UNCERTAINTY/SENSITIVITY ANALYSIS OF AIRPORT FINANCIAL MODEL AND SOFTWARE DEVELOPMENT

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Abstract

Forecasting is never able to correctly predict the future. Its main purpose therefore is to gain some understanding of the future. Hardly anyone these days will make multi-million euros plans and implement them without at least trying to simulate the future and studying some possible scenarios. Decision making is the core management activity. As airport business environments become more and more complex and dynamic it is increasingly difficult to make the "right" decisions. Especially when it comes to fundamental decisions, such as how to design the future of their business, managers face considerable problems. Although a lot of research is carried out, decisions are still often made intuitively. Development of the tools which can be used to assist decision makers' intuition and help them solve the strategic and operational problems is a challenge. Delft University of Technology Airport Development Center (TUD-ADC) was founded to conduct and apply research to develop tools, such as the Airport Business Suite (ABS), to help airport decision makers.

The ABS project engaged in developing models and software to simulate the operation of the airport from the physical capacity, environmental capacity, and the financial point view.

My work was to implement and integrate the financial model(Model 4 & 5, part of ABS) which deals with the nature of the revenues, costs, and investments of the airport; and also to gain some insights of the model via theoretical analysis.

Using this model the basic information of the financial situation of the airport can be estimated. It can forecast the future financial performance based on the current data, economic factors, and expansion plans, etc. I implemented the model with Visual Basic and make simulation after specification of the model. Moreover, I introduced exploratory analysis, which seeks to gain a broad understanding of a problem domain before going

into details for particular cases. Its focus is to understand comprehensively the consequences of uncertainty, which requires a good deal more than normal sensitivity analysis. An uncertainty/sensitivity analysis (Morris method, correlation ratio) and exploratory analysis of the model were conducted with software system Unicorn and Matlab. I found the most important parameters of the model, and optimized strategies for different cases via the cobweb plot from Unicorn. This high efficiency and reliability of exploratory analysis will give useful advice for the airport manager and other interest-related people.

This thesis is divided into two parts: Part one is concerned with implementation. It describes some Visual Basic knowledge, then introduces the implementation and integration of financial model. Part two is concerned with uncertainty/sensitivity analysis, exploratory analysis (policy optimization). In addition, some conclusions and recommendations will be given in the last chapter of the thesis.

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Delft, The Netherlands Yaomin Jin
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Chapter 1

Introduction

TU Delft Airport Development Center (TUD-ADC) was established in 2001 as a joint initiative of TU Delft's faculties of Aerospace Engineering and Technology, Policy and Management. Its mission is to conduct and apply research to help organizations in the air transport sector meet their strategic and operational challenges through the development and use of tools and solutions enabled by innovative concepts and advanced technologies.

Over the years, constant population growth, deregulation, and ever-increasing demand for faster transportation have led to a dramatic increase in air traffic. A growing number of airports suffer from congestion, overcrowding, the subsequent deterioration of airport services, and money losing. The continued growth of air traffic at about 5 percent per annum will place airport and traffic control systems under tremendous pressure, especially as current capacity is already inadequate in many airports and flight regions[14]. Problems will be aggravated by pressure from environmentalists for the reduction of both airport noise and aircraft emissions. In order to find a good solution to all this kind of problems, we want to know different choices' consequences beforehand.

Running an airport is a business. An airport operates in a competitive, dynamic, complex, and unpredictable environment. In order to remain successful and competitive, an airport needs information and decision support tools to help it secure its competitive position and make good business decisions quickly and at low cost.There is demand for develop a decision maker tool.

The TUD-ADC is in the process of developing an integrated set of tools—that can be used to help any airport generate information for decision making in an efficient, effective, and consistent manner. The tools can be used to address a wide range of issues confronting airports, both at the operational and strategic level, under a wide variety of circumstances, in situations of high uncertainty. There currently does not exist such a set of integrated, consistent tools to analyze the various facets of an airport's business – a wide range of operational and strategic problems at the appropriate level of aggregation. The TUD-ADC's first set of tools will be focused on this market.

This project dealt with the development of a first generation Airport Business Suite (ABS), which was aimed at gathering, modelling and integrating available knowledge on the airport as a business. After the first generation toolbox has been developed, the toolbox will be continuously updated in close cooperation and communication with air transport businesses and other stakeholders.

1.1 Background of ABS

ABS is an integrated set of tools developed by TUD-ADC, which can be used to project an airport's future annual report, taking the present situation as a baseline and assuming different scenarios and strategic business plans[6].

The research plan for developing the first generation ABS was based on the integral system structure shown in Fig. 1.1. The lower right portion of the figure represents the airport's demand for the transport of both passengers and freight. This is the unconstrained primary demand, which is transformed by the airlines (based on the strategic and operational requirements of the airlines operating at the airport, including their associated aircraft and operating policies) into a desired schedule for flights at the airport. The lower middle portion of the figure represents the airport's capacity (for a given level of quality - e.g., punctuality). The capacity is a function of its physical and operational situation (infrastructure, air traffic control procedures, etc.) and government regulations (e.g., related to noise and safety). Confronting the desired airline schedule with the capacity and quality limitations produces an actual flight schedule.

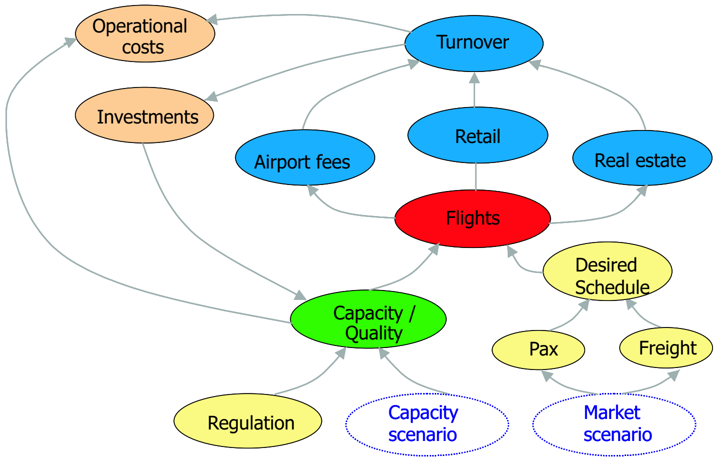

Figure 1.1: Airport Business Suite structure

The area above the oval representing flights is devoted to the airport's revenue generation activities. The flight activities directly generate airport fees, indirectly generate revenues at the airport's shops, and even more indirectly generate revenues from real estate activities (e.g., renting space within the terminal and renting facilities outside the terminal). All of these revenue sources are combined into a total turnover for the airport. Excluding a shareholder margin, the turnover is then used in two ways: (1) to pay for the operational costs of running and maintaining the airport, and (2) to acquire new facilities and infrastructure to improve the capacity and/or quality of the airport.

Based on this conceptual framework, the TUD-ADC is building an integrated system of five models. The five models (which are identified in Fig. 1.2) are:

1. Demand for airport capacity ('desired schedule')
2. Supply of airport capacity ('available capacity')
3. Matching demand and supply ('flights')
4. Airport Turnover ('turnover')
5. Investments and operational costs

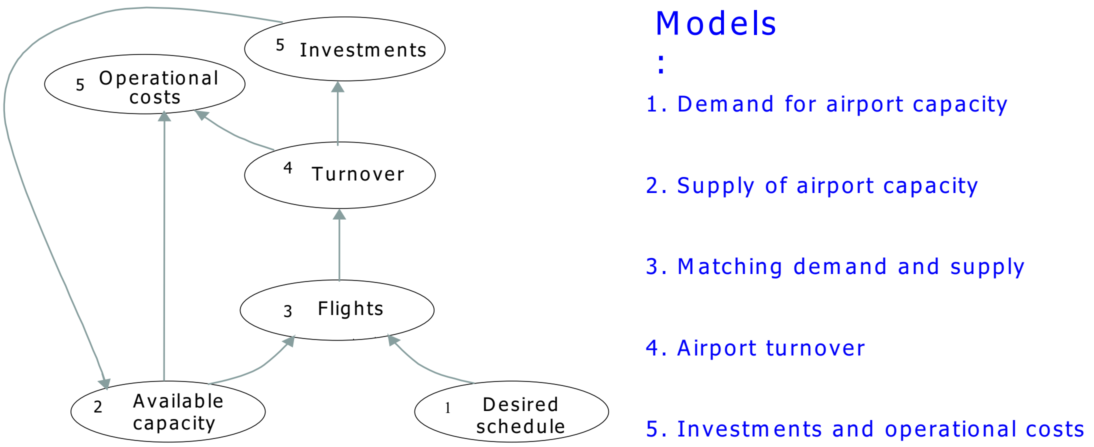

Figure 1.2: Models comprising the airport business suite

The models have been designed so that the outputs of one model can be used as the inputs of the next model in the series. A graphical user interface (GUI) makes the model easy to operate and the outputs easy to understand.

Demand model (Model 1) produces a desired schedule for arriving and departing aircraft on a certain airport for some future year with base year data and without taking any restrictions of noise, capacity and whatsoever into account. It includes two modules. The first module (Forecast Model, FM) models the passenger flows in the future year cases, based on economic growth factors. The second module (Scheduling Model, SM) takes these passenger flows as input and determines the desired arrival and departure schedule (i.e., unconstrained flight schedule).

Capacity model (Model 2) consists of 3 modules: (1) FAA Airfield Capacity Model (FAACM) and delay model; this module calculates the runway capacity of a given airport configuration and the delays caused by the difference between capacity and demand. (2) Terminal capacity model; this one estimates the amount of space needed inside the terminal (such as check-in, security control, passport control, shopping, baggage, custom, etc.) for a specified level of service (LOS). (3) Noise model. Conducts noise analysis with the Integrated Noise Model (INM) of the airport, and estimates the noise contour produced by a given schedule of aircraft arrivals and departures.

The financial model (Model 4 & 5) is an important part of the ABS. It contains two models. One model describes the turnover and operational costs, the other the finance and investments. It uses the number of passengers and aircraft movements to calculate the revenues (i.e. passenger fee revenue, landing fee revenue, parking fee revenue, handling fee revenue, retailing fee revenue, car parking fee revenue, real estate revenue, utilities revenue, etc.), operational costs (employees cost, depreciation cost, maintenance cost, service costs, interest costs, administration cost, etc), and investment of the airport (replacement investments and expansion investments). The finance and investment model gives the basic configuration of an airport business situation. The results are shown in a revenue and cost sheet and a new balance sheet. From the results the user can easily read the current economic situation of the airport. Besides, the user can change policy parameters (e.g. passenger fee and landing fee) to know what the influence of these parameters is to the turnover and costs.

The process of building each model follow the same basic set of five steps, here each step is briefly described.

Step 1: Identify Possible Models

In the first phase of developing the first prototype of the toolbox, we were aiming at consistent integration of available knowledge in the models. This means that we were not focused on finding innovative approaches for any of the models in this period. Some pieces of the system have been modelled previously in some manner or other. The innovation is the integration of these models into a consistent system and their scalability (use at different levels of aggregation). Thus, Step 1 was to skim the literature to identify the models that have been used previously for equivalent purposes, rules of thumb that have been used in the models (relationships linking the inputs to the outputs), the primary inputs and outputs, the primary drivers of the model's outputs, and the various levels of aggregation for which models have been built in the past. Also the strength and weaknesses of the available models were reviewed.

The output from this step was a broad description of the possibilities for each given model, including which types of models have been used where, for what purposes; what mistakes have been made in modelling this aspect of the airport system in the past; and recommendations for how we might proceed.

Step 2: Review and Evaluate the Possible Models

In this step, the various possible formulations for each of the models were reviewed by members of the model team, plus a representative of the integration team. For each model, we reviewed its characteristics and potential requirements, consider a range of issues, including feasibility, complexity, consistency, data requirements, and software, and decision of a preferred conceptual design. A cost-benefit analysis was performed for each model in order to choose the appropriate levels of detail, scenarios, and time scale to be used. The output from this step (over all of the models) was a conceptual design for the entire system of models.

Step 3: Specify Models

In this step, each of the models was designed and a plan for building was developed. The specification include the algorithms to be used, modelling assumptions, software, and data, also detailed descriptions of the model's inputs, outputs, functionality (e.g., parameters that can be varied by the user), and linkages with other models in the system. This step was performed by the model team in cooperation with the integration team.

Step 4: Build and Test Models

In this step, a first generation version of each of the models was built and tested. This step include fitting any internal relationships needed for the model (to represent the system being modelled), creating the input database, collecting the data needed to test the validity of the model, coding the model, and testing the model. This step was performed by the model team in conjunction with the integration team.

Step 5: Document Models

In order to useful to others in the future, a set of documents have been prepared for the ABS. This include three kinds of documentation:

- An executive summary, which provides an overall description of the ABS, its characteristics, its uses, and its software, hardware, and data requirements. It provides overviews of each of the models, their capabilities, and their potential applications.
- A user's manual, which provides step-by-step information for users concerning how to run the ABS and interpret the results. It explains the assumptions underlying

a model, how to initiate the model, the default parameter settings, how to change the default settings, how to select the outputs to be displayed, and what the output means. It also explains how the results can be saved for future use, and how the outputs from one run can be compared to the outputs from previous runs.

- A programmer's manual, which provides information for the ABS developers concerning the model's internal details and (input and output) data specifications. This enable the generic models to be customized for specific applications. And also for the maintenance and future updated.

1.2 Objectives

The goal of this study was consists of two parts. First is specification of the financial model which deals with nature of the revenues, costs, and investments of the airport. Then implement and integrate with demand model and capacity model using Visual Basic. After the implementation and integration of the financial model, we start to analyze the model and gain some insight of the financial model. Because the program itself is not the user interested. What they want to know is which lies behind the ABS, which parameter is the most important in the financial model, and how to use software to help make decision. All these questions will be answered by the subsequent uncertainty/sensitivity analysis and exploratory analysis (policy optimization).

Chapter 2

The Financial Model

The introductory chapter shows that know the financial model uses the number of passenger and aircraft movement to calculate the revenue, cost and investment. It reflects the financial situation of the airport. In this chapter we will explain how the financial model works.

2.1 Introduction of the Financial Model

The financial model considers the economics of the airport business. It uses the number of passengers and aircraft movements to calculate the revenues (i.e. passenger fee revenue, landing fee revenue, parking fee revenue, handling fee revenue, retailing fee revenue, car parking fee revenue, real estate revenue, utilities revenue, etc.), operational costs (employees cost, depreciation cost, maintenance cost, service costs, interest costs, administration cost, etc), and investment of the airport (replacement investments and expansion investments).

2.2 Model assumption

We make following assumptions for the financial model:

1. The annual numbers of arrival and departure passengers are equal, the same for yearly aircraft movements.
2. The landing fee only depends on the aircraft category, i.e. the maximum take-off weight of an aircraft.
3. Handling fee for cleaning and tanking depends on aircraft category.
4. Freight handling is not taken into account.

5. Transfer passengers not need check-in, so the Transfer passenger fee is lower than the Origin/Destination passenger fee.
6. The proportion of handling contracted out and the height of the concession fee is the same for all handling categories.
7. Only departing aircrafts will be charged for handling fees for catering.
8. Taxi, bus and railway companies will not have to pay concessions for respect taxi ranks, bus stops and railway station.
9. There are two different average rents for the office. A high rent for the offices at the top location and a low rent for the offices at the secondary location (e.g. Schiphol has Schiphol Centrum and Schiphol Oost), which change different rent.
10. Car parking fees from hotel visitors and from office employees are included in the price respectively a hotel room and the rent per m^2.
11. For aircraft parking fee revenue, no distinction is made between different aircraft types.
12. Employee costs of real estate are negligible.
13. Maintenance will not be contracted out.
14. A profit margin of 20% on the recharge of services.
15. Runway systems and car parking don't consume utility services. Only terminal area (including office area for airport authorities) and office area (for rent for third parties) do.
16. According to Doganis, the other aeronautical and non-aeronautical revenues add up to 11% of the total revenues. The administration costs contribute four percent of the total costs. The other operational costs contribute eleven percent of the total costs.

2.3 Model parameters

- Type of passenger
  We distinguish the following 'pairs' of passengers: Arrival/Departure, Origin & Destination/Transfer, Business/Non-Business and European Union/Non-European Union /Intercontinental, abbreviated respectively with A/D, OD/TRF, Bu/NBu and EU/NEU/ICO. All possible combinations lead to 24 passenger segments (2 x 2 x 2 x 3). This 24 segments of passengers of the base year (1999) was shown in Table 2.1.

$a_{i,j,k,l}$=number of passenger in segment (i,j,k,l) of base year
$i = 1, 2$—Arriving/Departing
$j = 1, 2$— Origin & Destination/Transfer
$k = 1, 2$—Business/Non-Business
$l = 1, 2, 3$—European Union/Non-European Union/Intercontinental
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i,j,k,l)

Table 2.1: number of different segment passengers in the base year($\times 10^3$)

segment	AR/OD/BU/EU	AR/OD/BU/NE	AR/OD/BU/IC	AR/OD/NB/EU
number	669	716	286	1258
variable	$a_{1,1,1,1}$	$a_{1,1,1,2}$	$a_{1,1,1,3}$	$a_{1,1,2,1}$
segment	AR/OD/NB/NE	AR/OD/NB/IC	DE/OD/BU/EU	DE/OD/BU/NE
number	689	763	669	716
variable	$a_{1,1,2,2}$	$a_{1,1,2,3}$	$a_{2,1,1,1}$	$a_{2,1,1,2}$
segment	DE/OD/BU/IC	DE/OD/NB/EU	DE/OD/NB/NE	DE/OD/NB/IC
number	286	1258	689	763
variable	$a_{2,1,1,3}$	$a_{2,1,2,1}$	$a_{2,1,2,2}$	$a_{2,1,2,3}$
segment	AR/TR/BU/EU	AR/TR/BU/NE	AR/TR/BU/IC	AR/TR/NB/EU
number	851	461	978	1021
variable	$a_{1,2,1,1}$	$a_{1,2,1,2}$	$a_{1,2,1,3}$	$a_{1,2,2,1}$
segment	AR/TR/NB/NE	AR/TR/NB/IC	DE/TR/BU/EU	DE/TR/BU/NE
number	533	1548	851	461
variable	$a_{1,2,2,2}$	$a_{1,2,2,3}$	$a_{2,2,1,1}$	$a_{2,2,1,2}$
segment	DE/TR/BU/IC	DE/TR/NB/EU	DE/TR/NB/NE	DE/TR/NB/IC
number	978	1021	533	1548
variable	$a_{2,2,1,3}$	$a_{2,2,2,1}$	$a_{2,2,2,2}$	$a_{2,2,2,3}$

- Aircraft movement

  There are 9 categories of aircraft movement. This classification refers to the weight of the aircraft. In ABS, we have the classfication of aircraft as follows (Table 2.2):

  Following Table 2.3 is 9 categories aircraft movements of the base year.

  $t = 1, \cdots, 9$, category of aircraft
  b_t=number of aircraft movements of category t in base year
  r_{b_t}=growth rate of number of aircraft movements of category t

- r=proportion of handling contracted out,0.5
- h =height of concession fee, 0.1

Table 2.2: 9 categories of aircraft

Aircraft category	Aircraft Noisy	type Quiet	(in)continental I or C	passenger range
1	BAEJ31	BAEJ31	C	1-19
2	FK27	FK50	C	20 -45
3	FK28MK2	FK70	C	46 - 75
4	B727-200	B737-300	C	76-150
5	B707	B757PW	C	151 - 225
6	A300	B767-300	I	151- 225
7	DC10-30	B777-200	I	226 - 300
8	B747-200	B747-400	I	301 - 425
9	A380	A380	I	426 - 550

Table 2.3: Number of aircraft movements in the base year

category	b_1	b_2	b_3	b_4	b_5
number	0	2459	43983	45082	5420
category	b_6	b_7	b_8	b_9	
number	3349	11708	1866	0	

- Airport infrastructure parameters

  In an aiport, it has many infracture facilities, such as runway, car parking, office, terminal, etc. In our model, we use some airport infracture parameters (Table 2.4).

Table 2.4: Airport infrastructure parameters(See Table 2.3)

Parameter	Value
ACP = total car parking area (m^2)	40,000
AO = total office area (m^2)	5000
AT= total terminal area (m^2)	8000
NR = number of runway systems	2
ATT = total airport area used by third parties(m^2)	7000
ATA = total terminal area used by the airport itself (m^2)	8000

2.4 The various types of airport revenues

An airport's revenues are generally functions of the yearly number of passengers. Revenues of airports are classified into nine different categories: Passengers Fees Revenues, Landing Fees Revenues, Aircraft Parking Fees Revenues, Handling Fees Revenues, Retail Revenues, Car Parking Fees Revenues, Real Estate Revenues, Utilities Revenues and

Other Revenues[1, 11, 10, 18].

Passengers Fees Revenues(z_1,€/year)

Passenger fees, passenger service charge, also known as terminal service fees, are intended to cover costs related directly to the use of passenger buildings. Their application and method of collection vary considerably from country to country. In the great majority cases today, the airlines, rather than individual passengers, pay this fee for each passenger they carry. The airlines presumably adjust their ticket prices accordingly, to recover the fee from passengers. The amount paid is computed on the basis of the actual number of passengers on each flight. Origin/Destination (O&D) passengers will be charged a higher fee than transfer passengers. Because the Origin/Destination passenger usually use more facilities than the transfer passenger.

The formula for passenger fees revenues is:

$$z_1 = 0.5 \sum_{\substack{i,j,k=1,2 \\ l=1,2,3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})x_j$$

where,
z_1=passenger fee revenue, €/year
$a_{i,j,k,l}$=number of passenger in segment (i, j, k, l) of base year
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)
x_1 = Origin & Destination passenger fee
x_2 = Transfer passenger fee

Landing Fees Revenues(z_2, €/year)

The landing fee is the most universal type of aeronautical user charge. It is the fee that the aircraft pay for the use of the airfield. The airfield costs that it covers include capital costs, operational and maintenance costs, and the cost of providing such services as fire fighting, snow plowing, and security. In our model, noise charges are also collected as part of the landing fee. In the overwhelming number of instances, the landing fee is computed with reference to the weight of the aircraft. Typically the maximum takeoff weight(MTOW) is used for this purpose. In our model, we consider both MTOW and noise and distinguish 9 categories of aircrafts, each with one landing fee. The larger and noisier the aircraft, the higher the landing fee. The landing fees are assumed to be uniformly distributed (See Table). This model in principle will link with previous models with respect to the number of aircraft categories. If this number is too big, some categories will be aggregated. The airports derive the amount of the landing fee in one of the following ways:

- In direct proportion to the weight(by far the most common in practice)
- As a fixed charge up to a specified weight threshold plus an amount that is directly proportional to any weight above that threshold
- In proportion to the weight of the aircraft but with a changing rate per unit of weight for different ranges of weight (e.g., x $ per ton up to 50 tons and y $ per ton for any weight above 50 tons)

The formula for landing fees revenues is:

$$z_2 = 0.5 \sum_{i=1}^{9} b_i(1 + r_{b_i})y_i$$

where,
b_t=number of aircraft movements of category t in base year, €/year
r_{b_t}=growth rate of number of aircraft movements of category t
y_i = landing fee for category i aircraft movement(€/movement)

Aircraft Parking Fees Revenues(z_3, €/year)

When an aircraft lands on an airport, it will also be charged for a parking fee. Aircraft parking fees are charges for the use of contact and remote apron stands, and hangar space. Aircraft parking fees are typically proportional either to the weight of the aircraft or to its dimensions. At many airports, there is no parking charge for "normal" use of a stand, i.e., for occupancies of less than a specified amount of time. In our model, the height of this tariff (a certain amount per unit of time), determined by the airport's authority, depends on the type of aircraft parked, and the duration of the aircraft stay at the apron. This model includes the turnaround stand and overnight parking. From model 2 the average turnaround time and the number of overnight parking aircrafts will be given (In this version of ABS, the turn around time is 1 hour, no aircraft parking at night). The number of aircrafts that stay over for the night is a user input variable. In this first version of ABS we do not make any distinction between different aircraft type, but consider only the time they stay in apron. This model can be extended for different aircraft types, based on different wingspan classes. A night consists of six hours.

The formula for aircraft parking fees revenues is:

$$z_3 = \sum_{i=1}^{9} b_i(1 + r_{b_i}) * TAT * ACPF + r \sum_{i=1}^{9} b_i(1 + r_{b_i} * 6 * ACPF$$

where,
z_3=aircraft parking fees revenues, €/year
b_i=number of aircraft movements of category i in base year, €/year

r_{b_i}=growth rate of number of aircraft movements of category i
TAT=average turnaround-time,h
ACPF=aircraft parking fee,€/h

Handling Fees Revenues(z_4, €/year)

The diverse and important category of handling fees is subdivided into ramp handling fees, and traffic handling fees for service that are provided within the passenger or cargo buildings. Table 2.5 lists the principal handling services at airports. This model covers baggage handling, catering, check-in, aircraft cleaning and tanking of fuel.

Table 2.5: Principal handling services at airports

Traffic handling services	Ramp handling services
Passenger handling	Baggage handling and sorting
Ticketing	Loading and unloading of aircraft
Check-in	Interior cleaning of aircraft
Boarding supervision and services	Toilet service
Executive lounge/”club” operation	Water service
Cargo and mail handling	Passenger transport to/from
Some information services	Passenger transport to/from remote stands
Preparation of various handling and load-control documents	Catering transport
Various supervisory or administrative duties	Routine inspection and maintenance of aircraft at the stands
	Aircraft starting, marshalling, and parking
	Aircraft fueling
	Aircraft de-icing

On most airports, some or all of these services are subcontracted. In that case, the airport will charge the subcontractors concession fees. The percentage subcontracted handling services differs from airport to airport. In this model, first the total potential revenues of the airport are being calculated. These are the revenues, if the airport doesn’t put any handling out to contract. A parameter expresses the proportion of handling done by the airport and subcontracted to others. If this parameter is 0.4 for example, the airport puts then 40% of all handling out to contract and 60% of all handling is done by itself. i.e. the airport receives 60% of the total potential handling fees revenues and receives concession fees over the remaining 40%. The airport authority determines the height of this concession fee. This concession fee is also expressed as a proportion parameter. If this parameter is, for example, 0.15 then the airport receives 15% of the handling fees revenues of subcontractors.

The formula for handling fees revenues is:

$$
\begin{aligned}
z_4 \quad = \quad & [(1-r)+rh][(HF_{Bag}+0.5HF_{Cat})\sum_{\substack{i,j,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}) \\
& +HF_{Chi}\sum_{\substack{j=1\\ i,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})+0.5\sum_{i=1}^{9} b_i(1+r_{b_i})(HF_{Cle,i}+HF_{Tnk,i}))]
\end{aligned}
$$

where,
z_4=handling fees revenues,€/year
r=proportion of handling contracted out,0.5
h =height of concession fee, 0.1
HF_{Bag} = baggage handling,€/passenger
HF_{Cat} = catering handling,€/passenger
HF_{Chi} = check-in handling,€/passenger
$HF_{Cle,t}$ =aircraft cleaning, λ_t,€/movement
$HF_{Tnk,t}$ =aircraft fueling, ω_t,€/movement

Retail Revenues(z_5, €/year)

Retail revenues are those generated from commercial activities, such as direct sales and/or concessions (operation of duty-free shops, retail shops, bars and restaurants, bank and currency exchange branches, newsstands, game arcades, etc.). In this model, an average expenditure per passenger is assumed in 24 different segments. Each passenger in each segment will bring an average number of visitors, who also buy in the airport shops (although not tax-free). The proportion of direct sales and concession fees will be introduced in the model in the same way as described in section Handling Fees Revenues.

The formula for retail revenues is:

$$
z_5 \quad = \quad [(1-r)+rh][\sum_{\substack{i,j,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})(v_{i,j,k,l}+u_{i,j,k,l}s)+c]
$$

where,
z_5=retail revenue,€/year
r=proportion of handling contracted out,0.5
h =height of concession fee, 0.1
$u_{i,j,k,l}$=average number of visitors per passenger in segment(i,j,k,l)(visitors/passenger)

Table 2.6: Car parking fee parameters

i	1	2	3	4	5	6	7	8
α_i	0.6	0.6	0.1	0.1	0	0	0	0
β_i	0.2	0.2	0.5	0.5	0.4	0.4	0.8	0.8
f_i	12	12	120	120	36	36	240	240
g_i	1	1	2	2	1	1	2	2
p_i	1.5	1.5	1	1	1.5	1.5	1	1
q_i	4	4	3	3	4	4	3	3

$v_{i,j,k,l}$=average passenger spending (€/passenger)
$a_{i,j,k,l}$=number of passenger in segment (i, j, k, l) of base year
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)
s=average visitors spending, €/visitor
c=revenues from ”fun-shoppers”, €

Car Parking Fees Revenues(z_6, €/year)

Car parking fees (car parking and car rentals) is fast growing sources of revenues for airports around the world. Arrangements with regard to automobile parking facilities and services vary considerably across airports. These revenues are also a function of the number of passenger. Remark about segment OD/TRF: Transfer passenger don't lead to car parking fees revenues, because they arrive and leave by plane. All possible combinations lead to eight passenger segments ($2 \times 1 \times 2 \times 2$).

Each passenger segment has a certain division how the major parts of that segment will arrive at or leave the airport. These characteristics can be summarized in the following table (see Table 2.6).

Passengers entering the airport by their own car and thus leaving the airport by their own car, only have to pay car parking fee when leaving the airport. Usually A/OD/Bu,NBu/ICO segments passengers' cars stay longer than the others. Important note is that arriving passengers are the passenger who arrive by airplane and thus are going to leave the airport!

The coefficients f and g aren't necessarily different for all segments (i, j, k, l). One can imagine that all collected passengers will park on average one hour per passenger. Because passengers who arrive at the airport by their own car not have to pay, all coefficients f_i equal zero, when segment i concerns departing passengers.

The coefficients p and q can be equal for different i. This is the case when, for example, only two parking fees are assumed, such as a short-term and a long-term tariff.

The formula for car parking fees revenues is:

$$\rho_1 = \sum_{\substack{i,j,k=1\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_2 = \sum_{\substack{i=2\\j,k=1\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_3 = \sum_{\substack{i,j,k=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_4 = \sum_{\substack{i=2\\j,k=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_5 = \sum_{\substack{i,j=1\\k=2\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_6 = \sum_{\substack{j=1\\i,k=2\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_7 = \sum_{\substack{i,j=1\\k=2\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_8 = \sum_{\substack{i,k=2\\j=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$z_6 = [(1-r)+rh]\sum_{i=1}^{8} \rho_i(\alpha_i\beta_i f_i + g_i p_i q_i)$$

where,
z_6=car parking fees revenues, €/year
$a_{i,j,k,l}$=number of passenger in segment (i,j,k,l) of base year
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i,j,k,l)
r=proportion of handling contracted out, 0.5
h=height of concession fee, 0.1
α_i=proportion of passengers in segment (i,j,k,l) arrived at or left the airport by their own car
β_i=proportion of passengers in segment (i,j,k,l) collected from or taken to the airport
f_i=average Parking time for passengers in segment(i,j,k,l) arrived at or left the airport by own car, h/passenger
g_i= average Parking time for passengers in segment (i,j,k,l) collected from or taken to the airport, h/passenger
p_i=parking fee for passengers in segment (i,j,k,l) arrived at or left the airport by own car, €/h
q_i=parking fee for passengers in segment (i,j,k,l) collected from or taken to the airport, €/h

Real Estate Revenues(z_7, €/year)

The real estate revenues can be divided into income from hotels and from office rents (also their car parking fees revenues). This model covers a high and a low office rent. Schiphol has such a price policy for Schiphol Centrum and Schiphol Oost; here we assume all airports to have this policy.

The formula for real estate revenues is:

$$z_7 = [(1-r)+rh][g_{OA}(NOA_{HR}HR + NOA_{LR}LR) + g_{HB}NHB365b]$$

where,
z_7=real estate revenue, €/year
r=proportion of handling contracted out
h=height of concession fee
NOA_{HR}=total office area with high rents, m^2
NOA_{LR}=total office area with low rents, m^2
NHB=number of hotel rooms
g_{OA}=occupancy of office area
g_{HB}=occupancy of hotel beds
HR=average high rent for one m office area, €/m^2
LR=average low rent for one m office area, €/m^2
b=average price for one room, €/room

Utilities Revenues(z_8, €/year)

The airport charges tenants for services such as electricity, water and so on, so called utilities. These charges aren't included in any rent or concession fee. Since the airport can sell these utilities against a higher price than the cost price, it can earn profit on that charges.

The formula for ultilities revenues is:

$$z_8 = [(1-r)+rh]au$$

where,
z_8=utilities revenues, €/year
r=proportion of handling contracted out
h=height of concession fee
a=total airport area used by third parties,m^2
u=selling price of one square meter utility, €/m^2

Other Revenues(€/year)

This general revenue item is estimated by the model as a percentage of the total revenues. Advertising income is an example of 'other revenues'. Besides, a number of major European airports are increasingly becoming engaged in providing consulting services and educational and training services to other airports.

Total Revenues (€/year)

The total revenues are the sum of the outputs of the previous sections.

The formula for total revenues is:

$$TR = \sum_{i=1}^{8} z_i/0.89$$

where,
TR=total revenue, €/year
$z_i((i = 1, \cdots, 8))$=all kinds of revenues, €/year

2.5 The various types of airport costs

The airport's fixed costs are generally functions of its capacity. Its variable costs are generally functions of the revenues. In The Airport Business [18], we found an average cost structure for Western-European airports. This cost structure is converted to functions of fixed and variable costs, respectively functions of capacity and revenues (see Table 2.7). Furthermore in this model there is an extra category included namely Retail Costs.

Table 2.7: Different types of costs

Cost	Function with parameters	Percentage of average total cost
Employee costs	f(capacity, revenues)	42%
Depreciation and interest costs	f(capacity)	22%
Maintenance costs	f(capacity)	9%
Service costs	f(capacity, revenues)	12%
Administration costs	f(capacity, revenues)	4%
Other operational costs	f(total costs)	11%

Employee costs(z_9,€/year)

The employee costs consist of a fixed and a variable part. The variable costs are function of the number of passenger and aircraft movements. The variable costs are then the employee costs for retail, handling and the car parking.

The formula for employee costs is:

$$z_9 = (1-r)(ACP * ECC + NR * ECR + \sum_{\substack{i,j,k=1,2 \\ l=1,2,3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}}) * ECP + \sum_{i=1}^{9} b_i(1 + r_{b_i}) * ECM)$$

where,
z_9=employee costs,€/year
r=proportion of handling contracted out

ECC=employee costs for one m car parking area, €/m^2
ECR=employee costs for one runway system, €
ECP=employee costs per passenger, €/passenger
ECM=employee costs per aircraft movement, €/movement

Depreciation costs(z_{10},€/year)

All capital will yearly be depreciated with a certain percentage of the purchase price.

The formula for depreciation costs is:

$$z_{10} = (ACP * PC * k_{CP}) + (AO * PO * k_{OA}) + (AT * PT * k_{Ter}) + (NR * PR * k_{RWS})$$

where,
z_{10}=depreciation costs, €/year
PC=purchase price for one m^2 car parking area, €/m^2
PO=purchase price for one m^2 office area, €/m^2
PT=purchase price for one m^2 terminal area, €/m^2
PR=purchase price for one runway system, €
$k_{CP}, k_{OA}, k_{Ter}, k_{RWS}$ = Depreciation percentage for resp. car parking, office area, terminal area and runway system

Maintenance costs (z_{11},€/year)

The maintenance costs are fully a function of the capital. These costs exclude the staff element (according to Doganis [11]).

The formula for maintenance costs is:

$$z_{11} = (ACP * MCP) + (AO * MCO) + (AT * MCT) + (NR * MSR)$$

where,
z_{11}=maintenance costs, €/year
MCP=maintenance costs for one m^2 car parking area, €/m^2
MCO=maintenance costs for one m^2 office area, €/m^2
MCT=maintenance costs for one m^2 terminal area, €/m^2
MCR=maintenance costs for one runway system, €

Utility Service costs,(z_{12},€/year)

The service costs consist of a fixed and a variable part. The fixed part consists of the service costs for water, electricity and so on, which are fully to the account of the airport.

The variable service costs are those that will be recharged to tenants and thus are a function of the utilities revenues.

The formula for utility service costs is:

$$z_{12} = [ATA * (1 - USC_w)u] + [ATT(1 - USC_w)u(1 - r)]$$

where,
z_{12}=utility service costs,€/year
USC_w =profit margin on recharge of utilities
r=proportion of handling contracted out
ATT=total airport area used by third parties, m^2
ATA=total terminal area used by the airport itself, m^2
u=selling price of one square meter utility, €/m^2

Retail costs(z_{13},€/year)

The cost price of all sold retail products comes under retail costs. The products will be sold with a certain profit margin. This profit is not the net profit on retail, because costs such as employee costs etc. have to be subtracted.

The formula for retail costs is:

$$PRR = [\sum_{\substack{i,j,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})(v_{i,j,k,l} + 2u_{i,j,k,l}) + 10^7]$$

$$z_{13} = (1 - r)(1 - PM)PRR = 0.4[\sum_{\substack{i,j,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})(v_{i,j,k,l} + 2u_{i,j,k,l}) + 10^7]$$

where,
z_{13}=retail costs,€/year
r=proportion of handling contracted out
PM=profit margin on retail
PRR=potential retail revenues, €
$u_{i,j,k,l}$=average number of visitors per passenger in segment(i,j,k,l),visitors/passenger
$v_{i,j,k,l}$=average passenger spending, €/passenger
$a_{i,j,k,l}$=number of passenger in segment (i, j, k, l) of base year
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)

Administration costs(z_{14},€/year)

The administration costs are overhead costs and we assume these costs to be the sum of a fixed part and a fixed percentage of the total revenues.

The formula for adminstration costs is:

$$z_{14} = PAC * TR + FAC$$

where,
z_{14}=administration costs,€/year
PAC=proportion of administration costs
TR=total revenues,€/year
FAC=fixed administration costs,€

Interest Costs(z_{15},€/year)

The item interest costs, consists of the interest paid over the loans, needed for the purchase of capital.

The formula for interest costs is:

$$z_{15} = [TI_t - (TR - TC + DC) + (LR_t - LR_{t-1}) + DeC_{t-1}]ri$$

where,
z_{15}=interest costs,€/year
TI_t=investment next year ($t + 1$),€
TR=total revenues,€/year
TC=total costs,€/year
LR_t=liquid resources for the next year ($t + 1$),€
LR_{t-1}=liquid resources in the reference year (t),€
De_{t-1}=liquid resources in the reference year (t),€
ri=interest rate for next year($t + 1$)

Since the new balance sheet derived from the former year balance sheet. In order to simplify the calculation, here we only predict next year situation based on the baseyear and assume the interest cost for next year is zero.

Total investment(TI,€/year)

Total investment is the sum of the replacement investment and expansion investment. Here we have assumed that the replacement investment is equal to the depreciation costs.

The formula for total investments is:

$$TI = z_{10} + FAa_{EI} \sum_{\substack{i,j,k=1,2 \\ l=1,2,3}} a_{i,j,k,l} r_{a_{i,j,k,l}} / \sum_{\substack{i,j,k=1,2 \\ l=1,2,3}} a_{i,j,k,l}$$

where,
TI=total investments,€/year
z_{10}=depreciation costs,€/year
$a_{i,j,k,l}$=number of passenger in segment (i, j, k, l) of base year
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)
FA=fixed assets,€
a_{EI}=proportion of investment with respect to passengers growth

Other operational costs(z_{16},€/year)

This general cost item is a fixed percentage of the total costs.

The formula for other operational costs is:

$$z_{16} = POC * TC$$

where,
z_{16}=other operational costs,€/year
POC=proportion of other operational costs
TC=total costs,€/year

Total costs,€/year

The total costs are the sum of the outputs of the previous sections.

The formula for total costs is:

$$TC = \sum_{i=9}^{14} z_i/(1 - poc)$$

where,
TC=total costs,€/year
$z_i(i = 9, \cdots, 14)$=all kinds of revenues,€/year
poc= the proportion of other operational costs is 11% of the total cost

2.6 Financial model output—profit

Profit is the difference between total revenue and total cost. The financial model with 44 parameters was defined as follows:

$$\begin{aligned}\Phi = & \sum_{\substack{i,j,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})[0.5365x_j + 0.1408(v_{i,j,k,l}+2u_{i,j,k,l})+1.2088] \\ & +1.1804\sum_{\substack{j=1\\ i,k=1,2\\ l=1,2,3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}) + 0.5902\sum_{i=1}^{8}\rho_i(\alpha_i\beta_i f_i + g_i p_i q_i) \\ & +\sum_{i=1}^{9} b_i(1+r_{b_i})[0.5365y_i + 0.2951(\lambda_i+\omega_i)+346.2315] - 7.31323\times 10^7\end{aligned}$$

where,

Φ=the annual profit of the airport

$a_{i,j,k,l}$=the base year segment (i,j,k,l) passenger number $r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i,j,k,l)

x_1 = Origin & Destination passenger fee

x_2 = Transfer passenger fee

b_t=number of aircraft movements of category t in base year

r_{b_t}=growth rate of number of aircraft movements of category t

y_i =landing fee for category i aircraft movement(€/movement)

$v_{i,j,k,l}$=average passenger spending (€/passenger)

$u_{i,j,k,l}$=average number of visitors per passenger in segment(i,j,k,l)(visitors/passenger)

α=proportion of passengers in segment (i,j,k,l) arrived at or left the airport by own car

β=proportion of passengers in segment (i,j,k,l) collected from or taken to the airport

f=average Parking time for passengers in segment(i,j,k,l) arrived at or left the airport by own car(h/passenger)

g= average Parking time for passengers in segment (i,j,k,l) collected from or taken to the airport (h/passenger)

p = Parking fee for passengers in segment (i,j,k,l) arrived at or left the airport by own car (€/h)

q= Parking fee for passengers in segment (i,j,k,l) collected from or taken to the airport (€/h)

ρ =passenger number related to car parking.

b_i =the base year aircraft movement number

λ_t =different aircraft cleaning fee, (€/movement)

ω_t =aircraft fuelling fee.

All these constant coefficients assigned come from the statistics of the historical data or expert judgement.

$$\rho_1 = \sum_{\substack{i,j,k=1\\ l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_2 = \sum_{\substack{i=2\\ j,k=1\\ l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_3 = \sum_{\substack{i,j,k=1\\l=3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}}), \rho_4 = \sum_{\substack{i=2\\j,k=1\\l=3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})$$

$$\rho_5 = \sum_{\substack{i,j=1\\k=2\\l=1,2}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}}), \rho_6 = \sum_{\substack{j=1\\i,k=2\\l=1,2}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})$$

$$\rho_7 = \sum_{\substack{i,j=1\\k=2\\l=3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}}), \rho_8 = \sum_{\substack{i,k=2\\j=1\\l=3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})$$

(Note: all these parameters' default values can be found in Appendix A.)

Chapter 3

Model implementation and integration

After identification and evaluation of possible models of ABS, we start the software development. First we will introduce the phase of the software development and design principles, then we focus on the implementation and integration of financial model. We will explain the reason for using Visual Basic and analyze the ABS structure diagram. Furthermore, the detailed description of the implementation and integration process will be given from an evolutionary point of view. Finally we will discuss the lessons and conclusions learned from the software development.

3.1 Introduction

This document describes the results of the software development of Financial Model(FM) as a part of the development of the ABS. The FM communicates with the user and other models about the economic aspects. All the operations (such as passenger fee change, runway change, etc.) that can affect on the financial situation of airport will be reflected in the result of this model. The model uses the annual number of passenger and aircraft movements to calculate the revenues (passenger fee revenue, landing fee revenue, parking fee revenue, handling fee revenue, retailing fee revenue, car parking fee revenue, real estate revenue, utilities revenue, etc.), costs (employees cost, depreciation cost, maintenance cost, service costs, interest costs, administration cost, etc), and investment of the airport (replacement investments and expansion investments). The FM gives the basic configuration of the airport business situation. The results are shown in the revenue and cost sheets, and the new balance sheet. From the results the user can see the current economic situation of an airport, whether it is healthy or not and take remedial steps. Further, the user can change the policy parameters (e.g. passenger fee and landing fee) to assess the influence of these parameters on the revenue and cost.

3.2 Phases of the software development

The software development process is like building a house, the builder does not start by piling up the bricks. Rather, the requirements and possibilities of the client are analyzed first, taking into account such factors as family structure, hobbies, finances and the like. The architect takes these factors into consideration when designing a house. Only after the design has been agreed upon is the actual construction started.

It is expedient to act in the same way when constructing the software. First, the problem to be solved is analyzed and the requirements are described in a very precise way. Then a design is made based on these requirements. Finally, the construction process, i.e. the actual programming of the solution, can be started. There are a distinguishable number of phases in the development of software[20]. The phases as discussed in this chapter are depicted in Fig. 3.1.

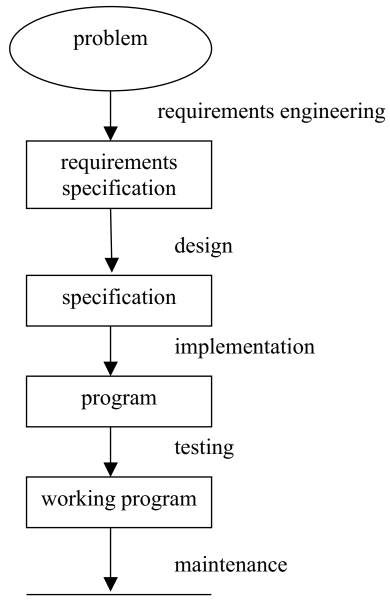

Figure 3.1: A simple view of software development

The process model depicted in Fig. 3.1 is rather simple. In reality, things will be more complex. For instance, the design phase is often split into a global, architectural design phase and a detailed design phase, and often various test phases are distinguished. The basic components, however, remain as given in figure. These phases have to be passed through in each project. Depending on the kind of project and the working environment, a more detailed scheme may be needed. Also, development is not a simple linear process, the latter phase always get some feedbacks and back to improve the previous styles.

In Fig. 3.1, the phases have been depicted sequentially. For a given project these activities are not necessarily separated as strictly as indicated here. They may and usually overlap. It is, for instance, quite possible to start implementation of one part of the system while some of the other parts have not been fully designed yet. As we will see in the latter, there is no strict linear progression from requirements engineering to design, from design to implementation, etc. Later tracking to earlier phases occurs, because of errors discovered or changing requirements.

3.3 Design principles

The Airport Business Suite (ABS) is a computer-based system for decision support that enables advisors to an airport's strategic decision makers to obtain, through a single graphical user interface, consistent information about all facets of the airport's business now and for future situations at the desired level of aggregation. During the design of the ABS, we followed four principles:

- Improve the effectiveness and efficiency of producing information for airport decision making;
- Coordinate and integrate the decision making tools;
- Place the user in control;
- Make the system flexible, adaptable, and easy to maintain;

These principles are elaborated in the following four subsections.

Improve the effectiveness and efficiency of producing information for airport decision making

The ABS applies design principles articulated over the last few years by researchers and practitioners who have been involved in the development and implementation of management information systems and decision support systems[5, 12]. These dimensions along which the toolbox improve the current airport planning tools include providing:

- Previously unavailable information (or information that was difficult to obtain). This information might be anything from raw data to the implications of new business strategies.
- More timely information.
- Better ways to access, display, and understand information.
- Better tools for projecting alternative future situations and estimating the effects of alternative strategies.

- Automation of previously performed manual calculations.
- Coordination and integration of the planning process.
- Better ways to explain decisions to others (and to obtain support for those decisions).
- Better capabilities for monitoring the developments at an airport and for responding to those developments. This can include feedback to measure how well the management's objectives are being met, methods for investigating deviations to determine their causes, and means for correcting unsatisfactory performance or adjusting plans in light of altered conditions.

Coordinate and integrate the decision making tools

The ABS consists of many interlinked computer models, planning loops involving the models, in which strategies, parameters, and constraints used in the models can be varied and their differential effects assessed, and output data files for use by all models in the system. For internal consistency and integration, it has the following characteristics.

- A common, centralized, integrated database for the use of all of the models to ensure consistency of results. The database retains all relevant information for reports, inquiries, and input to models in an organized, systematic manner. It draws its data from several sources, both internal and external to the TUD-ADC. Information generated by one model will automatically become available to all other modules requiring that information.
- A common high-level programming language for the models to facilitate updating and maintenance.

Place user in control

The ABS emphasis on the decision processes that it is designed to support instead of computer models. The ABS was built around the advisors to the decision makers and is responsive to their needs. It combines the analytic power and technological capabilities of the computer with the judgments, needs, and problem-solving processes of the advisors and decision makers – thereby extending their capabilities, but not replacing their judgment. The end user, not an operator, will be in the controls of the ABS. Through a command language he/she will interact with both an integrated database and an interlinked system of fast, flexible models. Because the user will typically not be computer literate, there should be an easy to learn and easy to use graphical user interface. The user should be comfortably able to:

- request information from the database;
- change data in the database;

- specify parameters and input data for a module;
- run a model or sequence of models;
- tailor output reports (e.g. in terms of scope, level of aggregation, time period covered and format);

Use of a common platform and graphical user interface for the toolbox serve to coordinate and integrate its many pieces. The system also responds quickly to user requests. These activities are inherently interactive and investigative processes in which intermediate results suggest the direction for subsequent analysis. Experience with these kinds of models strongly suggests that on-line access to the models and data facilitates their most effective use and that the system should be able to provide:

- on-line access to the modules
- on-line access to the database
- facilities for the statistical analysis of data
- graphical displays

In this man machine system, the machine acts as man's servant. If the user does not desire to adjust parameter values or specify new input data, the system supply default values. However, the user be able to overwrite any of the default values.

Make system flexible, adaptable, and easy to maintain

The ABS was designed to be easy to modify to meet changing needs, knowledge, and situations. It should be able to deal with unanticipated problems, test new strategies, and adapt as circumstances change. For the database, this means that procedures must be established for continual updating. Decision support system often fall into disuse because the input data gradually become out of date and it is costly and inconvenient to collect the required new data on an ad-hoc basis.

For the models, this means that they must be:

- flexible: easy to change and revise
- versatile: permit the use of new variables
- dynamic:amenable to revision in response to changes in the data on which they are based

This requires that they should be well documented and easily updated. Updating procedures should be incorporated in the routine maintenance of the system so that changes are made to the models to match changes in the environment. Some changes

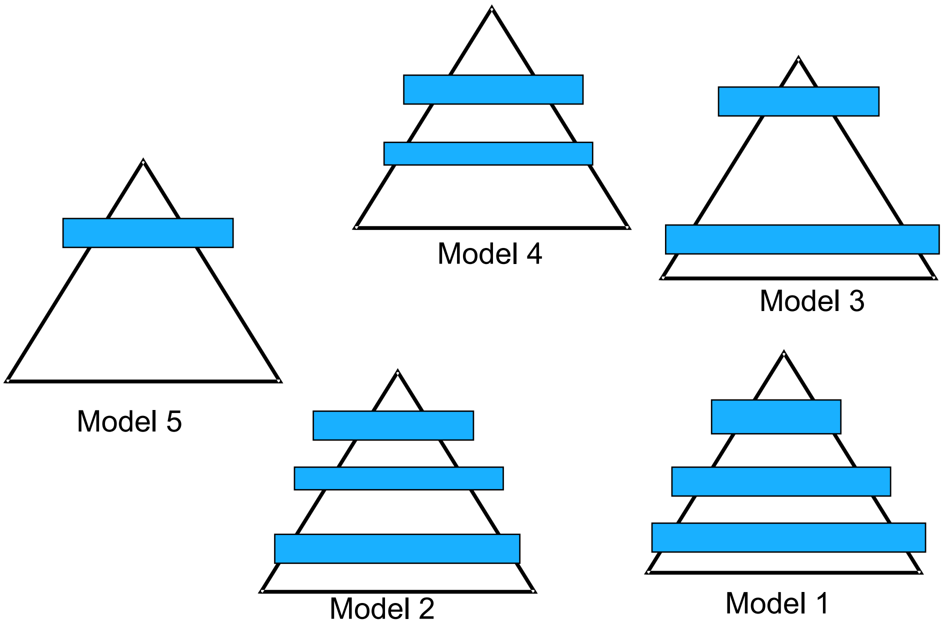

Figure 3.2: Different levels of abstraction

can be made automatically—e.g. changes in the input data and new parameter values that are calculated from information in the (continually updated) database.

Flexibility and adaptability will also be made easier by the use of several small, simple modules instead of a few large, complex models. The modules should be able to be easily modified to analyze new situations or answer new questions in a dynamic environment.

Another design principle that will make the system easy to update and maintain is to make the data required by the modules as easy to obtain as possible. The input data should not require extensive preparation or previous analysis and should be routinely collected by the TUD-ADC or by the customer.

Model construction and implementation

Different models have different levels of abstraction (see Fig. 3.2). These different abstraction levels serve different purposes and have different costs and benefits. For example, the demand model (model 1) has four levels of abstraction, different model has different level, how to make them consistent and communicate each other is the first problem we need to solve.

After we chose the level of abstraction to fit the needs, we got the impression of how the ABS should look shown in Fig. 3.3.

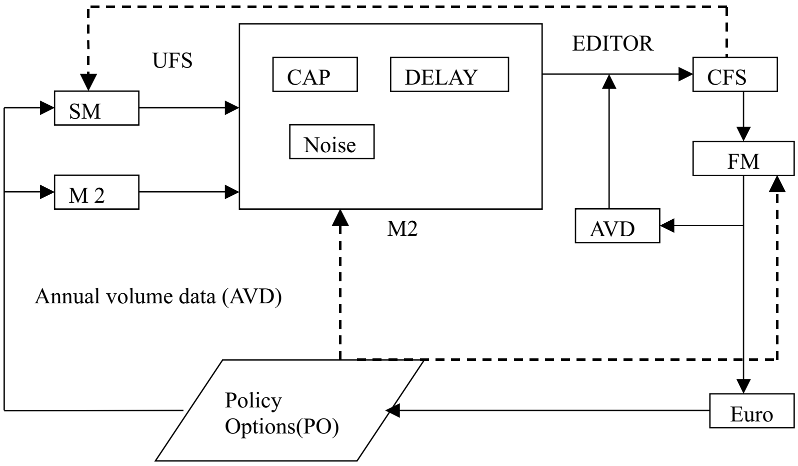

Figure 3.3: ABS flow structure

The user input the available base year annual volume data into schedule model (SM) and get an unconstrained flight schedule (UFS). After running the capacity model (CAP) and delay model (DELAY) of model 2, we get the constrained flight schedule (CFS). Based on this schedule, we can calculate the revenue, cost, investment and noise contour. Model 1 and 2 only calculate the forecasting year (target year) but not the year in between, while the model 4&5 need yearly data. Here we apply the growth rate shortcut, iteration the yearly data between the base year and target year. In this way, all the models are work together. Besides, the user can put in a policy option (PO) until the model outcomes are satisfactory. Then you can run M 4+5 and you'll have the financial outcomes. Similarly you can put in a policy option (PO) in the SM as M 2. The airport, the policy option and the scenario that is chosen to fix the outcomes.

After the model concepts and parameters are specified, we start to consider what computer language will be used for the model implementation. From the software experiment conducted before, we know Visual Basic (VB) is a good language.

3.4 Why Visual Basic

There are literally hundreds of programming languages. Each was developed to solve a particular type of problem. Most traditional languages, such as BASIC, C, COBOL, FORTRAN and Pascal are considered procedural languages. That is, the program specifies the sequence of all operations step-by-step. Program logic determines the next instruction to execute in response to conditions and user requests.

VB uses a different approach: Object Oriented/Event Driven (OOED) program, it uses objects which respond to events; uses small segments of code for each object[3]. It is easy to work with, because it is more intuitive than traditional programming methods. It is a high level computer language. The programmer using English words and clearly defined syntax; these codes converted or translated into binary for computer to implement. As the programmer, you not take control and determine the sequence of execution. Instead, the user can press keys and click on various buttons and boxes in a window. Each user action can cause an event to occur, which triggers a BASIC procedure that you have written. For example, the user clicks on a command buttons labelled Calculate. The clicking causes the button's Click event to occur, and the program automatically jumps to a BASIC procedure you have written to do the calculation.

VB is designed to allow the programmer to develop applications that run under Windows without the complexity generally associated with Window programming. With very little effort, the programmer can design a screen that holds standard Windows elements, such as command buttons, check boxes, option buttons, text boxes, and list boxes. Each of these Window objects operates as expected, producing a "standard" Window user interface.

The basic features of VB as follows:

- Advanced computer language;
- Next generation of BASIC working with Windows operation system;
- Designed to be user friendly(Graphical User Interface, GUI);
- Event driven language(clicking a mouse button, typing a character on keyboard);
- Key product of Microsoft, compatible with other software;
- Easy to learn, which makes it an excellent tool for understanding elementary programming concepts.

The answer to what makes Visual Basic a great programming language is simply that VB provides more of the actual code for a programmer than any other non-visual programming language. If you've ever programmed in the older BASIC or other command line programming language, then you'll remember that the programmer had to write the code for the entire user interface. Today's windows, buttons, lists, and other application features such as menus were not built-in to the BASIC programming language. Programmers had to create the code for these features on their own!

As much as 80% of a programmer's time was spent writing code to create the user interface to his applications (the visual interface). To eliminate this huge drain on a programmer's time, Microsoft has provided VB with the built-in capability to create the user interface using nothing more than a mouse.

This built-in interface creation capability has had the further benefit of standardizing the user interface to Windows applications. Today, users can move from one Windows program to another and see the same basic interface tools to work with— allowing them to concentrate solely on the unique capabilities of the application.

The bottom line is that you can create an entire application shell (the user interface) very quickly and then spend most of your time working on the features which characterize the application.

3.5 Conclusions from the software experiment

The software experiment of model 2 focused on creating the user interface and databases for the airside capacity and delay models. It enabled the user to input data easily through a graphic user interface, and to transform the data to generate the input file required by the FAA Airfield Capacity Model (FAACM).

From the software experiment, we learned that VB is a good language to implement the ABS. Integration of different program parts that were made separately (for debugging purposes), worked well.

The software experiment was a success. It attains the expected goals and also gives us a chance to gain experience with VB. The experiment we have conducted indicated that VB is a suitable language to use for implementation, easy to learn, implement and compatible with other languages (such as Excel, MS-Access). For the final integration of this and other models, a more component based approach could be preferred. VB allows for the development of ActiveX components that might be useful for this purpose. In fact, ActiveX components are separate computer programs that can be integrated into other programs. This makes it possible to follow a modular approach and to separate the software development into two parts. One is the core—model implementation and integration, the other is interface. In the end, these two parts will integrated together by the ActiveX. From now on, we will start to explain the implementation and integration of the financial model.

3.6 Parameter specification

During the model and parameter specification, we defined 3 kinds of inputs: system parameters, policy parameters, and scenario parameters. For system parameters, it is easy to understand how they relate to the specific airport infrastructure, such as the number of runways, the terminal area, the parking area, etc. All these data should be predefined before the model calculation. There are some differences between the policy parameters and scenario parameters. Scenario parameters are these that are not under the control of the airport management. Policy parameters represent the data that are controlled by the airport management. For example, the passenger number can not be control by the airport administration, so it is a scenario data. Passenger fees , on the other hand, are controlled by management. We make a table which contains all the parameters' name, unit, description, type, etc (see Appendix A).

3.7 Writing Visual Basic programs

When we write a Visual Basic program, we follow a three-step process:

1. Define the user interface. When we define the user interface, we create the forms and controls that we designed in the planning stage. This is the first step when we define all the programs which will used in the project.

2. Set the properties. When we set the properties of the objects, we give each object a name and define such attributes as the contents of a label, the size of the text, and the words that appear on top of the command button and in the form's title bar. This is the step to think of when we describing each object.

3. Write the Visual Basic code. We will use BASIC programming statements (called BASIC code) to carry out the actions needed by the program. This is the third step as defining the actions of the program.

3.8 Programming

3.8.1 Description of the program

After confirmation of the model structure and specified the parameters, we start the programming part. In order to make the process clear and easy to understand, we describe the process in an evolutionary way as Fig. 3.4 depicts. The process consists of two phases, from simple to complex. At first we can calculate one year's revenue and cost sheet and balance sheet(Phase 1), then we use the iteration and we can calculate not only the target year but also every year in between(Phase 2).

Before we start the description, we will show what the revenue and cost sheet and balance sheet look like (see Fig. 3.5, 3.6). On the left side of Revenue & Cost Sheet, all kinds of revenues (passenger fee revenue, landing fee revenue,aircraft parking fee revenue, handling fee revenue, retail revenue, car parking fee revenue, real estate revenue, utilities revenue, and total revenue) are listed, on the right side, there list all kinds of costs (employee cost, depreciation cost, maintenance cost, service cost, retail cost, administration cost, interest cost, total cost, and profit in that year). In the balance sheet,

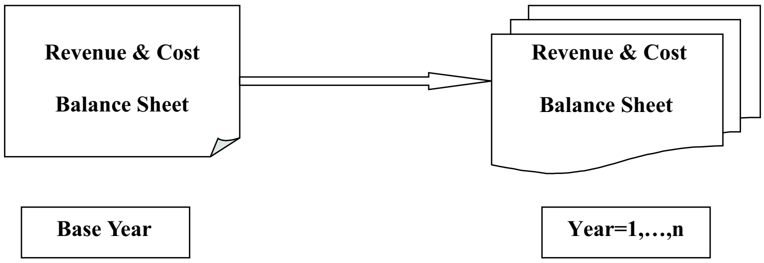

Figure 3.4: Evolution of the program

the left side lists liquid resources, fixed assets, and total active; the right side lists private capital, debt capital, and total passive. Total active is equal to the total passive.

3.8.2 Phase 1

In this phase, attention was paid to the FM itself. Our goal was to get the financial model running.

First we set up the interface as the Fig. 3.7 shows. In the upper single column list box, the revenue and cost sheet, and the balance sheet are displayed vertically in the column from which the user select either of them, the corresponding contents of the sheet will appear. Where all the calculation results are shown in that embedded window.

The property settings for the form and each of the controls can be found in Appendix B.

After we set the properties of the object, we start to write the program. Based on the design experience and theoretical knowledge, the program was separated into two parts. In the first part, all values of the input and system parameters are assigned and process are initialized. The other one is calculation part, different revenues, costs, and profits are calculated using the given model.

This phase 1 version was used to show the feasibility of the Visual Basic programming. It can calculate the single year's revenue, cost and new balance sheet. All values of the parameters are assigned in the first part of the program. Then use the function and subroutine to calculate the value of the revenues and cost. Finally the results are shown in the interface. Since all parameters have assigned value in the program using default values, and the program which runs calculation was controlled by the button in the interface. The whole calculation takes some seconds. The results, the revenue and cost sheet, new balance sheet are displayed vertically in the single column list box from which the user can select one by one. Once you click the any one of them, the contents of the sheet will be shown in the right side of the interface (see Fig. 3.7), in which the new revenue and cost sheet is displayed.

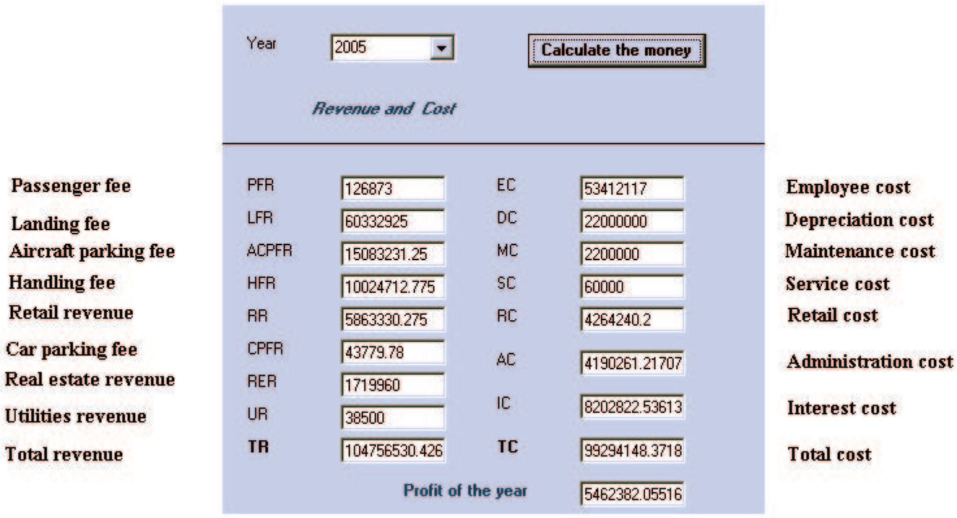

Figure 3.5: Revenue & Cost Sheet

Program structure

This program consists of three forms, frmMoney, frmFinmod, and frmRevecost. The former two are used to show results. frmMoney sets up the list box. FrmFinmod make the new balance sheet. FrmRevecost include all the calculation programs making revenue and cost sheets.

This phase 1 version of software was a test version that provide the core and basis for future improvements. Since there are communications between model 4 & 5, we need to set up linkage between different models. The core only calculates one year and assumes all the parameters values are known. However it is not enough. What the user usually want to know is a series of yearly financial projections. We therefore need to make it possible to do iterative calculation for several years. We did this in phase 2.

3.8.3 Phase 2

In order two make the program that calculates a series of years' revenues, costs, and new balance sheets. Some improvements of the phase 1 version were made.

1. User friendly interface

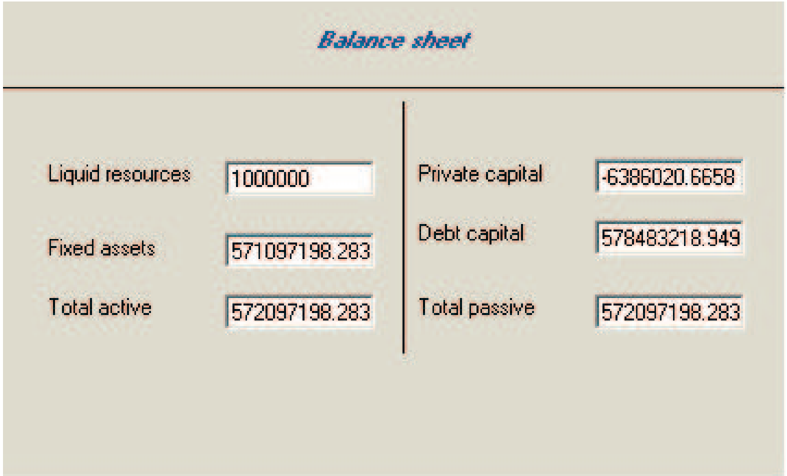

Figure 3.6: Balance Sheet

2. External system data
3. Policy parameters considered
4. Calculation part make a big change due to the input change, it include some functions and subroutines.
5. Integrated with other models

We see from the Fig. 3.8 that the interface can be separated into three parts. First is the initialization of the system. Before the calculation, the user needs to set all the default values and read the inputs from output file of the model 1. This can be done by pressing the button "Initialize the system" (see Fig. 3.9). In order to see whether the process is finished, we use a message box. This is a special type of Visual Basic window in which you can display a message to the user. After the initialization finished, "The system initialization has been finished, You can go to next step!" will appear in the message box.

The second part is the policy parameter settings(see Fig. 3.9). At this moment, we make the Origination/Destination passenger fee, Transfer passenger fee, and landing fee for different category of aircraft movements changeable. The user can choose and input new value if he/she not satisfied with current value. After the user click the button "User defined Policy data", then comes out message box "Do you want to change the policy parameter?". This time the message box used as a function, the user can choose the button "Yes" or "No". The function returns a value indicating which button was

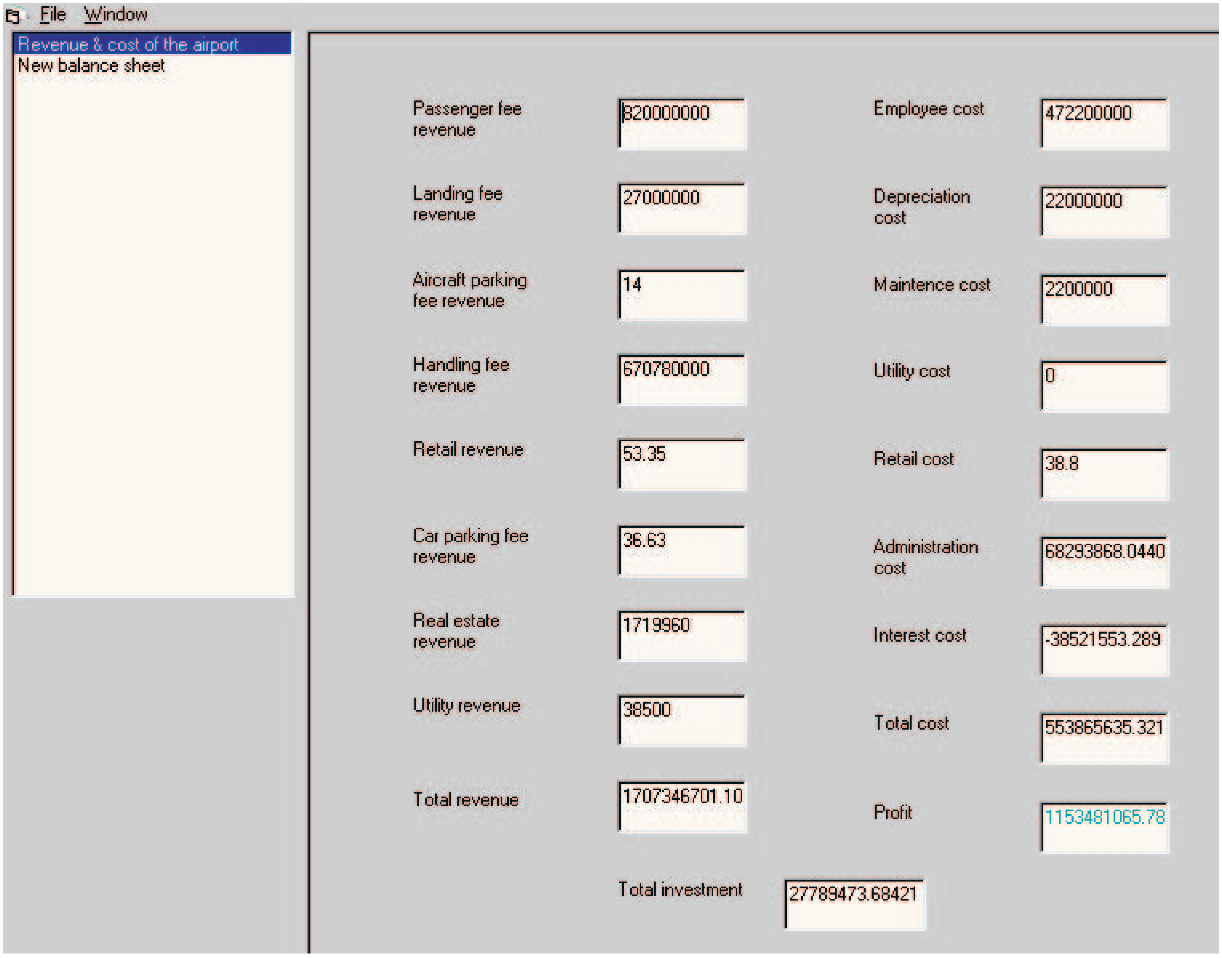

Figure 3.7: Interface of phase 1

processed. The user can change the passenger fees and/or landing fees, and see their influence on the revenue and balance sheet immediately.

The third part is the result. There is a dropdown combobox where the user can make a selection of the year between the base year and target year. In the left side is revenue & cost sheet, the right side is the new balance sheet. Both sheet are related to that specific year (see Fig. 3.10).

The system data are all saved in external Excel files. This makes the software easy to maintain. All the system parameters are saved in Excel files. For one airport, these data are fixed and defined beforehand. It contains the information of airport infrastructure, such as runway number, terminal area, office area, etc.

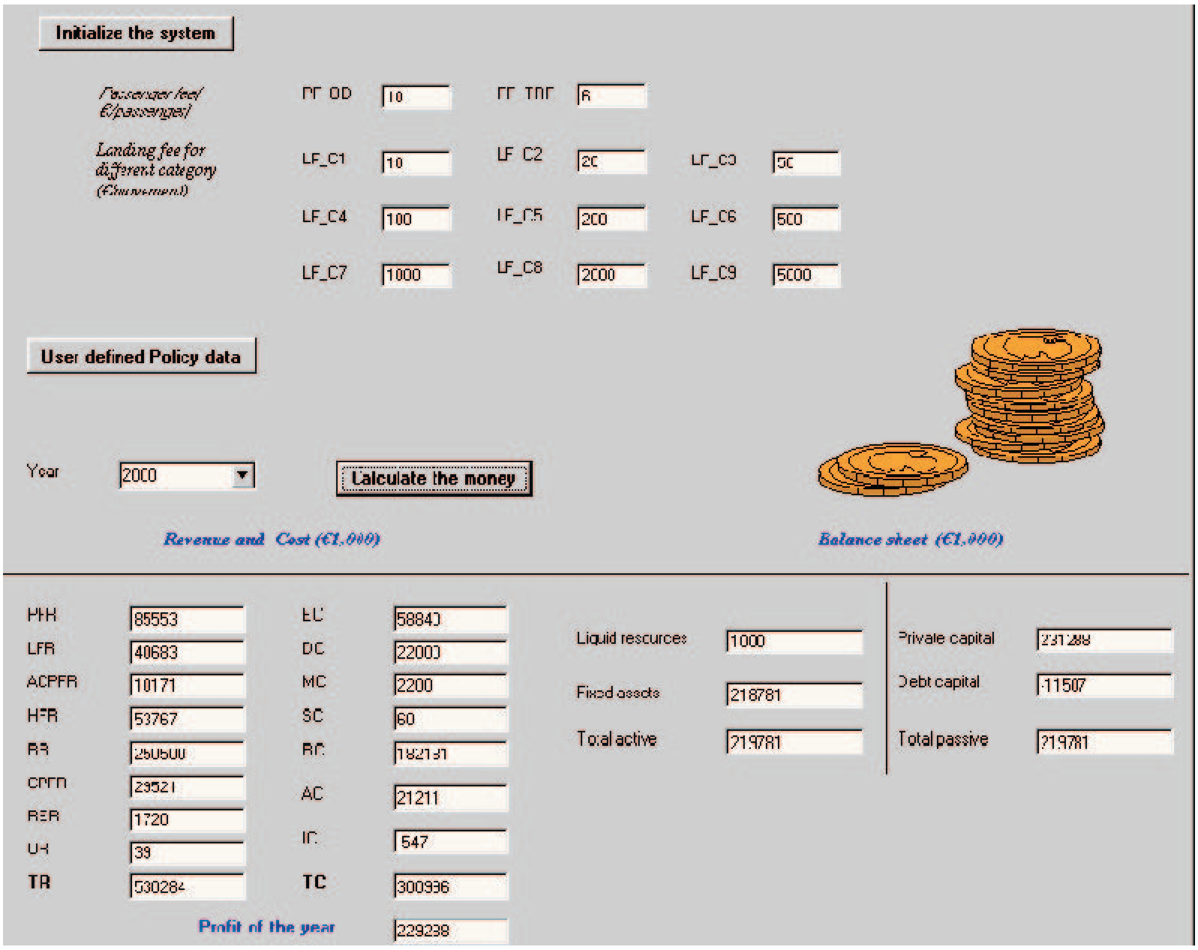

Figure 3.8: Interface of phase 2

The financial model needs the input file from model 1 (the Schedule Model (SM)). The SM produces the number of annual passengers number, and aircraft movement number and saved them in a ForModel45 table of MS-Access file. This table is one row 35 column structure. Each row consists of passenger numbers with respect to origin/destination, transfer passenger number, aircraft movements of 9 different categories, and 24 segments passenger number. In this phase 2 version, the dynamic linkage between model 1 and our model was set up. And the data can be changed automatically with model 1.

The remaining parameters and inputs are assigned values inside the program. The following are modifications we made:. Reading MS-Access file by using Database class (clsDatabase) and accessing its tables by SQL statements. After using the class, the program can do calculations for every year between the base year and target year. The

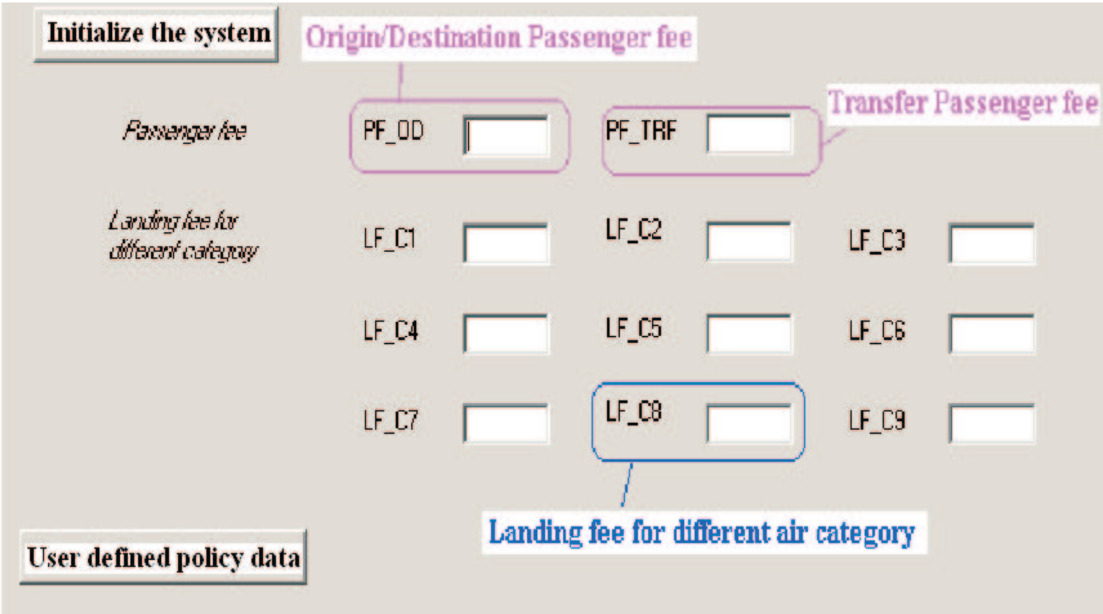

Figure 3.9: Initialization and policy change

results are saved in arrays, the user can choose the year then the revenue and cost sheet and balance sheet can be shown respectively.

The property settings for the form and each of the controls can be found in Appendix B.

3.9 Input and output

In this section a description is given of all the functions and subroutines in each (class) module used in the financial and investment model. It consists of main program and class module. The main program includes the data linkage part and calculation part.

3.9.1 Input

Data linkage part

Input system parameters from Excel sheets Input from model 1 comes from MS-Access database, and make it satisfy with the requirement of the financial and investment model by calculation.

clsDatabase

Main module. Can be called from 'outside'. Use this class to connect to an MS Access

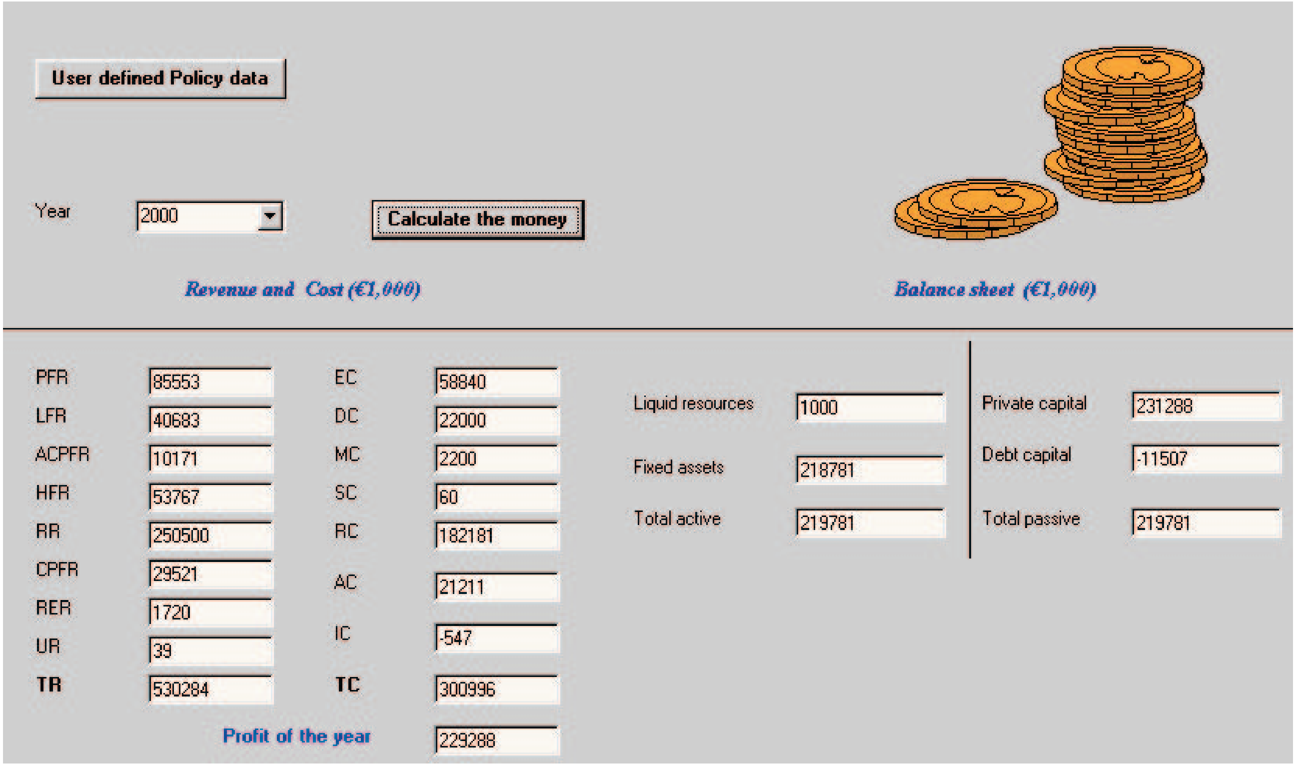

Figure 3.10: Revenue cost sheet and balance sheet

database and access its tables by SQL statements. Requires MS Data Access Object an MS Access variables:

$$\begin{array}{rl} db\_name: & nameandpathoftheaccessdatabasetobeused \\ dbh: & Databasehandler \\ ws: & Workspacehandler \end{array}$$

OpenConnection (subroutine)
Input: db_name
Opens connection with database.
Close Connection (subroutine)
Closes connection with database (dbh).

3.9.2 User interface

DoQuery (subroutine)
Input: query (string) Executes a query in MS-access
GetResults (function)
Input: query (string)
Output: Record set of query
CountResults (function)
Input: Record set of results
Output: Number of results

3.9.3 Calculation

Requires all data linkage to be run first. All these function defined based on the formulas given in section 2.4, 2.5, and 2.6.
PFR (function)
Input: Number of passengers flying Origin and Destination, transfer; Passenger fee for different passengers.
Output: Passenger fee revenue.
LFR (function)
Input: Number of aircraft movements for each category, landing fee for different category aircraft.
Output: landing fee revenue.
ACPFR (function)
Input: Number of aircraft movements for each category, Number of overnight parking aircraft per day, average turnaround time, aircraft parking fee for different category aircraft and overnight aircraft.
Output: parking fee revenue.
HFR (function)
Input: Number of passengers flying Origin and Destination, transfer; Number of aircraft movements of different category, proportion of handling contracted out, baggage handling fee, Handling fee for catering, Handling fee for check-in, Handling fee for cleaning of different category aircraft.
Output: handling fee revenue.
RR (function)
Input: Number of passengers in different segments(arriving/departing, O&D/transfer, business/non-business and European Union/Non-European Union/intercontinental, abbreviated respectively with A/D, OD/TRF, Bu/NBu and EU/NEU/ICO. All possible combinations lead to 24 passenger segments (2 x 2 x 2 x 3)). Proportion of retail contracted

out, Height of concession fee, average number of visitors per passenger in segment I, average passengers spending in segment I, average visitors spending, revenues from ”fun-shoppers”.
Output: Retail revenue.
CPFR (function)
Input: Number of passengers in different segments (arriving/departing, O&D, business/non-business and inside continent/intercontinental, abbreviated respectively with A/D, OD, Bu/NBu and CO/ICO. All possible combinations lead to 8 passenger segments (2 x1 x 2 x 2)). Proportion of car parking contracted out, Proportion of passengers in segment i arrived at or left the airport by own car, Proportion of passengers in segment i collected from or taken to the airport, average parking time for passengers in segment i arrived at or left the airport by own car, average parking time for passengers in segment i collected from or taken to the airport, Parking fee for passengers in segment i arrived at or left the airport by own car, Parking fee for passengers in segment i collected from or taken to the airport.
Output: Car parking fee revenue.

RER (routine)
Input: Total office area with high rents, Total office area with low rents, Proportion of real estate contracted out, Height of concession fee, occupancy of office area, occupancy of hotel beds, average high rent for one m^2 office area, average low rent for one m^2 office area, average price for one room.
Output: Real estate revenue
UR (routine)
Input: Total airport area used by third parties, Selling price of one squarer meter utility, Proportion of utility services contracted out, Height of concession fee.
Output: Utilities revenue
TR (routine)
Input: Proportion of other revenues.
Output: Total revenue
EC (routine)
Input: Total car parking area, Number of runway systems, Number of passengers, Number of aircraft movements, Employee costs for one m2 car parking area, Employee costs for one runway system, Employee costs per passenger, Employee costs per aircraft movement, Proportion of operations contracted out.
Output: Employees cost
DC (routine)
Input: Total car parking area, Total office area, Total terminal area, Number of runway systems, Purchase price for one m2 car parking area, Purchase price for one m^2 office

area, Purchase price for one m2 terminal area, Purchase price for one runway system, Depreciation percentage or respectively car parking office area, terminal area and runway system.
Output: Depreciation cost
MC (routine)
Input: Total car parking area, Total office area, Total terminal area, Number of runway systems, Maintenance costs for one m2 car parking area, Maintenance costs for one m^2 office area, Maintenance costs for one m^2 terminal area, Maintenance costs for one runway system.
Output: Maintenance cost
SC (routine)
Input: Total airport area used by third parties, Total terminal area used by the airport itself, Selling price of one squarer meter utility, Proportion of utility services contracted out, Profit margin on recharge of utilities.
Output: Utilities service cost
RC (routine)
Input: Potential retail revenues, Proportion of retail contracted out, Profit margin on retail.
Output: Retail cost
AC (routine)
Input: Total revenues, Proportion of administration costs, Fixed administration costs. Output: Administration cost IC (routine) Input: Debt Capital in the reference year t-1, Liquid resources in the reference year t-1,t, Investments in year t, Total revenues of year t, Depreciation costs of year t, Total costs of year t, certain percentage leading to the amount of redeemed loans next year, percentage of interest. Output: Interest cost
TC (routine)
Input: Proportion of other operational costs.
Output: Total cost
TI (routine)
Input: Depreciation costs, Number of passengers in year t-1, t, Fixed assets, Proportion of investment with respect to passengers growth.
Output: Total investment

3.9.4 Output

Cost and Revenue sheet, New balance sheet shows the value of parameters.

3.9.5 Active X file

After we finished the programming of the phase 2 version of the FM and how to link to the other models, we start to consider how to relate it to the GUI, which was written in Delphi. Active X is a good choice, it works in prototype. We edit some class module of input parameters and output parameters in our current program. In this way, the Active X files become a function which can be called from outside, and return the calculation results to the interface where they were shown.

In order to use the ABS in the TBM/LR course "Strategic planning for airport systems " (TB9152) designed our own interface using VB and produced an education version of ABS (see Fig. 3.11).

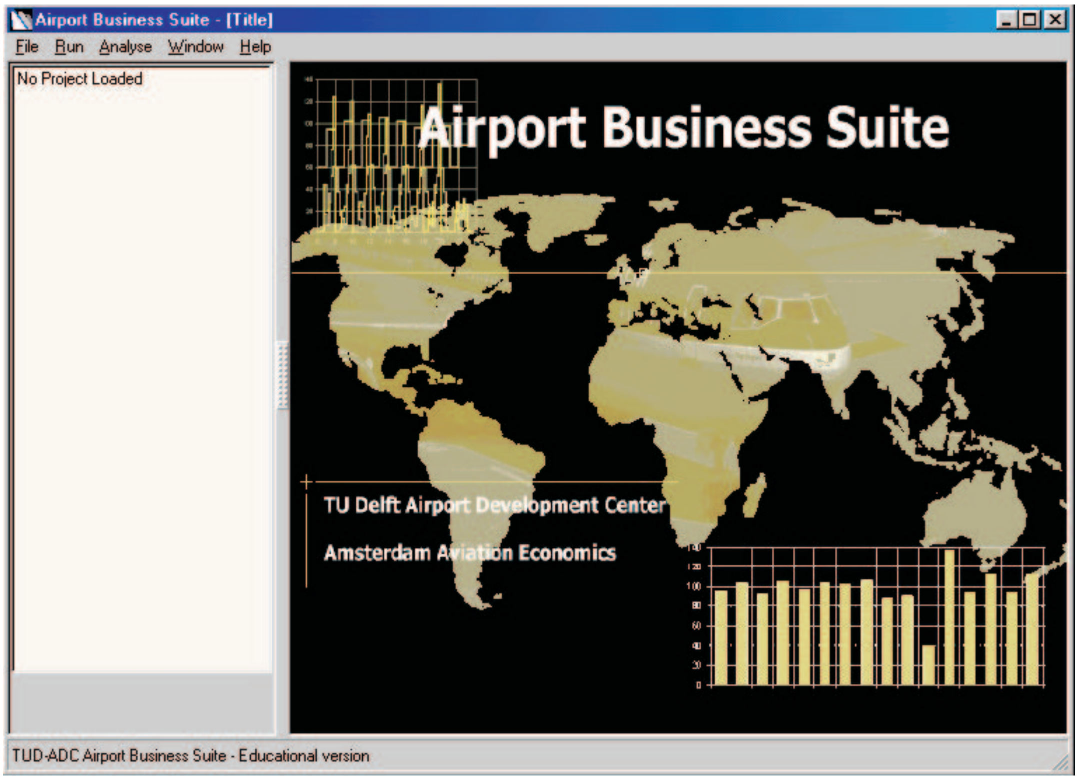

Figure 3.11: Interface of education version of ABS

3.10 Conclusions

Visual Basic proved to be a suitable language for the implementation of the model. For the final integration of this and other models, a more component based approach could be preferred. Visual Basic allows development of so-called Active X components that might be useful for this purpose. In fact, Active X components are separate computer programs that can be integrated into other programs. This makes it possible to follow a modular approach, so it is a good option for our development. The software development of financial model is a success. It consider not only the implementation and integration of the models, but also the maintenance and future improvement.

Chapter 4

The Uncertainty/Sensitivity Analysis of the Financial Model

After the implementation of the ABS, the user can use it to simulate the airport operations and make strategic decisions for airports in an efficient and effective way. ABS like a simulation machine can make all kinds of cases and show what will happen if some policies change. From these simulations, the user can get some information. But it is not enough. As we know that the financial model is a deterministic model for a specific year. Once all these parameters are known, the model's output (estimated profit) is certain. However, future profits are far from certain. The user is interested in the profit of the future years, how much it fluctuates, and how to maximize the profit using the available sources (i.e., find the sensitive parameter, main driver of the model). Therefore, we conduct the uncertainty/sensitivity analysis on the financial model to find the important input parameters of the model and optimize the policy based on the results.

In the first three sections of this chapter, we will give a general introduction and overview of sensitivity analysis, then we will explain two sensitivity analysis techniques: Morris' method and correlation ratio. This is followed by the results got from these two methods. In the fourth section we use the Cobweb plot from Unicorn to optimize the policy and analyze the model parameters' relations. Finally, some conclusions will be given in the last section.

4.1 Sensitivity Analysis

The aim of the sensitivity analysis of a model is to find a limited set of parameters which accounts for most of the uncertainty in the model's output.

4.1.1 Overview of sensitivity analysis

We use mathematical and computational models for a variety of settings and purposes, often to gain insight of possible outcomes of one or more courses of action. This may concern a financial investment, the choice on whether and how much to insure, the assessment of industrial practices and environmental impacts. Models and uncertainty go hand in hand; models are only approximation of reality. Uncertainty looms on model selection, on model quality assurance and especially on model use.

Sensitivity Analysis (SA) is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation[19].

Sensitivity Analysis (SA) aims to ascertain how the model depends upon the information fed into it, upon its structure and upon the framing assumptions made to build it. This information can be invaluable, as

- Different level of acceptance (by the decision-makers and stakeholders) may be attached to different types of uncertainty.

- Different uncertainties impact differently on the reliability, the robustness and the efficiency of the model.

Originally, SA dealt only uncertainties in the input variables and model parameters. Over the course of time the ideas have been extended to incorporate model conceptual uncertainty, i.e. uncertainty in model structures, assumptions and specifications. As a whole, SA is used to increase the confidence in the model and its predictions, by providing an understanding of how the model outputs respond to changes in the inputs, be they data used to calibrate it, model structures, or factors, i.e. the model independent variables. SA is thus closely linked to uncertainty analysis (UA), which aims to quantify the overall uncertainty associated with the response as a result of uncertainties in the model input.

Here we cite the loose definition of SA given by A. Saltelli [19].

Definition 1 (Sensitivity Analysis). *Sensitivity analysis studies the relationships between information flowing in and out of the model.*

4.1.2 Why carry out the sensitivity analysis

In the context of numerical modelling, SA means different things to different people. But they have the same aim to investigate how a given computational model responds to variations in its inputs. By conducting the SA, we can determine:

- if a model resembles the system or processes under study; the model does not properly reflect the processes involved if it exhibits strong dependence on supposedly non–influential factors or if the range of model predictions is not a sound one.
- the factors that mostly contribute to the output variability and that require additional research to strengthen the knowledge base; SA can assist the modeler in deciding whether the parameter estimates are sufficiently precise for the model to give reliable predictions. If not, further work can be directed towards improved estimation of those parameters that give rise to the greatest uncertainty in model predictions. SA will open up the possibility of improving the model by prioritizing measurement of the most influential factors. In this way, the impacts of measurement errors on computational results can be minimized.
- the model parameters (or parts of the model itself) that are insignificant, and that can be eliminated from the final model;
- if any which factors interact with each other. This last point is an important technicality: often factors have combined effects that cannot be reduced to the sum of the individual ones. This is relevant, since the presence of an interaction has implication for all of the above points (calibration, determination of critical points, etc.).

4.1.3 Various types of sensitivity analysis techniques

Sensitivity analysis (SA) of a model output aims to quantify the relative importance of each input model parameter in determining the value of assigned output variable. Before conducting an analysis, we may want to filter out unimportant parameters to reduce modelling effort. Screening techniques are designed for this purpose. After an analysis has been carried out, we want to identify important parameters to support subsequent decisions. Many different methods have been developed for SA, this discipline being very much application driven. According to the problem setting, we classified various techniques in two main branches: local SA methods and global SA methods. Screening methods also can be viewed as either local or global[19].

Screening

In dealing with models that are computationally expensive to evaluate and have a large number of input parameters, screening experiments can be used to identify the parameter subset that controls most of the output variability (with low computational effort). This is based on the experience that often only a few of the input parameters have a significant effect on the model output. As a drawback, these 'economical' methods tend to provide order of sensitivity measures, i.e. they rank the input factors in order of importance, but do not quantify how much more important a given factor is than another. In contrast, a quantitative method would give, for example, the exact percentage of the total output variance that each factor (or group of factors) is accounting for. There is clearly a trade-off between computational cost and information.

Several approaches to the problem of screening have been proposed in the literature. Such as one-factor-at-a-time (OAT) experiment proposed by Morris, the design of Cotter, the iterated fractional factorial designs (IFFDS) introduced by Andres, and sequential bifurcation proposed by Bettonvil [19]. Here we only describe the OAT experiment proposed by Morris. It is the simplest class of screening designs. In these designs, the impact of changing the values of each factor is evaluated in turn. The standard OAT design use the 'nominal' or 'standard' value per factor; often this value is taken from literature. The combination of nominal values for the k factors is called the 'control' scenario. Two extreme values are usually proposed to proposed to represent the range of likely values for each factor; normally the 'standard' value of a factor is 'midway' between the two extremes. The magnitudes of the differences between the outputs for the extreme inputs and 'control' are then compared to find those factors that significantly affect the model.

Local SA

Local SA concentrates on the local impact of the factors on the model. Local SA is usually carried out by computing partial derivatives of the output functions with respect to the input variables. In order to compute the derivatives numerically, the input parameters are allowed to vary within a small interval of fractional variation around a nominal value. The interval is usually the same for all of the variables and is not related to our degree of knowledge of the variables. Present-day computational tools for local SA allow large numbers of sensitivity coefficients to be computed simultaneously. This is often used to solve a so-called 'inverse problem. One can see local SA as a particular case of one-factor-at-a-time (OAT) approach, since when one factor is varied, all others are held constant.

Local methods are less helpful when SA is used to compare the effect of various factors on the output, as in this case the relative uncertainty of each input should be weighted. This can be achieved by some kind of differential analysis, where an incremental ratio is considered. There is an example in Capaldo and Pandis[4].

When the model is nonlinear and various input variables are affected by uncertainties of different orders of magnitude, a global SA method should be used[9]. There are various local importance measures that give contributions in selected regions of the sample space[19]. Such as First Order Reliability Method (FORM) and Local Probabilistic Sensitivity Measure (LPSM) [15, 7].

Global SA

Global SA apportions the output uncertainty to the uncertainty in the input factors, described typically by probability distribution functions that cover the factors' ranges of existence. The ranges are valuable, since they represent our knowledge or lack of it with respect to the model and its parameterizations. Global SA is different in two aspects: First, the space of the input factors is explored within a finite (or even infinite) region and, second, the variation of the output induced by a factor is taken globally—that is, averaged over the variation of all the factors.

A global SA technique thus incorporates the influence of the whole range of variation and the form of the probability density function of the input. A global method evaluates the effect of x_i while all others x_j, $j \neq i$, are varied as well. In contrast, the local perturbative approach is based on partial derivatives, the effect of the variation of the input factor x_i when all other x_j are keep constant at their nominal value.

Several global SA measures have been proposed in the literature: expected gain of information, linear regression coefficients, rank correlation coefficients,partial rank correlation coefficients, correlation ratios, Sobol indices.

The simplest idea is to regress the parameter of interest onto other parameters of that model. Coefficients obtained this way (linear regression, product moment rank or partial correlation) can give us information of non-linearity or/and dependencies in our model. None of them are really satisfactory. The linear regression, the product moment and partial correlations often perform poorly when the relationships between the input and output variables are non-linear as they measure the linear strength of the association. Sometimes this problem can be solved by use of rank correlation that measures the strength of monotonic relationship. When the relationship between input and output variables is not monotonic this measure can be very unsatisfactory. For the rich exposition of the mentioned problems with examples and references see Helton and Davis in Satelli[19].

Exploratory analysis was proposed by Steven C. Bankes[2]. It is some kind of sensitivity analysis, it considers not just excursions taken one at a time but rather all cases corresponding to value combinations defined by an experimental design.

In the following section we will present the Morris' method.

4.2 Morris' method—OAT designs

Computer models of physical processes have become important tools in all areas of science. Two properties shared by many large-scale models are the requirement of considerable computer time for each run and the dependence on a large number of input variables. Computational experiments are often performed using such models, with the aim of creating an approximation of the model, or simply to discover which inputs have the greatest influence on outputs. In many cases, most inputs are unimportant; so the problem of designing computational experiments to determine which inputs have important effects on an output is considered. Morris' experimental plans are composed of individually randomized one-factor-at-a-time designs, and data analysis is based on the resulting random sample of observed elementary effects, those changes in an output due solely to changes in a particular input. Advantages of this approach include a lack of reliance on assumptions of relative sparsity of important inputs, monotonicity of outputs with respect to inputs, or adequacy of a low-order polynomial as an approximation to the computational model.

4.2.1 Why have we chosen Morris' method

Because Morris' method is a simple method and has an advantage of relatively low computational cost, it can be used to find the important factors quickly and economically.

Since ABS require the software effectively and efficiently (i.e. program runing time), we use Morris' method to find the important parameters for the financial model, and use this information to help the decision maker make reasonable decision.

4.2.2 Method description

We have chosen Morris' method[17] because it is a screening method that belongs to the OAT (one factor at a time) class, but the baseline changes at each step; that is, this method wanders in the space of the input factors rather than oscillating around the baseline as in elementary OAT.

It estimates the main effect of a factor by computing r number of local measures at $x_1, x_2, \cdots, x_r$ in the input space and taking the average. This reduces the dependence on the specific point. It needs computer runs proportional to **k** (number of factors), and determines which factor have (a)negligible effects,(b) linear and additive effects, (c)nonlinear and interaction effects.

The k-dimensional factor vector **x** for the simulation model has components x_i that have p values in the set $0, 1/(p-1), \cdots, 1$. Each realization of **x** will then be scaled to a suitable input vector for the model as it follows:

$$x_i = A_i + x_i(C_i - A_i)/(p-1)$$

where A_i and C_i are the extreme values of the range of variability chosen for x_i (see Table 4.5.2). The region of the experiment Ω is a k dimensional p level grid. In practical applications, the values sampled in Ω are subsequently rescaled to generate the actual (non-standardized) values of the simulation factors. Let Δ be a predetermined multiple of $1/(p-1)$.

Define elementary effect of i-th factor at given point x as:

$$d_i(x) = \frac{[y(x_1, x_2, \cdots, x_{i-1}, x_i + \Delta, x_{i+1}, \cdots, x_k) - y(x)]}{\Delta}$$

where $\mathbf{x} = (x_1, \cdots, x_n)$ is any value in Ω selected such that the perturbed point $x + \Delta$ is still in Ω. A finite distribution F_i of elementary effects for the i-th input factor is obtained by sampling x from Ω. The number of elements of each F_i is $p^{k-1}[p - \Delta(p-1)]$.

The characterization of the distribution F_i through its mean μ and standard deviation σ gives useful information about the influence on the output; a high mean indicates a factor with an important overall influence on the output, a high standard deviation indicates either a factor interacting with other factors or a factor whose effect is nonlinear.

In the simplest form, the total computational effect required for a random sample of r values from each distribution F_i is $n = 2rk$ runs. Each elementary effect requires the evaluation of y twice. Morris defines the economy of design as the number of elementary effects estimated by the design, divided by the number of runs. The larger the value of the economy for a particular design, the better it is in terms of providing information for sensitivity and uncertainty analysis. The simplest form of Morris design has an economy $rk/2rk = 1/2$.

Morris proposed a more economical design than this simple design. This design is based on the construction of a $(k+1) - by - k$ matrix B^* called orientation matrix, which has the property that for every column $i = 1, 2, \cdots, k$, there are two rows of B^* that differ only in their i-th entries. Thanks to this particular property, the $k+1$ rows of B^*, representing $k+1$ realizations of $\mathbf{x}$, produce $(k+1)$ output values for the model, allowing the calculation of k elementary effects, one for each input factor $i = 1, 2, \cdots, k$. Since a given orientation matrix B^* produces one elementary effect per input, if r is the size selected for the sample of elementary effects that we extract from F_i, the whole experiment necessitates the construction of r orientation matrices. Thus, the total cost of the experiment would be $n = r(k+1)$ model executions.

The construction of an orientation matrix B^*, with the above described property, starts with the selection of a $(k+1) - by - k$ sampling matrix **B** which is a strictly lower triangular matrix of 1's. Then, the matrix **B'**, given by

$$B' = J_{k+1,1}X^* + \Delta B$$

where $J_{k+1,1}$ is a $(k+1) \times k$ matrix of 1, Δ is the selected increment for the components of $\mathbf{x}$, x^* is randomly chosen base value of $\mathbf{x}$.

This **B'** could be used as a design matrix for which the corresponding experiment would provide k elementary effects, one for each input, based on only $k+1$ runs.

However,these would not be random selections from the distributions F_i. In order to obtain random selections, a randomized version B^* of the sampling matrix is employed for the design. The randomized orientation matrix B^* is given by

$$B^* = (J_{k+1,1}x^* + (\Delta/2)[(2B - J_{k+1,k})D^* + J_{k+1,k}]P^*)$$

where D^* is k dimensional diagonal matrix in which each diagonal element is either +1 or -1 with equal probability, and P^* is $k \times k$ random permutation matrix, in which each column contains one element equal to 1 and all the others equal to 0, and no two columns have 1's in the same position.

Since B^* provides one elementary effect per factor that is randomly selected, r different orientation matrices B^* have to be selected in order to provide a r-dimensional sample from each distribution F_i.

The main advantage is its relatively low computational cost. The design requires about one model per computed elementary effect, and a number r of elementary effects is computed for each factor. Thus, the economy of the design is $rk/r(k+1) = k/(k+1)$. The main disadvantage is that individual interactions among the factors can't be estimated. It only gives us an overall measure of the interactions of a factor with the rest of the model. And we can only distinguish the important factors from the unimportant ones. When the factors have interactions, it's difficult to say which one is the more important or less important and so on. So this method is a simple method that can be used to find the important factors quickly and economically.

An illustration of the sampling strategy for 3-dimensional parameter space is shown in Fig. 4.1.

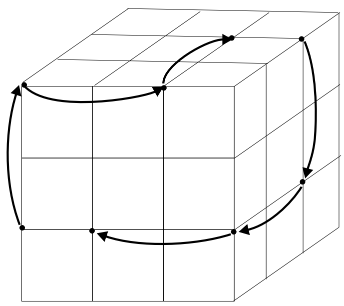

Figure 4.1: Two samples of elementary effects of each parameters in case of 3-dimensional parameter space with 4-level grid.

An orientation matrix example of 3-dimensional parameter space with 4 level grid was given in Appendix C.

There are many screening methods are known in literature. For the review and references consult Compolongo and Kleijnen in Salteli[19].

Next section we will introduce some measures of dependence and correlation ratio.

4.2.3 Measures of dependence

We present the most popular dependence measures (product moment correlation and rank correlation) that are used in practice. Here we only give the simple definition. For detailed properties please refer to the Uncertainty Analysis course book[15].

Product moment correlation

The product moment correlation is also called linear or Person correlation.

Definition 2 (Product moment correlation). *The product moment correlation of random variables X,Y with finite expectation and variances, is*

$$\rho(X,Y) = \frac{E(XY) - E(X)E(Y)}{\sigma_X \sigma_Y}.$$

Rank correlation

Definition 3 (Rank correlation). *The rank correlation of random variables X,Y with cumulative distribution functions F_X and F_Y is*

$$\rho_r(X,Y) = \rho(F_X(X), F_Y(Y)).$$

From the relationship between product moment and rank correlation shown in the above definition we see that the rank correlation is symmetric and takes values in the interval $[-1,1]$.

4.3 Correlation ratio

The correlation ratio is one of the most important non-directional measures of uncertainty contribution[15].

We consider a function $G = G(X,Y)$ of random vectors X and Y with $\sigma_G^2 < \infty$. In analogy with e.g. linear regression coefficients method, we may ask for which function $f(X)$ with $\sigma_{f(X)}^2 < \infty$ is $\rho^2(G, f(X))$ maximum? The answer is given in two facts (see Appendix C)[15, 16].

The computations frequently use Monte Carlo methods. We would like to find an efficient computation method. Efficiency in this context usually means 'on-the-fly'. That is we would like to perform all necessary calculations on a sample, then discard the sample and proceed to the next sample. A calculation that involves retaining the entire sample is not efficient.

Computing correlation ratio may be difficult in some cases. However, if we can sample Y' from the conditional distribution $(Y|X)$ independently of Y, and if the evaluation of G is not too expensive, then the following simple algorithm may be applied [13]:

1. Sample (x, y) from (X, Y),
2. Compute $G(x, y)$,
3. Sample y' from $(Y|X = x)$ independent of $Y = y$,
4. Compute $G' = G(x, y')$,
5. Store $Z = G * G'$,
6. Repeat.

The average value of Z will approximate $E(E^2(G|X))$, from which the correlation ratio may be computed as

$$CR(G, X)\frac{E(E^2(G|X)) - E^2(G)}{\sigma_G^2}$$

Of course, if Y and X are independent, then this algorithm poses no problems. If Y and X are not independent, then it may be difficult to sample from $(Y|X)$. In this case there is no alternative to the 'pedestrian' method: save a large sample, compute $E(G|X = x_i \pm \epsilon)$ for suitable $x_1, \cdots, x_n$, and compute the variance of these conditional expectations. To do this for a large number of variables can be slow.

The notion of the correlation ratio can be generalized by introducing the following definition

Definition 4 (Correlation ratio). *Correlation ratio G with $X_{i_1}, \cdots, X_{i_s}$ is*

$$CR(G, \{X_{i_1}, \cdots, X_{i_s}\}) = \frac{Var(E(G|\{X_{i_1}, \cdots, X_{i_s}\})}{Var(G)}.$$

Since this method has been implemented in Excel sheets by Daniel Lewandowski[16], we can use Unicorn[15] to generate the sample file and calculate the correlation ratio.

Since we use Unicorn to generate the sample file, we make a small introduction of Unicorn.

4.4 Unicorn

UNICORN (Uncertainty analysis with CORrelatioNs, ©TU Delft) is a stand-alone uncertainty analysis software system with extended dependence modelling, reporting and graphics facilities[8]. The model to be analyzed is typically coded within Unicorn(through Unicorn may also linked to external models). Consistent with this purpose, the main design choices are: random sampling; marginal distributions represented by precalculated quantiles; dependence represented by rank correlation trees; mathematical modelling support.

UNICORN contains a graphical feature that enables interactive visualization of a moderately high dimensional distribution. These choices are independent, but are ultimately related to the fact that CPU time on a PC is essentially free; there is no economic reason for limiting the number of runs. With large numbers of variables and runs the samples cannot be stored and analyzed in memory. All calculations must be performed on the fly: A sample is drawn, calculations are performed, relevant results stored, and the sample is stored on disk. The sample is read back into memory piece by piece for additional processing. After we generate the sample file, we can calculate the Correlation ratio and generate the cobweb plot for further policy optimization.

4.5 Financial model and uncertain parameters

Here we review the mathematical formula of the FM and decide the uncertainly of the parameters. We repeat the formula indicating which parameters are used in the model.

4.5.1 Financial model: mathematical formula

$$\Phi = \sum a_{i,j,k,l}(1 + r_{a_{i,j,k,l}})[0.5365x_j + 0.1408(v_{i,j,k,l} + 2u_{i,j,k,l}) + 1.2088]$$

$$+1.1804 \sum_{\substack{j=1 \\ i,k=1,2 \\ l=1,2,3}} a_{i,j,k,l}(1 + r_{a_{i,j,k,l}}) + 0.5902 \sum_{i=1}^{8} \rho_i(\alpha_i \beta_i f_i + g_i p_i q_i)$$

$$+\sum_{i=1}^{9} b_i(1 + r_{b_i})[0.5365y_i + 0.2951(\lambda_i + \omega_i) + 346.2315] - 7.31323 \times 10^7$$

If we not consider the constant coefficients, we can simplify the formula as this function:

$$\Phi = f(r_{a_{i,j,k,l}}, r_{b_t}, x_i, y_t) \quad \substack{t=1,\cdots,9 \\ i,j,k=1,2 \\ l=1,2,3}$$

where,
Φ=the annual profit of the airport
$a_{i,j,k,l}$=the base year segment (i,j,k,l) passenger number $r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)
x_1 = Origin & Destination passenger fee
x_2 = Transfer passenger fee
b_t=number of aircraft movements of category t in base year
r_{b_t}=growth rate of number of aircraft movements of category t
y_i =landing fee for category i aircraft movement(€/movement)

$v_{i,j,k,l}$= average passenger spending (€/passenger)
$u_{i,j,k,l}$= average number of visitors per passenger in segment(i,j,k,l)(visitors/passenger)
α=proportion of passengers in segment (i,j,k,l) arrived at or left the airport by own car
β=proportion of passengers in segment (i,j,k,l) collected from or taken to the airport
f=average Parking time for passengers in segment(i,j,k,l) arrived at or left the airport by own car(h/passenger)
g= average Parking time for passengers in segment (i,j,k,l) collected from or taken to the airport (h/passenger)
p = parking fee for passengers in segment (i,j,k,l) arrived at or left the airport by own car (€/h)
q= parking fee for passengers in segment (i,j,k,l) collected from or taken to the airport (€/h)
ρ=passenger number related to car parking.
b_i= the base year aircraft movement number
λ_t=different aircraft cleaning fee, (€/movement)
ω_t=aircraft fuelling fee.
All these constant coefficients assigned come from the statistics of the historical data or expert judgement.

$$\rho_1 = \sum_{\substack{i,j,k=1\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_2 = \sum_{\substack{i=2\\j,k=1\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_3 = \sum_{\substack{i,j,k=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_4 = \sum_{\substack{i=2\\j,k=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_5 = \sum_{\substack{i,j=1\\k=2\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_6 = \sum_{\substack{j=1\\i,k=2\\l=1,2}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

$$\rho_7 = \sum_{\substack{i,j=1\\k=2\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}}), \rho_8 = \sum_{\substack{i,k=2\\j=1\\l=3}} a_{i,j,k,l}(1+r_{a_{i,j,k,l}})$$

4.5.2 Uncertain parameters—-range and distribution setting

For the FM, growth rate of passenger and aircraft movements, Origin/ Destionation (O/D) and Transfer (TR) passenger fee, and landing fee are variables on which SA will be performed. Among them passenger fee and landing fee are controllable variables, while growth rate of passenger and aircraft movement are uncontrollable. These latter parameters all have a range, before the decision maker make decision, they are uncertain. We have two ways to treat their uncertainty, Morris' method runs model across the space of cases defined by discrete values of the parameters within their plausible domains, Unicorn uses a distribution to describe this range.

From a theoretical point of view, we can use expert judgment to find the range and distribution of these uncertain parameters. But in this project, we did not use formal expert judgment but relied on informal assessments of in-house experts. This range comes from the deep discussions with experts (Jan Veldhuis, Philip Rompa, and Nadja Cramer). Because the distribution of the parameters is unknown and shortage of the relate information, so we use this method. Finally, we decide the range of the parameter, and define all the distribution as uniform.

The growth rates of all kinds of passengers ($r_{a_{i,j,k,l}}$) and aircraft movements(r_{b_t}) are uniformly distributed on [0.09,0.11].

Table 4.1: Passenger fee(x_i) and landing fee (y_i)

Type	Passenger fee	Mean	Distribution	Range
Passenger fee for different	x_1 = O/D passenger fee	15	U(10,20)	[10,20]
passenger(€/passenger)	x_2 = TR passenger fee	5	U(0,10)	[0,10]
Type	Aircraft category t	Mean	Distribution	Range
Landing fee	1	5	U(0,10)	[0,10]
	2	15	U(10,20)	[10,20]
for different	3	35	U(20,50)	[20,50]
	4	75	U(50,100)	[50,100]
category of	5	150	U(100,200)	[100,200]
	6	350	U(200,500)	[200,500]
aircraft movement	7	750	U(500,1000)	[500,1000]
	8	1500	U(1000,2000)	[1000,2000]
(€/movement)	9	3500	U(2000,5000)	[2000,5000]

4.6 Results of Morris' method

Parameters of the experiment were set respectively to $k = 44$,$p = 4, \Delta = 2/3$ and $r = 36$.

Using the same representation as in Morris, the values obtained for the sensitivity measures mean and standard deviation are displayed in Fig. 4.2, where $(\bar{d}_i, S_i)$ is plotted for each input, numbers on the graph identify the inputs 4.2. The green lines, constituting a wedge, are described by $\bar{d}_i = \pm 2S_i/\sqrt{r}$, where $S_i/\sqrt{r}$ is the standard error of the mean elementary effect (SEM_i). If a parameter has coordinates $(\bar{d}_i, S_i)$ below the wedge formed by these two lines, i.e. $|d_i| > 2S_i/\sqrt{r}$, this is a strong indication that the mean elementary effect of the parameter is non-zero. A location of the parameter coordinates above the wedge indicates that interaction effects with other parameters or non-linear effects are dominant.

Table 4.2: Number of different input parameters shown in graph

No	Name	Description
$1, \cdots, 24$	$Ra1, \cdots, Ra24$	Growth rate of segment passenger $1, \cdots, 24$
$25, \cdots, 33$	$Rb1, \cdots, Rb9$	Growth rate for aircraft movement of 9 different category
34	pfod	Origin/Destination passenger fee
35	pftr	Transfer passenger fee
$36, \cdots, 44$	$Lf1, \cdots, Lf9$	Landing fee for category 9

From a practical standpoint, judgment about the importance of particular values of $\bar{d}_i$ and S_i will usually be context dependent. We examine the plotted values of Fig. 4.2 relative to each other to see which appear to be most important. Fig. 4.3,4.4 are the zoom in of the Fig. 4.2.

Inputs 34,35, and 42 have average change estimation $\bar{d}_i$ to be 5×10^7, 6×10^7, and 3.5×10^6 respectively due to a change of $2/3$ is scaled x_1, they are significantly different from 0 by comparison to SEM_i and separated from the cluster of remaining outputs.

Almost all the parameters estimated means and standard deviations were non zero except inputs 25,33,36,and 44. This is due to the fact that coefficient of these inputs are zero. 26,29,30,32, and 37 are close to 0. All the rest parameters have coordinates below the wedge and different from 0.

Inputs 4,10,18, and 24 also have nonzero means, but each has a substantial standard deviation around 45000 relative to mean (about 5%), indicating potentially extensive patterns of interaction or curvature in the effects (see Fig. 4.4).

Considering both means and standard deviations together, we conclude that the input 35(pftr, TR passenger fee), 34 (pfod, O/D passenger fee), and 42(Lf_7, landing fee for category 7 aircraft movement) are the most important inputs and that of those have big standard deviations appear to have effects that involve either curvature or interaction. If we only compare the importance of the landing fee for different category aircraft movement. We get the importance order of 9 categories of aircraft movements landing fees as follows (see Fig. 4.4): $42 > 39 > 43 > 38 > 41 > 40 > 37 > 44 > 36$ ($Lf_7 > Lf_4 > Lf_8 > Lf_3 > Lf_6 > Lf_5 > Lf_2 > Lf_9 > Lf_1$).

However, the order of importance usually determined by the mean and standard deviation together, there is no absolute standard. Some people propose to use the distance between the origin and point to define the importance, i.e. $\sqrt{d^2 + SEM_i^2}$. However, this choice is not practically well motivated.

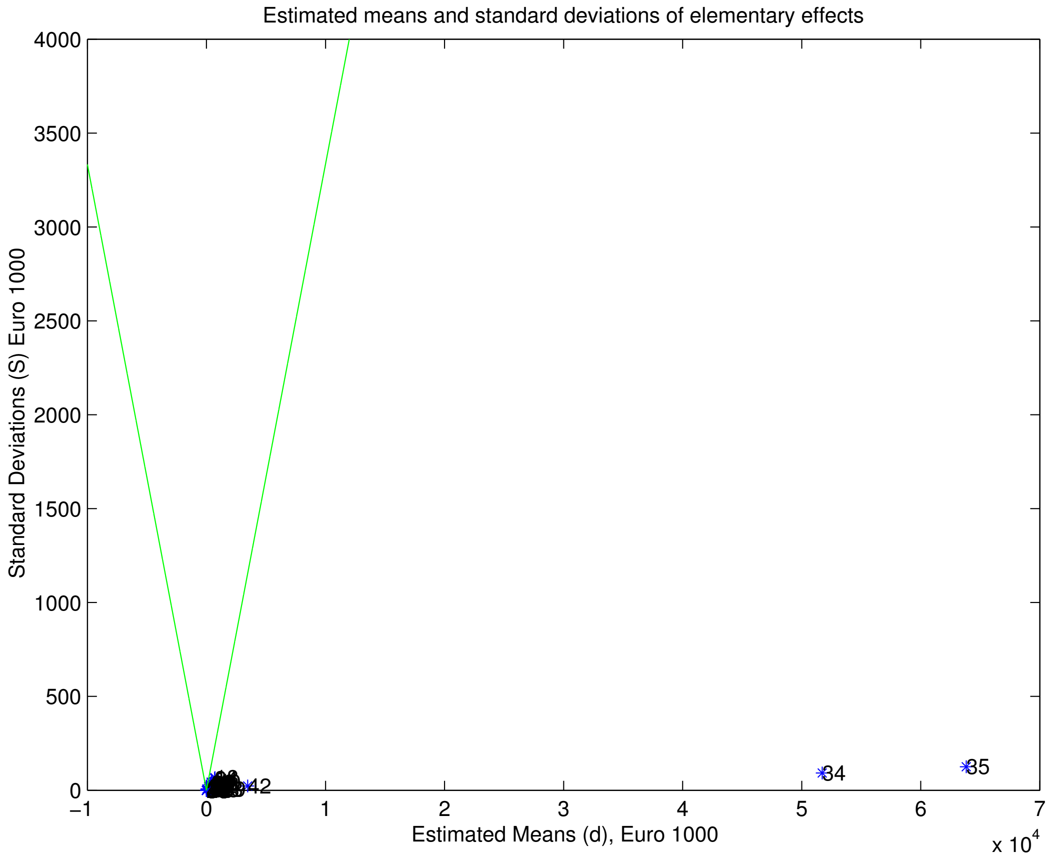

Figure 4.2: Estimated Means($\bar{d}_i$) and Standard Deviations(S_i) of the distributions of Elementary Effects in the experiment. Lines correspond to $\bar{d}_i = \pm 2SEM_i$

4.7 Results of correlation ratio

The 11 most important parameters (passenger fees and landing fees) resulting from the Morris' method have been selected for further investigation. Next we will use correlation ratio method to find uncertainty contribution of these parameters.

4.7.1 Case 1: Correlation ratio for passenger fees and landing fees

We use the Unicorn sample file to calculate the correlation ratio of the growth rate for passengers and aircraft, passenger fees, and landing fees (see Table C.1). In this case, all the input parameters are independent.

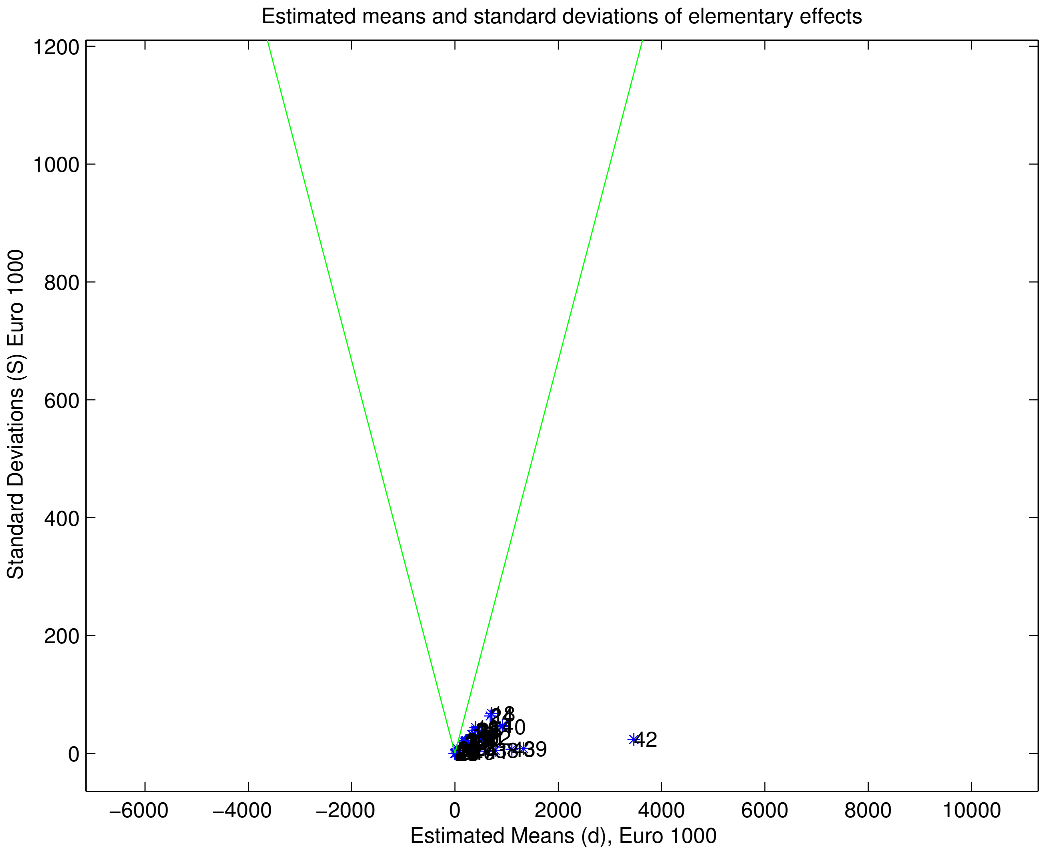

Figure 4.3: Zoom in Estimated Means($\bar{d}_i$) and Standard Deviations(S_i) of the distributions of Elementary Effects in the experiment. Lines correspond to $\bar{d}_i = \pm 2SEM_i$

(Note: here we only choose the biggest 5 input parameters, the complete table was given in the Appendix C. This rule also used for case 3 and 4.)

From Table C.1 we know the passenger fees are dominant parameters for the profit. Their correlation ratios with the profit are 0.6046879 (TR passenger fee) and 0.4024714 (O/D passenger fee), respectively. The biggest Correlation Ratio of the rest parameters is only 0.03. Compared to passenger fee, they are not so important, i.e. their influence on the profit is not so large. Therefore, the passenger fee are the most important driver for the model.

Furthermore, we calculate the product moment correlation of parameters. From the result we can see that the square of the product moment correlation is similar to the correlation ratio, but always a bit smaller than the correlation ratio. This is in good agreement with the fact that correlation ratio is the maximum compare to the product

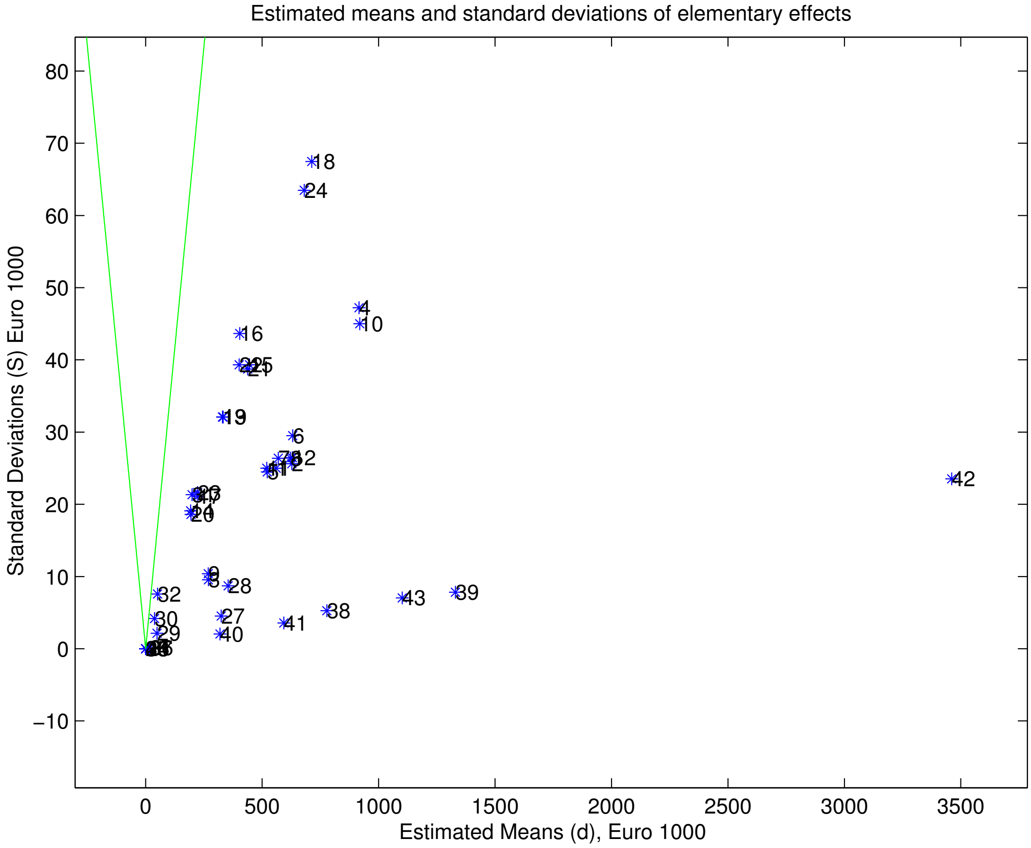

Figure 4.4: Zoom in Estimated Means($\bar{d}_i$) and Standard Deviations(S_i) of the distributions of Elementary Effects in the experiment. Lines correspond to $\bar{d}_i = \pm 2SEM_i$

moment correlation(see Appendix C). And we can infer there exists some extent linearity between $pftr$, $pfod$ and the profit, because they have similar values of the square of the product moment correlation and correlation ratio.

Besides, we plot the condition expectation $E(profit|X)$ versus X (X=pftr, pfod)in Fig. 4.5.From the figure we know the relation between condition expectation of profit given $pftr$ or $pfod$ is in linear relation with the $pftr$ or $pfod$ respectively.

From the above discussion, we know $pftr$ and $pfod$ are very important to the profit.

4.7.2 Case 2: Correlation ratio of landing fee

The landing fee revenue is related only to the landing fee and aircraft movement numbers.

Table 4.3: Case 1: Correlation ratio of input parameters

No	Name	Description	Correlation ratio	square of product moment correlation	Sort
35	pftr	Transfer passenger fee	0.6046879	0.5929	1
34	pfod	Origin/destination passenger fee	0.4024714	0.36	2
4	Ra4	Growth rate of segment passenger 4	3.121572E-02	0.0004	3
32	Rb8	Growth rate for aircraft movement 8	2.964654E-02	0.0004	4
44	Lf9	Landing fee for category 9	2.928326E-02	0.0004	5

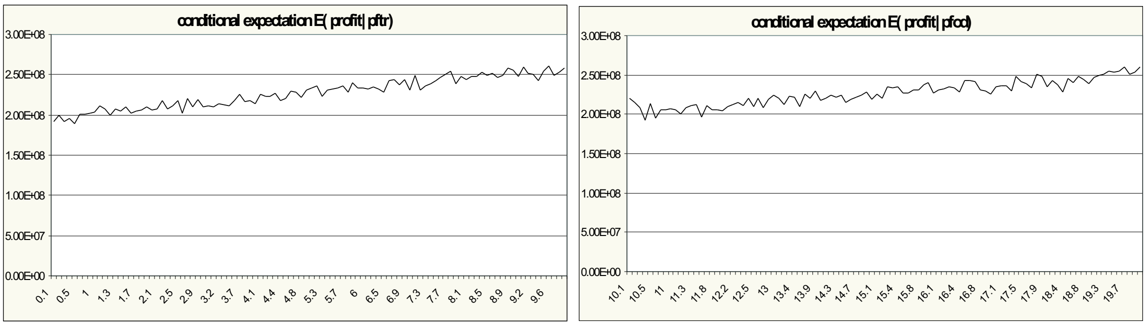

Figure 4.5: Condition expectation $E(profit|X)$ versus X (X=pftr, pfod)

Formula

$$z_2 = 0.5 \sum_{i=1}^{9} b_i(1 + r_{b_i})y_i$$

Where,

y_i is Landing fee for category i aircraft movement(€/movement)

Therefore, we analyze the landing fee revenue separately to see which aircraft category is most important for the landing fee revenue. Table C.2 showes the correlation ratio for the landing fees for the nice different categories of aircraft in ranked order (from biggest CR to smallest.

The order of the importance of different category aircraft landing fee is (see Table C.2): $Lf7 > Lf4 > Lf8 > Lf3 > Lf6 > Lf8 > Lf2 > Lf5 > Lf1$. This order is in good agreement with the former results got from Morris' method (see Fig. 4.4). The landing fee of the category 7 and 4 are different from the rests,the correlation ratio with landing fee revenue are 0.7477599 and 0.1200564 respectively. They have dominant influence on the landing fee revenue. Therefore, when the user wants to change landing fee, they should take account of their sensitiveness very carefully, especially the landing fee of category 7 and 4.

Table 4.4: Case 2: Correlation ratio results for landing fees

No	Name	Description	Correlation ratio	Sort
42	Lf7	Landing fee for category 7	0.7477599	1
39	Lf4	Landing fee for category 4	0.1200564	2
43	Lf8	Landing fee for category 8	7.332083E-02	3
38	Lf3	Landing fee for category 3	5.278557E-02	4
41	Lf6	Landing fee for category 6	4.729696E-02	5
44	Lf9	Landing fee for category 9	2.986048E-02	6
37	Lf2	Landing fee for category 2	1.965712E-02	7
40	Lf5	Landing fee for category 5	1.84122 E-02	8
36	Lf1	Landing fee for category 1	1.471829E-02	9

4.7.3 Case 3: Dependency between passenger fee

Usually the passenger fee for O/D and TR passengers will increase or decrease at the same time. Either one increasing or decreasing will cause the other make a change also. For example, when the airport operator decides to increase the charge of the passenger fee, they usually raise both types of passenger fees at the same time. In order to simulate this dependence relation, we use the rank correlation in Unicorn. In Unicorn, the same model may be processed with different dependence structure. Alternatively, the same random variables and dependence tree may be used with different models. Here we assume the rank correlation of $pfod$ and $prtr$ is 0.9 (see Table C.4).

Table 4.5: Case 3: Correlation ratio results(Rank(pfod,pftr)=0.9)

No	Name	Description	Correlation ratio	Sort
35	pftr	Transfer passenger fee	0.9579887	1
34	pfod	Origin/destination passenger fee	0.9355703	2
16	Ra16	Growth rate of segment passenger 16	3.221454E-02	3
11	Ra11	Growth rate of segment passenger 11	3.066314E-02	4
10	Ra10	Growth rate of segment passenger 10	2.902001E-02	5
29	Rb5	Growth rate for aircraft movement 5	2.888815E-03	6

From the Table C.4, we find the correlation ratio of passenger fees are very big compared to the rest parameters. They are still the dominant parameters for profit. But unlike the former case 1 this time their correlation ratio is almost the same, this is due to dependence between them. And this rank correlation does not change their dominance for the model. From this case we know we can use Unicorn to simulate some relation between the parameters.

4.7.4 Case 4: Dependency between passenger fee and landing fee

Similarly, there exists a symmetric dependence structure for 9 different categories of landing fees. So we assume the rank correlation between landing fees equal to 0.81 and get following results(see Table C.5). The rank correlation between the passenger fees is still 0.9.

$$\rho_r(lf_i, lf_j) = 0.81$$

for all $i, j = 1, \cdots, 9, i \neq j$

$LATENT1$
|
|---(0.9) lf_1
|---(0.9) lf_2
|---(0.9) lf_3
|---(0.9) $\cdots$
|---(0.9) lf_8
|---(0.9) lf_9

Table 4.6: Case 4: Correlation ratio results(Rank(pfod,pftr)=0.9),latent of 9 landing fees

No	Name	Description	Correlation ratio	Sort
35	pftr	Transfer passenger fee	0.9542702	1
34	pfod	Origin/destination passenger fee	0.9329531	2
40	Lf5	Landing fee for category 5	3.558477E-02	3
11	Ra11	Growth rate of segment passenger 11	3.156199E-02	4
43	Lf8	Landing fee for category 8	3.024813E-02	5

From the table we find the passenger fee dominant position is not much affected compared to the former case. Besides, it not make any sense of the importance between different category landing fees. In order to get better understanding of this, we analyze another case, which only consider the effect of landing fees to the landing fee revenue.

4.7.5 Case 5: Correlation ratio from landing fee revenue with rank correlation between landing fee is 0.81

If we consider only contribution of 9 category of landing fees to the landing fee revenue, we got Table C.3. The dependence between the landing fees is the same as the case 4.

Table 4.7: Case 5: Correlation ratio results for landing fees

No	Name	Description	Correlation ratio	Sort
42	Lf7	Landing fee for category 7	0.9339667	1
39	Lf4	Landing fee for category 4	0.8357345	2
43	Lf8	Landing fee for category 8	0.823983	3
38	Lf3	Landing fee for category 3	0.8228938	4
40	Lf5	Landing fee for category 5	0.811032	5
41	Lf6	Landing fee for category 6	0.8108537	6
44	Lf9	Landing fee for category 9	0.7822999	7
37	Lf2	Landing fee for category 2	0.7746494	8
36	Lf1	Landing fee for category 1	0.7699545	9

From this table, we can clearly find The order of the importance of different category aircraft landing fee is (see Table C.2): $Lf7 > Lf4 > Lf8 > Lf3 > Lf5 > Lf6 > Lf9 > Lf2 > Lf1$. This order is similar to the case 2. When we assign the dependence between the landing fees, Lf7 is still the most important, but the other variables are also important.

From above calculation of Correlation Ratio, we can find the most importance parameters for the model is TR and O/D passenger fee. And the landing fee importance is $Lf7 > Lf4 > Lf8 > Lf3 > Lf6 > Lf9 > Lf2 > Lf5 > Lf1$. All these results are in good agreement with the former results from Morris' method (see Fig. 4.4). Although we can not simulate all the cases here, these cases illustrate how to use Unicorn and correlation ratio to get the information of importance of parameters. Besides, we find Unicorn builds a dependence tree that is not accessed from the field MODEL but from the field DEPENDENCE. The same model may be processed with different dependence structure. This will help us in gaining the insight of model. We can construct all kinds of relations between parameters according to our understanding of their relations.

4.8 Cobweb plot and policy optimization

In the former section we saw that the correlation ratio give us some information of importance of parameters. Although it is useful for the decision maker, it is not enough. If they have more information about the consequences of policy, then the decision will be made much easier and reasonable. This the next step: cobweb plot and policy optimization.

First we use an example to explain the cobweb plot. For example, we have a sample problem containing three random variables ($v1$,$v2$,and $v3$, all uniform distribution in $[0, 1]$) and one formula($formula1 = v1 + v2 - v3$). Suppose we represent the possible values of these variables as parallel vertical lines. One sample from this distribution is a three-vector. We mark the three values on the three vertical lines and connect the marks by a jagged line. If we repeat this 1000 times we get a Fig. 4.6 below resembling a cobweb. The graphs at the top are the 'cross densities'; they show the density of line crossings midway between the vertical axes.

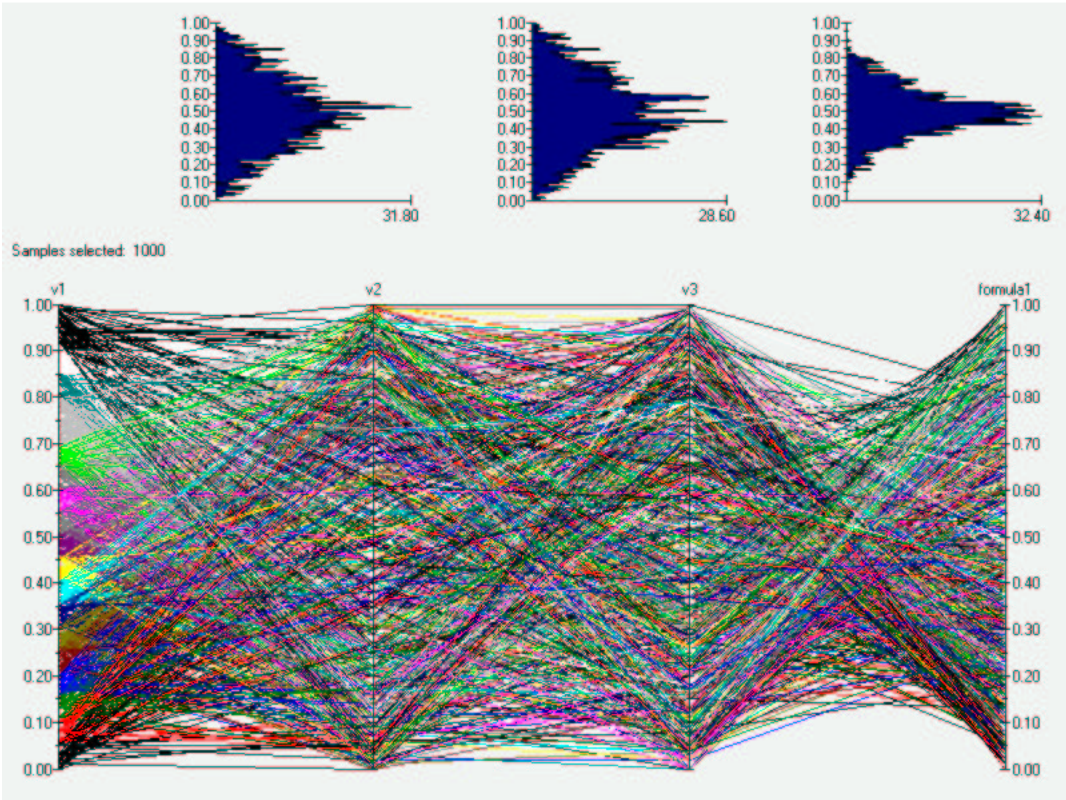

Figure 4.6: Example of cobweb plot

Here is some summary information on cobweb plots: we assume the adjacent v1 and v2 in a coweb plot and have rank correlation $r(v1, v2)$.

- If $r(v1, v2) = 1$, then all lines between v1 and v2 are horizontal.
- If $r(v1, v2) = 0$, then the lines criss-cross in such a way that the density of crossings on the midline between v1 and v2 is triangular.
- If $r(v1, v2) = -1$, then all lines cross in one point.

From assumption we know the $v1$, $v2$, and $v3$ are independent. The rank correlation between them are zero so the density crossing between them is triangular. This was proved in Fig. 4.6.

Besides, we can use Cobweb plots to support interactive conditionalization. Here we choose lower and higher 10% of the formula1, then we get the Cobweb plot(Fig. 4.7). It shows the conditional joint distribution on the selected percentiles. When formula1 goes higher part, the $v3$ go down to the lower part or in the middle. This can be conclude from the formula $formula1 = v1 + v2 - v3$.

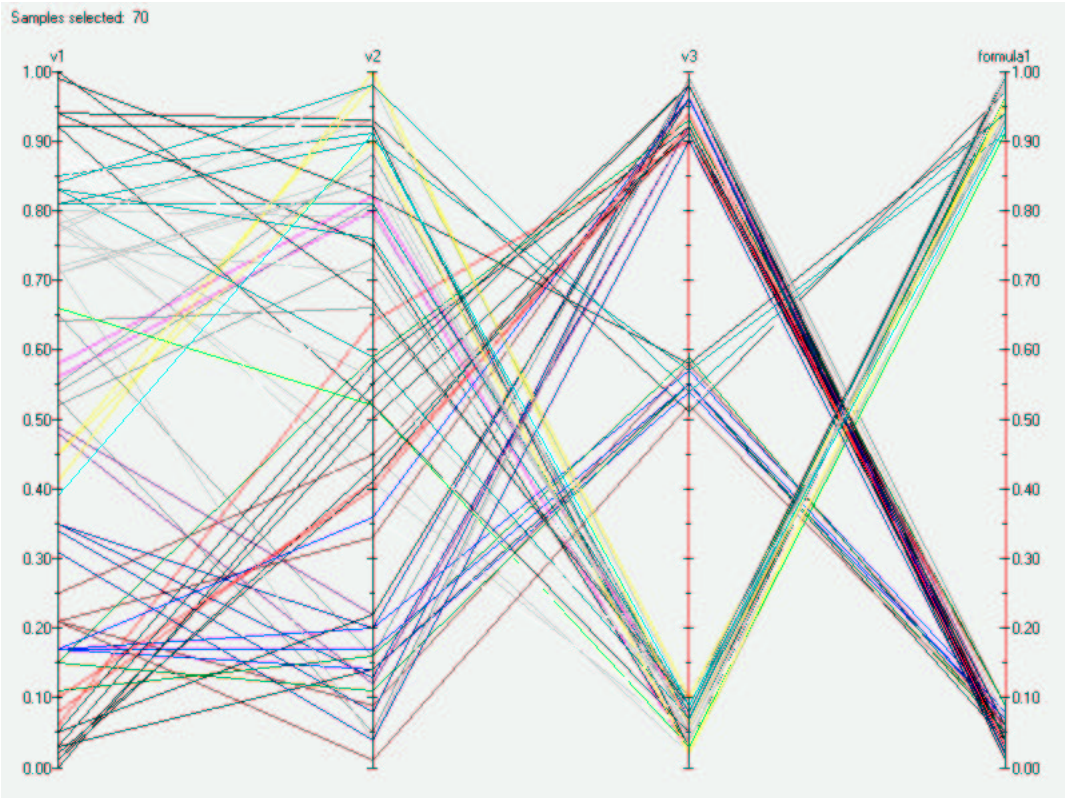

Figure 4.7: Conditional joint distribution of cobweb plot

A conditional distribution defined in the above manner may consist either of the percentiles, as seen in the percentile cobweb plot; or may consist of the natural values, as seen in the natural scale cobweb plot.

For our model, we have a problem with 44 uncertain variables, we use the cobweb plots from the simulation of 200000 samples. We assume the input parameters are independent. The cobweb plots shown in Fig. 4.8:

Each broken line corresponds to one sample. The realized quantiles of the input and output variables are the intersections with the vertical lines corresponding to input and output variables. From this Fig. 4.8, what we can see is everything is a mess. We can change the ordering of variables by clicking on the variable name and dragging to the appropriate position. In order to see whether the profit has strong relation with other parameters (see Fig. 4.9). When we choose the lower 10% and higher 10% of the profit,

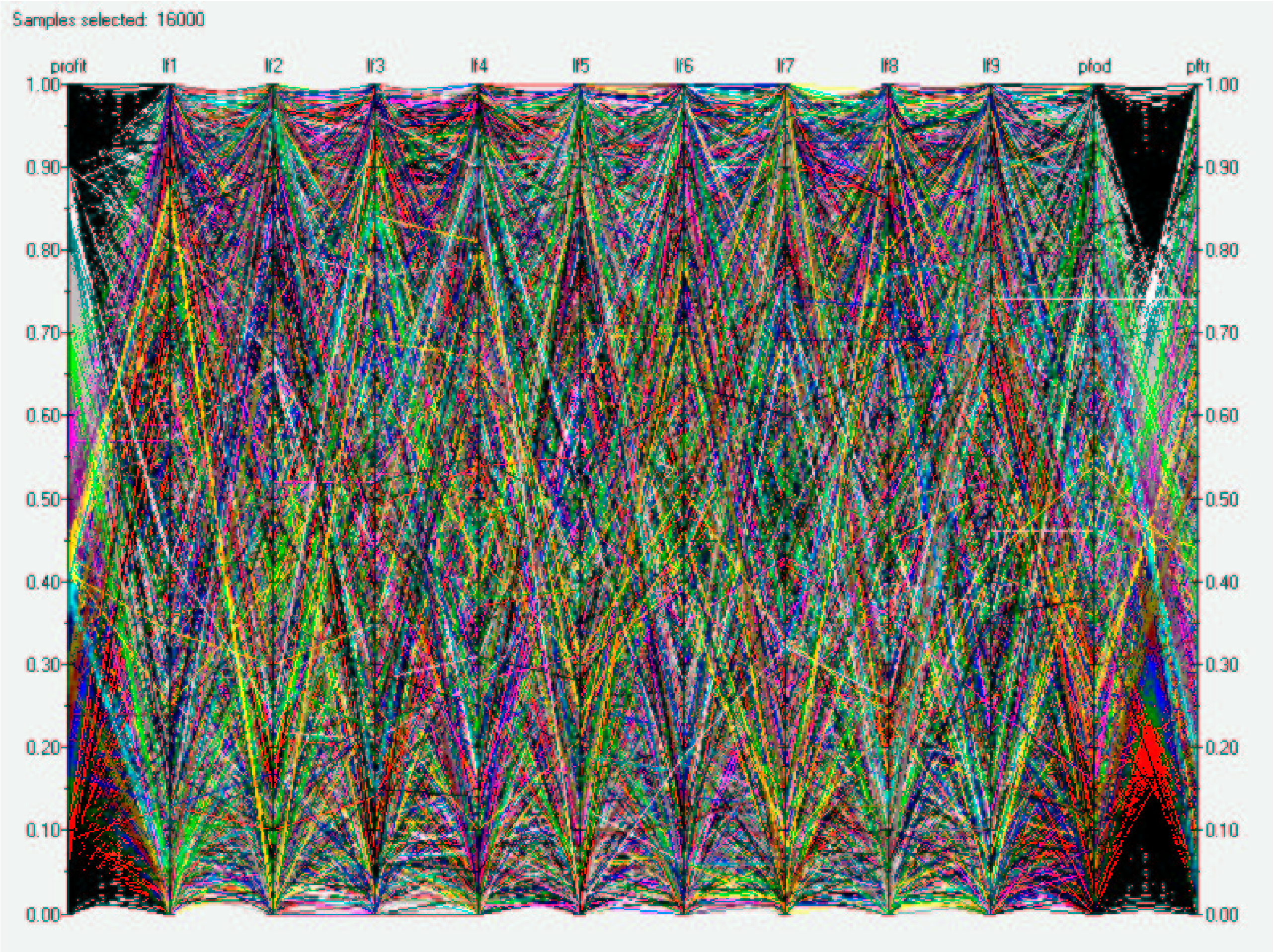

Figure 4.8: Cobweb plot of the model

we find O/D passenger fee and TR passenger fee have strong positive relation with the profit.

4.8.1 Exploration process—-policy optimization

After we draw the cobweb plot, we can optimize the policy directly in the plot. The optimization process policy is an exploration and iterative process. Start with an initial policy, say P1. Generate a range of plausible circumstances, say $C_1, \cdots, C_k$, a circumstance is a series of C where and test whether the policy performs adequately under each one. We will probably find at least one circumstance that ”breaks” the initial policy, and

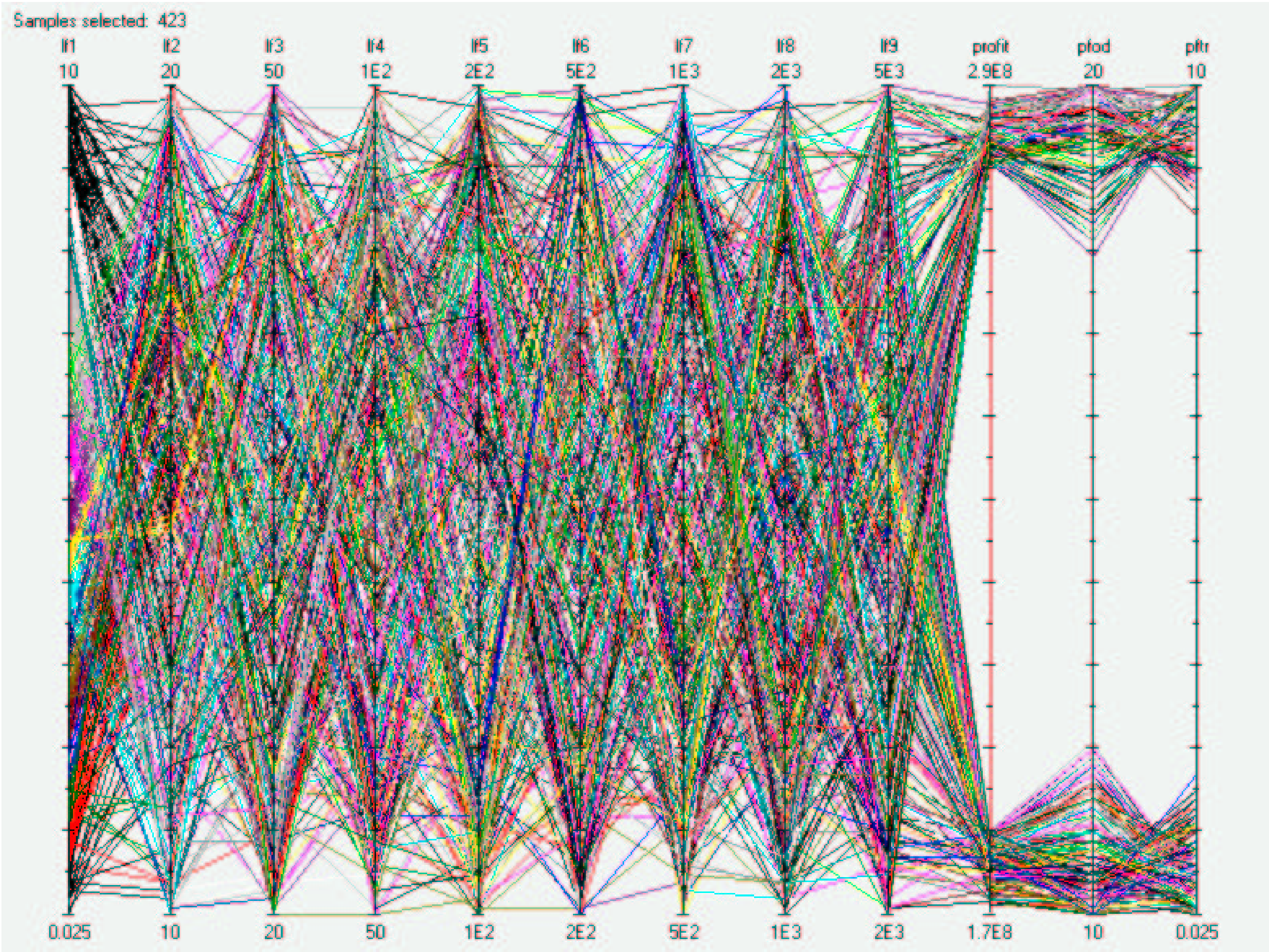

Figure 4.9: Check the relation between parameter and profit

we may find several. For the next iteration, then, we design a new policy P2 (it is a revision or improvement of P1) that fixed the problems of P1. We may have to give up some performance in circumstances where the previous policy did well, but we will improve performance in circumstances that broke the previous policy (see Fig. 4.10).

Now iterate once more. Test the new policy against an augmented set of scenarios in an attempt to break it. Then design another policy, one that withstand all these challenges. We continue iterating until we find a satisfactory policy, or (more likely) until we run out of time and/or money to continue looking.

In the following we will use three examples to describe how to use the cobweb plot to optimize the policy.

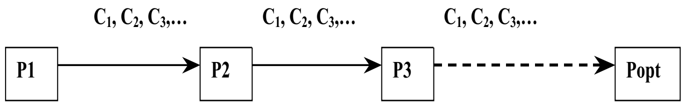

Figure 4.10: The exploratory analysis—–policy optimization

4.8.2 Case 1

Question: We want to make some given amount of profit in the next year, please give us some policy choices beforehand.

Answer: First we can make some assumption of the range of parameters of that year. Then ask Unicorn to run simulation. Using the simulation results, we get the cobweb plot. From the plot, we can choose the profit that we prefer. Corresponding to this profit there are many combinations of the policy parameters that can be chosen. In order to find a preferred solution, we make some assumptions of these policy parameter and make the choice step by step. This will narrow the possible choices, in the end it will give us some satisfactory policies. This is a backward method. It starts from the goal (amount of profit), and find the optimal solution in the cobweb plot. This can be realized in cobweb plot just using the mouse to drag and click.

For example, we want the profit to be in the highest 10% in the interval [1.7E8, 2.9E8]. First we can choose this interval in the cobweb plot. After this click and drag, we get Fig 4.11. From the figure we clearly see that passenger fee positive influence the profit. Since we know the aircraft movement number of category 3,4,5,6 are very big. So the landing fee for these categories are very important. However, it affects not only the profit but also the airliner companies. Before we make decision of these charges, we have to consider all kinds of policy consequences and make an optimized decision(this will be explained in detail in the following section). Here we hope all these landing fees take values in the lower part. After we do this, the rest choices are shown in the plot. There are only five possible choices in the plot (every choice corresponds to one line with the same color). It will be very easy for the user to make choice now. Above demonstration is only shows how the user can make choice by the cobweb. There are many possible policy combinations in the plot. The use can choose using his own criteria (for example, the profit of that year, passenger fees within some interval, etc.).

4.8.3 Case 2

Question: What is the possible profit when policy constraints are given?

Answer: We use the given constraints to make choice in cobweb plot. Then we can get the possible profit in the plot. It directly gives an impression what will happen.

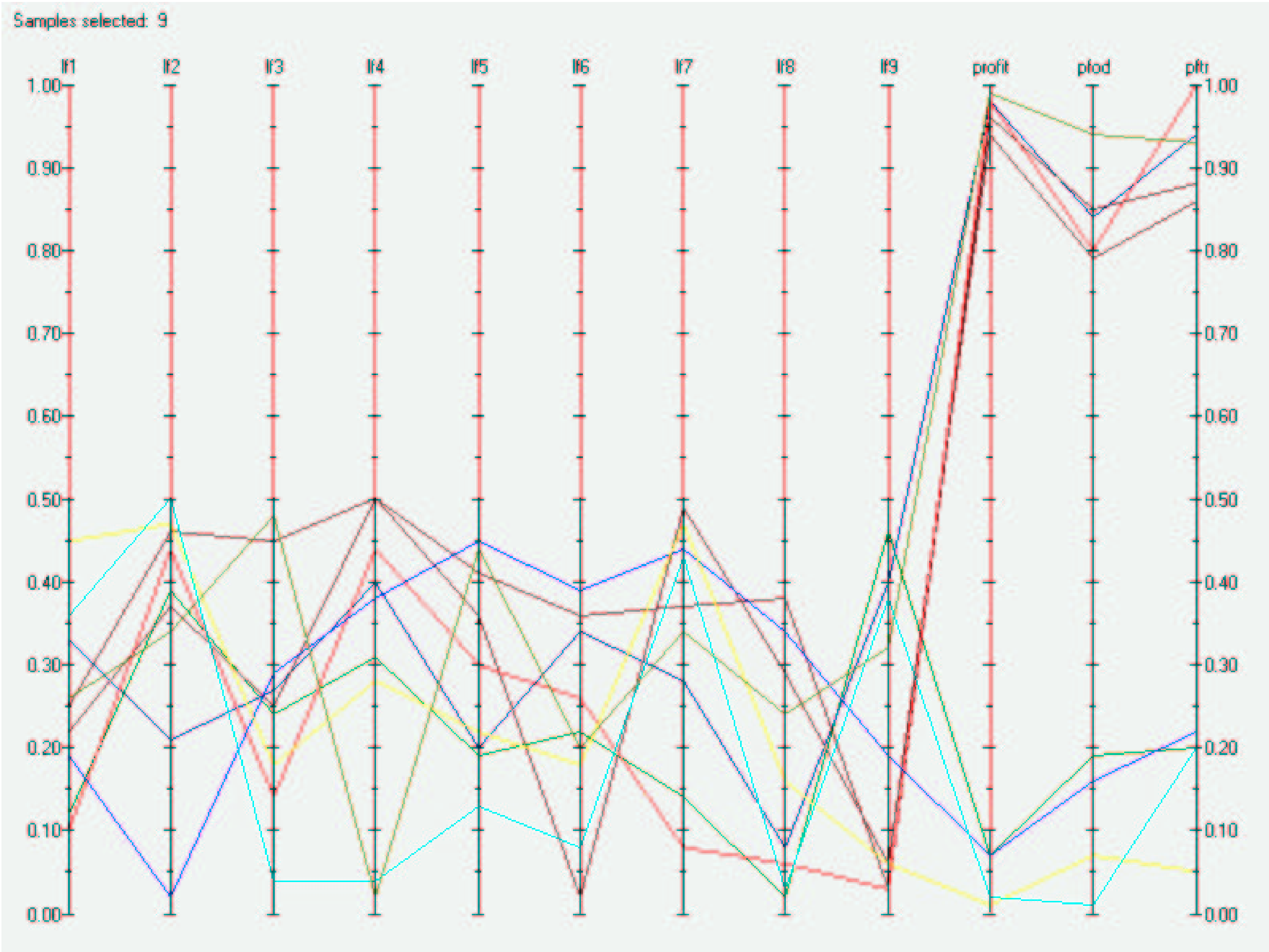

Figure 4.11: Optimize the policy from profit

Before we use the cobweb plot to find the solution, we need to define the constraints on the charge. Here we assume all the landing fee charges go to the lower part, and ask what will happen with the profit. The user also can make choice of the profit further and see which choice satisfies the requirement. This can be done very easily in the cobweb (see Fig. 4.12). This process of serching optimal policies is similar to the former case 1.

4.8.4 Case 3

Question: Which landing fee is the most important to the landing fee revenue.

Answer: The landing fee revenue is the only one segment of revenue which is related to the landing fee. Therefore, we analyze the landing fee revenue separately using the

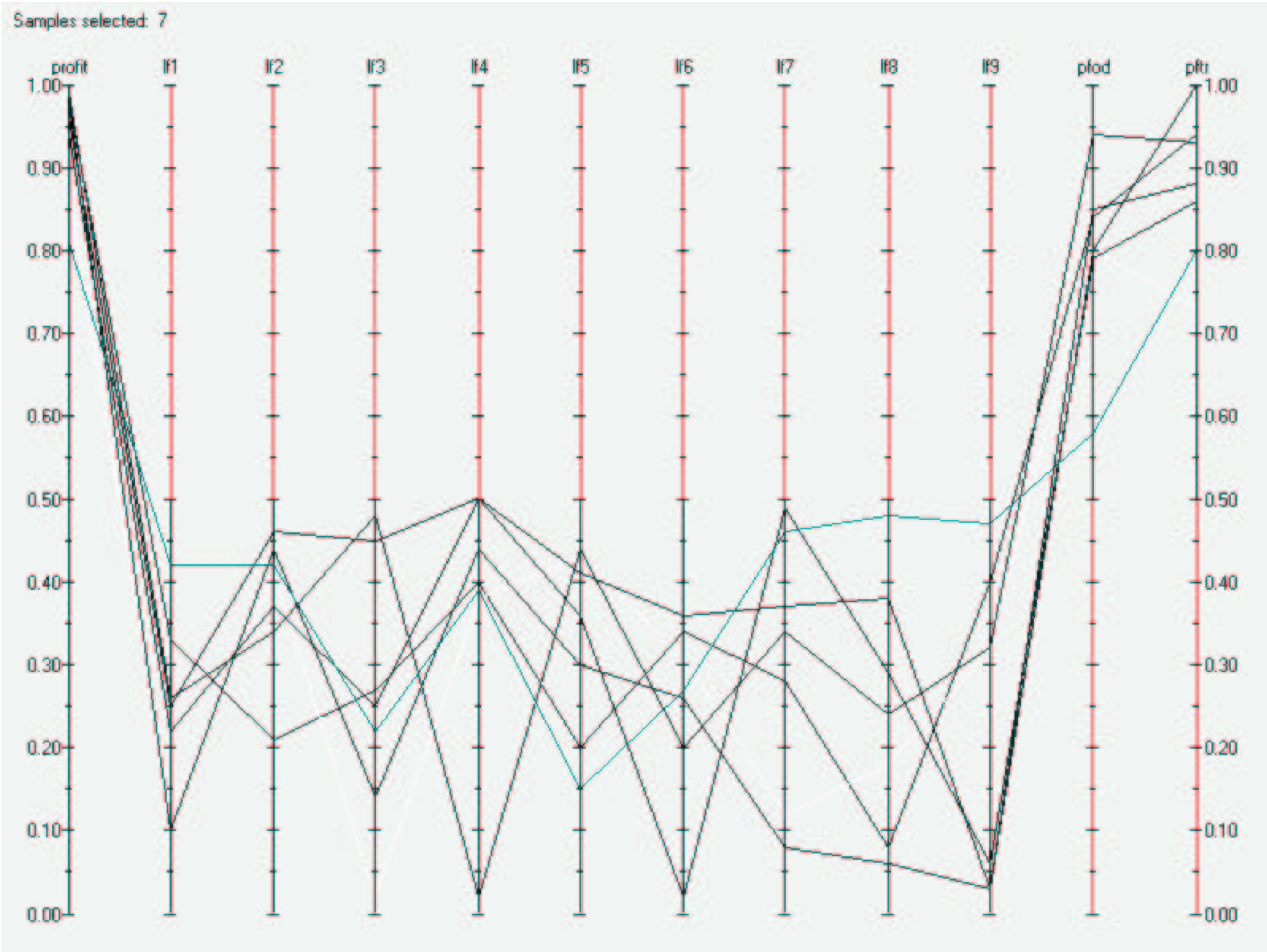

Figure 4.12: Optimize the policy from policy consequence

correlation ratio for different categories landing fees (see correlation ratio section "Case 2: Correlation ratio of landing fee"). The order of the importance is: $Lf7 > Lf4 > Lf8 > Lf3 > Lf6 > Lf5 > Lf2 > Lf5 > Lf1$. We can also use the Unicorn cobweb to see which one is important to the landing fee. From the plot, we know the landing fee for category 7 is the most important, then the landing fee category 4 (see Fig. 4.13).

Above three case demonstration tell us how to use cobweb plot to get some idea for policy optimization. But when we construct the Unicorn model, we have to do some theoretical analysis of different parameters and try to combine such information into Unicorn model. In this way, we can make the policy optimization more precisely. This is done in following section.

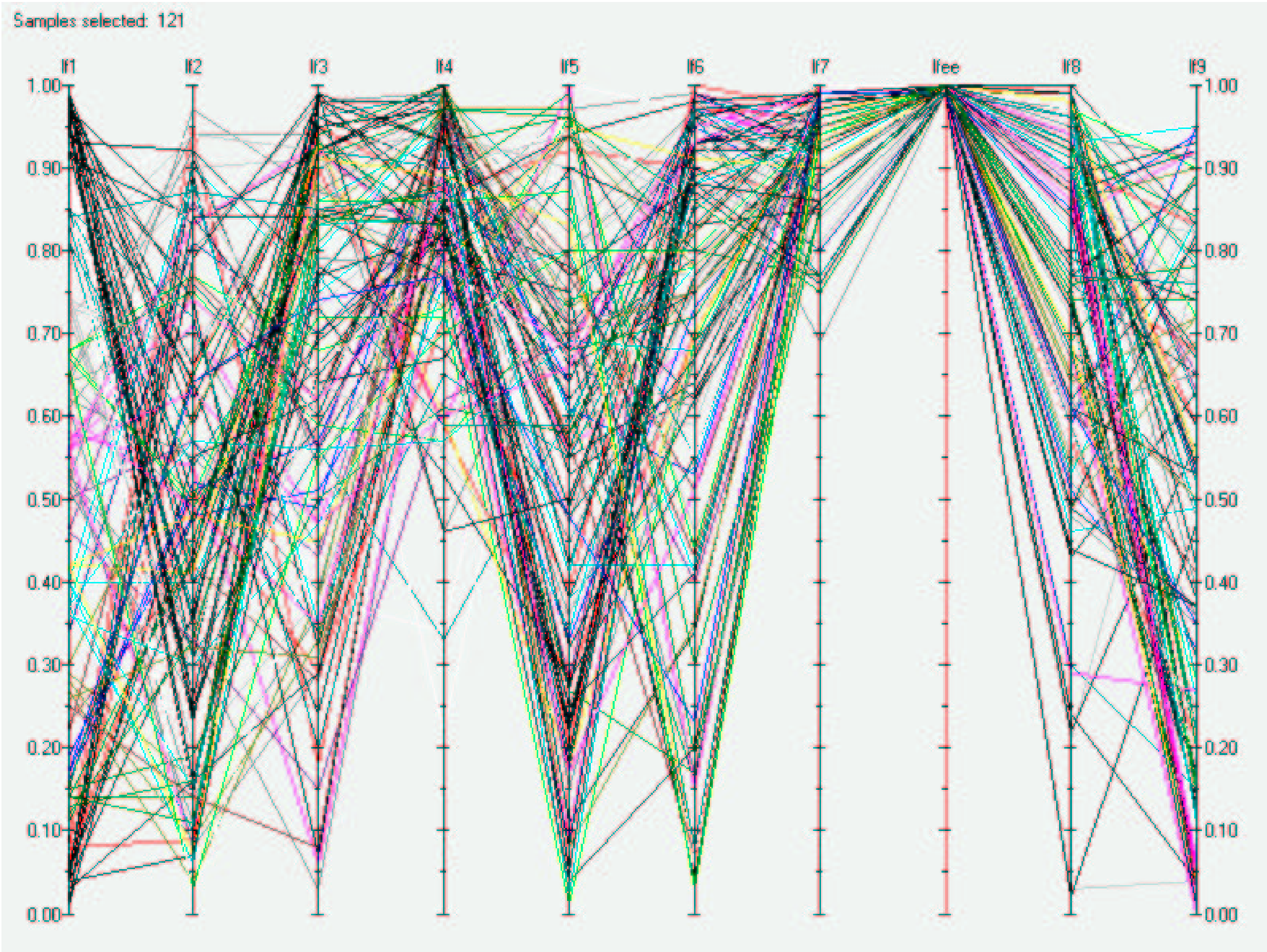

Figure 4.13: Which landing fee is important to the landing fee revenue

4.9 Theoretical analysis of the model parameters

There are some relations between passenger fee, landing fee, passenger growth rate, and aircraft movement growth rate. We make a diagram (Fig. 4.14) to show the relation between different kinds of parameters. In the left circle, the parameters are under people control. In the right side, they are not under control, but we can use the controllable parameters to influence them. In reality, the administration can make policy or regulation to attain their goals.

Although there is no direct linkage between the passenger fee and landing fee, they can influence each other indirectly. In the following table we know there are 16 possible combinations of these parameters. Here we explain 4 typical cases of them. Two of them

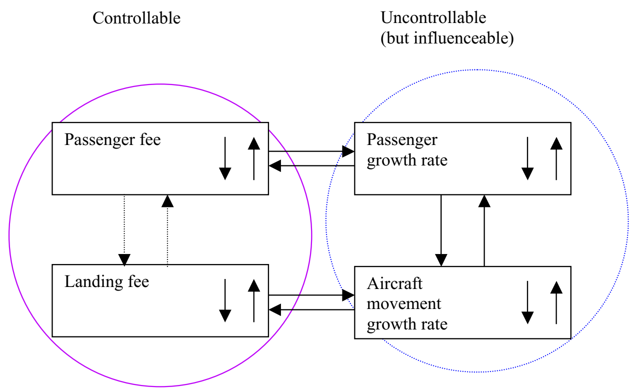

Figure 4.14: Relation between parameters

are start changing from passenger fee, the rest are from landing fee.

Table 4.8: Relation between the passenger fee, landing fee and growth rate of passenger and aircraft movement

No.	Passenger fee	Passenger growth rate	Aircraft movement growth rate	Landing fee
1	⇑	⇓	⇓	⇓
2	⇓	⇑	⇑	⇑
3	⇓	⇓	⇓	⇑
4	⇑	⇑	⇑	⇓

All these assume that the $pfod$ changes in the same direction as $pftr$.

(1) When the passenger fee rises, it will cause the passenger number growth rate to decrease or not increase so fast. This will also cause the aircraft movement growth rate to decrease or not increase. When this happens, if the airport management keeps the current landing fee without change, it will result in less aircraft movement. However, this situation is not what the airport management wants to see, they still want to make money. So they will prevent it and take some measures such as decreasing fee. Although in the short time period, the airport will lose some money. But once the situation changes, they may make more profit.

(2) Decrease the passenger fee, then the people compare the plane with other travel options and more people will choose to take the plane, the number of passenger will increase. Once the passenger number increases, the demand of the aircraft movements will increase. If the number of aircraft is large, the airport does not want to operate so many aircraft because of its limit capacity, so they will raise the charge of landing.

(3) The consequence of increasing the landing fee is that the aircraft movement growth rate will decrease. If this happens, then the passenger number is too much for the reduced aircraft movement, then they will charge more passenger fee to passenger force some of them will not take the plane and choose the alternative transport.

(4) When the landing fee decreases, then the aircraft movement growth rate has some drive to increase. It reduces more passenger to take the plane, otherwise it will lose money. Usually they will not do such a stupid thing. They always take measures when the aircraft number cannot satisfy the demand of passenger number. It's conservative attitude but it will take less risk like this.

After the above discussion, we know there is a dynamic balance among these four kinds of parameters. The manager of the airport will try to find an optimized solution for different cases. In simulation, the most important thing is how to consider the relations between these variables. Unicorn can solve this problem. We can use the rank correlation to simulate the dependency among different parameters. After Unicorn runs these different cases, we can find the optimized policy in the plot very easily.

Here we use one case as an example to show how Unicorn works. We assume the relation of aircraft movement growth rate and landing fee can be depicted as the following graph(Fig. 4.15).

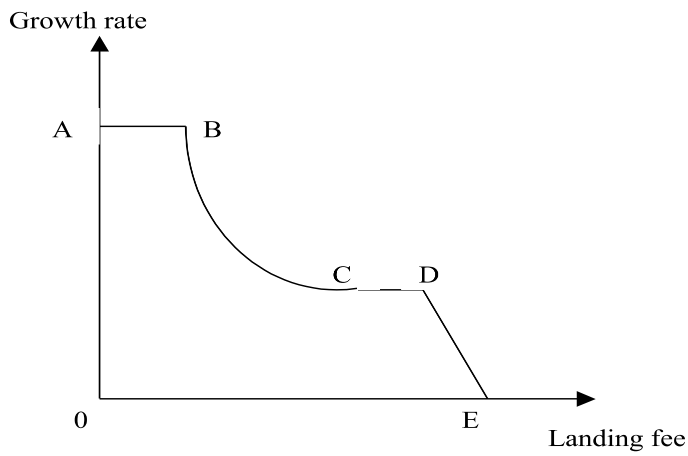

Figure 4.15: Relation of landing fee and growth rate

When landing fee (lf) is 0, the growth rate of aircraft movements (rb) goes to maximum value (point A). This value is a threshold for an existing airport for its available infrastructure and sources, and environmental restriction. With the increase of lf, the rb first is horizontal line AB, it stays constant, then decreases (line BC), constant again (line CD), and in the end, it decreases (line DE).

We focus on the phase ABC and use two ways to simulate this relation between landing fee and growth rate of aircraft movement, one is rank correlation, the other is function.

4.9.1 Rank correlation

We define the rank correlation between lf_i and $rb_i (i = 1, \cdots, 9)$ as negative rank correlation, i.e., when one is increasing, the other is decreasing. Fig. 4.16 is the cobweb plot(rank correlation=-0.9).

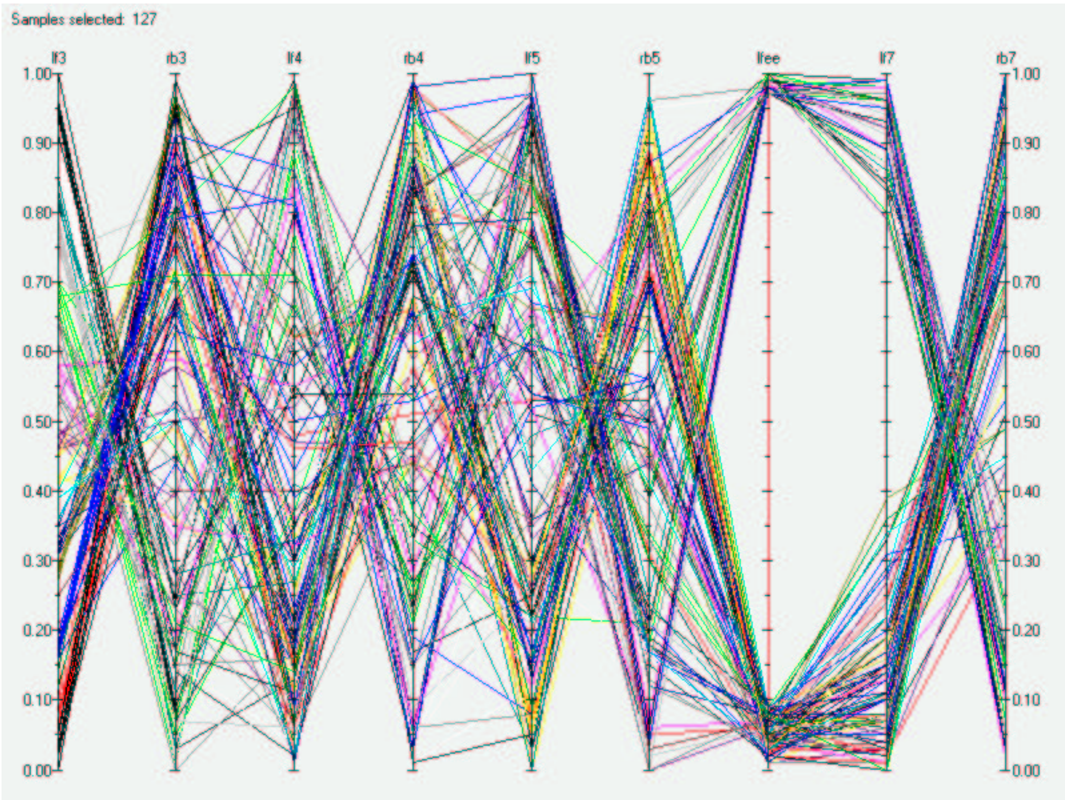

Figure 4.16: Relation of landing fee and growth rate(rank correlation=-0.9)

4.9.2 Function

We can also formulate a function to simulate the relation between lf and rb.

$$
\begin{aligned}
rb &= 0.5*(\frac{1}{a*lf+b}+c-|\frac{1}{a*lf+b}-c|) \\
where, & \\
a &= \frac{\frac{1}{rb_1}-\frac{1}{rb_2}}{lf_2-lf_1} \\
b &= \frac{\frac{lf_2}{rb_2}-\frac{lf_1}{rb_1}}{lf_2-lf_1} \\
& Coordinates: B(rb_2, lf_1), C(rb_1, lf_2)
\end{aligned}
$$

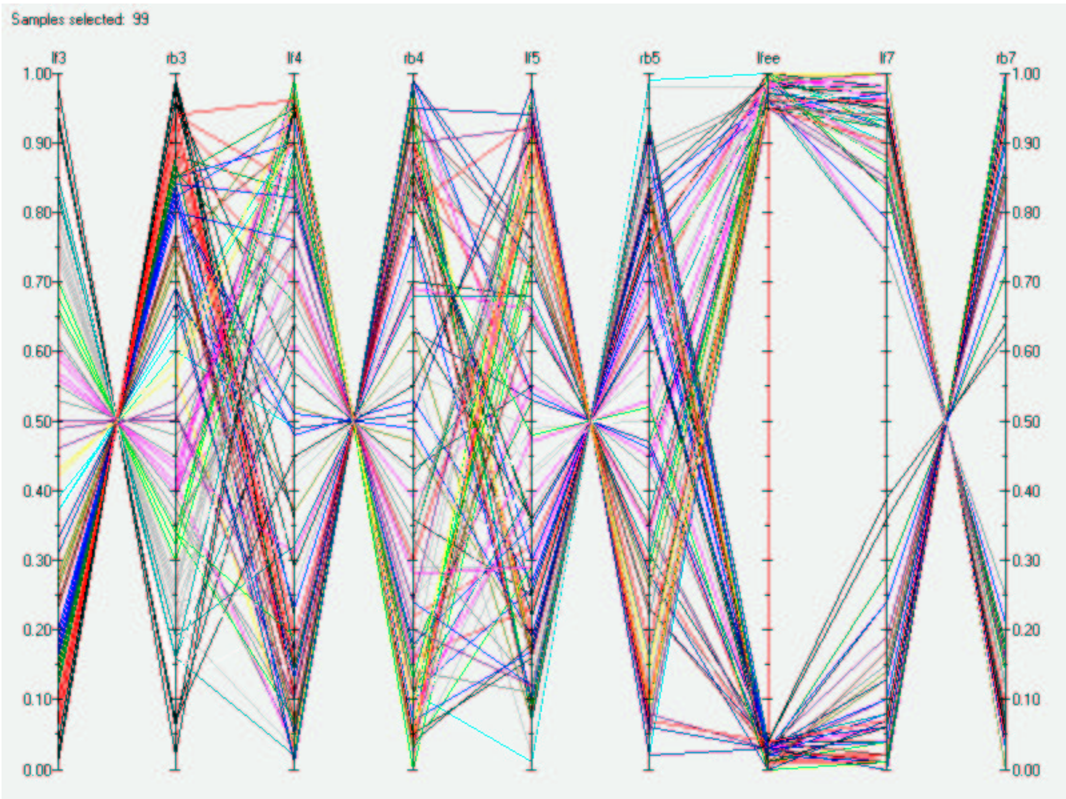

Figure 4.17: Relation of landing fee and growth rate(function)

From the plot(Fig. 4.17) we can see both methods describe the relation between the landing fee and aircraft movement growth rate well. The rank correlation is much easier to use, it only needs to define the dependency, but it is an approximation. The function way is much more precise. Therefore, we suggest user first use the rank correlation to approximate the relation to get some rough idea then if necessary, we can use the formula to make it more precise. But all these are only one key step in the process of policy optimization.

4.10 Summary of the Morris' method and correlation ratio

The results of Morris' method and correlation ratio were summarized in following Table 4.9.

Table 4.9: Results of the Morris' method and correlation ratio results

method	importance order	remark
Morris' method	$pftr > pfod > lf_7 > \cdots$	the global importance
	$lf_7 > lf_4 > lf_8 > lf_3 > lf_6 > lf_5 > lf_2 > lf_9 > lf_1$	landing fee
Correlation ratio	$pftr > pfod > ra4 > rb8 > lf9$	case 1
	$lf7 > lf4 > lf8 > lf3 > lf6 > lf9 > lf2 > lf5 > lf1$	case 2
	$pftr \sim> pfod > ra16 > ra11 > ra10$	case 3
	$pftr \sim> pfod > lf5 > ra11 > lf8$	case 4
	$lf7 > lf4 > lf8 > lf3 > lf5 > lf6 > lf9 > lf2 > lf1$	case 5
Note	case 1,2: all parameters are independent;	
	case 3: rank correlation of $pfod$ and $pdtr$ is 0.9;	
	case 4,5: rank cprrelation of passenger fee is 0.81.	

4.11 Conclusions

In summary the foregoing analysis suggests that the following conclusions:

- Two methods of sensitivity analysis were conducted in our research. One is Morris' method, the other is correlation ratio. The results of two methods are similar (Table 4.9). (1) Morris' method, all the parameters have influence on the financial model. The O/D and TR passenger fee and Landing fee for category 7 are the most important parameters. (2) Correlation ratio method, O/D and TR passenger fee are dominant parameters of the financial model.
- For the landing fee revenue, we get the landing fee importance order: $7 > 4 > 8 > 3 > 6 > 9 > 2 > 5 > 1$. This can also be seen from the plot of Morris' method. The

position of $lf9$ is a little different due to there is no category 9 aircraft exist in this case.

- Unicorn is good software for uncertainty analysis. Prior to using Unicorn, we have to analyze the relation between parameters and take all this knowledge into account during the setting of the model in Unicorn. The policy optimization is an exploratory and iteration process with the help of cobweb plot. In the end, we can get the optimized policy.

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Appendix A

Model parameters and their default value

Table A.1: Main parameters list

Name and description
$a_{i,j,k,l}$=number of passenger in segment (i, j, k, l) of base year
$i = 1, 2$—Arriving/Departuring
$j = 1, 2$— Origin & Destination/Transfer
$k = 1, 2$—Business/Non-Business
$l = 1, 2, 3$—European Union/Non-European Union/Intercontinental
$r_{a_{i,j,k,l}}$=growth rate of passenger in segment (i, j, k, l)
$t = 1, \cdots, 9$, category of aircraft
b_t=number of aircraft movements of category t in base year
r_{b_t}=growth rate of number of aircraft movements of category t
f=average parking time for segment(i,j,k,l) passengers arrive/leave airport by own car(h/passenger)
g=average parking time for segment (i,j,k,l) passengers collected/taken to the airport (h/passenger)
p = parking fee for passengers in segment (i,j,k,l) arrived at or left the airport by own car (€/h)
q= parking fee for passengers in segment (i,j,k,l) collected from or taken to the airport (€/h)
LR_{t-1}=liquid resources in the reference year (t),€
PRR = potential retail revenues (€)
$u_{i,j,k,l}$= average number of visitors per passenger in segment(i,j,k,l)(visitors/passenger)
$v_{i,j,k,l}$= average passenger spending (€/passenger)
x_1 = Origin & Destination passenger fee
x_2 = Transfer passenger fee
y_i = landing fee for category i aircraft movement(€/movement)
α=proportion of passengers in segment (i,j,k,l) arrived at or left the airport by own car
β=proportion of passengers in segment (i,j,k,l) collected from or taken to the airport
ρ = passenger number related to car parking.
λ_t = different aircraft cleaning fee, (€/movement)
ω_t =aircraft fuelling fee.
Φ = the annual profit of the airport

Table A.2: parameters and their default values

Parameter	Value
a = total airport area used by third parties (m^2)	7000
ACP = total car parking area (m^2)	40,000
$ACPF$=aircraft parking fee,€/h	300
AO = total office area (m^2)	5000
AT= total terminal area (m^2)	8000
ATA = total terminal area used by the airport itself (m^2)	8000
ATT = total airport area used by third parties(m^2)	7000
b =average price for one room (€/room)	150
c = revenues from "fun-shoppers" (€)	10 million
ECC = employee costs for one m car parking area (€/m^2)	5
ECM = employee costs per aircraft movement (€/movement)	100
ECP = employee costs per passenger (€/passenger)	1
ECR= employee costs for one runway system (€)	1 million
FAC= fixed administration costs (€)	0
g_{OA} = occupancy of office area	0.8
g_{HB} = occupancy of hotel beds	0.8
h = height of concession fee	0.1
HF_{Bag} = baggage handling (€/passenger)	2
HF_{Cat} = catering handling (€/passenger)	2
HF_{ChI} = check-in handling (€/passenger)	2
$HF_{Cle,t}$ =aircraft cleaning, λ_t (€/movement)	category 1 to 9 respect to 1,2,5,10,20,50,100,200,500
$HF_{Tnk,t}$ =aircraft fueling, ω_t (€/movement)	category 1 to 9 respect to 2,4,10,20,40,100,200,400,1000
HR = average high rent for one m office area (€/m^2)	408
$k_{CP}, k_{OA}, k_{Ter}, k_{RWS}$ = depreciation percentage for resp. car parking, office area, terminal area and runway system	$k_{CP}0.1k_{OA}0.1k_{Ter}0.1k_{RWS}0.05$
LR = average low rent for one m office area (€/m^2)	216
MCP = maintenance costs for one m^2 car parking area (€/m^2)	10
MCO = maintenance costs for one m^2 office area (€/m^2)	200
MCT = maintenance costs for one m^2 terminal area (€/m^2)	200
MCR = maintenance costs for one runway system (€)	20 million
NHB = number of hotel rooms	60
NOA_{HR} = total office area with high rents (m^2)	1000
NOA_{LR} = total office area with low rents (m^2)	1000
NR = number of runway systems	2
PAC = Proportion of administration costs	0.04
PC = purchase price for one m^2 car parking area (€/m^2)	100
PM = profit margin on retail	0.2
PO = purchase price for one m^2 office area (€/m^2)	2000
POC= proportion of other operational costs	0.11
PR = purchase price for one runway system (€)	200 million
PT= purchase price for one m^2 terminal area (€/m^2)	2000
r= proportion of handling contracted out	0.5
ri=interest rate for next year($t + 1$)	0.05
rp= percentage of aircraft that overnight parking per day	0
s = average visitors spending (€/visitor)	2
TAT=average Turnaround-time (h)	1.25
u = selling price of one squarer meter utility (€/m^2)	10

Table A.3: number of different segment passengers in the base year ($\times 10^3$)

segment	AR/OD/BU/EU	AR/OD/BU/NE	AR/OD/BU/IC	AR/OD/NB/EU
number	669	716	286	1258
variable	$a_{1,1,1,1}$	$a_{1,1,1,2}$	$a_{1,1,1,3}$	$a_{1,1,2,1}$
segment	AR/OD/NB/NE	AR/OD/NB/IC	DE/OD/BU/EU	DE/OD/BU/NE
number	689	763	669	716
variable	$a_{1,1,2,2}$	$a_{1,1,2,3}$	$a_{2,1,1,1}$	$a_{2,1,1,2}$
segment	DE/OD/BU/IC	DE/OD/NB/EU	DE/OD/NB/NE	DE/OD/NB/IC
number	286	1258	689	763
variable	$a_{2,1,1,3}$	$a_{2,1,2,1}$	$a_{2,1,2,2}$	$a_{2,1,2,3}$
segment	AR/TR/BU/EU	AR/TR/BU/NE	AR/TR/BU/IC	AR/TR/NB/EU
number	851	461	978	1021
variable	$a_{1,2,1,1}$	$a_{1,2,1,2}$	$a_{1,2,1,3}$	$a_{1,2,2,1}$
segment	AR/TR/NB/NE	AR/TR/NB/IC	DE/TR/BU/EU	DE/TR/BU/NE
number	533	1548	851	461
variable	$a_{1,2,2,2}$	$a_{1,2,2,3}$	$a_{2,2,1,1}$	$a_{2,2,1,2}$
segment	DE/TR/BU/IC	DE/TR/NB/EU	DE/TR/NB/NE	DE/TR/NB/IC
number	978	1021	533	1548
variable	$a_{2,2,1,3}$	$a_{2,2,2,1}$	$a_{2,2,2,2}$	$a_{2,2,2,3}$

Table A.4: Number of aircraft movements of base year

category	b_1	b_2	b_3	b_4	b_5
number	0	26549	173975	160940	17809
category	b_6	b_7	b_8	b_9	
number	15720	45685	7955	0	

Table A.5: Average number of visitors per passenger in segment(i,j,k,l)(visitors/passenger) and average passenger spending (€/passenger)

(i,j,k,l)	(1,1,1,1)	(1,1,1,2)	(1,1,1,3)	(1,1,2,1)	(1,1,2,2)	(1,1,2,3)	(2,1,1,1)	(2,1,1,2)
u	0.2	0.3	0.4	0.75	1	1.25	0.2	0.3
v	10	20	30	10	20	30	10	20
(i,j,k,l)	(2,1,1,3)	(2,1,2,1)	(2,1,2,2)	(2,1,2,3)	(1,2,1,1)	(1,2,1,2)	(1,2,1,3)	(1,2,2,1)
u	0.4	0.5	0.75	1	0	0	0	0
v	30	10	20	30	10	20	30	10
(i,j,k,l)	(1,2,2,2)	(1,2,2,3)	(2,2,1,1)	(2,2,1,2)	(2,2,1,3)	(2,2,2,1)	(2,2,2,2)	(2,2,2,3)
u	0	0	0	0	0	0	0	0
v	20	30	10	20	30	10	20	30

Table A.6: Car parking fee parameters

i	1	2	3	4	5	6	7	8
α_i	0.6	0.6	0.1	0.1	0	0	0	0
β_i	0.2	0.2	0.5	0.5	0.4	0.4	0.8	0.8
f_i	12	12	120	120	36	36	240	240
g_i	1	1	2	2	1	1	2	2
p_i	1.5	1.5	1	1	1.5	1.5	1	1
q_i	4	4	3	3	4	4	3	3

Appendix B

Object property setting

Table B.1: Revenue and cost sheet

Object	Property	setting	Object	Property	setting
Form	Name	frmRevecost			
	Caption	Form1			
Label1	Name	Label1	Label11	Name	Label11
	Caption	Passenger fee revenue		Caption	Employee cost
Text1	Name	Text1	Text10	Name	Text11
	Caption	(blank)		Caption	(blank)
Label2	Name	Label2	Label12	Name	Label12
	Caption	Landing fee revenue		Caption	Depreciation cost
Text2	Name	Text2	Text11	Name	Text12
	Caption	(blank)		Caption	(blank)
Label3	Name	Label3	Label13	Name	Label13
	Caption	Aircraft parking fee revenue		Caption	Maintence cost
Text3	Name	Text3	Text12	Name	Text12
	Caption	(blank)		Caption	(blank)
Label4	Name	Label4	Label14	Name	Label14
	Caption	Handling fee revenue		Caption	Utility cost
Text4	Name	Text4	Text13	Name	Text13
	Caption	(blank)		Caption	(blank)
Label5	Name	Label5	Label15	Name	Label15
	Caption	Retail revenue		Caption	Retail cost
Text5	Name	Text5	Text14	Name	Text14
	Caption	(blank)		Caption	(blank)
Label6	Name	Label6	Label16	Name	Label16
	Caption	Car parking fee revenue		Caption	Administration cost
Text6	Name	Text6	Text15	Name	Text15
	Caption	(blank)		Caption	(blank)
Label7	Name	Label7	Label17	Name	Label17
	Caption	Real estate revenue		Caption	Interest cost
Text7	Name	Text7	Text16	Name	Text16
	Caption	(blank)		Caption	(blank)
Label8	Name	Label8	Label18	Name	Label18
	Caption	Utility revenue		Caption	Total cost
Text8	Name	Text8	Text17	Name	Text17
	Caption	(blank)		Caption	(blank)
Label10	Name	Label10	Label19	Name	Label19
	Caption	Total revenue		Caption	Profit
Text9	Name	Text9	Text19	Name	Text19
	Caption	(blank)		Caption	(blank)
Label9	Name	Label9			
	Caption	Total investment			
Text18	Name	Text18			
	Caption	(blank)			

Table B.2: Balance sheet

Object	Property	setting	Object	Property	setting
Form	Name	frmFinmod			
	Caption	Form1			
Label1	Name	Label1	Label11	Name	Label11
	Caption	Extra cash needed		Caption	Liquid resources(t-1)
Text1	Name	Text1	Text11	Name	Text11
	Caption	(blank)		Caption	(blank)
Label2	Name	Label2	Label12	Name	Label12
	Caption	Profits(t)		Caption	Desired liquid resource
Text2	Name	Text2	Text12	Name	Text12
	Caption	(blank)		Caption	(blank)
Label3	Name	Label3	Label13	Name	Label13
	Caption	Depreciation costs(t)		Caption	Extra cash needed
Text3	Name	Text3	Text13	Name	Text13
	Caption	(blank)		Caption	(blank)
Label4	Name	Label4	Label14	Name	Label14
	Caption	Investments(t)		Caption	Profits(t)
Text4	Name	Text4	Text14	Name	Text14
	Caption	(blank)		Caption	(blank)
Label5	Name	Label5	Label15	Name	Label15
	Caption	Redemption of loans(t)		Caption	Depreciation costs(t)
Text5	Name	Text5	Text15	Name	Text15
	Caption	(blank)		Caption	(blank)
Label6	Name	Label6	Label16	Name	Label16
	Caption	To be balanced		Caption	Cash flow(t)
Text6	Name	Text6	Text16	Name	Text16
	Caption	(blank)		Caption	(blank)
Label7	Name	Label7	Label17	Name	Label17
	Caption	Liquid resources		Caption	Investments(t)
Text7	Name	Text7	Text17	Name	Text17
	Caption	(blank)		Caption	(blank)
Label8	Name	Label8	Label18	Name	Label18
	Caption	Private capital		Caption	Redemption of loans(t)
Text8	Name	Text8	Text18	Name	Text18
	Caption	(blank)		Caption	(blank)
Label9	Name	Label9	Label19	Name	Label19
	Caption	Fixed assets		Caption	To be balanced
Text9	Name	Text9	Text19	Name	Text19
	Caption	(blank)		Caption	(blank)
Label10	Name	Label10			
	Caption	Debt capital			
Text10	Name	Text10			
	Caption	(blank)			

Table B.3: Final version of model 4 & 5

Object	Property	setting	Object	Property	setting
Form	Name	frmModel45			
	Caption	Form1			
CommandButton	Name	cmdGetExcelData			
	Caption	Initial the system			
Label1	Name	LabelPassfee	lblPFOD	Name	lblPFOD
	Caption	Passenger fee		Caption	PF_OD
Text19	Name	Text19	lblPFTRF	Name	lblPFTRF
	Caption	(blank)		Caption	PF_TRF
text29	Name	Text29	LabelLandingfee	Name	LblLandingfe
	Caption	(blank)		Caption	Landing fee
lblLFc1	Name	lblLFc1	Text30	Name	Text30
	Caption	LF_C1		Caption	(blank)
lblLFc2	Name	lblLFc2	Text31	Name	Text31
	Caption	LF_C2		Caption	(blank)
lblLFc3	Name	lblLFc3	Text32	Name	Text32
	Caption	LF_C3		Caption	(blank)
lblLFc4	Name	lblLFc4	Text33	Name	Text33
	Caption	LF_C4		Caption	(blank)
lblLFc5	Name	lblLFc5	Text34	Name	Text34
	Caption	LF_C5		Caption	(blank)
lblLFc6	Name	lblLFc6	Text35	Name	Text35
	Caption	LF_C6		Caption	(blank)
lblLFc7	Name	lblLFc7	Text36	Name	Text36
	Caption	LF_C7		Caption	(blank)
lblLFc8	Name	lblLFc8	Text37	Name	Text37
	Caption	LF_C8		Caption	(blank)
lblLFc9	Name	lblLFc9	Text38	Name	Text38
	Caption	LF_C9		Caption	(blank)
CommandButton	Name	cmdPolicy			
	Caption	User define Policy data			
LblYear	Name	LblYear	ComboYear	Name	ComboYear
	Caption	Year		Text	2000
CommandButton	Name	cmdShow			
	Caption	Calculate the moeny			
lblReCo	Name	lblReCo			
	Caption	Revenue and Cost			
Label1	Name	Label1	Label10	Name	Label10
	Caption	PFR		Caption	EC
Text1	Name	Text1	Text10	Name	Text10
	Caption	(blank)		Caption	(blank)
Label2	Name	Label2	Label11	Name	Label11
	Caption	LFR		Caption	DC
Text2	Name	Text2	Text11	Name	Text11
	Caption	(blank)		Caption	(blank)
Label3	Name	Label3	Label12	Name	Label12
	Caption	ACPFR		Caption	MC
Text3	Name	Text3	Text12	Name	Text12
	Caption	(blank)		Caption	(blank)
Label4	Name	Label4	Label13	Name	Label13
	Caption	HFR		Caption	SC
Text4	Name	Text4	Text13	Name	Text13
	Caption	(blank)		Caption	(blank)

Table B.4: Final version of model 4 & 5 (continue)

Object	Property	setting	Object	Property	setting
Label5	Name	Label5	Label14	Name	Label14
	Caption	RR		Caption	RC
Text5	Name	Text5	Text14	Name	Text14
	Caption	(blank)		Caption	(blank)
Label6	Name	Label6	Label15	Name	Label15
	Caption	CPFR		Caption	AC
Text6	Name	Text6	Text15	Name	Text15
	Caption	(blank)		Caption	(blank)
Label7	Name	Label7	Label16	Name	Label16
	Caption	RER		Caption	IC
Text7	Name	Text7	Text16	Name	Text16
	Caption	(blank)		Caption	(blank)
Label8	Name	Label8	Label17	Name	Label17
	Caption	UR		Caption	TC
Text8	Name	Text8	Text17	Name	Text17
	Caption	(blank)		Caption	(blank)
Label9	Name	Label9	Label18	Name	Label18
	Caption	TR		Caption	Profit of the year
Text9	Name	Text9	Text18	Name	Text18
	Caption	(blank)		Caption	(blank)
Label29	Name	Label29			
	Caption	Balance sheet			
Label20	Name	Label20	Label23	Name	Label23
	Caption	Liquid resources		Caption	Private capital
Text20	Name	Text20	Text23	Name	Text23
	Caption	(blank)		Caption	(blank)
Label21	Name	Label21	Label24	Name	Label24
	Caption	Fixed assets		Caption	Debt capital
Text21	Name	Text21	Text24	Name	Text24
	Caption	(blank)		Caption	(blank)
Label22	Name	Label22	Label25	Name	Label25
	Caption	Total active		Caption	Total passive
Text22	Name	Text22	Text25	Name	Text25
	Caption	(blank)		Caption	(blank)

Appendix C

Example, proofs, and result tables

Example of Morris' method

Example 1. *We suppose that* $p = 4, k = 3$*, and* $\Delta = 2/3$ *, that is, we examine two factors that may have values in the set* $\{0, 1/3, 2/3, 1\}$*. Then* ***B*** *is given by*

$$B = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 1 \end{pmatrix}$$

and the randomly generated ***x*****, ***D***** *and* ***P***** *happen to be*

$$x^* = (1/3, 1/3, 0)$$

$$D^* = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

$$P^* = I$$

This gives

$$(\Delta/2)[(2B - J_{k+1,k})D^* + J_{k+1,k}] = \begin{pmatrix} 0 & 0 & \Delta \\ \Delta & 0 & \Delta \\ \Delta & \Delta & \Delta \\ \Delta & \Delta & 0 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 2/3 \\ 2/3 & 0 & 2/3 \\ 2/3 & 2/3 & 2/3 \\ 2/3 & 2/3 & 0 \end{pmatrix}$$

and we get

$$B^* = \begin{pmatrix} 1/3 & 1/3 & 2/3 \\ 1 & 1/3 & 2/3 \\ 1 & 1 & 2/3 \\ 1 & 1 & 0 \end{pmatrix}$$

or

$$x^{(1)} = (1/3, 1/3, 2/3), x^{(2)} = (1, 1/3, 2/3), x^{(3)} = (1, 1, 2/3), x^{(4)} = (1, 1, 0)$$

Facts of correlation ratio

Proposition C.0.1. *Let* $G = G(X, Y)$ *with* $\sigma^2_G < \infty$*; then*
(i) $Cov(G, E(G|X)) = \sigma^2_{E(G|X)}$,
(ii) $max_{f,\sigma^2_{f(X)}<\infty}\rho^2(G, f(X)) = \rho^2(G, E(G|X)) = \frac{\sigma^2_{E(G|X)}}{\sigma^2_G}$

Proof.

$$(i)Cov(G, E(G|X)) = E(E(GE(G|X)|X) - EGE(E(G|X))) = E(E^2(G|X)) - E^2(E(G|X)).$$

(ii) Let $\delta(x)$ be any function with finite variance. Put $A = \sigma^2_{E(G|X)}, B = Cov(E(G|X), \delta(x)), C = \sigma^2_G, andD = \sigma^2_\delta$. Then

$$\rho^2(G, E(G|X) + \delta(x)) = \frac{(A + B)^2}{C(A + D + 2B)} \tag{C.0.1}$$

In the formula (C.0.1).

$$\rho^2(G, E(G|X) + \delta(x)) = \frac{(A + B)^2}{C(A + D + 2B)};$$

$$\frac{\sigma^2_{E(G|X)}}{\sigma^2_G} = \frac{A}{C}.$$

$$\frac{(A + B)^2}{C(A + D + 2B)} \leq \frac{A}{C} \Leftarrow: B^2 \leq AD.$$

The latter inequality follows from the Cauchy-Schwarz inequality. □

The quantity $\frac{\sigma^2_{E(G|X)}}{\sigma^2_G}$ is called the correlation ratio, and may be taken as the general sensitivity of G to X. Note that the correlation ratio is always positive, and hence gives no information regarding the direction of the influence. The following propositions explore some properties of the correlation ratio. The first is straightforward, the second uses Proposition 2.2.1.

Proposition C.0.2. *Let* $G(X, Y) = f(X) + h(Y)$ *where* f *and* g *are invertible functions with* $\sigma^2_f < \infty$,$\sigma^2_h < \infty$ *and* X, Y *are not both simultaneously constant(*$\sigma^2_G > 0$*). If* X *and* Y *are independent then*
$\rho^2(G, E(G|X)) + \rho^2(G, E(G|Y)) = 1$.

Proof. We have $E(G|X) = E(G|f(X))$, and $h(Y) \perp E(G|f(X)), f(X) \perp E(G|h(Y))$; therefore,

$$\begin{aligned}
\sigma^2_G &= Cov(G, G) = Cov(G, f(X) + h(Y)) \\
&= Cov(G, f(X)) + Cov(G, h(Y)) \\
&= Cov(E(G|f(X)), f(X)) + Cov(E(G|h(Y)), h(Y)) \\
&= Cov(E(G|f(X)) + E(G|h(Y)), f(X) + h(Y)) \\
&= Cov(E(G|f(X)) + E(G|h(Y)), G) \\
&= Cov(E(G|X) + E(G|Y), G) \\
&= \sigma^2_{E(G|X)} + \sigma^2_{E(G|Y)}
\end{aligned}$$

The result now follows. □

Proposition C.0.3. *Let* $G = G(X, Y)$ *with* $Cov(E(G|X), E(G|Y)) = 0$*; then* $\rho^2(G, E(G|X)) + \rho^2(G, E(G|Y)) \leq 1$*.*

Proof. We have $E(G|X) = E(G|f(X))$, and $h(Y) \perp E(G|f(X)), f(X) \perp E(G|h(Y))$; therefore,

$$\begin{aligned} \rho(E(G|X), G - E(G|Y)) &= \frac{Cov(E(G|X), G - E(G|Y))}{\sigma_{E(G|X)}\sqrt{\sigma_G^2 - \sigma_{E(G|Y)}^2}} \\ &= \frac{\sigma_{E(G|X)}}{\sqrt{\sigma_G^2 - \sigma_{E(G|Y)}^2}} \leq 1 \\ \sigma_{E(G|X)}^2 + \sigma_{E(G|Y)}^2 &\leq \sigma_G^2 \end{aligned}$$

□

Correlation ratio results for 5 cases

We use the Unicorn sample file calculate the correlation ratio of the growth rate for passengers and aircraft, passenger fee, and landing fee (see Tab. C.1). In this case, all the parameters are independent.

Note:

$Ra_i(i = 1, \cdots, 24)$*—growth rate of 24 segments of passengers.*
$Rb_i(i = 1, \cdots, 9)$*—growth rate of 9 category of aircraft movement.*
$Lf_i(i = 1, \cdots, 9)$*—Landing fee for different category aircraft.*
pfod—Origin/Destination passenger fee.
pftr—Transfer passenger fee.

Table C.1: Case 1: Correlation ratio results (Case 1)

No	Name	Description	Correlation ratio	Sort
35	pftr	Transfer passenger fee	0.6046879	1
34	pfod	Origin/destination passenger fee	0.4024714	2
4	Ra4	Growth rate of segment passenger 4	3.121572E-02	3
32	Rb8	Growth rate for aircraft movement 8	2.964654E-02	4
44	Lf9	Landing fee for category 9	2.928326E-02	5
26	Rb2	Growth rate for aircraft movement 2	2.74261 E-02	6
28	Rb4	Growth rate for aircraft movement 4	2.680617E-02	7
20	Ra20	Growth rate of segment passenger 20	2.678887E-02	8
27	Rb3	Growth rate for aircraft movement 3	2.615546E-02	9
7	Ra7	Growth rate of segment passenger 7	2.606898E-02	10
30	Rb6	Growth rate for aircraft movement 6	2.598725E-02	11
22	Ra22	Growth rate of segment passenger 22	2.360643E-02	12
6	Ra6	Growth rate of segment passenger 6	2.272913E-02	13
9	Ra9	Growth rate of segment passenger 9	2.061332E-02	14
21	Ra21	Growth rate of segment passenger 21	2.059246E-02	15
38	Lf3	Landing fee for category 3	2.01974 E-02	16
24	Ra24	Growth rate of segment passenger 24	1.995069E-02	17
37	Lf2	Landing fee for category 2	1.973867E-02	18
3	Ra3	Growth rate of segment passenger 3	1.888379E-02	19
29	Rb5	Growth rate for aircraft movement 5	1.803615E-02	20
11	Ra11	Growth rate of segment passenger 11	1.745242E-02	21
19	Ra19	Growth rate of segment passenger 19	1.740278E-02	22
14	Ra14	Growth rate of segment passenger 14	1.670839E-02	23
33	Rb9	Growth rate for aircraft movement 9	1.660239E-02	24
1	Ra1	Growth rate of segment passenger 1	1.652406E-02	25
36	Lf1	Landing fee for category 1	1.589496E-02	26
42	Lf7	Landing fee for category 7	1.486241E-02	27
23	Ra23	Growth rate of segment passenger 23	1.485778E-02	28
43	Lf8	Landing fee for category 8	1.478728E-02	29
31	Rb7	Growth rate for aircraft movement 7	1.449952E-02	30
39	Lf4	Landing fee for category 4	1.445239E-02	31
17	Ra17	Growth rate of segment passenger 17	1.39667 E-02	32
8	Ra8	Growth rate of segment passenger 8	1.358813E-02	33
40	Lf5	Landing fee for category 5	1.340511E-02	34
13	Ra13	Growth rate of segment passenger 13	1.324781E-02	35
16	Ra16	Growth rate of segment passenger 16	1.30975 E-02	36
5	Ra5	Growth rate of segment passenger 5	1.219831E-02	37
41	Lf6	Landing fee for category 6	1.207409E-02	38
12	Ra12	Growth rate of segment passenger 12	1.184338E-02	39
25	Rb1	Growth rate for aircraft movement 1	1.130686E-02	40
18	Ra18	Growth rate of segment passenger 18	1.08684 E-02	41
15	Ra15	Growth rate of segment passenger 15	1.036136E-02	42
10	Ra10	Growth rate of segment passenger 10	8.942016E-03	43
2	Ra2	Growth rate of segment passenger 2	8.725949E-03	44

Table C.2: Case 2: Correlation ratio results for landing fees

No	Name	Description	Correlation ratio	Sort
42	Lf7	Landing fee for category 7	0.7477599	1
39	Lf4	Landing fee for category 4	0.1200564	2
43	Lf8	Landing fee for category 8	7.332083E-02	3
38	Lf3	Landing fee for category 3	5.278557E-02	4
41	Lf6	Landing fee for category 6	4.729696E-02	5
44	Lf9	Landing fee for category 9	2.986048E-02	6
37	Lf2	Landing fee for category 2	1.965712E-02	7
40	Lf5	Landing fee for category 5	1.84122 E-02	8
36	Lf1	Landing fee for category 1	1.471829E-02	9

Table C.3: Case 5: Correlation ratio results for landing fees with rank correlation between landing fee is 0.81(latent structure)

No	Name	Description	Correlation ratio	Sort
42	Lf7	Landing fee for category 7	0.9339667	1
39	Lf4	Landing fee for category 4	0.8357345	2
43	Lf8	Landing fee for category 8	0.823983	3
38	Lf3	Landing fee for category 3	0.8228938	4
40	Lf5	Landing fee for category 5	0.811032	5
41	Lf6	Landing fee for category 6	0.8108537	6
44	Lf9	Landing fee for category 9	0.7822999	7
37	Lf2	Landing fee for category 2	0.7746494	8
36	Lf1	Landing fee for category 1	0.7699545	9

Table C.4: Case 3: Correlation ratio results(Rank(pfod,pftr)=0.9)

No	Name	Description	Correlation ratio	Sort
35	pftr	Transfer passenger fee	0.9579887	1
34	pfod	Origin/destination passenger fee	0.9355703	2
16	Ra16	Growth rate of segment passenger 16	3.221454E-02	3
11	Ra11	Growth rate of segment passenger 11	3.066314E-02	4
10	Ra10	Growth rate of segment passenger 10	2.902001E-02	5
29	Rb5	Growth rate for aircraft movement 5	2.888815E-03	6
6	Ra6	Growth rate of segment passenger 6	2.777146E-02	7
14	Ra14	Growth rate of segment passenger 14	2.586076E-02	8
24	Ra24	Growth rate of segment passenger 24	2.497247E-02	9
41	Lf6	Landing fee for category 6	2.470245E-02	10
30	Rb6	Growth rate for aircraft movement 6	2.434382E-02	11
25	Rb1	Growth rate for aircraft movement 1	2.26262 E-02	12
26	Rb2	Growth rate for aircraft movement 2	2.191059E-02	13
8	Ra8	Growth rate of segment passenger 8	2.134181E-02	14
20	Ra20	Growth rate of segment passenger 20	2.131386E-02	15
36	Lf1	Landing fee for category 1	2.100047E-02	16
12	Ra12	Growth rate of segment passenger 12	2.092942E-02	17
2	Ra2	Growth rate of segment passenger 2	2.069675E-02	18
1	Ra1	Growth rate of segment passenger 1	2.047202E-02	19
13	Ra13	Growth rate of segment passenger 13	2.011842E-02	20
28	Rb4	Growth rate for aircraft movement 4	1.943023E-02	21
32	Rb8	Growth rate for aircraft movement 8	1.941594E-02	22
9	Ra9	Growth rate of segment passenger 9	1.840377E-02	23
19	Ra19	Growth rate of segment passenger 19	1.833211E-02	24
33	Rb9	Growth rate for aircraft movement 9	1.796752E-02	25
17	Ra17	Growth rate of segment passenger 17	1.731293E-02	26
15	Ra15	Growth rate of segment passenger 15	1.575721E-02	27
21	Ra21	Growth rate of segment passenger 21	1.558251E-02	28
3	Ra3	Growth rate of segment passenger 3	1.552051E-02	29
23	Ra23	Growth rate of segment passenger 23	1.545509E-02	30
38	Lf3	Landing fee for category 3	1.525489E-02	31
43	Lf8	Landing fee for category 8	1.475415E-02	32
18	Ra18	Growth rate of segment passenger 18	1.473427E-02	33
27	Rb3	Growth rate for aircraft movement 3	1.388997E-02	34
4	Ra4	Growth rate of segment passenger 4	1.337934E-02	35
31	Rb7	Growth rate for aircraft movement 7	1.332324E-02	36
42	Lf7	Landing fee for category 7	1.301205E-02	37
40	Lf5	Landing fee for category 5	1.260208E-02	38
44	Lf9	Landing fee for category 9	1.254698E-02	39
39	Lf4	Landing fee for category 4	1.233264E-02	40
7	Ra7	Growth rate of segment passenger 7	1.218416E-02	41
37	Lf2	Landing fee for category 2	8.995946E-03	42
5	Ra5	Growth rate of segment passenger 5	8.501398E-03	43
22	Ra22	Growth rate of segment passenger 22	7.484133E-03	44

Table C.5: Case 4: Correlation ratio results(Rank(pfod,pftr)=0.9),latent structure of 9 landing fees

No	Name	Description	Correlation ratio	Sort
35	pftr	Transfer passenger fee	0.9542702	1
34	pfod	Origin/destination passenger fee	0.9329531	2
40	Lf5	Landing fee for category 5	3.558477E-02	3
11	Ra11	Growth rate of segment passenger 11	3.156199E-02	4
43	Lf8	Landing fee for category 8	3.024813E-02	5
18	Ra18	Growth rate of segment passenger 18	2.997947E-02	6
38	Lf3	Landing fee for category 3	2.94012 E-02	7
37	Lf2	Landing fee for category 2	2.841216E-02	8
16	Ra16	Growth rate of segment passenger 16	2.523176E-02	9
44	Lf9	Landing fee for category 9	2.498472E-02	10
22	Ra22	Growth rate of segment passenger 22	2.44498 E-02	11
12	Ra12	Growth rate of segment passenger 12	2.420909E-02	12
1	Ra1	Growth rate of segment passenger 1	2.389323E-02	13
19	Ra19	Growth rate of segment passenger 19	2.366148E-02	14
39	Lf4	Landing fee for category 4	2.34716 E-02	15
42	Lf7	Landing fee for category 7	2.300636E-02	16
15	Ra15	Growth rate of segment passenger 15	2.287912E-02	17
29	Rb5	Growth rate for aircraft movement 5	2.279115E-03	18
17	Ra17	Growth rate of segment passenger 17	2.258908E-02	19
31	Rb7	Growth rate for aircraft movement 7	1.993658E-02	20
41	Lf6	Landing fee for category 6	1.978774E-02	21
25	Rb1	Growth rate for aircraft movement 1	1.975878E-02	22
24	Ra24	Growth rate of segment passenger 24	1.886804E-02	23
13	Ra13	Growth rate of segment passenger 13	1.87066 E-02	24
3	Ra3	Growth rate of segment passenger 3	1.867934E-02	25
36	Lf1	Landing fee for category 1	1.866303E-02	26
9	Ra9	Growth rate of segment passenger 9	1.723072E-02	27
20	Ra20	Growth rate of segment passenger 20	1.709138E-02	28
8	Ra8	Growth rate of segment passenger 8	1.700802E-02	29
10	Ra10	Growth rate of segment passenger 10	1.671986E-02	30
28	Rb4	Growth rate for aircraft movement 4	1.671118E-02	31
5	Ra5	Growth rate of segment passenger 5	1.536354E-02	32
33	Rb9	Growth rate for aircraft movement 9	1.52723 E-02	33
4	Ra4	Growth rate of segment passenger 4	1.522723E-02	34
14	Ra14	Growth rate of segment passenger 14	1.503563E-02	35
32	Rb8	Growth rate for aircraft movement 8	1.407109E-02	36
2	Ra2	Growth rate of segment passenger 2	1.401192E-02	37
30	Rb6	Growth rate for aircraft movement 6	1.398136E-02	38
27	Rb3	Growth rate for aircraft movement 3	1.314192E-02	39
21	Ra21	Growth rate of segment passenger 21	1.27506 E-02	40
26	Rb2	Growth rate for aircraft movement 2	1.142921E-02	41
7	Ra7	Growth rate of segment passenger 7	1.140592E-02	42
23	Ra23	Growth rate of segment passenger 23	1.107025E-02	43
6	Ra6	Growth rate of segment passenger 6	5.38147 E-03	44

Appendix D

Matlab code of Morris' method

(1) main program

```
clear;clc;clf; format long p=4;delta=p/(2*(p-1)); di=36; tic for
to=1:di

%Get the initial matrix B
    BI=zeros(45,44);BB=zeros(44,44);
    for a=1:44
        for b=1:44
            if a>=b
             BB(a,b)=1;
            else
             BB(a,b)=0;
            end
         BI(a+1,:)=BB(a,:);
% sampling matrix k+1-by- k, k is the number of factors
        end
    end

%Get the matrix J, k+1 by k matrix of 1's
    Jstar=zeros(45,44);
    Jstar(:,:)=1;

% Get the matrix D*, k-dimensional diagonal matrix in which each diagonal
  element is either +1 or -1 with equal probability
    D=eye(44,44);
    r=randperm(44);
        for c=1:44
         D(c,c)=(-1)^(r(c))*D(c,c);
        end
% Get matrix P*, k-by-k random permutation matrix in which each column contains
  one element equal to 1 and all others equal to 0 and no two columns have
  1s in the same position
    P=zeros(44,44);
    rr=randperm(44);
        for e=1:44
         P(e,rr(e))=1;
```

```
        end

% get the range of x value, from 0 to 1-delta
    mm=0:(1-delta)*(p-1);
    xvalue=1/(p-1)*mm;

   for m=1:44
   % the number of factors, i.e. #  of random number, and give the intial
     value to x
     xn=randperm((1-delta)*(p-1)+1);
       if rand < .5
        xi(m)=xvalue(1);
       else
        xi(m)=xvalue(2);
       end
%if xn(1)-2~=0
  %      xi(m)=xvalue(1);
  %     else
  %      xi(m)=xvalue(2);
  %     end
    end

% Transform and get the orient matrix B*, one elementary effect per input,
  but one which is randomly selected
    BO=(Jstar(:,1)*xi+(delta/2)*((2*BI-Jstar)*D+Jstar))*P;

% calculate  the elementary effect
    ele=zeros(44);inx1=zeros(1,44);inx2=zeros(1,44);
    %ele(i,j) denote the j-th factor's elementary effect
    for k=1:44
        for q=1:44
             if BO(k,q)>BO(k+1,q)
              inx1=BO(k,:);
              inx2=BO(k+1,:);
              ele(k,q)=(fun2(inx1)-fun2(inx2))/delta;
             elseif    BO(k,q)<BO(k+1,q)
              inx1=BO(k+1,:);
              inx2=BO(k,:);
              ele(k,q)=(fun2(inx1)-fun2(inx2))/delta;
             else
              ele(k,q)=0;
             end
        end
    end

% Get every factor elmentary effect
    for u=1:44
        for v=1:44
```

```
            if ele(u,v)~=0
             tele(to,v)=ele(u,v);
            end
            if ele([1:44],v)==0
             tele(to,v)=0;
            end
        end
    end
end


% Mean and standard deviation
   sum=zeros(1,44);%1-by-# of factors
    for w=1:44 %# of factors
        for tt=1:di % # of samples
         sum(1,w)=tele(tt,w)+sum(1,w);
        end
    end

   mean=sum/di; % devide by # of samples

   for y=1:44 % # of factors
        for l=1:di % # of samples
         de(l,y)=tele(l,y)-mean(y);
        end
    end

%Standard error deviation
   desq=de.*de;
   Sem=zeros(1,44);
    for z=1:44 % # of factors
        for tt1=1:di % # of sample
         Sem(1,z)=desq(tt1,z)+Sem(1,z);
        end
    end
 Semplot=sqrt(Sem/(di-1));

   % plot the S vernus mean
plot(mean,Semplot,'*','MarkerSize',6) calculate_time=toc

for ti=1:44
    text(mean(ti),Semplot(ti),num2str(ti))
end

xlabel('Estimated Means (d), Euro 1000') ylabel('Standard
Deviations (S) Euro 1000') title('Estimated means and standard
deviations of elementary effects ') hold on
%axis([-20,100,0,80])
```

```
refx1=[-10000:1:0]; refx2=[0:1:12000]; refy1=-2*refx1/sqrt(di);
refy2=2*refx2/sqrt(di); plot(refx1,refy1,'g');
plot(refx2,refy2,'g'); hold off mean; Semplot;
```

(2)function

```
function profit = fun2(inx1)

x=inx1; %input x

OD=0;TR=0; a=1000*[669 716 286 1258    689 763 669 716     286
1258 689 763     851 461 978 1021    533 1578 851 461    978 1021
533 1548]; b=[0 2459 43983 45082 5420 3349 11708 1866 0];

ra=inx1(1,[1:24])*0.02+0.09;

rb=inx1(1,[25:33])*0.02+0.09; PFOD=10+10*inx1(1,34);
PFTR=10*inx1(1,35); for i=1:24
    if i<=12
        OD=OD+a(1,i)*(1+ra(i));
    else
        TR=TR+a(1,i)*(1+ra(i));
    end
end pf=0.5*(PFOD*OD+PFTR*TR);
    LF=[10 20 50 100 200 500 1000 2000 5000];
    LFT=zeros(1,9);
for i=1:9
    if i==1
        LFT(1,i)=10*inx1(1,36);
    else
        LFT(1,i)=LF(1,i-1)+inx1(1,35+i)*(LF(1,i)-LF(1,i-1));
    end
end
    lft=0;aircpfr=0;
    for i=1:9
        lft=lft+0.5*b(i)*(1+rb(i))*LFT(1,i);
        aircpfr=aircpfr+375*b(i)*(1+rb(i));
    end
    hfr=0;
    HFCle=[1 2 5 10 20 50 100 200 500];
    HFTnk=[2 4 10 20 40 100 200 400 1000];
    for i=1:9
    hfr=hfr+0.55*(OD*5+TR*3+0.5*(b(i)*(1+rb(i))*(HFCle(1,i)+HFTnk(1,i))));
    end
    arr=[0.2 0.3 0.4 0.75 1 1.25 0.2 0.3 0.4 0.5 0.75 1 0 0 0 0 0 0 0 0 0 0 0 0];
    ps=[10 20 30 10 20 30 10 20 30 10 20 30 10 20 30 10 20 30 10 20 30 10 20 30];
    acpfr=[0.6 0.6 0.1 0.1 0 0 0 0];
    bcpfr=[0.2 0.2 0.5 0.5 0.4 0.4 0.8 0.8];
```

```
    fcpfr=[12 12 120 120 36 36 240 240];
    gcpfr=[1 1 2 2 1 1 2 2];
    pcpfr=[1.5 1.5 1 1 1.5 1.5 1 1];
    qcpfr=[4 4 3 3 4 4 3 3];
    rr=0;
    for i=1:24
    rr=rr+0.55*(a(i)*(1+ra(1,i))*(ps(i)+arr(1,i)*2)+10000000);
    end
    cpfr=0;
    pax(1)=a(1,1)*(1+ra(1))+a(1,2)*(1+ra(2));
    pax(2)=a(1,7)*(1+ra(7))+a(1,8)*(1+ra(8));
    pax(3)=a(1,3)*(1+ra(3));
    pax(4)=a(1,9)*(1+ra(9));
    pax(5)=a(1,4)*(1+ra(4))+a(1,5)*(1+ra(5));
    pax(6)=a(1,10)*(1+ra(10))+a(1,11)*(1+ra(11));
    pax(7)=a(1,6)*(1+ra(6));
    pax(8)=a(1,12)*(1+ra(12));
 for i1=1:8
    cpfr=cpfr+0.55*(pax(i1)*(acpfr(i1)*fcpfr(i1)*pcpfr(i1)
         +bcpfr(i1)*gcpfr(i1)*qcpfr(i1)));
 end
    rer=0.55*(0.8*(408*1000+216*1000)+0.8*60*365*150);
    ur=0.55*70000;
    totar=(pf+lft+aircpfr+hfr+rr+cpfr+rer+ur)/0.89;
    ec=0;
    for i=1:9
        ec=ec+100*b(i)*(1+rb(i));
    end
ec=0.5*(ec+OD+TR+2.2*10^6); dc=40000*10+5000*200+8000*200+2*10^7;
mc=400000+5000*200+8000*200+4*10^7; sc=640000+280000;
rc=0.4*rr/0.55; oc=0.04*totar; tc=(ec+dc+mc+sc+rc+oc)/0.89;

% get the value of function
profit=(totar-tc)/1000;
```