main interest of the research institute. Furthermore, a set of policies should be developed based on these mechanisms.

The model contains the mechanisms that are involved in the cognitive decision sequence related to information acquisition, alternative evaluation and choice. Furthermore, it contains simplified mechanisms that drive the supply-side of the market in order to analyse the dynamics between supply and demand. It is believed that the boundaries of the model are sufficiently broad to include the most obvious factors for the development of policies while they are sufficiently narrow to avoid any over-complexity and loss of overview.

There is however a drawback at reducing the number of mechanisms inside the system boundaries. As it seems, not all behaviour can be explained. The model represents mainly the interactions between passenger and between passengers and airlines, in which the airlines have a passive role. In reality airlines are much more active in terms of providing additional supply even before it is demanded in order to attract demand. The role of the airport is also more elaborate since in reality airports have to maintain a constant balance between the needs of the passengers and the airlines.

The explanations given by the model are only several possible of many other explanations. It is therefore required to stress that the model is not to be used to make predictions about what will happen in the future, rather it is a tool to explore the possible dynamic behaviours that can be obtained by using mechanisms contained by the model. The insights rather than the numerical outcomes are then used to understand the real world.

To conclude, the model is useful in a sense that it provides the first experience with system dynamics modelling in passenger choice. The lessons drawn from this study are valuable for future modelling exercises. The model provides a good starting point to test hypothesis related to explaining the observed behaviour after the introduction of the tax as long as the limitations of the model are kept in mind.

8.5.2. Did we build the model right?

The analysis of the structure and units and the simulations in the test cases showed that the model is specified with consistent and realistic units, and that its behaviour corresponds to common-sense and intuition. The equations have been analysed and adapted where necessary to avoid numerical errors. The simulation setup is checked to ensure that the behaviour independent of the integration method and time step.

In the next part the model behaviour will be analysed under the normal conditions and for a number of policy measures.
Part IV.

Analysis of Results and Conclusions
Chapter 9.

Explanation of behaviour

This chapter is dedicated to the description of the behaviour of the model. The main goal is to find out about how the different mechanisms that are conceptualised in Chapter 4 contribute to the development of the three airports. It is not the goal to most accurately mimic and describe the real-world behaviour. In some of the cases, parameters have been varied in order to be able to better study the dynamics of the system.

The analysis has been divided into three parts. Each part contains a section with the observations in the model and an explanation for these observations, and a part in which lessons are described that are deduced from the observations and explanations. In Section 9.1 the period before the implementation of the ticket tax is analysed with the model. In Section 9.2 the model analysis of the period during the tax is described. In the last section, Section 9.3 the analysis of the post-tax period is described.

9.1. Pre-tax

9.1.1. Observations and explanation

In the pre-tax phase of the simulation, passenger numbers at all three airports are increasing. There are two reasons for this growth. The first reason is the autonomous growth, or increasing propensity to fly in each region. This is accounted for in the model by an exogenous growth rate. The second effect is that of increasing awareness of foreign airports. Initially in all three regions, the local users are aware of their own airport but are not (completely) aware of the airports in other regions. This awareness is however not a constant value, but a variable that is updated through different means as explained in Chapter 7. As the existence of viable alternatives spreads among the flying population, the autonomous growth generated within the region is reinforced with an additional growth derived from other regions.

To illustrate the composition of the growth factor, the model has been run with a constant and equal growth rate for all three airports. It is assumed that there is no communication between the regions, only from the German region to the Dutch region and from the Belgium to the Dutch region in order to account for the marketing efforts. In this case the awareness of other airports outside the region can only be updated by direct experience. However, due to the constant mixing of users, i.e. a user might decide to depart from Weeze this month but flies from Eindhoven the next month, the awareness within a region of a foreign airport does increase. This increase takes place at a slower pace compared to the case there would have been communication.
In Figure 9.1 the development of the annual trend is illustrated. No ticket tax or other exogeneous shocks are introduced. After initialisation, Weeze clearly grows faster than Eindhoven, while the autonomous growth is set equal at 10% (0.1) for both. At the end of the simulation, the trend line of Weeze starts to slowly converge towards the 10%. This indicates that the awareness is reaching an equilibrium. The magnitude of the awareness gain component in the annual trend depends mostly on the speed at which awareness is created. For example, consider that everyone in the Dutch region suddenly knows about Weeze. The gain of passengers at Weeze will then take place within a short time interval. Figure 9.2 depicts the trend lines in this situation. An initial small boost takes place as a result of the sudden awareness of Weeze in the Dutch region. The second larger boost is due to the occurrence that the perceived utility of Weeze within the German region exceeds the perceived utility of Eindhoven because airlines respond to the additional demand by scheduling more flights.
9.1.2. Lessons

With respect to marketing efforts, it can be concluded that there is a right timing, intensity and duration of a marketing campaign. There are several fundamental observations that play a role. Firstly, the market share is directly influenced by the awareness as can be seen in Equation 7.18 in Chapter 7. The maximum obtainable market share is achieved in case of full awareness and is set by the relative attractiveness of an airport. However, due to forgetting of alternatives, the awareness for a group of non-users will never reach 1. Hence, an equilibrium awareness level exists that depends on the market shares and the forgetting rate.

Marketing artificially increases the awareness above the normal equilibrium level. This is sometimes desired for two reasons. The first reason is to notify consumers about quality changes and thus to accelerate the updating of the utility perception. The second reason is to create awareness of the airport in order to increase traffic. This second reason is however only efficient when supply is able to react to the additional awareness. By adding extra flights or lowering prices the relative airport attractiveness increases and the market share increases. This results in a new awareness equilibrium that is higher than the previous. The minimum duration of the marketing campaign highly depends on the speed at which the supply-side is able to respond. If the campaign ends before all the additional demand is facilitated, awareness falls back to a level between the initial and maximum obtainable level. Over time, the relative contribution of marketing compared to word-of-mouth and learning diminishes, reducing the cost-effectiveness of the campaign.

Another interesting finding that is related to the development of Weeze is that initially, due to the limited number of flights offered at the airport, a substantial number of the inhabitants of the German region chooses for Eindhoven. This is of course given that they are aware of the airport. It is found that if there is no supply-push at weeze, i.e. the airline offers as much flights as demanded, Eindhoven will grow at the expense of Weeze. There are however
no capacity constraints included in the model of which it is known that they have played a role. Figure 9.3 shows the difference between the total passengers at Eindhoven and Weeze if additional supply is provided and if supply matches demand. The autonomous growth rate is kept constant at 10% and in the case of supply push, 1 additional flight is added on top of the demanded flights at Weeze per month. With a supply push, the number of passengers at Weeze rises faster at the expense of Eindhoven.

![Figure 9.3.: Difference with supply push](image)

In the case of a constant growth rate and an equal development of awareness of an airport in all three regions, market shares will remain equal over time. Market shares can change for three reasons. The first is that awareness does not increase at the same speed for all airports. An intensive marketing campaign for example can boost the awareness of a specific airport. The second reason is the actual change in relative airport quality. Airport quality continuously improves as the supply side reacts on the increasing demand. Since the growth rate for all airports are considered constant in this case, the quality ratio remains constant. Only by offering additional supply or improving other quality aspects such as price and access time, the relative attractiveness of an airport can increase. Finally, the third reason is an unequal autonomous growth component in the regions. In Figure 9.4 the growth components are graphically depicted. The size of the bars are indicative and not based on empirical facts.
9.2 During tax

9.2.1 Observations and explanation

In essence, the tax that was introduced on the first of July 2008 changed the relative attractiveness of the airports in the system. The attractiveness of Eindhoven decreased while it increased at Weeze and Charleroi. The news that Eindhoven has become more expensive spreads quickly among the users of Eindhoven, however it is unlikely that everyone was fully informed about the actual price increase of €11.25. The people that are aware of Weeze and Charleroi adjust their choice. On the group level, this is reflected by an increasing market share of Weeze and Charleroi in the Dutch region. The average awareness however only increases slowly since the initial market share of Weeze and Charleroi in the Dutch region was low. The market shares will therefore not respond directly to the lower relative utility at Eindhoven but develop parallel with awareness. The increase takes place until the awareness equilibrium is reached again. In Figure 9.5 the perceived ticket price of Eindhoven and the actual ticket price at Eindhoven is depicted. A much sharper increase in perceived price can be observed among users of Eindhoven due to learning from direct experience. The users of Weeze take more time to become informed about the new price. It can also be observed that business passengers are informed faster than leisure passengers because they fly more. The more media attention surrounding the implementation of the tax, the higher the level of the perceived price and hence the higher the impact of the taxation on market shares.
The implementation of the tax was surrounded with intensive media attention. This did not only spread the word about the increased price, but also pointed out which airports could be used as alternatives. The effect of this media attention is comparable to a marketing campaign. It will result in an artificial increase of awareness, i.e. above the equilibrium value, of other airports. Similar to a marketing campaign, the media attention was finite and hence the awareness dropped to its new equilibrium value. The intensity of the media/marketing efforts determine the speed at which the awareness is obtained and the height of the awareness. The faster the awareness is obtained and the higher the level, the larger the number of passengers that change airport.

The taxation causes a change in market shares in the Dutch, German and Belgian regions. In the Dutch region, both Weeze and Charleroi gain market share at the expense of Eindhoven. To determine which of the two foreign airports gains a larger number of passengers two factors play a role. The first is the difference in awareness. The higher the awareness of one airport, the larger the gain. The second factor is the relative attractiveness of an airport. Charleroi has the disadvantage of being rather distant for a large part of the Dutch region whereas Weeze is more conveniently situated. Once again by using the logit function it can be concluded that the larger the relative attractiveness, the larger the market share. It can be concluded from the simulations that the larger the gain as a result of the tax, the larger the gain in equilibrium awareness. If the gain is too small, the equilibrium awareness is unlikely to change at all. Figure 9.6 and 9.7 show the development of the market shares and the awareness in the Dutch region respectively.

The figures show two situations. In the first situation only a small amount of additional marketing is conducted. In the second situation a large effort is put into marketing. The first case clearly shows that market shares return back to the pre-tax levels whereas in the second case market shares increase compared to pre-tax levels. The awareness shows a similar
9.2 During tax tendency. The drop in market share for Eindhoven results in a lower equilibrium awareness. Charleroi initially increases in market share and awareness but does not manage to attract sufficient traffic to sustain the additional market shares.

It should be noted that the intensity of marketing, captured by the effectiveness coefficient is based on an assumption. By varying this marketing effectiveness, the contribution that the marketing mechanism has to the overall behaviour is determined. In practise this will help to understand how marketing efforts could contribute, it does not depict how the marketing has actually been in reality.

![Figure 9.6.: Market share development Dutch region](image1)

![Figure 9.7.: Awareness development Dutch region](image2)
9.2.2. Lessons

The previous analysis has shown that the effect of the ticket tax is influenced by at least two factors. First the relative attractiveness between the airports determines which airport gains more in absolute terms. The second factor is the intensity of media attention and marketing effort. This effect has two sides. Marketing ensures that the perceived utility is updated faster and thus the maximum perceived price at Eindhoven increases, leading to a larger difference in relative attractiveness. Second, the awareness of the airports is increased, leading to the situation that more people are aware of the existence of the two foreign airports. The combination of the two sides leads to an increase of market share above the increase without media attention and marketing. This additional increase can be crucial for an airport since if an airport is unable to gain a sufficient market share, its relative attractiveness will not increase sufficiently and the market share will drop again to the pre-tax level. The airport will not obtain a larger post-tax market share in this case. If the gain in market share is large enough the post-tax market share will remain higher than the pre-tax market share.

For the foreign airports, the general rule is that the more the airports can increase the relative attractiveness during the tax, the higher the post-tax awareness and thus market share. To maximise the gain from a taxation abroad, an airport has to ensure sufficient marketing and the airlines have to ensure that the additional demand can be facilitated. To counteract any effects of the taxation, the taxed airports can improve their relative attractiveness. The increasing awareness of other airports is however hard to counteract since this is mainly influenced by word-of-mouth and marketing efforts of the other airports.

The price mechanism that is included in the model acts as a counter weight to the tax. The increase of the ticket price due to the tax leads to a lower demand, which in turn leads to a lower loadfactor. In order to increase the loadfactor, airlines reduce the price of their tickets. Similarly at the airports that are not subject to the tax the load factor increases and the price goes up. If the price would be reduced with the same amount as the perceived tax, no changes would occur in relative attractiveness between the airports. The only effect that will take place is due to the increased awareness as a result of intensive media coverage and marketing efforts.

9.3. Post-tax

9.3.1. Observations and explanation

In the period after the tax has been abolished, the system goes back to its pre-tax state because the relative attractiveness between the airports is moving back to its original value (Figure 9.9). The speed at which the system moves back is however different from the speed at which it arrived at the tax levels. In Figure 9.10 the market shares of the three airports in the Dutch region are depicted. The graph clearly shows that the slope of the curve during the tax is larger than (and opposite to) the slope of the curve after the tax. Two explanations have been found for this asymmetry.

Let’s first start with restating that market shares are influenced by the perceived utility of the airports and the awareness of an airport. Now the first explanation that is found refers to awareness. The awareness of an airport can grow by social exposure and learning, and thus at the speed associated with them. However, awareness can only decrease by forgetting, and the
speed at which forgetting takes place. Utility on the other hand is not decreased by forgetting but by social exposure and learning. Without awareness included in the choice model, the speed of changes in market share would only be affected by the speed at which perceived utility changes occur. By including awareness, a drop in perceived utility is damped. Hence, all other things being equal, market shares will thus increase quicker than they decrease if the market share is above a certain minimum level. The higher the market share, the greater the difference between the speed of growth and decline. In Figure 9.10 this can been seen by comparing the during and after tax slopes of the three airports. Charleroi with the lowest market share has an almost equal slope while Eindhoven with a large market share has a large difference between the slopes. This difference leads to a second explanation.

Figure 9.8.: Price balancing
The second explanation is related to the way updating of awareness and utility are specified in the model. Consider the following example:
The pre-tax perceived utility of Eindhoven is 100. During the tax, the actual utility is decreased with 10. Assumed it takes 2 months to learn about the actual utility. The magnitude of change in the first time step is the largest and equals \( \frac{\Delta V_p}{\Delta t} = \frac{(90 - 100)}{2} = -5 \). Now suppose that in 1 year the perceived utility has reached 92 and the actual utility is set back at the original level of 100 again. The largest magnitude of change is now \( \frac{\Delta V_p}{\Delta t} = \frac{(100 - 92)}{2} = 4 \). Hence it will take longer before the perceived utility is back at its original value. It is concluded that if the perceived utility does not reach the actual utility before the actual utility is set back at the original value, the speed of updating of perceived utility is higher during the first change than during the second change.

The example shows that due to the formulation of perceived utility updating, the speed of change is proportional to the difference between the actual and perceived utility. The awareness is updated in a similar way except that instead of an actual awareness the maximum (or minimum in case of forgetting) awareness is used. The combination of the difference between learning and forgetting and the different update speeds results in asymmetric behaviour of market shares. Awareness acts as a damper in case of (relative) utility decreases at larger market shares.

Figure 9.11 illustrates the damping effect of awareness for former users of Eindhoven that now choose for Weeze. When the tax is introduced, the fraction of people that previously chose Eindhoven and now choose Weeze increases rapidly as utility and awareness are updated quickly. When the tax is abolished initially the fraction drops quickly as a result of quick updating of the perceived utility. After an initial quick drop the fraction then settles into a much slower decline. This slowing down occurs at a speed that is set by the forgetting speed of awareness.

Figure 9.11 shows a somewhat different picture for the users of Weeze making a repetitive choice for Weeze. The argumentation why in this case no quick drop occurs after the tax has been abolished is that users of Weeze only hear about the price decrease at Eindhoven and
do not directly experience it. Therefore, the speed at which they become informed about the actual price is lower than the speed in case of direct experience.

Besides the asymmetric response another observation is made at the users group level. As a result of the implementation of the tax, former users of Eindhoven decide to try Weeze or Charleroi. By changing to the other group of users, they transfer their awareness of Eindhoven, which is 1, to the new group. If the size of the group of new users relative to the group of existing users is large enough, the average awareness of Eindhoven in the group will increase significantly. Figure 9.12 shows an increase of awareness of Eindhoven among Weeze users right after the implementation of the tax. When the tax is abolished, the awareness decreases again due to forgetting. The level drops below the pre-tax level due to somewhat lower market share of Eindhoven before it finally approaches the pre-tax level again.

9.3.2. Lessons

The analysis of the post-tax behaviour pointed out that the awareness is an important factor for the speed at which market shares are recovered. Ideally from the perspective of the Dutch airport, the abolishment of the tax would be accompanied by measures that increase the speed of learning about the actual utility at Eindhoven combined with measures that reduce the awareness of alternative airports abroad.

In terms of loss of passengers a taxation for a specified period of time can cause a delay in the normal development of the airport. If the duration of the tax is long enough, or the change in market shares is long enough, the passenger number at the airport that is subject to the tax might completely stagnate or even decline. Simulations with the model where the Dutch tax was not abolished show that Eindhoven looses all of its passengers. This is attributed to two causes that reinforce each other. The first cause is the reduction of flights at Eindhoven because the forecasted demand is lower than the current demand. This results in a lower relative attractiveness of the airport, leading to an even lower forecasted demand. When
the market share reduces, people will more easily forget about the airport. The decreasing awareness is the second cause for the overall decline.
Chapter 10.

Policy Recommendations

In the next chapter several policy options are developed and tested in the model. In Section 10.1 three ways of influencing the consumer choice are described. In the second section, Section 10.2 policies are tested that are aimed at convincing people in the Dutch region to use Dutch airports. In the third section, Section 10.3 measures are tested that are aimed at convincing people from the German region to use Dutch airports. Section 10.4 summarises the tested policies.

10.1. Approach

Besides using a model to help researchers in explaining observed phenomena, a system dynamics model is a useful tool to develop and test policy options without having to go through the expenses of conducting a real-world experiment. It is important however to realise that the model that is developed in this research provides an indication of what possibly are the underlying causes of the observed behaviour. Besides the explanations given, there are most certainly many more possible explanations. The policy recommendations that are developed in this chapter are only based on the explanation derived by the current model and are therefore only a subset of the total set of policy options. The expected behaviour of the model to the policies is subject to the assumptions that underlie the structure and specification of the model.

There are three distinct approaches that can be used to influence the outcomes of the model. In the sensitivity analysis it became apparent that the airport attributes on which the decision is based are most influential to the outcome of the model. The first approach is therefore to directly influence the actual utility of an airport. The second approach is to influence the perception of utility. The third and final approach is to influence the awareness development. All three approaches can be used separately or in combination.

The next sections provide an indication of policies that can be implemented by the Dutch government in order to influence airport market shares and thus consumer choice. The policy descriptions are not meant to be detailed blueprints that should be used in the implementation, rather they provide a brief overview of what the desired situation is, what the intended goal of the policy is, how it is expected to achieve the goal and the results that are obtained from the model.

For this study, two goals for the Dutch government are assumed:

1. Retrieve passengers that changed airport at the time of the taxation.
2. Optimise gains if neighbour countries implement a tax.
In Figure 10.1 both the approaches and policy goals are depicted.

The model proved to be behaviourally insensitive, which means that the shape of the output variables did not change considerably. As all system dynamics models, there is a large degree of numerical sensitivity to the input parameters. The most influential parameters are the determinants of utility, as can be expected. More interesting however is that the factors related with the formation of a habit have a relatively large influence. Also factors that define the effectiveness of communication between groups contribute significantly to the outcome.

The set of policies discussed below can either be implemented by the government or by airports.

### 10.2. Retrieve lost passengers

In the analysis of the model behaviour it was found that if the gain in relative attractiveness as a result of a tax on another airport is large enough, the airport can obtain a structurally larger market share compared to the pre-tax market share. This means that a number of passengers that previously used the untaxed airport has changed to other airports during the tax and did not change back to their original airport after the tax is abolished.

### 10.2.1. Improve market transparency

In Chapter 4 consumer behaviour is described. The search for information about possible alternatives and their properties precedes the actual decision. Searching for information is costly in terms of effort, time and money and therefore heuristics are often used to simplify and reduce the effort required to make a decision. This implies however that if information is made more accessible and available, the effort to gather information is reduced, and the necessity of using heuristics that are often sub-optimal is reduced.

This increase in transparency can for example be achieved by providing a combined overview of the expenses that are made to arrive at the airport, the parking fee if applicable and the price of the airline ticket. All this information is relatively easy to retrieve automatically but requires substantial effort if done manually, especially if several alternatives are considered.
An example of increased transparency can be found on the website “tix.nl” where quality (experience) characteristics of airlines can be compared besides the price of a ticket. This could be further expanded with the price of transport to and from the airport and other charges that are not directly incorporated in the ticket price.

The result will be that decisions can be made that are closer to the optimal outcome because people will be more informed about the actual costs and benefits of their choice. They will also learn faster if changes occur in the values of the choice factors. In Figure 10.2, the difference in annual growth per airport is depicted for two cases. In the first case, a normal learning speed is assumed. In the second case learning is faster because the market is more transparent. The increased learning speed is simulated by decreasing the number of flights required to learn about an airport attribute. In the normal learning case, the normal learning time of 3 flights is used. In the fast learning case the learning time is reduced to 1 flight. The increased growth rate at the time of the tax indicates that the change from one airport to the other occurs in a smaller period of time. The higher the growth rates, the larger the number of flights will be added by the airline and hence the larger the increase in relative attractiveness.

As an indication for required price differences in airline tickets, Table 10.1 shows the parking fees and surface transport costs and the difference with the costs at Eindhoven. The city of Tilburg has been used as a departure point. For the parking fees a duration of 10 days is used based on the long term parking tariff. The price of an airline ticket at Weeze should be 14.60 euro lower than at Eindhoven and at Charleroi the difference should be 67.60 euro.

\[\text{For every flight } \frac{1}{3} \text{ of the difference between actual and perceived is added to the perceived value}\]
Table 10.1.: Cost comparison (cost not included in the ticket price)

<table>
<thead>
<tr>
<th></th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking (10d long term)</td>
<td>€ 59.00</td>
<td>€ 55.00</td>
<td>€ 88.00</td>
</tr>
<tr>
<td>Petrol</td>
<td>€ 7.40</td>
<td>€ 26.00</td>
<td>€ 46.00</td>
</tr>
<tr>
<td>Total</td>
<td>€ 66.40</td>
<td>€ 81.00</td>
<td>€ 134.00</td>
</tr>
<tr>
<td>Difference EIN</td>
<td>€ 14.60</td>
<td>€ 67.60</td>
<td></td>
</tr>
</tbody>
</table>

10.2.2. Improve access times

Directly after the tax has been abolished, the group of people that left the taxed airport is still very aware of the taxed airport and informed about the airport attribute values. Therefore it is unlikely that many people have already developed habitual behaviour. Because awareness of the taxed airport is still high it is not very effective to try to increase awareness or inform travellers about the attributes if there is no real increase in the relative attractiveness of the taxed airport. The relative attractiveness of the airport should therefore be increased.

The increase of relative attractiveness is mainly a task of the airport itself. The role of the government is limited to providing and improving the infrastructure to reduce access times and increase the connectivity. The improved access times have to be communicated to the potential users of the airport. Only relying on word-of-mouth communication might be sufficient if the airport has a large market share in the region. In regions where the market share is less the communication needs to be stimulated by media attention or marketing.

Improving the access time to the airport increases the relative attractiveness of an airport resulting in a larger market share given that people become aware of the improvements. The model runs show that if the access time to Eindhoven is reduced by 10% there is no visible effect on the market shares in the German region. Further inspection of the difference between perceived utility of Eindhoven show that in the Dutch region everyone becomes informed about the utility change fairly rapidly. In the German region there is almost no update of perceived utility, indicating that people in Germany simply do not know about the improved accessibility of the airport. Access time is considered as a partial experience attribute that you don’t communicate to friends or family outside of your own region. The only way to become informed about access time to an airport in an other region is to or directly experience, hear about it from people in your region that experienced it, or by marketing.

It is clear that improving accessibility only is not enough. Two other measures could accompany infrastructure improvements. The sensitivity analysis showed that the model is sensitive to inter-regional communication changes. For access time this is however not applicable since access time is not communicated between two regions. The other approach is through marketing efforts from The Netherlands that are targeted at the German and Belgian regions. Figure 10.3 shows that additional marketing has an opposite effect on the perceived access time. More marketing slows down the updating of utility. The explanation for this is that with marketing also communicates information about the number of flights and the average ticket price. While Weeze is still relatively more attractive than Eindhoven, marketing will increase the market share of Weeze.

The only effect of infrastructural improvements seems to be within the Dutch region itself. If in 2011 the access time is improved by 10% this results in a slightly higher market share compared to the case in which no reduction of access time is achieved and without additional inter-regional marketing.
10.2 Retrieve lost passengers

10.2.3. Attract airlines

The main structural difference between the situation before and after the tax is that Weeze surpassed Eindhoven in the number of flights that are offered. The relative attractiveness of Weeze therefore increased, attributing a larger share of the market to Weeze at the expense of Eindhoven. To get back in the race, Eindhoven can try to reduce the difference of possible flights and destinations with Weeze.

Airports have several strategies to attract additional or new airlines. The most common are incentive schemes for new destinations, and all sorts of cost transfer for example by paying for marketing or handling. A supply push was introduced in the model to simulate the effect of additional flights on the market share of the airport. The flights are offered on top of the normal demanded quantity of flights with an amount of 2 additional flights per month each month.

In turns out that given the assumptions in the model, if an airport has a low relative attractiveness, adding flights increases the market share in the region of the airport itself. If an airport has a high relative attractiveness, adding flights increases the market share of the airport in other regions. Because Eindhoven currently offers less flights than Weeze, expanding the offer would persuade people in The Netherlands to use Eindhoven instead of Weeze. The effect is however very small, but can be larger if more airlines and flights are attracted accompanied by marketing.

10.2.4. Facilitate competition

From a more institutional perspective, the Dutch government should make sure that airports are free to strengthen their competitive position within the boundaries of environmental and
safety constraints. Weeze strengthened its competitive position considerably due to the Dutch tax and the decision of Ryanair to expand its operations there. Airports thus compete for both passengers and airlines, and both have to be convinced that the airport is the best choice for them. In order to do that the airport has to develop at least as fast as its competitors. If this development is hindered by any means, there will be a loss of potential market share. If Eindhoven for example is limited by runway capacity, and at Weeze or Charleroi there is still sufficient capacity, Eindhoven will stop developing and lose market share whereas Weeze and Charleroi can continue to expand and gain market share. Of course these effects are stronger when "footloose" carriers are considered instead of network carriers.

This case can easily be demonstrated by putting a constraint on the number of flights that can depart from an airport. The constraint will not completely stop the growth of the number of flights but will just permit a small increase that is smaller than the increase required to facilitate demand. Figure 10.4 shows what happens if the monthly growth of Weeze is reduced to 35 flights in 2011. The relative attractiveness of Weeze in Germany will decrease since the most important competitor Eindhoven is not restricted in its growth.

10.3. Optimise gains neighbour taxes

At the moment of writing, there is a discussion in Germany about the introduction of a tax on airline tickets similar to the tax in The Netherlands. The implementation of this tax in Germany, will reduce the relative attractiveness of Weeze again and is therefore able to change the market shares in Germany, The Netherlands and Belgium.

The most profitable way for the Dutch airports is to make sure that everybody in The Netherlands knows about the price increase in Germany. Furthermore, it is nice to increase the
10.3 Optimise gains neighbour taxes

Inter-regional transfer of information is modelled to take place at a lower pace than information transfer within a region due to language barriers and a smaller probability to encounter one another. If a tax would be introduced in Germany without any notice, people in the Dutch region would find out about it only very slowly (direct experience and a little bit of marketing). The change in market shares will therefore not be large initially, but will increase over a longer period of time if the tax continues to exist.

The key now is to inform as many people about the price increase as possible within the shortest amount of time. Learning by experience is an effective way to get informed about the price, however the market share of Weeze in The Netherlands is rather small and will become even smaller at the time of the tax. The result is that the perceived price of a ticket from Weeze will not converge towards the actual ticket price but stabilises somewhere below (Figure 10.5).

If additional marketing is conducted, the perceived price stabilises at a slightly higher level. The marketing should only communicate the price difference since the number of flights offered at Weeze is still larger than at Eindhoven, making it more attractive. The effect of this additional marketing is however really marginal. In the sensitivity analysis the model proved to be sensitive to inter-regional communication. While testing a policy in which inter-regional communication was improved it was found that although this communication is more effective than marketing, it moved the market share in the wrong direction. The reason for this is that word-of-mouth communication between two regions transfers both information about the price and about the number of flights offered. As long as the relative awareness of the German people about the Dutch airport. Supply must respond immediately in order to gain a structural effect.

10.3.1. Inform Dutch about the tax

Figure 10.5.: Utility update normal conditions
10.3.2. Create awareness of Eindhoven in Germany

The number of passengers departing from Eindhoven is mainly limited by the size of the population in the Dutch region. If a tax would be implemented in Germany, people that used to fly from German airports might now consider to use a Dutch airport. The pre-condition is of course that these people know about the Dutch airports, just as the Dutch first had to know about the German airport before they start using it. In order to profit from a tax across the border in Germany, Dutch airports have to make sure that their name is known in Germany. Airports themselves are responsible for generating this awareness.

The awareness can be increased by two mechanisms. The most effective would be to improve inter-regional word-of-mouth communication. This can be achieved by for example hosting a website on which passengers can tell their experience with an airport. Another way is to organise events at the airport or related to the airport that attract an audience from abroad (we have seen this at Weeze airport as well). The other way is to launch a marketing campaign in Germany informing people about the possibility to fly from Eindhoven. Figure 10.6 shows the effect of the two approaches on passenger choice. It can be concluded that the effectiveness of both measures is low due to the high relative attractiveness of Weeze in the German region. The awareness of Eindhoven in the German region can be greatly increased if the word-of-mouth communication can be improved.

10.4. Summary of policies
### Table 10.2.: Policy overview

<table>
<thead>
<tr>
<th>Policy</th>
<th>Mechanism</th>
<th>Who</th>
<th>How</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transparency</td>
<td>Perception</td>
<td>Industry/partially government</td>
<td>Improve availability and accessibility of information</td>
<td>Decision based on more complete information</td>
</tr>
<tr>
<td>Access times</td>
<td>Actual</td>
<td>Government</td>
<td>Improve and expand infrastructures connecting the airport to its catchment area</td>
<td>Limited to a slightly higher market share in the Dutch region</td>
</tr>
<tr>
<td>Attract airlines</td>
<td>Actual</td>
<td>Airports</td>
<td>Incentive scheme, handling discounts, supply push at Eindhoven</td>
<td>Slight increase in market share in Dutch region</td>
</tr>
<tr>
<td>Facilitate competition</td>
<td>Actual and perceived utility</td>
<td>Government</td>
<td>Reduce regulatory pressure on airports, offer them the freedom to compete Eindhoven</td>
<td>Having any sort of limitation greatly reduces market share while the airport is in competition</td>
</tr>
<tr>
<td>Inform Dutch</td>
<td>Perceived</td>
<td>Airports/government</td>
<td>Market price changes of foreign airports in The Netherlands</td>
<td>Slight increase in market share of Eindhoven in The Netherlands</td>
</tr>
<tr>
<td>Create awareness</td>
<td>Awareness</td>
<td>Airports</td>
<td>Market Dutch airport in other regions</td>
<td>Slight increase of market share of Eindhoven in other regions</td>
</tr>
</tbody>
</table>
Chapter 11.

Conclusions

This final chapter of the thesis is dedicated to summarise all the insights that were obtained from the literature and from the analysis of and experiments with the simulation model. This chapter is subdivided into three parts. In Section 11.1 the research questions are answered. In the second part, Section 11.2 describes the limitations of the study and the model and clarifies the contribution. In the last part, Section 11.3 two suggestion for further research are brought forward.

11.1. Conclusions drawn from the modelling study

11.1.1. Literature review

Air travel demand, as can be measured by recording passenger statistics, is the product of millions of considerations and thousands of implicit and explicit choices made by air travellers. By understanding the way air travellers consider and decide about their travel itineraries, it is possible to explain how air travel demand is shaped.

The literature study provided an answer to the central question “Which mechanisms influenced the redistribution of air travel demand as a result of the Dutch ticket tax”, in The Netherlands, Belgium and Germany and how can this redistribution be explained over time?”. In order to answer the central question, first the process of decision making is analysed and an investigation is conducted to find out which information is required to make a decision and how this information is obtained. It is concluded that:

- The choice for a specific airport depends on the personal preferences of the traveller, the set of airports that a traveller is aware of and the attractiveness of an airport expressed in perceived utility.

- The awareness of airports and the information about the attractiveness of airports is obtained through social interaction, marketing and direct experience. Literature suggests that direct experience results in the most reliable and objective type of information, whereas information obtained through marketing has encountered the most resistance and biases. Information stemming from trustworthy sources such as friends and family is least likely to encounter resistance.

- Information of airports and their attributes is therefore often diffuse and incomplete which could possibly result in sub-optimal choices. In other words, an air traveller tends to make a rational decision based on the information she or he possesses, which does not necessarily have to be complete. The actual choice is based on bounded rationality.
The second question to answer is which subjective and objective attributes a consumer considers when deciding about an airport. From the literature it is concluded that:

- Three important choice factors are found in most studies. The price of an airline ticket is most often found to be the most important factor in airport choice. The number of flights and destinations offered is on the second place and the access time to the airport comes third.

- To measure personal preferences, stated and revealed preference studies are conducted. These studies are used to estimate the weight consumers give to the different characteristics of an alternative (choice factors).

The influence of airlines in the consumer decision is analysed. It is concluded that the airlines influence airport choice through the following behaviour:

- Airlines continuously try to optimise revenues by maximising the utilisation of their fleet. On routes where potential demand is high additional flights are scheduled while on routes where there is insufficient demand the number of flights will be reduced. Hereby airlines influence the attractiveness of an airport resulting in a dynamic interaction between airline and air traveller.

- The law of supply and demand is in charge in competitive markets to set the price for airline tickets. The higher the demand, the higher the price of an airline ticket and vice-versa. The price directly influences the attractiveness of an airport which results in a second form of dynamic interaction between airlines and air travellers.

In order to answer the question “Which methodology is most suitable for modelling consumer behaviour and airport competition?” the requirements to the modelling method have been derived first. These requirements are:

- The method that is selected should be able to represent the states of the system over time, allow for dynamic interaction between the elements in the model, specify the inner mechanism that drive the output behaviour (white box) and facilitate an easy way to specify soft factors such as perceptions and awareness.

To make the final selection, first the characteristics and the suitability of other methods that have been used in the past to investigate consumer behaviour and airport competition are investigated. These characteristics are:

- Three methods are currently widely applied in research on consumer choice and airport competition and demand forecasting. Cross-sectional regression analysis is the most common method to estimate models to predict consumer choice. Econometric simulations based on these regression models are used to predict relative long-term future demand for one or more airports. Trend extrapolation is used to predict short-term demand.

- None of the currently applied methods explicitly incorporates aspects of bounded rationality. Air travellers are assumed to know about all possible airports and their actual characteristics. This assumption can be made in case the model is estimated on empirical data that includes these effects of bounded rationality. It can however not be used to analyse the effects of bounded rationality on consumer choice.

- All of the currently applied methods focus on numerical accuracy instead of understanding the inner mechanisms of the system. This makes it more difficult to develop and test policies because the factors that could be influenced by the policies might lie inside the system instead of being a direct input of the system.
After the investigation it was concluded that:

- System dynamics is a suitable method to model consumer behaviour and airport choice. First, the processes of information acquisition and forgetting can be modelled endogenously. It allows for representation of behaviour over time and focuses on qualitative insight rather than on numerical accuracy. The method is suitable to study and unravel the dynamics of complex systems.

11.1.2. Model insights

The analysis of the model under normal conditions was used to identify which are the mechanisms that influence the redistribution of passengers between Dutch and German/Belgian airport. It is concluded that:

- Deduction from simulation result leads to the conclusion that at developing airports such as Weeze there should be at least three components that contribute to the overall growth rate. The first is related to autonomous growth that is based upon GDP development and should be available to all airports that experience the same GDP development. The second component is the contribution of supply factors such as price and destinations/frequency. The last component is the development of awareness of the new airport.

- Over-expectancy of the utility of an airport in the early stages of development can result in large differences in equilibrium market shares. Even though perceptions adjust when travellers start experiencing the airport, the additional demand that stems from over-expectations motivates the supply-side of the market to provide additional supply. The relative attractiveness of the airport is thus increases faster than under circumstances without over-expectancy.

- An airport can achieve a higher market share if the autonomous growth in the region is larger than the growth rate at other airports, if the relative attractiveness of the airport increases and if the level of awareness develops faster than for other airports. An increase of relative attractiveness can be obtained by expanding the services of airlines or reducing prices. Faster development of awareness can be achieved through marketing until full awareness is reached.

- The supply-side is a critical factor in obtaining the relative attractiveness advantage. This confirms that in the real-world a combination of a supply-driven and demand-driven market exist.

- The awareness of an airport reaches an equilibrium level that depends on market share, flights per passenger per time unit and the time it takes to forget about an airport. A marketing campaign can be used to increase the equilibrium awareness and thus to raise market shares. However, the intensity and duration of a marketing campaign should be cleverly determined. A campaign that is insufficiently intensive or too short might only have a temporary result in terms of increasing market shares. A campaign that takes too long might not be cost-effective since the effect of the campaign diminishes with increasing awareness levels.

- The tax that was introduced at airports in The Netherlands changed the relative attractiveness of the Dutch airports. This lead to a higher share of Dutch travellers choosing
for Weeze and Charleroi. This change is however not instantaneous. First the travelers that normally use Eindhoven have to become informed of the price increase. Then they have to become aware of the alternative airports. The learning about Eindhoven for users of Eindhoven is relatively fast, whereas users of other airports take longer to become informed.

- A fast response of the supply-side to the tax is critical in terms of obtaining a higher post-tax market share. If the airlines are not able to satisfy the demand, the relative attractiveness difference between the taxed and non-taxed airports decreases. The key is to generate the largest possible relative attractiveness difference at the time of the tax.

- The average ticket price acts as a counterweight for demand shifts. A sudden loss of demand at Eindhoven may lead to a decrease of the average ticket price at Eindhoven, which in turn results in a higher attractiveness of the airport. The larger the price change the smaller the net effect of the tax.

- Awareness functions as a brake on market share drops. If the perceived utility of an airport falls quickly, the speed at which market shares change is initially determined by the quick drop in perceived utility. Once everyone is aware of the new utility, the slowly decreasing awareness still leads to a decrease of market shares towards the new equilibrium. The speed of this decrease however is slower than the decrease of perceived utility due to the long forgetting time. An asymmetric response occurs due to the difference at which awareness is increased and decreased. Increasing of awareness takes place at the speed of learning, word-of-mouth and marketing. Decreasing of awareness takes place at the speed of forgetting, which can safely be assumed to be slower than learning.

- If the tax were to be kept in place this could have drastic consequences for the taxed airports in case of credible non-taxed competitors. These consequences are assumed to be worst in case there are no other taxed "donor" hub airports that can supply passengers to regional airports and hence keep their passenger numbers up.

The final research question that should be answered is "Which are the factors and mechanisms that can be used by the Dutch government to effectively influence airport choice of Dutch air travellers?". The first question to be answer is if any structural changes have occurred as a result of the Dutch ticket tax. It is concluded that:

- The increase in market shares obtained by the non-taxed airports depends partially on the intensity of the marketing/media attention and the relative attractiveness difference between the airports. If the airport is able to gain a sufficiently high market share as a result of the tax, the post-tax equilibrium awareness will be higher than the pre-tax awareness. Hence, a sufficiently large gain leads to a structural change in market shares. There seems to be a critical mass above which the airport fully takes over the market in the long run. This is under the assumption of a demand driven market.

Before intervention can be conducted effectively, it should be know which of the factors in the system result in the largest changes of system response when changed. The sensitivity analysis showed that:

- The three choice factors, price, frequency and access time, are factors that the model is by far most sensitive to. These sensitivities are influence by the values of the preference weights or beta values.
11.1 Conclusions drawn from the modelling study

- Intra-regional word-of-mouth does not contribute to demand shifts since the difference between perceived utility tends to be small within a region. Furthermore, the utility update is opposed to the actual direction of change if the sending party is less informed about the actual utility than the receiving party. Inter-regional word-of-mouth contributes more to perception updates and the model is found to be sensitive to the effectiveness of inter-regional communication.

- The model is relatively sensitive to changes in the time it takes to ignore other viable alternatives when a habit is formed. Because the duration of this period partially determines the average equilibrium awareness, it affects the maximum market share an airport can obtain given the difference in relative attractiveness.

Several policy measures have been tested in the model. It is found that:

- The role of the Dutch government is limited. If market transparency would improve, people might base their choice on more accurate information. A limited analysis of prices showed that the difference in travel costs for Dutch people between Eindhoven and Weeze is larger than the tax. Which means that if the average ticket price was equal, it does not make sense to travel to Weeze.

- The effect of infrastructure improvements to retrieve some of the passengers that changed to airports abroad is limited. The model is based on the assumption that people living in different countries do not communicate the travel time. The policy has limited results to improve market shares in The Netherlands and almost no result to improve market shares abroad.

- A better policy, that can be implemented by airports, would be to attract additional airlines or create an incentive for existing airlines to open more routes. This improves the relative attractiveness of Eindhoven and increases the market share of Eindhoven in the Dutch region.

- The most important conclusion is that airports must be able to compete in the market. Airports should be attractive to both passengers and airlines. The strategy of the airport should be based on finding a balance between the interests of these parties. If external influences limit the ability to take actions in order to improve competitiveness, this will have consequences for the market share. The government should allow sufficient freedom for the airports to compete. Furthermore, any legislation that reduces the relative attractiveness of an airport, will influence the market shares and its growth path.

- In case of a German tax, it pays of to inform the people in the Dutch region about the increased price abroad. Without additional marketing, the effect of a tax will be small as the perceived price difference remains limited. Important is that only the information about the price is communicated and not the information about the number of flights since the Weeze is still relatively more attractive due to the higher number of flights offered. The awareness increase policy also showed only small increases of the market share of Eindhoven in Germany.

- In general, all policies are found to have only small effects on market shares. The returning factor for each policy is that any change made in the actual airport attractiveness should be communicated to the potential users of the airport if the market share of the airport is insufficient to ensure an natural spread of information through word-of-mouth. In specific when the targeted group of potential users is in another region as the airport.
The most important side-effect of intervention was found to be:

- In case word-of-mouth or marketing is conducted, the airport with the largest relative attractiveness will benefit from that. If marketing would be only focused on the attributes that make the airport superior relative to its competitors, an airport with a lower relative attractiveness can profit. Marketing is the only means to focus the transfer of information on a specific attribute.

11.2. Limitations and contribution of the study

11.2.1. Limitations

One of the main limitations of the model is that the set of airports only consists of three relatively small regional airports. It is expected however that the larger hub airports function as passenger donors to regional airports since more people transfer from busy, expensive and impractical hub to smaller more comfortable airports that are also less expensive due to the presence of low-cost carriers. The consequence of this limited set of airports is that the model cannot explain the rapid development of Weeze since the increase cannot be derived only from Eindhoven.

Another limitation is the lack of endogenous supply driven influences. The model is completely demand driven, meaning that the supply only adds or removes flights and destinations in reaction to demand changes. In reality this is most certainly not the case since there will at least be a mix of a demand driven and a supply driven market. In order to obtain a better understanding of the dynamics that result from the supply-driven market structure, and to explain more of the observed behaviour, the airline behaviour model should be expanded.

The model includes only one airline that has similar characteristics and behaves similar on all three airports. In reality the market is more complex since different airlines with different business models act on each airport. Furthermore the routes that are offered are assumed to be equal at all airports and thus potentially competitive. In reality there is a set of unique routes for each airports which enables them to address a specific niche market without direct intervention of competitors.

In the model it is assumed that airport capacity and other institutional constraints related to capacity did not play a role in the development of air traffic at the three airports. This assumption might be valid for the short time frame of the taxation, but is certainly invalid if the model is simulated over a longer time frame. Due to the lack of capacity restrictions, the traffic might develop more rapidly than in reality could be achieved and more so without a limitation. To facilitate long term simulations, the model should be expanded with an airport strategy sub-model that reacts on demand from both airline and air traveller in order to create expansion plans.

The use of system dynamics required a high level of aggregation of the system. Passengers are therefore models as groups in which each individual shares the same average perception as its group members. A group exists of people that last used a particular airport and live in the same region. The tracking of perceptions and awareness therefore stops at the group level rather than at the individual level. This might work for understanding the dynamics of the system but is insufficient for obtaining numerical precision. Until a point, the model can be developed further to decrease the level of aggregation. The price is a loss of oversight and
comprehension of the dynamic behaviour and the model becomes harder to use for people that did not develop it. The winning would be the achievement of higher numerical precision. The balance is totally dependent on the purpose of the study and the application of the model.

The insights obtained by studying the model are valid within the system that is captured in the model. In order to use the insights outside the modelling environment the limitations of the model should be taken into account as well as the complexity of the outside environment in which the real system evolves. Furthermore, the insights depend a lot on assumptions and specific formulation of the model. In the most positive scenario the model could give suggestions what could happen under certain conditions, but can by no means be used to produce accurate numerical estimates.

The parameters that are used for the preferences are identical for both business and leisure passengers. In reality these preferences are different since it is known that the value of time of business travellers for example is higher than for leisure travellers. Another consideration is that the preference weight for the price is adjusted to match a price elasticity of about -1.5. This calibration is done directly at the logit function and therefore does not include the effect that awareness has on the market shares.

It seems that the three choice factors included in the model might be the ones that people use for making a decision but they do not cover the complete picture. Mainly the average ticket price is subject to bias since it does not include the surface transport costs to the airport and the parking fees. The model however does not facilitate a means to incorporate learning about the secondary costs, which might be a useful tool for policy making.

11.2.2. Contribution and added value

The main contribution of this research that should be put forward is the experience gained with the use of system dynamics in airport choice modelling. As far as I am aware of the has not been a model, that was dedicated to aviation, that has tried to model how consumers and airlines/airports interact. It has been a very first exploration of the potential of system dynamics in this field.

Related to the formulation of the problem at hand, the key question of the research was to find out about factors that drive the redistribution of travel demand, and more specifically the factors and mechanisms that are related to bounded rationality. The model contributes to our insight in these often complex factors and mechanisms by combining the knowledge obtained from the literature study into a simulation model, and hereby providing a well-structured overview of the elements and their relations that make up the system.

The simulation model allows us to experiment with the elements of the system and therefore gives us insight what possible states the system could reach under the assumptions made and how the different elements contribute to arrive at those states. The model has been used to determine the sensitivity of the outcomes to changes in factors, which in turn provides guidelines for policy development.

Mostly the model has supported the researchers in documenting and analysing the perceived relations that most people consider as evident, but of which most people are unable to oversee the combined effect. The model directs the process of reasoning and provides quantitative indications of how the system might respond to changes that are hard or even impossible to determine analytically. System dynamics serves well in this purpose as long as the limitations of the model and methodology are clear and explicit.
The limited time in which this study had to be completed brought the necessity to make choices about what to include and what not to include in the model. In terms of interactions, the model mainly captures the interaction among travellers and between travellers and airlines. This last type is however limited since it is assumed that the market is demand-driven. The insights that are derived from the model are thus mainly based on consumer interaction and choice. These insights are useful to all parties involved in air transport that deal with the transportation of people. Airports, airlines and governments may use this model to get a grip on how changes in their business or legislation might evolve and influence other parties.

11.3. Further research

There are two directions for further research. The first is to expand the current model by adding more airports and elaborate on the supply-side behaviour. It is recommended to first add the three major hubs, Amsterdam Airport Schiphol, Düsseldorf International and Brussels Airport, that are in the vicinity of the regional airports. Most interesting is to see how they compete with the regional airports and how many passengers would be lost at Schiphol in case a tax would be introduced. Furthermore, with the recent discussions about the German "ticket tax" it is interesting to see what would be the effects on airport competition if Germany would introduce a tax.

The supply-side sub-model could be expanded by adding a second decision core for airport choice by airlines. In Graham (2008) a list of airport choice factors for passengers and for airlines is given. There is also ongoing research (PhD) by Franziska Kupfer of the University of Antwerp on airport choice for freighter operators. This might provide useful insights on the (weighting) factors that are important. For airlines the catchment area and potential demand, slot availability, fees and costs seem to be of great importance. Full service network carriers add network compatibility to this list. Given the level of aggregation, congestion seems to be an interesting factor to model endogenously.

Airline competition should be on intercontinental (ICA) and on low-cost services. An indication of the weight differences between ICA and low-cost travellers should be available. From the most recent PBL publication we already know that own price elasticity for air transport passengers is larger for short distance then for long distance trips. It is very interesting to see how the Schiphol passengers are distributed and how this affects the growth at Weeze.

An airport behaviour sub-model can be added to capture the decisions airports take to expand their facilities. This way the relative attractiveness of the airport to airlines and passengers can be influenced endogenously. It should be noted however that at this stage the model is more interesting to research airport development than to research the effect of a tax. The time frame for the simulation can be extended to include the more long term dynamics. It would be interesting to see what kind of development patterns new and existing airports can follow under competition and different institutional and other environmental influences.

A completely new start can be made if the model would be translated into an agent-based model. If the purpose would be to have a less aggregate model and to potentially obtain higher numerical precision, agent based modelling (see for example Gilbert 2008) could be a methodology that offers new opportunities. The precondition is however that there is

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1PlanBureau voor de Leefomgeving
2The own price elasticity is the measure economists use to indicate the change of demand of a product as a result of a 1% change in the price of that product.
11.3 Further research

sufficient and sufficiently disaggregate data to populate the model. This data should at least contain the population composition in the different geographical regions at a preferably small resolution, the route and flight schedules of all airlines that operate from the modelled airports, a basic idea on the strategies that the different airlines use and the differences between them, and finally the preference weights of the different traveller groups and most preferably also of the airlines themselves.

A more informal evaluation of the research project is found in Appendix G.


Appendix A.

System Diagram

The system diagram in Figure A.1 represents the modelled system within its boundaries (depicted by the dashed rectangle). The ovals on top indicate policy measures, the ovals on the left indicated exogenous factors and the ovals on the right indicate performance indicators.

Figure A.1.: Elaborate system diagram
Appendix B.

Specification

2005

Passengers and Flights

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<td>5917.44</td>
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<td>mov./month</td>
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<td>167.96</td>
<td>688.79</td>
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Pax data retrieved from airport websites, annual statistics divided by 52 to get per week
Flights data retrieved from airport websites

Initial fraction users per motive/ per region (Dmnl)

<table>
<thead>
<tr>
<th>Region</th>
<th>Motive</th>
<th>EIN*</th>
<th>NRN**</th>
<th>CRL***</th>
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<td>23%</td>
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<tr>
<td>Leisure</td>
<td>77%</td>
<td>77%</td>
<td>72%</td>
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* Annual report Eindhoven airport 2006
** Business pax at NRN unknown!!!
*** Annual report Brussels Tourist and Convention Bureau 2005

Global growth rate aviation (1/month)

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<tr>
<th>Region</th>
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<th>(1,1*(1/12))-1</th>
<th>10% annually</th>
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<tr>
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<td>0.00797</td>
<td>0.009</td>
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<tr>
<td>CRL</td>
<td>0.009</td>
<td>0.00797</td>
<td>0.01877</td>
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</table>

Frequency of flight (flight/month)

<table>
<thead>
<tr>
<th>Region</th>
<th>Motive</th>
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<th>NRN**</th>
<th>CRL***</th>
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<tr>
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<tr>
<td>NRN</td>
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Sensitivity test

Word-of-mouth effectiveness (1/month)

<table>
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<tr>
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<th>NRN</th>
<th>CRL</th>
</tr>
</thead>
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<tr>
<td>EIN</td>
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<td>0.00797</td>
<td>0.009</td>
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<tr>
<td>CRL</td>
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<td>0.00797</td>
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Marketing effectiveness (1/month)

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</thead>
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<td>CRL</td>
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Sensitivity test

Learning speed (flights)

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Initial awareness tables (Dmnl)

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<tr>
<td>Aware of..</td>
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<tr>
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<tr>
<td>CRL</td>
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Initial perceived utilities [min], [flight/month], [euro]

<table>
<thead>
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</tr>
<tr>
<td>EIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRN</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>CRL</td>
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Kept similar to actual utility initially, however are of course extremely interesting to change.

### EIN

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### NRN

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### EIN (freq)

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<th>CRL</th>
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### NRN (freq)

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### CRL (freq)

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<td>CRL</td>
<td>416</td>
<td>168</td>
<td>689</td>
</tr>
</tbody>
</table>

### EIN (fare)

<table>
<thead>
<tr>
<th>Users of...</th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>NRN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>CRL</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

### NRN (fare)

<table>
<thead>
<tr>
<th>Users of...</th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>NRN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>CRL</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

### CRL (fare)

<table>
<thead>
<tr>
<th>Users of...</th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>NRN</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>CRL</td>
<td>100</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

### Social exposure forgetting effect

- Reference social exposure (1/month) 0.001
- Slope of reference point (Dmnl) 50
- Maximum forgetting rate (1/month) $\left(2^{1/(12)}\right)-1$
- Forgetting time related to habit (month) 24

### Forecasting demand

- Time to perceive present condition (month) 1
- Time horizon for reference condition (month) 12
- Time to perceive trend (month) 1
- Forecast period (month) 0.5

### Normal average load factor (Dmnl)

| All airports | 0.8 |

KiM, 2010, Factsheet
<table>
<thead>
<tr>
<th>Seats per aircraft (seat/flight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All airports* 189</td>
</tr>
</tbody>
</table>

* based on Boeing 737-800 high-density

<table>
<thead>
<tr>
<th>Scheduling delay (month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>Delay</td>
</tr>
</tbody>
</table>

Based on KLM estimate obtained in interview with KLM

<table>
<thead>
<tr>
<th>Initial flights per airport (flight/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>Flights</td>
</tr>
</tbody>
</table>

Based on PAX numbers/ (aircraft capacity*average load factor)

<table>
<thead>
<tr>
<th>Average ticket price (eur)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airport</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>Price</td>
</tr>
</tbody>
</table>

Reference level, base year is 100

<table>
<thead>
<tr>
<th>Accessibility table (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>to airport</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>EIN</td>
</tr>
</tbody>
</table>

Based on ANWB routeplanner, distance chosen from airport to airport

NRN  | 68   | 30   | 152  |

Intrazonal times are reference values

CRL  | 116  | 152  | 30   |

<table>
<thead>
<tr>
<th>Betas</th>
</tr>
</thead>
<tbody>
<tr>
<td>fare</td>
</tr>
<tr>
<td>leisure</td>
</tr>
<tr>
<td>frequency</td>
</tr>
</tbody>
</table>

Partially used from study Terpstra fare is adapted based on own price elasticity of -1.5

| !!!CALCULATIONS!!! |

<table>
<thead>
<tr>
<th>Initial aggregate actual utilities [CALCULATED] (Dmnln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>NRN</td>
</tr>
<tr>
<td>CRL</td>
</tr>
</tbody>
</table>

Multiplication of actual utilities and betas for each user group

<table>
<thead>
<tr>
<th>Passenger choice per region (probability) [CALCULATED]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users of..</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>NRN</td>
</tr>
<tr>
<td>CRL</td>
</tr>
<tr>
<td>Totals</td>
</tr>
</tbody>
</table>

Logit function uses betas, actual utilities and awareness

| Users of.. |
| EIN  | NRN  | CRL  | Sum |
| EIN  | 0.2049 | 0.7951 | - | 1 |
| NRN  | - | 1.0830 | - | 1 |
| CRL  | - | 0.9418 | 0.0582 | 1 |
| Totals | 0.0683 | 0.9123 | 0.0194 | 1 |

| Users of.. |
| EIN  | NRN  | CRL  | Sum |
| EIN  | 0.0150 | - | 0.9850 | 1 |
| NRN  | - | 0.0051 | 0.9949 | 1 |
| CRL  | - | 1.0000 | - | 1 |
| Totals | 0.0050 | 0.0017 | 0.9933 | 1 |
## Initial People in Area (pax/week) [CALCULATED]

Population in Area*

<table>
<thead>
<tr>
<th></th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>EIN</td>
<td>NRN</td>
<td>CRL</td>
<td>Totals</td>
</tr>
<tr>
<td>EIN</td>
<td>74641.406</td>
<td>192431</td>
<td>0.9723</td>
<td>0.8192</td>
</tr>
<tr>
<td>NRN</td>
<td>18228.67</td>
<td>0.0198</td>
<td>0.3403</td>
<td>0.0635</td>
</tr>
<tr>
<td>CRL</td>
<td>0.0079</td>
<td>0.0079</td>
<td>0.0079</td>
<td>0.0079</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Region</th>
<th>Originating</th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business</td>
<td>34335</td>
<td>8385.19</td>
<td>59679.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leisure</td>
<td>34843.29</td>
<td>84216.5</td>
<td>429503</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>379176.34</td>
<td>92601.6</td>
<td>485180</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motive</th>
<th>EIN</th>
<th>NRN</th>
<th>CRL</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td>EIN</td>
<td>NRN</td>
<td>CRL</td>
<td>Totals</td>
</tr>
<tr>
<td>EIN</td>
<td>61145.576</td>
<td>8595.78</td>
<td>4900.05</td>
<td>74641.406</td>
</tr>
<tr>
<td>NRN</td>
<td>1244.9347</td>
<td>16630.2</td>
<td>353.555</td>
<td>18228.67</td>
</tr>
<tr>
<td>CRL</td>
<td>499.13806</td>
<td>31.1605</td>
<td>98891.8</td>
<td>99422.09</td>
</tr>
<tr>
<td>Total</td>
<td>62889.649</td>
<td>25257.1</td>
<td>104145</td>
<td>192292.17</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial market shares</th>
</tr>
</thead>
<tbody>
<tr>
<td>To</td>
</tr>
<tr>
<td>EIN</td>
</tr>
<tr>
<td>NRN</td>
</tr>
<tr>
<td>CRL</td>
</tr>
</tbody>
</table>

* Derived from fractions of people choosing for a specific airport and total passengers per airport.
Appendix C.

Test Case 1

Figure C.1.: Case 1: Overview
(a) Average awareness

(b) Passenger choice per region

Figure C.2.: Case 1: Overview cont’d.
Appendix D.

Test Case 2

Figure D.1.: Case 1: Overview
Appendix E.

Test Case 3

Figure E.1.: Capacity constraint load factor
Appendix F.

Sensitivity Analysis

F.1. Procedure

A sensitivity analysis has been conducted by varying all exogenous factors by + and - 10%. Figure lists all the factors that have been changed. First a base line simulation was made, the results of it were stored in an excel sheet. The procedure for each factor has been identical. The model is simulated while in each run, one of the factors either increased or decreased by 10%. The results of each run (2 per factor) were then stored in an excel sheet. With the use of a macro the differences between each run and the base line simulation have been calculated according to the three metrics specified in Section \[8.3\]. The source code of the macro can be found in the second part of this appendix.
<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Word-of-mouth effectiveness (1/month)</td>
<td>Intraregional:</td>
</tr>
<tr>
<td></td>
<td>Interregional, same language:</td>
</tr>
<tr>
<td></td>
<td>Interregional, different language:</td>
</tr>
<tr>
<td>Marketing effectiveness (1/month)</td>
<td>Intraregional:</td>
</tr>
<tr>
<td></td>
<td>Interregional, same language:</td>
</tr>
<tr>
<td></td>
<td>Interregional, different language:</td>
</tr>
<tr>
<td>Learning speed (flights)</td>
<td></td>
</tr>
<tr>
<td>Reference social exposure (1/month)</td>
<td></td>
</tr>
<tr>
<td>Slope of reference point (Dmnl)</td>
<td></td>
</tr>
<tr>
<td>Maximum forgetting rate (1/month)</td>
<td></td>
</tr>
<tr>
<td>Forgetting time related to habit (month)</td>
<td></td>
</tr>
<tr>
<td>Time to perceive present condition (month)</td>
<td></td>
</tr>
<tr>
<td>Time horizon for reference condition (month)</td>
<td></td>
</tr>
<tr>
<td>Time to perceive trend (month)</td>
<td></td>
</tr>
<tr>
<td>Forecast period (month)</td>
<td></td>
</tr>
<tr>
<td>Scheduling delay (month)</td>
<td>Eindhoven</td>
</tr>
<tr>
<td></td>
<td>Niederrhein</td>
</tr>
<tr>
<td></td>
<td>Charleroi</td>
</tr>
<tr>
<td>Initial flights per airport (flight/week)</td>
<td>Eindhoven</td>
</tr>
<tr>
<td></td>
<td>Niederrhein</td>
</tr>
<tr>
<td></td>
<td>Charleroi</td>
</tr>
<tr>
<td>Accessibility table (minutes)</td>
<td>Intraregional:</td>
</tr>
<tr>
<td></td>
<td>EIN-NRN</td>
</tr>
<tr>
<td></td>
<td>EIN-CRL</td>
</tr>
<tr>
<td></td>
<td>CRL-NRN</td>
</tr>
<tr>
<td>Betas</td>
<td>Fare</td>
</tr>
<tr>
<td></td>
<td>Access</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
</tr>
<tr>
<td>Frequency of flight</td>
<td>Business</td>
</tr>
<tr>
<td></td>
<td>Leisure</td>
</tr>
</tbody>
</table>

Figure F.1.: Overview of exogenous factors
Sub Calculate_Metrics()
Dim BaseLine(), TimeStep(), maxNormDif(), intNormDif(), sqIntNormDif(),
Sheet_Names(), Temp_Matrix(), Calculation_Matrix(), SumOfRow, sqSumOfRow, rowMax
(), Area As Variant
Dim Counter As Integer
Dim strRange As String

strRange = "B4:ATF48" 'define the range for the datasets
strTimeStep = "B1:ATF1" 'define the range for the time step
Baseline = Sheets("BASELINE").Range(strRange).Value
TimeStep = Sheets("BASELINE").Range(strTimeStep).Value
Counter = 1

'Populate Sheet_Names array
For i = 1 To Sheets.Count
ReDim Preserve Sheet_Names(Counter)
Sheet_Names(Counter) = Sheets(i).Name
Counter = Counter + 1
Next i

'Populate Temp_Matrix and calculate values to grow additional column to metric
matrices
ReDim Preserve Calculation_Matrix(UBound(Baseline), UBound(Baseline, 2))
ReDim Preserve intNormDif(UBound(Baseline), UBound(Sheet_Names))
ReDim Preserve sqIntNormDif(UBound(Baseline), UBound(Sheet_Names))
ReDim Preserve rowMax(UBound(Baseline, 2))

'Loop through the sheets to calculate the metrics, basecase will always be the
reference
For j = 2 To UBound(Sheet_Names) - 2
Temp_Matrix = Sheets(Sheet_Names(j)).Range(strRange).Value 'load the temporary
matrix
For k = 1 To UBound(Baseline) 'Loop through the rows to calculate the values for
the different variables
SumOfRow = 0
sqSumOfRow = 0
MaxOfRow = 0
For l = 1 To UBound(Baseline, 2) 'loop through the columns to calculate the
difference between t and t-1
If BaseLine(k, l) = 0 Then
Calculation_Matrix(k, l) = 0
Else
Calculation_Matrix(k, l) = Abs(Temp_Matrix(k, l) - BaseLine(k, l)) / Abs(BaseLine(k, l))
End If
rowMax(l) = Calculation_Matrix(k, l)
If l >= 2 Then
Area = (DateValue(TimeStep(1, l)) - DateValue(TimeStep(1, l - 1))) * _
(Calculation_Matrix(k, l - 1) + _
(Calculation_Matrix(k, l))) * 1 / 2 'This should be the area
instead of the normal sum
SumOfRow = SumOfRow + Area
sqSumOfRow = sqSumOfRow + Area ^ 2 'Same with this
End If
intNormDif(k - 1, j - 2) = SumOfRow
sqIntNormDif(k - 1, j - 2) = sqSumOfRow
End Sub
Next l
MaxOfRow = Application.Max(rowMax)
maxNormDif{k - 1, j - 2} = MaxOfRow

Next k

Next j

'Select the last sheet
Sheets("Metrics").Range("C3:AN47").Value = intNormDif
Sheets("Metrics").Range("C52:AN96").Value = sqIntNormDif
Sheets("Metrics").Range("C101:AN145").Value = maxNormDif

End Sub
Appendix G.

Process reflection

Learning is a feedback process of taking action, make mistakes, evaluate (reflect on) the outcomes and reconsider what actions should be taken consecutively to obtain the desired results. The more often you have looped through this process, the closer you get to the desired results, mistakes though, will always be made.

If you start your MSc. research project the probability is high that it is your first real research project. At least this was true in my case. This means that you have never completely gone through the feedback process and therefore it is likely that after the first iteration, you end up somewhere else than at your desired result. A reflection in this case is useful to anchor the lessons learnt and to be able to do a slightly better job the next time.

There are several things in this project of which I think I should have done differently and that I would like to bring to the attention. First there is the literature study that I conducted in the first two months of the research. I have spend at least a month on searching for literature on consumer behaviour, marketing and choice modelling. In hindsight I consider that this might have taken too much time. A more general knowledge of consumer choice could have been sufficient to come up with the same mechanisms I included now. Moreover, these mechanisms are not new in system dynamics. The added value to me is that I now understand very well how many psychological effects are actually embedded in the formulation of the model.

The second point concerns the model itself. System dynamics is a method used to explore the behaviour that can be obtained from a set of interconnected elements. As argued often in this thesis, it is not a method for numerical accuracy. Given the chosen boundaries of the model it might have been better to divert some attention from specifying parameters to expanding the set of interconnected elements. What I mean with this is that the most interesting dynamics might not be obtained with the set of elements (concerning passengers and reactive airlines) that I chose now, but that proactive airlines and airports are required.

My third and final point is related to the planning of work. It is a truth that pressure rises when the date of a deadline approaches. There is no point to deny this and I am almost 99% sure that this is valid for anyone. However, this does not mean that you cannot use it in your favour. By scheduling deadlines from the early beginning of the project, you are able to spread the pressure over a longer period of time and thereby reducing its intensity. I had scheduled two deadlines (after 1 and 2 months) to deliver the chapters based on the literature study. After that, the project took me and I did not have fixed dates on which I had to deliver part of my work. This led to two problems. One, I had to write a large part of the work in just the 5 weeks before the pre-greenlight meeting while I was still working on the development of the model. This proved to be insufficient time to finish the foundation of the thesis. The second problem was that since I had to keep writing for the rest of the time, I feel that I did not have time to divert my attention from the text in order be able
to continue improving with a fresh mind. I did have this time for the chapters based on the literature study, and I still feel that these chapters are now the best written chapters in the thesis.

Looking back at the six months I have spend working on this project, I see a pathway full of new discoveries, interesting experiences and hard lessons. It has opened my eyes on doing actual research.