# DECISION SUPPORT FOR COLLABORATIVE AIRPORT STRATEGIC PLANNING

R.A.A. Wijnen

**DECISION SUPPORT FOR COLLABORATIVE AIRPORT STRATEGIC PLANNING**

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,

in het openbaar te verdedigen
op woensdag 3 april 2013 om 10.00 uur

door
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ingenieur luchtvaart en ruimtevaart
geboren te Valkenswaard

Dit proefschrift is goedgekeurd door de promotoren:
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**TRAIL Thesis Series** nr. T2013/8, the Netherlands TRAIL Research School

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ISBN: 978-90-5584-165-3

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Printed in the Netherlands

# Preface

Or as the Tjech would say:
*A JE TO*.

BUURMAN & BUURMAN

The world has become complex and is changing fast. The only way to reduce complexity and deal with change is to create and maintain a common language. Creating and using such a language can only be done in a collaborative setting. That is what this dissertation is about. This dissertation is the result of my PhD. research at Delft University of Technology. I started the research around 2003 and concluded the research in 2011. I've not been working full-time on this research. During 2005-2009 I also worked half-time on a large European research project which was also about decision support for airport strategic planning. From 2009-2011 I've been working as an independent consultant.

During this entire period I've explored knowledge and wisdom and learned many new skills. It is great to see that I have been able to put this knowledge, wisdom and skills into practice. Actually, I'm using everything I have learned in my current job as a Business Consultant at Business Models Inc., an international business modeling agency. The reason that I mention this is the following. Some people I meet are surprised to find out about my background in aeronautical engineering when they hear I'm facilitating people to create value together. That link might indeed not be so obvious. However, it makes more sense if I tell people more about my curiosity in exploring new fields of knowledge, wisdom and practice.

It is actually this curiosity that produced the dissertation that you're about to read if you can spare the time. No worries if you don't have the time to read it. The most important lessons from the research are revealed here. During my research, I've been questioning my approach and thinking all the time. This led

me from an optimization mindset through a policy analysis mindset to a mindset that is focused on bringing people together. The reason for changing my mind was the pursuit of a way to better support airport strategic planning in a multi-stakeholder context.

I have always intuitively understood that connecting people is essential for their ability to think and act together towards a common goal. This insight comes from my training and experience as an aikidoka. In aikido you work with your fellow aikidoka's to advance both your abilities. The purpose of training is to learn together, not to prepare for a 'fight'. I see a strong analogy between aikido and collaborative approaches to strategic planning and thinking in the scientific and managerial world.

I would like to say thanks to the following people who supported me on my journey. My mom and dad, Bianca and Leo, who provided me a playground for learning. My brother, Matthijs, who asked me simple, yet powerful questions and led me to a number of wonderful books and insights. My wife, Jacqueline, who kept bugging me to finish the thing. My sons, Mees and Stan, who inspire me with their curiosity and creativity. Peter Bacas sensei and Fujita sensei for pushing me to apply aikido outside the dojo. My aikido friends from the Hagukumi dojo and beyond for throwing me around the tatami. Warren, who inspired me to move beyond optimization and educating me about policy analysis. Dries, who triggered the idea for this research. Theo and Michel, who led the multi-disciplinary group where I could do my work. My former colleagues at the Faculty of Aerospace Engineering, especially Dirk en Ronald for asking me 'how are you doing?'. Doug for the inspiring visit to Brisbane and the opportunity to present my work down under. My former colleagues at the Faculty of Technology, Policy and Management, especially Jan and Menno for the many discussions about a wide range of subjects and Vincent and Ricky for supporting me in wrapping up this work. Nico for his fascination with scenario thinking and building a value proposition around our combined knowledge and experience. Camilla and Patrick for sharing the vision about value creation and group facilitation and inviting me to their team.

Roland Wijnen
Eersel, February 2013

# Contents

**Preface** i

**Contents** iii

**List of Figures** xi

**List of Tables** xiii

**List of Acronyms** xv

**1 Introduction** 1
- 1.1 Airport strategic planning . . . 2
- 1.2 The problems with airport strategic planning . . . 5
  - 1.2.1 Problem Area I: Lack of involvement of the stakeholders 5
  - 1.2.2 Problem Area II: Inadequate approach for dealing with the future . . . 6
  - 1.2.3 Problem Area III: Inefficient problem solving process . 7
- 1.3 Motivation for a decision support system . . . 7
  - 1.3.1 State of practice . . . 8
  - 1.3.2 State of the art . . . 8
  - 1.3.3 Gap between decisionmaking needs and decision support . . . 9
- 1.4 Research questions . . . 9
- 1.5 Presentation of the research . . . 10
- 1.6 Scope and limitations . . . 11
- 1.7 Outline of the dissertation . . . 12

References . . . 15

**I Broad Perspective** **19**

**2 Airport Strategic Planning** **23**
2.1 Strategic planning . . . 23
2.1.1 Definition . . . 24
2.1.2 History . . . 24
2.1.3 Schools of strategic management . . . 25
2.1.4 Strategic thinking . . . 27
2.1.5 Social corporate responsibility . . . 28
2.2 Approaches to airport strategic planning . . . 30
2.3 Approaches to airport strategic planning versus the three problem areas . . . 34
2.4 The resources involved in a strategic planning effort . . . 36
2.4.1 People . . . 36
2.4.2 Data and information . . . 37
2.4.3 Tools . . . 37
2.4.4 Underlying cause of the three problem areas . . . 38
2.5 Summary and conclusion . . . 39
References . . . 39

**3 The Airport as a Socio-technical System** **43**
3.1 The technical perspective . . . 44
3.1.1 The airspace . . . 46
3.1.2 The airfield . . . 47
3.1.3 The terminal system . . . 51
3.1.4 The ground access system . . . 53
3.1.5 Physical capacity . . . 54
3.2 The social perspective . . . 57
3.2.1 Noise . . . 57
3.2.2 Emissions . . . 59
3.2.3 Third-party risk . . . 60
3.2.4 Environmental capacity . . . 60
3.3 Bringing the perspectives together . . . 64
3.3.1 The need for an integral view on airport performance . . . 64
3.3.2 The airport as a socio-technical system: Conclusion . . . 66
References . . . 67

**4 Computer-based Systems for Airport Performance Analysis** **75**
4.1 Tools for airport performance analysis . . . 76
4.1.1 Capacity and delay . . . 77
4.1.2 Noise . . . 78
4.1.3 Emissions . . . 78

4.1.4 Third-party risk . . . . . 79
4.1.5 Limitations of tools for use in strategic planning studies 79
4.2 Projects to develop computer-based systems . . . . . 80
4.2.1 TAPE . . . . . 81
4.2.2 OPTAS . . . . . 82
4.2.3 OPAL . . . . . 83
4.2.4 SPADE . . . . . 84
4.2.5 Airport Business Suite . . . . . 85
4.3 Problems with existing computer-based systems . . . . . 87
4.3.1 Levels of decisionmaking and support . . . . . 87
4.3.2 Discussion of specific problems . . . . . 89
4.4 Summary and conclusion . . . . . 92
References . . . . . 93

**II Decision Support Design 99**

**5 What is Needed? 103**
5.1 Vision about decision support . . . . . 104
5.1.1 High-level goals . . . . . 104
5.1.2 Problem statement related to decision support for airport strategic planning . . . . . 106
5.1.3 HARMOS: A DSS for airport strategic planning . . . . 107
5.2 Key design principles . . . . . 109
5.2.1 Policy analysis approach . . . . . 109
5.2.2 Integrating resources . . . . . 117
5.3 DSS development process . . . . . 122
5.3.1 Traditional approach . . . . . 123
5.3.2 Modern software engineering . . . . . 125
5.4 Scope of the HARMOS development effort . . . . . 129
5.5 Summary and conclusion . . . . . 132
References . . . . . 132

**6 Architecture of the HARMOS DSS 139**
6.1 Software architecture . . . . . 140
6.2 Logical view of the architecture . . . . . 142
6.2.1 Graphical User Interface Layer . . . . . 145
6.2.2 Domain Layer . . . . . 146
6.2.3 Technical Services Layer . . . . . 147
6.3 Functional view of the architecture . . . . . 148
6.3.1 Define Decisionmaking Context . . . . . 149
6.3.2 Calibrate Study . . . . . 151

6.3.3 Specify System Characteristics . . . 152
6.3.4 Develop Scenarios . . . 152
6.3.5 Define Strategy . . . 153
6.3.6 Evaluate Strategy . . . 154
6.3.7 Execute Performance Analysis . . . 155
6.3.8 Compare Strategies . . . 156
6.4 Summary . . . 156
References . . . 157

**III Implementation of the HARMOS Architecture 161**

**7 The HARMOS Domain Model 165**
7.1 The HARMOS software development process . . . 166
7.1.1 Activities carried out within the disciplines . . . 166
7.1.2 Iterations . . . 167
7.1.3 Visualizing the design . . . 168
7.2 High-level overview of the Domain Model . . . 169
7.2.1 Core classes . . . 169
7.2.2 Workflow . . . 170
7.3 Study Module . . . 172
7.3.1 Study Service . . . 173
7.3.2 Study . . . 173
7.3.3 Context . . . 174
7.3.4 Case . . . 175
7.4 System Module . . . 177
7.4.1 Modeling the system . . . 177
7.4.2 Exploiting object orientation . . . 178
7.5 External Factor Module . . . 182
7.5.1 Scenario Service . . . 183
7.5.2 Scenario . . . 183
7.5.3 Traffic Demand . . . 183
7.6 Strategy Module . . . 186
7.6.1 Strategy Service . . . 187
7.6.2 Strategy . . . 188
7.6.3 Operational Plan . . . 188
7.6.4 Scorecard Service . . . 190
7.7 Outcome of Interest Module . . . 191
7.8 Performance Analysis Module . . . 192
7.8.1 Analysis Service . . . 194
7.8.2 Tool Adapters . . . 195

7.9 Summary and conclusion . . . . . 195
References . . . . . 199

**8 Proof of Concept for the HARMOS DSS 201**
8.1 The HARMOS concept: Closing the gap between decisionmaking needs and decision support . . . . . 202
8.2 Specific problems related to airport strategic planning . . . . . 203
8.2.1 Schiphol Group . . . . . 203
8.2.2 Air France-KLM . . . . . 204
8.2.3 Air Traffic Control the Netherlands . . . . . 205
8.2.4 The Government and Ministries . . . . . 205
8.2.5 The Community . . . . . 206
8.2.6 Summary of the specific problems in each of the problem areas . . . . . 207
8.3 Problem Area I: Lack of involvement of the stakeholders . . . . 207
8.3.1 Define Decisionmaking Context . . . . . 208
8.3.2 Compare Strategies . . . . . 208
8.4 Problem Area II: Inadequate approach for dealing with the future 209
8.4.1 Develop Scenarios . . . . . 209
8.4.2 Define Strategy . . . . . 210
8.5 Problem Area III: Inefficient problem solving process . . . . . 211
8.5.1 Calibrate Study . . . . . 211
8.5.2 Evaluate Strategy . . . . . 211
8.6 Compatibility with Master Planning . . . . . 212
8.7 Summary . . . . . 214
References . . . . . 216

**9 Proof of Usefulness of the HARMOS DSS 217**
9.1 Approach for testing DSS usefulness . . . . . 217
9.1.1 Methodology and technology . . . . . 218
9.1.2 Design of the workshop . . . . . 218
9.1.3 Potential users . . . . . 218
9.2 Workshop results . . . . . 219
9.2.1 Part I: Open question about key challenges in airport strategic planning . . . . . 219
9.2.2 Part II: Specific problems in each of the problem areas. . 220
9.2.3 Part III: Feedback on specific functionality of the HARMOS DSS . . . . . 223
9.3 Response to the workshop results . . . . . 228
9.3.1 Part I: Open question about key challenges in airport strategic planning . . . . . 228

9.3.2 Part II: Specific problems in each of the problem areas . 230
9.3.3 Part III: Feedback on specific functionality of the HARMOS DSS . . . 232
9.3.4 Discussion of the workshop results . . . 234
9.4 Implications of the workshop results for using HARMOS . . . 235
9.5 Conclusions about the usefulness of the HARMOS DSS . . . 236
References . . . 237

**IV Epilogue 241**

**10 Answering the Research Questions 245**
10.1 Research Question 1 . . . 246
10.2 Research Question 2 . . . 247
10.3 Research Question 3 . . . 247
10.4 Research Question 4 . . . 248
10.5 Research Question 5 . . . 248
References . . . 249

**11 Next Steps and Reflection 251**
11.1 Next Steps . . . 251
11.1.1 Growing the HARMOS DSS . . . 252
11.1.2 Adopting agile development . . . 254
11.2 Reflection . . . 255
11.2.1 Involvement in other DSS projects . . . 255
11.2.2 Other applications for the HARMOS DSS . . . 256
11.2.3 Learning approach to software engineering . . . 256
11.2.4 Changes to our mental model . . . 256
References . . . 259

**V Appendix on the HARMOS Graphical User Interface 263**

**A Graphical User Interface 265**
A.1 Overview of the Graphical User Interface . . . 265
A.1.1 Components . . . 265
A.1.2 Menu structure . . . 266
A.2 Study Manager . . . 268
A.3 Calibrator . . . 270
A.4 Scenario Builder . . . 271
A.5 Strategy Builder . . . 273
A.6 Strategy Evaluator . . . 274

A.7 Strategy Comparator . . . . . 277
A.8 Summary and Conclusion . . . . . 277
References . . . . . 278

**Summary** **281**

**Samenvatting** **297**

**About the author** **315**

**TRAIL Thesis Series** **319**

# List of Figures


1.1 The airport conceptualized as a socio-technical system . . . . . 3
1.2 The MOKA Life Cycle . . . . . 11
1.3 Schematic overview of the research . . . . . 14

2.1 The trade-off between economic and societal performance . . . . . 29
2.2 Current planning: potential conflicts and a huge coordination effort. 36

3.1 The airport described from a technical perspective . . . . . 45
3.2 Primary runway configurations used at AAS . . . . . 48
3.3 Different terminal designs. . . . . 52
(a) Linear design . . . . . 52
(b) Pier finger design . . . . . 52
(c) Pier satellite design . . . . . 52
3.4 Passenger handling processes. Source: Kohse (2003) . . . . . 53
3.5 Expected waiting time in queue with increasing demand . . . . . 55
3.6 The need for a comprehensive view . . . . . 67

4.1 Level of detail and aggregation . . . . . 76
4.2 Capacity and delay analysis tools . . . . . 77
4.3 The OPAL architecture . . . . . 83
4.4 The SPADE workflow . . . . . 84
4.5 The Supporting Platform for Airport Decisionmaking and Efficiency Analysis (SPADE) architecture . . . . . 85
4.6 The ABS architecture . . . . . 86
4.7 Decisionmaking levels and support . . . . . 89

5.1 Added value potential as a function of the planning interval. . . . . 105
5.2 HARMOS—bringing people together. . . . . 108

5.3 The policy analysis framework . . . 111
5.4 The policy analysis process . . . 113
5.5 Roles of the people involved and their information. . . . 119
5.6 Generic design of a Decision Support System (DSS). . . . 124
5.7 The DSS development process. . . . 124
5.8 An example of a (limited) Domain Model for an airport. . . . 126
5.9 Iterative software development process. . . . 128

6.1 Overlapping areas of domain, business, and technology aspects. . . . 141
6.2 Screenshot of the Boa Constructor Integrated Development Environment . . . 143
6.3 Logical view of the Holistic Airport Resource Management and Optimization System (HARMOS) architecture. . . . 144
6.4 Functional view of the HARMOS architecture. . . . 150

7.1 Package diagram presenting the core classes of the Domain Model . 170
7.2 Activity diagram showing the HARMOS workflow . . . 171
7.3 Class diagram showing the classes within the study module . . . 173
7.4 Classes within the system model module . . . 179
7.5 Class diagram for the external factor module . . . 182
7.6 The Traffic Demand class . . . 185
7.7 Classes within the strategy module . . . 186
7.8 The Operational Plan class . . . 189
7.9 Class diagram for the outcome of interest module . . . 191
7.10 Classes within the performance analysis module . . . 193

8.1 Multi-stakeholder Context for Amsterdam Airport Schiphol . . . 204
8.2 Strategy Evaluator providing an integral view on airport performance 212

11.1 The evolution of policy analysis. Source: Davis *et al.* (2005). . . . 259

A.1 The panels of the Study Manager . . . 269
(a) Study Overview Panel . . . 269
(b) Decisionmaking Context Panel . . . 269
A.2 The Specify System Characteristics Panel of the Calibrator . . . 271
A.3 The Scenario Builder . . . 272
A.4 The Strategy Builder . . . 274
A.5 Two panels of the Strategy Evaluator . . . 276
(a) Overview Panel . . . 276
(b) Noise Analysis Panel . . . 276
A.6 The Strategy Comparator . . . 278

# List of Tables


2.1 Approaches versus Problem Areas . . . . . 34

3.1 Aspects of environmental capacity . . . . . 63

5.1 An example scorecard for comparing strategies . . . . . 117
5.2 Examples of external factors . . . . . 120
5.3 Examples of strategies. . . . . 121
5.4 Examples of system elements. . . . . 121
5.5 Examples of outcomes of interest and outcome indicators. . . . . 122

6.1 Actor-goal list . . . . . 149

7.1 Operations of the Study class . . . . . 174
7.2 Operations of the Context class . . . . . 175
7.3 Operations of the Case class . . . . . 176
7.4 Operations of the RunwaySystem class . . . . . 181
7.5 Operations of the Scenario class . . . . . 184
7.6 Operations of the Strategy class . . . . . 189
7.7 Computational services provided by the Analysis Service . . . . . 194
7.8 Realization of the HARMOS functionality . . . . . 198

8.1 Specific problems within the three problem areas . . . . . 207
8.2 Master Planning versus HARMOS' functionality. . . . . 213
8.3 How HARMOS addresses the problems in each of the problem areas . 215

# List of Acronyms

| | |
|---|---|
| **AA** | American Airlines |
| **AAS** | Amsterdam Airport Schiphol |
| **ABS** | Airport Business Suite |
| **AC** | Advisory Circular |
| **ACC** | Area Control Center |
| **ACI** | Airport Council International |
| **AEDT** | Aviation Environmental Design Tool |
| **AIP** | Aeronautical Information Publication |
| **AIXM** | Aeronautical Information Exchange Model |
| **ALP** | Airport Layout Plan |
| **ANSP** | Air Navigation Service Provider |
| **APM** | Automated People Mover |
| **APMT** | Aviation Environmental Portfolio Management Tool |
| **APU** | Auxiliary Power Unit |
| **A-SMGCS** | Advanced Surface Movement Guidance and Control Systems |
| **ATC** | Air Traffic Control |
| **ATM** | Air Traffic Management |
| **AUP** | Agile Unified Process |
| **BDUF** | Big Design Up Front |
| **BaU** | Business as Usual |
| **CAEP** | Committee on Aviation Environmental Protection |
| **CAMACA** | Commonly Agreed Methodology for Airside Capacity Assessment |
| **CBA** | Cost Benefit Analysis |
| **CBM** | Cost Benefit Model |
| **CDA** | Continuous Descent Approach |
| **CDE** | Collaborative Development Environment |
| **CDTI** | Cockpit Display of Traffic Information |
| **CROS** | Commissie Regionaal Overleg Schiphol |

| | |
|---|---|
| **CSR** | Corporate Social Responsibility |
| **CTAS** | Central TRACON Automation System |
| **DA** | Decision Advisor |
| **DADC** | Delft Airport Development Centre |
| **DBMS** | Database Management System |
| **DCA** | Delft Center for Aviation |
| **DDD** | Domain Driven Design |
| **DE** | Decision Advisor |
| **DFW** | Dallas Forth Worth |
| **DGMS** | Dialogue Generation Management System |
| **DIA** | Denver International Airport |
| **DM** | Decision Maker |
| **DSS** | Decision Support System |
| **DSP** | Dynamic Strategic Planning |
| **EC** | European Commission |
| **EDMS** | Emissions and Dispersion Modeling System |
| **EIA** | Environmental Impact Statement |
| **EUP** | Enterprise Unified Process |
| **FAA** | Federal Aviation Administration |
| **FP** | Framework Program |
| **GA** | General Aviation |
| **GDSS** | Group Decision Support System |
| **GIS** | Geographic Information System |
| **GSE** | Ground Support Equipment |
| **GUI** | Graphical User Interface |
| **HARMOS** | Holistic Airport Resource Management and Optimization System |
| **IATA** | International Air Transport Association |
| **ICAO** | International Civil Aviation Organization |
| **IDE** | Integrated Development Environment |
| **IFR** | Instrument Flight Rules |
| **INM** | Integrated Noise Model |
| **IOC** | Initial Operational Capability Milestone |
| **IP** | Iteration Plan |
| **IPO** | Initial Public Offering |
| **IT** | Information Technology |
| **J2EE** | Java 2 Enterprise Edition |
| **KBE** | Knowledge Based Engineering |
| **KLM** | Royal Dutch Airlines |
| **LAX** | Los Angeles International Airport |
| **LCC** | Low Cost Carrier |
| **LCO** | Lifecycle Objective Milestone |
| **LCA** | Lifecycle Architecture Milestone |

| | |
|---|---|
| **LTPA** | Long Term Policy Analysis |
| **LVNL** | Air Traffic Control the Netherlands |
| **MACAD** | Mantea Airfield Capacity and Delay |
| **MBMS** | Model Base Management System |
| **MIS** | Management Information System |
| **MLS** | Microwave Landing System |
| **MS** | Management Science |
| **MSS** | Main Succes Scenario |
| **NAP** | Noise Abatement Procedure |
| **NATS** | National Air Traffic Services |
| **NGO** | Non Governmental Organization |
| **OAG** | Official Airline Guide |
| **ODSS** | Organizational Decision Support System |
| **OPAL** | Optimization Platform for Airports, including Landside |
| **OPTAS** | Optimization of Airport Systems |
| **OO** | Object Orientation |
| **OOL** | Object Oriented Language |
| **OR** | Operations Research |
| **PAF** | Policy Analysis Framework |
| **PMIS** | Predictive Management Information System |
| **PNID** | Precision Navigation Instrument Departure |
| **PoC** | Proof of Concept |
| **PR** | Product Release Milestone |
| **PRAS** | Preferential Runway Advisory System |
| **PSZ** | Public Safety Zone |
| **RC** | Research Question |
| **RDBMS** | Relational DataBase Management System |
| **RNAV** | Area Navigation |
| **ROT** | Runway Occupancy Time |
| **RUP** | Rational Unified Process |
| **SA** | Software Architecture |
| **SAE** | Society of Automotive Engineers |
| **SAD** | Software Architecture Document |
| **SD** | System Dynamics |
| **SDLC** | System Development Life Cycle |
| **SDP** | Software Development Plan |
| **SID** | Standard Instrument Departure |
| **SLAM** | Simple Landside Aggregate Model |
| **SPADE** | Supporting Platform for Airport Decisionmaking and Efficiency Analysis |
| **SS** | Supplementary Specification |
| **STAR** | Standard Arrival Route |

| | |
|---|---|
| **SuD** | System under Description |
| **SD** | System Dynamics |
| **SWOT** | Strengths, Weaknesses, Opportunities, Threats |
| **TAAM** | Total Airspace and Airport Modeler |
| **TAPE** | Total Airport Performance Evaluation |
| **TMA** | Terminal Maneuvering Area |
| **UCM** | Use Case Model |
| **UFACM** | Upgraded FAA Airfield Capacity Model |
| **UML** | Unified Modeling Language |
| **VMC** | Visual Meteorological Conditions |
| **WHO** | World Health Organization |

CHAPTER 1

# Introduction

> True knowledge exists in knowing that you know nothing.
>
> SOCRATES

The history of powered flight over the past 100 years has been one of constant change: it took off after decades of empirical research, continued to be developed by trial and error, was accelerated by World War I, became more and more a means of mass transportation after World War II, and now has become a force that moves the planet. Airports are the elements of the aviation system that provide the ground infrastructure that is required for enabling organized flight across the globe.

Today, the aviation industry is in the midst of rapid change (Stelter *et al.*, 2004), stimulated by both internal forces (e.g. airline mergers and low cost carriers) and external forces (e.g. terrorist threats and environmental regulations). Airports have been and are constantly affected by these changes, which force their operators to adapt accordingly. Looking at airport developments in retrospect shows that adapting is not always easy.

Privatization and liberalization put pressure on airport decisionmaking: opportunities have to be seized and threats dealt with quicker than ever before. Merely trying to keep pace with growing travel demand is not enough. Airport planners and decisionmakers have to anticipate changes to their environment and come up with strategies for mitigating the adverse effects of the airport operation that are satisfactory to their stakeholders (e.g. communities, airlines, governments). Doing this successfully is difficult. Many airport strategic plans fail to deliver their promise and there is growing opposition from an increasing number of stakeholders against airport expansion plans.

We intend to address these issues through an in depth investigation into airport strategic planning with the purpose of identifying what is needed in terms of *decision support*.

The content of this introduction is as follows. Airport strategic planning is introduced in Section 1.1. The problems with current airport strategic planning are identified in Section 1.2. The motivation for this research is given in Section 1.3, followed by the research questions in Section 1.4. Section 1.5 introduces the way we present the content of this research and Section 1.6 discusses the scope and limitations.This chapter is concluded with an outline of the dissertation in Section 1.7.

## 1.1 AIRPORT STRATEGIC PLANNING

The term airport strategic planning is used by many authors in different contexts (Janic, 2005; de Neufville and Odoni, 2003; Zografos, van Eenige, and Valdes, 2005), but is hardly ever defined[1]. From an airport management perspective, Wells and Young provide the following definition:

> Strategic planning is the activity that encompasses all other planning activities [facility, economic, financial, organizational, and environmental planning] into a coordinated effort to maximize the future potential of the airport to the community (Wells and Young, 2004, p.368).

This definition does not imply a *specific approach* to airport strategic planning. There are many different ways to coordinate an all encompassing planning effort with the intention to maximize the future potential of an airport. Besides that, by whom and how should the future potential of an airport be defined? The airport operator, but also each of the airport stakeholders defines the potential of the airport differently, because they have different *value systems* and *interests*. Within such a multi-actor or multi-stakeholder decisionmaking and planning context, different perceptions of the problem are likely to exist. We are very aware of this (and deal with it later), but for descriptive purposes a generalized problem situation is used for the moment.

An airport operator has to find an appropriate match between capacity and demand, given a number of constraints (e.g. environmental and financial). An airport has to be managed and planned such that demand for services matches

[1]The need to better understand the strategic planning concept has also been recognized by the United States Transportation Research Board (TRB). The call for a 'Guidebook for Strategic Planning in the Airport Industry' can be found at `http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=143`. The project was awarded to Ricondo & Associates, who produced ACRP Report 20 'Strategic Planning in the Airport Industry'.

the capacity of the infrastructure, not only in the short term but also in the long term. At the same time, the airport operator has to manage the economic, environmental, and land-use effects of the current and future airport operation.

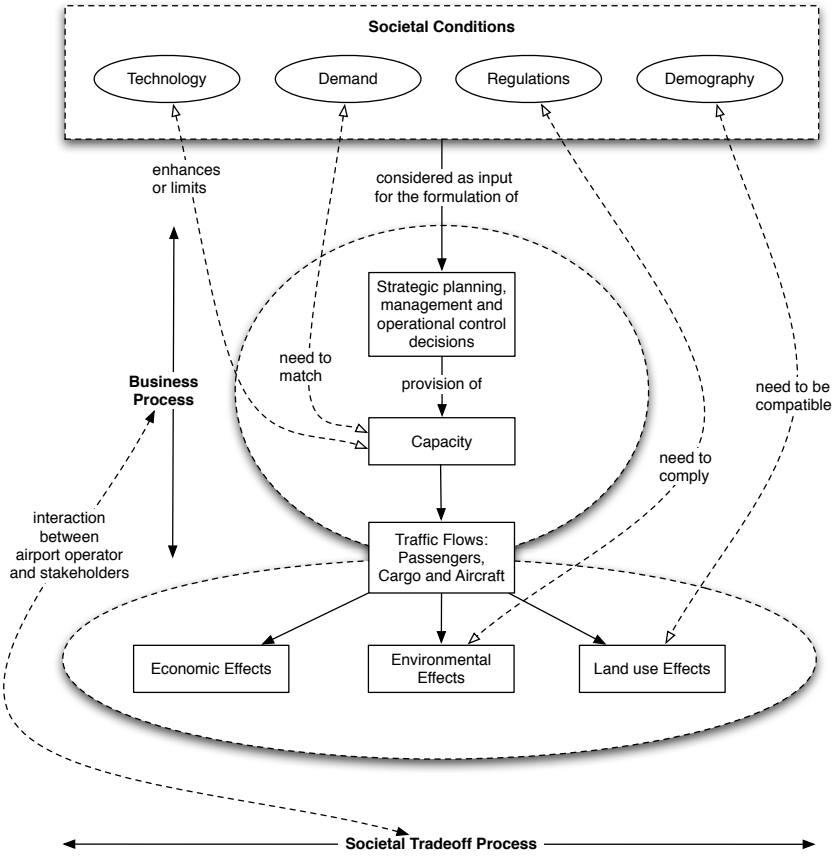


Figure 1.1: The airport conceptualized as a socio-technical system. Source: adapted from Keur and Walker (2003).

Figure 1.1 illustrates this problem situation, conceptualizing the airport as a *socio-technical* system. An airport has a finite capacity, which should be matched with demand. If capacity is below demand, the users of an airport incur high costs because of delays. If capacity is much higher than demand, the airport operator faces substantial costs of maintaining facilities that are underutilized. In both cases, passenger, cargo, and aircraft flows are created. Processing these flows generates revenues for the airport operator, and provides connections for

passengers and freight. Also other impacts, such as economic impacts (e.g. employment), and environmental impacts (e.g. degradation of air quality, increase in noise levels) are produced. Additionally, the presence of an airport impacts land-use planning in a wide area surrounding an airport (e.g. because of safety zones, noise zones and buffers). We call these impacts *social* impacts because they affect *society* at large and many specific actors in particular, and usually result in strong public and policy debate.

There are also societal conditions that develop (shown at the top of Figure 1.1). Regulations are implemented to mitigate environmental impacts. Technology improves or lags behind, which either enhances or limits airport capacity. Demographic developments in the airport region should be compatible with land-use patterns. These social conditions are to a more or lesser extent considered by an airport operator when formulating strategies.

The airport operator deals with the problem situation by controlling the airport's short-term operations (through operational control decisions), allocating and managing resources on the mid-term (through management control decisions), and formulating and implementing strategies for the long-term (through strategic planning decisions). Each of these activities are part of the *business process*, which is a process internal to the airport.

The potential strategies of an airport operator (e.g. building a new runway, or not accommodating specific demand such as low cost airlines) affect the stakeholders quite differently, which is why, in addition to business considerations, a *societal tradeoff process* is needed (or emerges) to determine the strategies that are satisfactory to most, but preferably all stakeholders.

The business process must take into account the societal trade-off process, which goes on simultaneously. This process is external to the airport. The interaction between the business process and the societal trade-off process is stronger for decisions that affect long-term performance, i.e. the strategic planning decisions. The strong interaction clearly manifests itself whenever airport operators present their long-term development plans. Most of the time, these plans are publicly discussed and debated over an extended period among the airport operator and its stakeholders.

For example, public discussion about the future of Amsterdam Airport Schiphol seems to reignite every now and then, unfortunately without the emergence of a shared vision and strategies for its future (WRR, 2003, pp.96–103).

The description above makes clear that the 'problem' conceptualized in Figure 1.1 is a wicked problem (Rittel and Webber, 1973) or a social mess (Horn, 2001, following Ackoff (1974), who speaks of a mess). A wicked problem can not be solved. The problem situation can only be improved or re-solved time after time (Rittel and Webber, 1973, p.160), which is why planning needs to be a continuous, collaborative, and learning process among all stakeholders. The next section provides an in-depth analysis of this problem situation.

## 1.2 THE PROBLEMS WITH AIRPORT STRATEGIC PLANNING

The way airport strategic planning is currently undertaken leads to a number of different problems, which have been discussed by many scholars. Caves and Gosling (1999) provide a broad overview of the practice of airport planning around the world. Dempsey (1999) presents a global survey of airport developments, describing failures and successes related to airport planning. Based on a case study of Denver International Airport (DIA), Goetz and Szyliowicz (1997) conclude that decision making and planning theory should be revisited to better account for uncertainty and stakeholder interests. Examples of airport design mistakes and planning failures are frequently used as illustration by de Neufville and Odoni (2003).

We identified similar and additional problems. For the sake of discussing and addressing them, a division in three problem areas is used:

I. Lack of involvement of the stakeholders;
II. Inadequate approach for dealing with the future;
III. An inefficient problem solving process.

Each of these problem areas is discussed in more detail in the following sections.

### 1.2.1 Problem Area I: Lack of involvement of the stakeholders

Stakeholders are not meaningfully involved in the airport operator's planning process, which leads to the following problems.

**Exclusion of stakeholders or their concerns.** Stakeholder concerns are not taken into account or the stakeholders themselves are completely excluded from the planning process. This causes serious problems when an airport operator tries to implement its strategic plan. If some stakeholders feel that the plan for an airport's development does not satisfy their objectives, they will hamper the implementation of the strategy, through lack of commitment for executing the plan, legal actions and lobbying, among others. Numerous examples exist of (legal) actions, some of them very successful, from the excluded stakeholders to prevent a plan from becoming reality (BBC News, 2003; Caves and Gosling, 1999; Cidell, 2003; Dempsey, 1999; Goetz and Szyliowicz, 1997).

**Conflicts.** Caves and Gosling (1999) explicitly mention that within airport planning studies there is a general failure to achieve a transparent balance in areas of competition, air transport, regional development, and local citizen's rights. This unbalance often lead to conflicts among the various stakeholders (Kolk and van der Veen, 2002; May and Hill, 2006; Soneryd, 2004). Stakeholders are likely to argue about results, assumptions, and the methodologies that were used during the planning process, either because they were not involved or they do not understand each other (or both).

Two examples of plans that faced major opposition and implementation delay are the plans for the new runways at Boston Logan Airport (proposed in 1973 and opened in 2006) and the so-called 'Polderbaan' at Amsterdam Airport Schiphol (proposed in the 1970s and opened in 2003).
So, current practice does not facilitate easy and comprehensive collaboration among the people involved in a planning study nor with the airport stakeholders.

### 1.2.2 Problem Area II: Inadequate approach for dealing with the future

The future is uncertain, and so is the future of aviation. Airport planning practice does not recognize this very well, which leads to the following problems.

**Single view of the future.** Many airport development plans are based on only a single view of the future. A single prediction of the future is used as the basis for determining which airport facilities are required. Such a 'predict-and-control' approach to airport planning is likely to produce a poorly performing plan, because it is very unlikely that the predicted future will also become the actual future. Although the disadvantages of forecasting have been already been put forward in the late 1970s (Ascher, 1978; Milch, 1976), forecasts are still widely used and misused. The warning from Ascher that 'the forecast is always wrong, which has been repeated by many others (Flyvbjerg, 2007; van der Heijden, 1999; de Neufville and Odoni, 2003) has not seriously been taken into consideration by airport planners.

**Lack of consideration of external factors.** The future that is considered is usually based on only a single trend extrapolation of demand. Other external factors, such as technology, regulations, and demographics, are not considered in detail, if at all. Besides the economic factors that drive traffic demand, other external factors should be considered. Technology (e.g. the introduction of the new A380 aircraft), regulations (e.g. more stringent noise standards), and demographics (e.g. regional housing and industry development), should be explicitly considered when thinking about the future, because they have an impact on the demand itself, the airport operations, and the airport's performance.

**Too few alternatives are analyzed.** It is apparent that a single view of the future through a demand forecast does not evoke *strategic thinking*. Only a short list of alternatives is usually considered—those that solely focus on accommodating predicted demand. Caves and Gosling (1999) as well as Bishop and Grayling (2003) report that the focus in planning studies is almost exclusively on provision of capacity to meet forecast demand. This lack of creativity can be explained by a choice bias—habit motivates the selection of an option because of its familiarity, which in turn is deemed to be more reliable (Davis, Kulick, and Egner, 2005, p.15). Groupthink

is another problem that constrains a thorough exploration of alternatives (van der Heijden, 1999, p.45), because decisionmakers stick to the current frame of thinking and way of doing things (Huys and Kroesen, 2007).

So, current practice inadequately addresses the uncertain future, leading to either severe congestion or excess capacity at airports, both of which are very costly (Karlsson, 2003; de Neufville and Odoni, 2003).

### 1.2.3 Problem Area III: Inefficient problem solving process

For organizational purposes, planning problems facing an airport operator are usually divided into smaller subproblems (related to e.g airport capacity and delay, noise and emissions, or finance). The results from the subproblems are later integrated to become part of the solution to the overall planning problem, which leads to the following problems.

**Inconsistencies.** The specific questions related to a particular planning problem are usually not on the table at the same time, and they may be on different tables within the organization, leading to inconsistent information, and contradictory assumptions. The risk of introducing inconsistencies is higher within large airport organizations, because different business units, departments, or external consultants are involved, who do not continuously keep each other informed of their progress, preliminary results, and findings.

**Lack of an integral view.** Often, people (or organizations) focusing on different aspects of the system work on different parts of the problem and its analysis, each using different models/tools, assumptions, and data. It is therefore difficult to produce a consistent, integrated set of results that can be used to assess the effect of changes to the airport system (Odoni *et al.*, 1997; SPADE Consortium, 2003; Walker *et al.*, 2003; Zografos *et al.*, 2005). An integral view of the airport's performance can be produced only by manually collecting, combining, and post-processing the individual results, which is very time consuming, and often leads to inconsistent results.

So, the airport strategic planning activity is inefficient in terms of time and resources. For example, the Master Plan for Los Angeles International Airport (LAX), which was agreed upon in 2006, took ten years to develop. Such a time-span for a Master Planning effort is more the rule than the exception.

## 1.3 Motivation for a decision support system

Currently, the airport Master Plan is the core artifact of airport planning. Master Planning was born out of the need to interact with existing land use planning processes and to justify investments (FAA, 1985). The Master Plan is *intended to be the strategy* for the development of the airport.

### 1.3.1 State of practice

Master Planning does, however, not provide an adequate way to deal with the uncertain future (Problem Area II). Involvement of the stakeholders (Problem Area I) is addressed somewhat better by the recent update of the Federal Aviation Administration's Advisory Circular (AC) on Master Planning (FAA, 2007). It is now strongly advised to identify and involve all stakeholders as early as possible within a Master Planning study.

Dynamic Strategic Planning (DSP) (de Neufville and Odoni, 2003) is a new approach to airport strategic planning that is well equipped to deal with the uncertain future (Problem Area II). In our opinion, it does not provide an adequate way to meaningfully involve the stakeholders in the planning process (Problem Area I). In an earlier paper, discussing DSP for technology policy, de Neufville assumes a fair negotiation process will take place among stakeholders after the plan is going public (de Neufville, 2000, p.7). DSP has been applied on a few occasions only (see for example: de Neufville, 1991).

So, the new guidelines on Master Planning and Dynamic Strategic Planning do not address all the problem areas.

### 1.3.2 State of the art

With respect to the problem solving process (Problem Area III), both Master Planning and DSP leave the use of various tools—to generate the relevant information for decisionmaking—up to the people involved in a particular strategic planning effort. We believe that this negatively affects the efficiency of strategic planning studies. Studies are not efficient because too much time is required for coordination of resources—people, data and information, tools.

Within a strategic planning study, one of the major tasks is to quickly and easily evaluate the effect on various airport performance aspects due to changes to the airport system and operation. Doing this manually, requires many tasks to be performed related to preparing data for the various tools, running and coordinating the use of these tools, and processing all of their outputs.

Such repetitive tasks are much better performed by a computer-based system, which led to many projects that focus on designing and building systems for airport performance analysis (see for example: SPADE consortium, 2004; Visser *et al.*, 2003; Zografos *et al.*, 2005). The focus of these projects is on integrating tools in a single computer-based system for airport performance analysis. So far, many of these systems have been developed—a detailed overview will be provided in Chapter 4. Practitioners do however not use them for their strategic planning.

### 1.3.3 Gap between decisionmaking needs and decision support

Dynamic Strategic Planning and the computer-based systems for airport performance analysis do not seem to directly satisfy the needs of planners and decisionmakers, since neither of them have been widely adopted by airport operators.

We believe that the lack of adoption is because both attempts to improve and support airport strategic planning address only one problem area that exists with airport strategic planning today. Dynamic Strategic Planning mainly focuses on the problem of dealing with the future (Problem Area II), while the computer-based systems focus on the problem of the efficiency of problem-solving (Problem Area III).

Our research will address all three problem areas concurrently, thereby closing the gap between the needs of decisionmakers and planners and the decision support.

The increasingly complex and dynamic set of circumstances in airport planning motivates the need for a DSS that offers systematic problem analysis and that supports multiple stakeholders addressing a range of planning problems that cannot be specified in advance.

The goal of this research is to find out how to better support airport strategic planning practice through a DSS. We use the definition of DSS by Turban (1995):

> An interactive, flexible, and adaptable computer-based information system, developed for supporting the solution of a non-structured management problem for improved decision making.

This definition implies that the support is about formulation and (quantitative) analysis of different courses of action (or strategies), so that these can be compared, and one or more can be selected for implementation.

## 1.4 RESEARCH QUESTIONS

The objective of this research is to address the three problem areas identified in Section 1.2 by a DSS that supports formulation, analysis, and interpretation of the problem situation presented in Section 1.1.

In order to meet this objective, we have formulated five research questions, presented below.

> **Research Question 1**: *How should the concept of strategic planning be understood within the airport decisionmaking and planning context?*
>
> **Research Question 2**: *What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?*
>
> **Research Question 3**: *How can airport strategic planning be supported through a DSS and how should the decision support system be designed?*
>
> **Research Question 4**: *How is the architecture to be implemented such that the DSS vision is realized and a solid foundation for growing the DSS into a business application is created?*
>
> **Research Question 5**: *How can a proof of concept and a proof of usefulness be provided?*

## 1.5 Presentation of the research

This research draws upon knowledge from various different fields, such as aeronautical engineering, policy analysis, software engineering and management science. In order to present how we captured and combined all this knowledge and used it to arrive at and implement our solution for decision support, we present the research through a framework from Knowledge Based Engineering (KBE).

We will use the Life Cycle from the MOKA framework (MOKA Consortium, 2000) as shown in Figure 1.2 for presenting the research. This is a lifecycle for KBE that provides a systematic and powerful approach to knowledge modeling in engineering. We use this life cycle to explicitly show how knowledge from various fields and disciplines is brought together in order to answer the research questions. The life cycle provides six stages for turning various sources of knowledge into use for engineering products. The six stages are:

1. Identify: study the industrial need and assess technical feasibility for a Knowledge Based Engineering application;
2. Justify: study the profitability, validate the scope, and analyze risks;
3. Capture: collect and structure raw knowledge;
4. Formalize: develop product and process models;
5. Package: develop application;
6. Activate: introduce, use, and maintain.

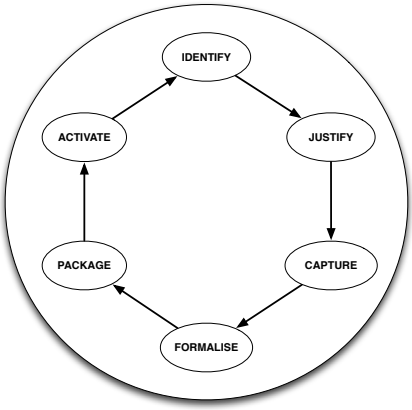


Figure 1.2: The MOKA Life Cycle

We use a customized version of these stages, as will be described when we present the outline of this dissertation in Figure 1.3. Before we provide the outline of the dissertation in Section 1.7, the research scope and limitations are presented in the next section.

## 1.6 Scope and limitations

This research is about strategic planning for single airports. Of course, airports may be components of multi-airport systems, and are interconnected in the air transport system and even the wider transport system. The fact that the airport is a node in the air transportation network will be taken into account by considering airline networks in terms of traffic demand.

Dealing with multiple decisionmakers and stakeholders brings complexity to defining strategic planning problems, comparing, and selecting strategies (among others). Researchers from a rationalist school might propose some innovative, mathematical method (e.g. multi-objective optimization) for comparing strategies that identifies the 'best' strategy. Actually, many DSSs have been developed around such methods (Weistroffer and Narula, 1997). We believe, however, that a good and acceptable strategy can only be formulated and implemented by facilitating *collaboration* among the airport operator and its stakeholders. An enabler for collaboration is the ability to openly discuss and challenge each other's vision, perception of the problem situation, objectives, and proposed strategies. We believe that no totally quantitative method can do that. We will therefore not look into quantitative methods for finding a best strategy.

This research is not done from a planning theory perspective, but more from a planning practice perspective. With respect to planning theory, we favor the theory of collaborative planning as proposed by Innes and Booher (2000). Their argument for such a theory is based on the fact that today's networked and information society is a complex system that requires collaboration to successfully adapt to its changing environment.

The type of strategies we will deal with are those strategies that directly change the airport system in terms of its infrastructure (e.g. building a new runway), operation (e.g. the introduction of advanced noise abatement procedures), and management (e.g. depeaking the annual demand). We will not consider generic strategies such as diversification, cost-cutting, mergers and acquisitions, and the like. Similarly, we will not look at so-called Grand Strategies, such as the Airport City strategy of Amsterdam Airport Schiphol.

This research project is not sponsored or directly linked to an airport operator or another specific organization that is involved in airport strategic planning. The DSS design will therefore be generic, providing the basic functionality to address a wide range of airport planning problems. Customization of the DSS will be needed for a specific airport operator and its stakeholders.

The DSS that results from this research effort is not the final product i.e. it is not a business application ready to be deployed and used by an airport operator and its stakeholders. Our DSS development effort is used to prove (design, implement, and test) an *architecture* for the DSS, not to develop the entire business application itself. In other words, this research provides a *proof of concept* and a limited *proof of usefulness* for the DSS, not a proof of value (see the fifth Research Question).

## 1.7 Outline of the dissertation

This introduction identified three problem areas with respect to airport strategic planning. The remainder of the text is divided into four parts, as shown in Figure 1.3.

Part I provides and *justifies* a broad perspective on airport strategic planning, an airport system, and decision support systems. Chapter 2 explores strategic planning in general and airport strategic planning in particular. As such, this chapter addresses Research Question 1: 'How should the concept of strategic planning be understood within the airport decisionmaking and planning context?' The airport as a socio-technical system, as shown in Figure 1.1, is described in more detail in Chapter 3. Chapter 4 describes and discusses past and current efforts to support airport planning with computer-based systems. So, this chapter addresses Research Question 2: 'What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?'

Part II *captures* and combines the knowledge from Part I into a vision and design for a decision support system for airport strategic planning. Chapter 5 investigates what is needed in terms of decision support and the DSS development process. Chapter 6 *formalizes* the collected knowledge by turning the vision into an architectural design of the DSS. So, this part provides the answer to Research Question 3: 'How can airport strategic planning be supported through a DSS and how should the decision support system be designed?'

Part III describes the implementation of the architecture of the DSS. Chapter 7 presents the implementation of the Domain Model—being the heart of the DSS, which *packages* domain knowledge into an executable version of the architecture of the DSS. As such, this chapter addresses Research Question 4: 'How is the architecture to be implemented such that the DSS requirements are realized and a solid foundation for growing HARMOS into a business application is created?' A proof of concept is provided in Chapter 8 by showing how the DSS is *used* for addressing specific problems in each of the three problem areas identified in Section 1.2. Chapter 9 provides a proof of usefulness by describing feedback on the DSS from potential users. So, these chapters address Research Question 5: 'How can a proof of concept and a proof of usefulness be provided?'

Part IV is the epilogue of this dissertation. Chapter 10 summarizes the answers to the research questions and draws conclusions. The next steps and a reflection are presented in Chapter 11. The appendices include a description of the components of the Graphical User Interface.

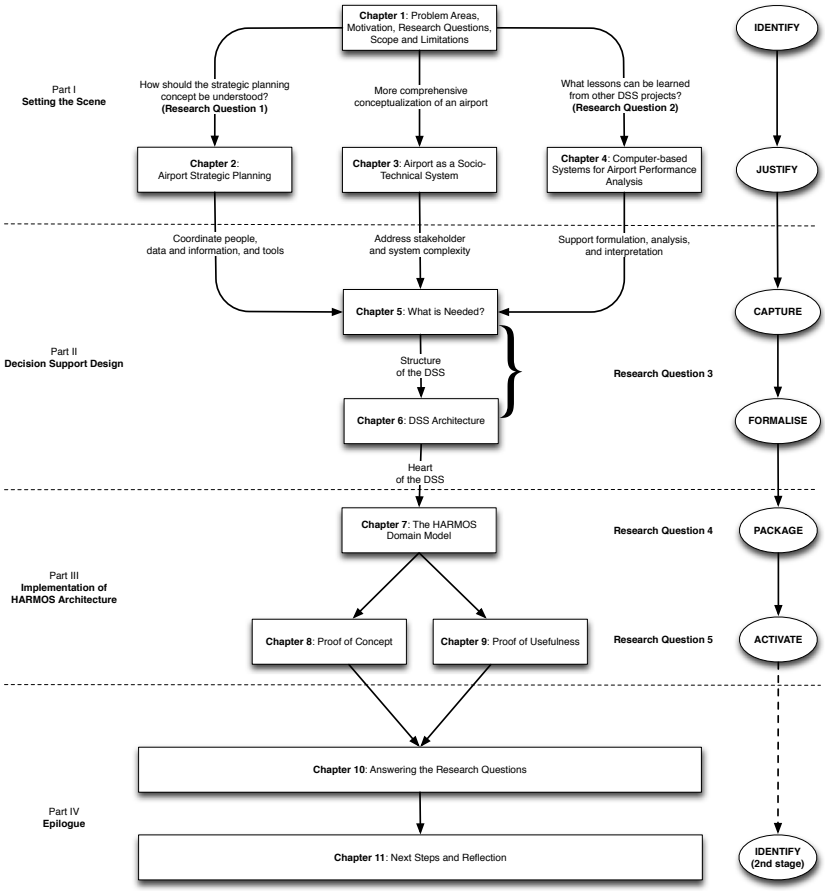


Figure 1.3: Schematic overview of the research

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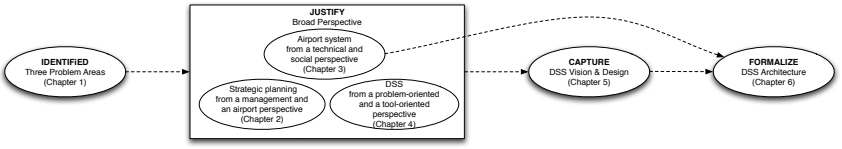
# Part I

# Broad Perspective

# Overview Part I




This part of the dissertation provides a *justification* for taking a broad perspective on respectively airport strategic planning (Chapter 2), an airport system (Chapter 3), and DSS development (Chapter 4). Each of the chapters structures knowledge from various sources, so that we can use it to envision and design decision support in Part II.

Chapter 2 provides the answer to Research Question 1: 'How should the concept of strategic planning be understood within the airport decisionmaking and planning context?'.

Chapter 3 structures knowledge about an airport system by describing it from a technical and a social perspective. This broad description of an airport system is input for architectural design (Chapter 6) and implementation (Chapter 7).

One particular area of research that intends to address the problems with airport strategic planning is the design of computer-based systems for airport performance analysis. Past and current initiatives in this research area are reviewed in Chapter 4. A thorough analysis of these computer-based systems is provided as well. So, at the end of this chapter we are able to provide an answer to the Research Question 2: 'What lessons can be learned from past and current efforts to build Decision Support Systems for airport strategic planning?'.

CHAPTER 2

# Airport Strategic Planning

> Perception is strong and sight weak. In strategy it is important to see distant things as if they were close and to take a distanced view of close things.
>
> *Book of Five Rings*
> MIYAMOTO MUSASHI

The introduction to this dissertation pointed out there is not a common definition for airport strategic planning. We decided to adopt the definition by Wells and Young (2004, p.368), which is a rather broad definition. Their definition does not imply a particular approach to strategic planning.

In order to better understand the concept of strategic planning in general, literature from the field of management science is reviewed first in Section 2.1. Section 2.2 describes different approaches to airport strategic planning. The extent to which the different approaches to airport strategic planning address the three problem areas (Section 1.2) is discussed in Section 2.3. The resources involved in a strategic planning effort are described in more detail in Section 2.4. A brief summary of this chapter and a conclusion is given in Section 2.5.

## 2.1 STRATEGIC PLANNING

Strategic planning is a well-known concept, used in many different contexts within the private as well as the public sector. Strategy formulation or making in general and strategic planning as a concept for developing strategies is a dedicated field of study in management science. In order to improve our understanding of the strategic planning concept, the next four sections respectively discuss a

definition of strategic planning, its history, schools of strategic management, and strategic thinking. Section 2.1.5 is about Corporate Social Responsibility (CSR).

### 2.1.1 Definition

It is impossible to provide a single definition for strategic planning, or strategy for that matter (Hafsi and Thomas, 2005), because the term strategic planning is used in so many different contexts by (management) scientists as well as practitioners. Strategic planning has been developed in the private sector, but the public and nonprofit sectors have adopted the concept as well. Bryson (1995, p.4–5), one of the authors that discusses strategic planning in the latter sectors, defines strategic planning as a broad concept:

> A disciplined effort to produce fundamental decisions and actions that shape and guide what an organization (or other entity) is, what it does, and why it does it.

Bryson (2004) stresses that strategic planning should be viewed as a set of concepts, procedures, and tools that must be carefully *tailored to a specific context* if desirable outcomes are to be achieved.

Designing an organization's approach to strategic planning needs to consider the way strategies (fundamental decisions) are developed and implemented (actions). The *identity* (what it is), the *purpose* (what it does) and the *values* (why it does it) of an organization also need to be considered[1].

This definition implies that there is not a single approach to strategic planning. Many approaches can be defined. Among such approaches are the systems for general management that will be discussed in the next section. Other approaches are the Harvard Policy Model, stakeholder management approaches, strategic issues management approaches, logical incrementalism, portfolio models, and competitive analysis (Bryson, 2004). In practice, strategic planning is usually a hybrid of a number of these and even other approaches.

### 2.1.2 History

In the 1960s, the concept of strategic planning was formulated as a 'system for general management' by scholars such as Ansoff (1986) and others. They demonstrated the need to match business opportunities with organizational resources and illustrated the usefulness of strategic plans. At the same time, the strategic planning concept was introduced in companies, most notably at General Electric (Vaghefi and Huellmantel, 1998). Strategic planning provided a framework for systematically thinking about the future of the company.

[1]The identity—what an organization is or should become—is usually expressed in a vision statement. The purpose of an organization is often expressed in a mission statement. It is also more and more common for organizations to publish the core values of the organization.

Ever since, strategic planning has been the subject of strong academic debate (Ansoff, 1985, 1994; Grant, 2003; Mintzberg, 1994a), mainly questioning whether or not strategic planning contributes to the success of a company (Rudd *et al.*, 2008). Some authors claim strategic planning helps in creating value (Glaister and Falshaw, 1999); others claim that it could actually strangle a company (Mintzberg, 1994b).

Very often, strategic planning efforts were failures. The reason for their lack of succes was the fact that many strategic planning systems that were 'installed' *replaced* thinking instead of *supporting* it. Strategic planning, therefore, did not contribute to *strategic thinking*, sometimes resulting in dramatic negative effects on company performance (Mintzberg, 1994a; Porter, 1987). Elaborate methods for *analysis* were developed, impeding decisionmaking and leaving no room for true strategic insights (Wilson, 1994).

The criticism made towards strategic planning seems to be directed more to specific approaches than to the concept itself. At General Electric, the concept of strategic planning is reported to work well because the approach to strategic planning has been *tailored* to the internal structure of the company and the ever changing market conditions by the leaders of the company (Ocasio and Joseph, 2008; Vaghefi and Huellmantel, 1998). So, continuous tailoring of the approach to strategic planning is essential (Lenz, 1987).

### 2.1.3 Schools of strategic management

From the previous section, it is clear that there is a lot of ambiguity about what strategic planning is and whether it works or not. Mintzberg, Ahlstrand, and Lampel (1998) clearly articulate that there is much confusion in the field of strategy/strategic management:

> We are the blind people and strategy formation is our elephant. Since no one has had the vision to see the entire beast, everyone has grabbed hold of some part or other and 'railed on in utter ignorance' about the rest. We certainly do not get an elephant by adding up its parts. An elephant is more than that. Yet to comprehend the whole we also need to understand the parts (Mintzberg, Ahlstrand, and Lampel, 1998, p.3, referring to the fable '*The Blind Men and the Elephant*' by Godfrey Saxe (1816-1887)).

In the overview work just cited, Mintzberg, Ahlstrand, and Lampel describe the field of strategy by describing ten schools of thought in strategic management. These schools are:

**The Design School.** Strategy formation as a process of conception. This school proposes a model of strategy making that tries to match the capabilities

(i.e. Strengths and Weaknesses—the letter S and W of SWOT) of an organization with its environment (i.e. the Opportunities and Threats—the letter O and T of SWOT). Strategy formation is seen as a deliberate, rational process.

**The Planning School.** Strategy formation as a formal process. This school basically takes the SWOT Model and divides it into specific steps, each accompanied with many checklists and techniques. Special attention is given to setting objectives at the start of the planning effort and the elaboration of budgets and operating plans at the end of the planning effort. Such formal strategic planning is not how we look at strategic planning as mentioned already in Section 2.1.1.

**The Positioning School.** Strategy formation as an analytical process. Strategies are seen as generic, identifiable positions (e.g. product differentiation and focused market scope) in the marketplace, which is economic and competitive. Analysts carry out calculations that provide insights about selecting these positions so that managers can make a choice.

**The Entrepreneurial School.** Strategy formation as a visionary process. The concept of vision is used as a mental representation of strategy in the head of the leader. A vision is usually an image as opposed to a fully articulated plan. Strategy is thus flexible and can be adapted to the leader's experiences.

**The Cognitive School.** Strategy formation as a mental process. This school 'investigates' the mind of the strategist in order to understand strategic vision and strategy formation under different circumstances. This school heavily draws on the work by Simon (2004), who introduced the concept of bounded rationality: Due to the large and complex world, decision making becomes a vain effort to be rational, because of the limited information-processing capacities of the human brain.

**The Learning School.** Strategy formation as an emergent process. This school points out that strategy emerges as people learn about a situation as well as their organization's capability to deal with it. An important contribution to this school is logical incrementalism, which is a characterization of the strategy making process by Quinn (1980). Continuing the type of work by Lindblom (1995)—who completely abandoned the idea of rationalism and instead viewed policy and strategy making as 'a science of muddling through'—Quinn found that firms perform better than merely 'muddling through' if they had a vision or dream (Davis *et al.*, 2005, p.35).

**The Power School.** Strategy formation as a process of negotiation. This school sees strategy as a process of influence, and the use of power and politics to negotiate strategies favorable to particular interests.

**The Cultural School.** Strategy formation as a collective process. This school sees strategy formation as a process rooted in the social force of culture. It started off to find the underlying reasons for the success of Japanese corporations.

**The Environmental School.** Strategy formation as a reactive process. This school sees the environment of an organization as the actor driving change. The organization is passive and reacts to the set of forces outside the organization.

**The Configuration School.** Strategy formation as a process of transformation. This school has two sides: Configuration, describing states of the organization and its surrounding context; and Transformation, describing strategy making as transformation from one state to another. As such this school provides a way to describe the strategy making process (according to any of the other schools) within a well defined context.

The models and systems for strategic planning originate from the Planning School. The focus on formalization in this school leads to a strategy making process that does however not result in new strategies itself, but merely in formal ways of controlling existing strategies (Mintzberg *et al.*, 1998, p.57 & 75).

The schools will not be further discussed here. They have been mentioned in order to show that there are many ways of looking at strategy making. In order to understand strategy making in the real world, appreciation and adoption of the ideas, principles, methods, and explanations provided by each of the schools is needed.

Our choice for adopting Bryson's definition is that strategic planning is defined as a broad concept, instead of defining it solely as a general management system. Bryson's definition is comprehensive and cannot be exclusively associated with any of the schools of thought. The definition draws upon ideas and principles from many of the schools. The first part of the definition, i.e. 'disciplined effort to produce fundamental decisions...' relates to the intentions of the design, planning, and positioning schools to deliberately make strategy. The inclusion of 'actions' in the definition acknowledges the emergence of strategies from within organizations as articulated by the learning school. The final part of the definition, i.e. 'shape and guide what an organization is, what it does, and why it does it' draws upon ideas from the entrepreneurial, cultural, and configuration schools.

### 2.1.4 Strategic thinking

Besides realizing that different schools of thought exist, it is useful to distinguish strategic planning from strategic thinking. Such a distinction is hardly ever made in the literature or by practitioners themselves (Bonn, 2001). Heracleous (1998) even reports that the lack of success with strategic planning led to pretty drastic

conclusions: some scholars concluded that there is no place for planning in organisations and strategic planning should be completely abandoned in favor of strategic thinking.

According to Sloan (2006, p.24) that is a major misunderstanding: strategic planning and strategic thinking are two sides of the same coin. They are just related to different modes of thinking. Graetz (2002) points out that strategic thinking is related to divergent, creative, or intuitive thinking; strategic planning is related to convergent, systematic, or rational thinking. These two modes are complementary and both are needed. So, within organizations it has to be ensured that there is a balance between strategic planning and strategic thinking (Sloan, 2006, p.226).

The focus of this dissertation is mainly about supporting the strategic planning process. However, it is strategic thinking that provides the strategies to be assessed through strategic planning in a systematic and rational way. So, we will frequently refer to this strategic thinking process creating and recreating the strategies that are to be assessed through the strategic planning process that we intend to support through a DSS. Strategic thinking is essential for any organization that wants to create sustainable, adaptable, and innovative strategies on a continual basis Sloan (2006).

Another aspect that is crucial for an organization's survivability is being socially responsible. If an organization is truly socially responsible, strategic thinking directly benefits from this, because such an organization looks at more that its own economic performance (Burke and Logsdon, 1996; de Geus, 1998). Being able to see things differently or having a broad perspective is one of the five elements that is required for good strategic thinking (Sloan, 2006, p.202 & 208). Therefore, social corporate responsibility is discussed in the next section.

### 2.1.5 Social corporate responsibility

Historically, airports have been developed as public utilities that are parts of transportation networks, with the *purpose* to provide an accessible and affordable means of air transportation to the public. Although airports are progressively being privatized, an airport operator should remain true to the airport's original purpose. This is why we are concerned about the Corporate Social Responsibility (Hardjono and van Marrewijk, 2001) of airport operators. If airport operators do not take their Corporate Social Responsibility seriously, no DSS or any other approach will be able to improve the strategic planning practice.

Figure 2.1 illustrates the relationship between economic and social performance of a company (Achleitner, Ansoff, and Haskins, 1983). The trends presented obviously apply to airport operators as well. Airports are intended to perform both a social, as well as an economic function. Throughout aviation

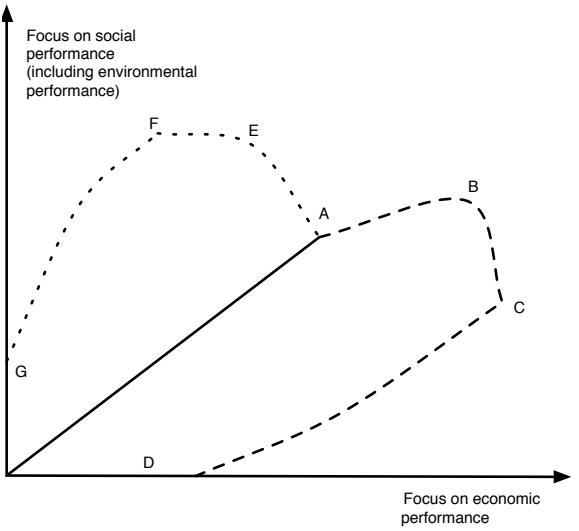



Figure 2.1: The trade-off between economic and societal performance. Source: Achleitner *et al.* (1983).

history, most airports have fulfilled both functions in mutual accord, as shown by the solid line in Figure 2.1.

As long as airport operators stay up to point A, both profit and social responsiveness can be increased. The lower, dashed curve shows what happens if an airport operator would single-mindedly pursue profit maximization. Initially, it is possible to increase profitability, but beyond point B its societal performance will significantly be degraded (e.g. because of inadequate respect for health and environmental regulations). Pushing for even greater profitability eventually results in an active and violent reaction by society against the violation of societal norms, which ultimately jeopardizes economic efficiency (point D).

We hypothesize that some airport operators have already arrived at or at least have been at point B or C, given the strong opposition against airport expansion. The upper, dotted curve shows the situation in which an airport operator is mainly focused on providing its public service, no matter what the cost. Initially, societal performance can be improved at the expense of economic performance (point E). Beyond point F, economic performance is degraded to such an extent that it will no longer be possible to maintain adequate social performance (point G).

Increasing privatization causes airport operators to move toward a more business-oriented management approach. Airport operators have indeed become

more entrepreneurial in the development of their business, which is not limited anymore to facilitating aircraft operations at their airfield (Jarach, 2001). The Airport City concept, developed by the Schiphol Group, is a good example of the result of *entrepreneurial* strategic planning (Schiphol Group, 2006).

Such an approach to strategic planning is responsive to the market, but only focuses on the products and services offered to the clients of the airport operator (Freathy, 2004; Freathy and O'Connel, 1999). There appears to be no explicit attention in the strategy formation process to the externalities (e.g. environmental impacts) of the airport operator's activities. Of course, the externalities are addressed by airport operators, but many times as an afterthought to comply with local, national, or international regulations.

It is therefore not advisable to just 'copy' an entrepreneurial approach to strategic planning/management that works in other sectors. Managing and planning an airport is fundamentally different from developing, for example, new consumer products. Obviously, there are similarities when the passenger perspective is considered. Passengers are the direct customers of an airport and hence a primary source of income. Developing new services that meet passenger needs (e.g. sport facilities, entertainment) makes perfect sense, as they are essential for creating a competitive advantage.

An approach to strategic planning for airports should, however, be more holistic. It should not only focus on the firm's products for their primary customers like passengers and airlines. Proper attention should be given to its 'by-products' as well. Since an airport is a very large system, occupying a vast amount of land and producing significant environmental impacts, there are many stakeholders (see also Figure 1.1). The airport operator needs to make sure that it offers a product mix, including the externalities an airport produces, that satisfies all stakeholders.

Maintaining the balance between economic and societal performance is essential for the sustainability of the airport. Obviously, airport operators should be economically sound and especially privatized airports need to be able to make a profit, but increasing profitability should not be stressed to the limit. Our design effort to decision support for airport strategic planning will therefore explicitly include a social perspective of an airport (see Section 3.2).

## 2.2 Approaches to airport strategic planning

The definition of airport strategic planning by Wells and Young, presented earlier in Section 1.1, does not imply a *specific approach* to airport strategic planning. There are many different approaches to coordinate an all encompassing planning effort with the intention to maximize the future potential of an airport. In the following sections, a number of such approaches to airport strategic planning are described.

*Master Planning*

The basic purpose of a Master Plan is to set out a plan for future development designed to meet projected needs taking environmental and socio-economic impacts into consideration (FAA, 2007; ICAO, 1987). Airport Master Plans are prepared to support the modernization or expansion of existing airports or the creation of a new airport.

In the United States, a Master Plan is required to receive funds from the Federal government. Although most other countries do not have such a formal requirement, many airport operators periodically create a Master Plan.

The Master Plan is primarily an engineering and architectural study. The main focus is on the development of the physical infrastructure (i.e. runways, buildings); operational concepts or management issues are not explicitly considered (de Neufville and Odoni, 2003, p.62). The main elements of a Master Plan, as described in the Federal Aviation Administration (FAA) guidelines, are (FAA, 2007, p.5):

**Pre-planning.** The pre-planning process is about determining the initial need for a Master Plan, selecting consultants, developing a study design, and apply for funding of the study.

**Public Involvement.** Once a consultant team is under contract, a public involvement program should be established and the key issues of the various stakeholders have to be identified.

**Environmental Considerations.** The environmental requirements need to be clearly understood to be able to move forward with each project in the recommended development program.

**Existing Conditions.** Inventory of pertinent data for use in subsequent plan elements.

**Aviation Forecasts.** Forecasts of aeronautical demand for short-, medium-, and long-term time frames based on a single view of the future.

**Facility Requirements.** Assessment of the ability of the existing airport, both airside and landside, to support the forecast demand. The demand levels that trigger the need for additions or improvements to facilities need to be established. The need for new facilities also needs to be determined.

**Alternatives Development and Evaluation.** Identification of options to meet projected facility requirements and alternative configurations for each major component. The expected performance of each alternative is to be assessed for a wide range of evaluation criteria, including its operational, environmental, and financial impacts. A recommended development alternative will emerge from this process and will be further refined in subsequent tasks. This element should identify the purpose and need for subsequent environmental documents.

**Airport Layout Plans.** A set of drawings that provides a graphic representation of the long-term development for an airport. The primary drawing is the Airport Layout Plan (ALP).

**Facilities Implementation Plan.** Provides a summary description of the recommended improvements and associated costs. The schedule of improvements depends on the levels of demand that trigger the need for expansion of existing facilities.

**Financial Feasibility Analysis.** Identification of the financial plan for the airport, describing the funding of the recommended projects in the Master Plan, and financial feasibility of the program.

Quantifying environmental and socio-economic impacts is not addressed in detail within Master Planning. The FAA only encourages planners to consider possible environmental and socio-economic costs associated with alternative development concepts, and identify possible means of avoiding, minimizing, or mitigating those impacts (FAA, 2007, p.23). Only after the Master Plan is completed, is a more detailed quantitative assessment of environmental impacts carried out, but this hardly affects the decisionmaking process (as shown by Soneryd (2004) for the Örebro airport in Sweden).

Most Master Planning studies take a very long time to complete and run the risk of becoming obsolete by the time they are completed, because of new conditions that had not been taken into account in the planning. This is typical because Master Planning assumes that a reasonable idea about the future can be determined by forecasting (Problem Area II, Section 1.2.2). Looking at the events in the aviation industry throughout history shows that there have been many surprises and discontinuities. Most of the time, Master Plans are inflexible and do not provide any means to respond to such events.

*Dynamic Strategic Planning*

Dynamic Strategic Planning (DSP) is an approach to airport planning that has been proposed by de Neufville and Odoni (2003, p.81):

> *Dynamic Strategic Planning emphasizes flexibility.* Its fundamental premise is that airport operators must dynamically adjust their plans and designs over time to accommodate the variety of futures that may occur. This emphasis distinguishes dynamic strategic planning from the traditional master or strategic planning, both of which build upon relatively fixed visions of the future.

One of the key principles of DSP is the examination of several forecasts instead of only one as is typically the case in Master Planning. Another key principle is

to encourage planners to be proactive and shape the loads on the system, rather that reacting passively to the load.
DSP extends Master Planning such that planning becomes proactive and flexible. The steps for preparing dynamic strategic plans as presented by de Neufville and Odoni (2003, p.84) are:

1. Prepare an inventory of existing conditions;
2. Forecast a range of future traffic, *along with possible scenarios for its major components (international, domestic, and transfer traffic, airline routes, etc.)*
3. Determine facility requirements *suitable for the several possible levels and types of traffic*;
4. Develop several alternatives for comparative analysis;
5. Select the most acceptable *first-phase development, the one that enables subsequent and appropriate responses to the possible future conditions*.

The elements in italics are additions to the Master Planning process. So, DSP still provides the orderly process of Master Planning, but encourages thinking strategically about an airport's future by examining the effects of the alternatives on airport performance for several forecasts rather than one. Actual implementation of the alternatives is done through a phased development, adapted to the events as they unfold in the real world. DSP therefore addresses both strategy formulation as well as strategy *implementation*. So far, DSP has been applied on only a few occasions (see for example de Neufville (1991)).

*Other approaches*

Other approaches for airport strategic planning have been discussed in the literature (Burghouwt and Huys, 2003; Caves and Gosling, 1999; Kwakkel, Walker, and Marchau, 2007).

Caves and Gosling (1999) state that airport planners should *adapt creatively for the future*. However, no specific approach for doing this is described by them. In an earlier paper, Caves (1995) provided a general overview of different attitudes towards the future, including a creative one, based on Gerardin (1973):

> A planning process is envisioned as defining and choosing between optional futures [...]. The paths to the futures must be feasible, following from an understanding of all the subsystems involved and how the interplay of tensions in the system are contained by thresholds triggered by social forces which will either alter or inhibit the trends.

Kwakkel *et al.* (2007) discuss how airport planning might potentially benefit from adopting an adaptive approach to policymaking. Their work provides examples of policies (or strategies) that could be implemented to better deal with the uncertain future. The benefit of an adaptive planning approach over Master Planning has been proved by computational experiments (Kwakkel, 2010).

Burghouwt and Huys (2003) propose a flexible planning approach, but this early work only describes characteristics of this planning approach and some basic advice on how to be prepared for the future (e.g. implementing backup systems, buying insurance). Burghouwt (2007) describes Flexible Strategic Planning in much more detail, outlining various methods and techniques (e.g. real options) that can be used by planners. However, the description lacks an overarching idea about how planners and decisionmakers are to be supported in practical planning studies.

## 2.3 Approaches to airport strategic planning versus the three problem areas

The question is to what extent the approaches to airport strategic planning as discussed in the previous section address the three problem areas identified in Section 1.2. Table 2.1 provides an overview, which is now discussed in more detail.

Table 2.1: Approaches versus Problem Areas

| **Problem Area** | **Approach** | | |
|---|---|---|---|
| | Master Planning | Dynamic Strategic Planning | Other Approaches |
| I: Lack of stakeholder involvement | Advice for early involvement | Fair negotiation process after design of a plan | Not addressed |
| II: Inadequate approach for modeling the future | Single demand forecast | Scenarios | Scenarios, among others |
| III: Inefficient problem solving process | Sequence of analytical steps | Advice to appropriately use computer-based tools | Not addressed |

The recent update of the FAA Advisory Circular (AC) on Master Planning pays more attention to involving the stakeholders (Problem Area I), by strongly advising to identify and involve stakeholders as soon as possible. The updated AC still does not provide a way to deal with the uncertain future (Problem Area II). The AC on Master Planning does provide support for the problem solving process (Problem Area III) by defining a series of elements that should be subsequently addressed within the Master Plan.

DSP does not provide any means to involve the stakeholders (Problem Area I). It is only assumed that a fair negotiation process will emerge (de Neufville, 2000, p.7). In order to facilitate this negotiation process, DSP includes procedures for dealing with the perspectives and powers of the participants in the planning process. This assumption is clearly based on the perspective of the Power School of Strategic Management as discussed in Section 2.1.3. DSP is an approach that recognizes uncertainty about the future very well and multiple scenarios and options analysis are used to deal with this uncertainty (Problem Area II). DSP is more complicated than Master Planning and therefore de Neufville and Odoni (2003, p.82) advise to manage the additional effort related to problem solving (Problem Area III) by the *appropriate use of computer-based tools*.

The 'Other Approaches' do not address the lack of stakeholder involvement (Problem Area I). Obviously, they do provide an adequate way to address the uncertain future (Problem Area II), very similar to DSP. These approaches do not address any aspect of the problem solving process (Problem Area III).

DSP and other approaches to strategic planning that promote flexibility have been around for a while, but have hardly been adopted by airport operators. The lack of adoption of new planning approaches could be due to a resistance to organizational change. Airport operators could also have a blind spot for the urgency to revise their planning approaches to the changing business environment.

In addition to such factors, we think that the lack of adoption could be caused by the fact that these new approaches leave the other two problem areas—the lack of involvement of the stakeholders (Problem Area I) and an inefficient problem solving process (Problem Area III)—untouched. In our opinion, a new way of supporting airport strategic planning should therefore *deal with all three problem areas concurrently*.

We have already seen that the involvement of the stakeholders is crucial for implementation of the proposed strategies. The strategic planning process cannot stay an internal business process that is, often asynchronously, accompanied by a societal trade-off process (see Figure 1.1). Both processes should merge into an open and single strategic planning process that empowers all stakeholders and allows the airport operator and their stakeholders to commit to action (i.e. implementing the strategies collectively agreed upon).

Airport strategic planning can be looked at from many perspectives. Problems identified may depend on the perspective taken. The same is true for the

underlying cause of the problems. From our *decision support perspective*, the focus will be on the *resources* required and used for a strategic planning effort. These resources are analyzed and described in more detail in the next section.

## 2.4 THE RESOURCES INVOLVED IN A STRATEGIC PLANNING EFFORT

Figure 2.2 provides a conceptual map of airport strategic planning and is not meant to represent any specific airport operator's setting. The map has been determined empirically and shows that many resources are involved, both from inside and outside the organization. A significant number of *people* (managers, consultants, experts, and planners), some using *tools*, participate in the effort to turn *data* into *information* that is relevant for decisionmaking by the airport's management.

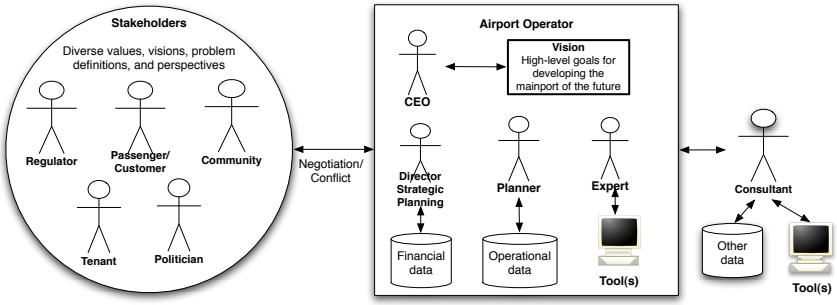



Figure 2.2: Current planning: potential conflicts (Problem Area I) and a huge coordination effort (Problem Area III)

The following description assumes that the airport operator is ultimately responsible for airport strategic planning and coordinates the planning effort. In reality, airport planning consultants might be heavily involved and even responsible for creating definitive plans. The relationship between the airport operator and the consultants depends on the local setting, size of the airport operator's organization, and the regulatory framework.

Each of these resources involved in a strategic planning effort is now discussed in more detail.

### 2.4.1 People

As can be seen in Figure 2.2, there are two types of people involved in planning—those outside and inside the airport operator's organization. People inside the airport operator's organization are the ones that are directly involved

in the strategic planning process. They carry out different types of activities in order to identify those strategies that have potential for realizing the airport's management vision.

People outside the airport operator's organization are typically associated with organizations or groups that have a stake in the airport's development, which we collectively call the airport stakeholders. These stakeholders (e.g. airlines, Air Navigation Service Provider (ANSP), aviation authorities, community groups) have *conflicting* goals and objectives with respect to the airport's development. The way the stakeholders are involved depends on the local setting and their role may vary from merely making their views known to being official partners in making agreements about the actual airport development and operations.

Stakeholders do have significant power (e.g. through public campaigns, lobbying, appealing to court) to influence an airport operator's planning process and will do so whenever they think their objectives and goals are not sufficiently taken into account.

### 2.4.2 Data and information

Creating an effective strategic plan requires consistent data and information about a wide range of aspects. The types of data and information are: (i) the business objectives, usually implicitly contained in an organization's vision and further specified (qualitatively or quantitatively) by the airport's management team; (ii) the future context for the airport's operation in terms of economic, technological, regulatory, and demographic developments; (iii) the airport system and its environment, modeled at the appropriate level of detail; (iv) system changes—infrastructural, operational, and managerial—due to strategies that are considered for implementation; and (v) quantitative airport performance information for the given future context and strategies.

With respect to airport performance, information at different levels of detail is required concerning capacity and delay, and environmental impacts—noise, emissions, and third party risk. Nowadays, the financial implications of a plan from the business perspective (as opposed to a socio-economic perspective) are also important. Often, outside consultants are contracted to provide information about some or all of these airport performance aspects.

### 2.4.3 Tools

Much of the data and information are generated using analytical tools for capacity and delay analysis, environmental impact analysis (noise, emissions, and third party risk), and financial analysis. In most cases, this data and information is not generated in a consistent, integrated way. Usually, only a single aspect of the airport's operation (e.g. its capacity and delay or noise or emissions) is

evaluated at a single time. Only if there is a problem to be expected with another aspect additional analyses are conducted.

The reason for this is that different aspects are assessed by different experts, who are not all from within the same organization. First, these experts needs to get appropriate data and information. Next, the data and information have to be processed in order to be used as input to the tools being used. Then the experts execute the appropriate runs with their tools, post-process the output, and return the results to an advisor, who either documents the (aggregate) results in a report or directly communicates the results to the decisionmaker. If either the decision advisor or the decisionmaker is not satisfied with the results, or if they need an assessment of another situation, the whole process is repeated.

### 2.4.4 Underlying cause of the three problem areas

In Section 2.2, we mentioned that de Neufville and Odoni (2003, p.82) state that the additional effort for creating a dynamic strategic plan can be managed by the appropriate use of computer-based tools. They also mention that:

> Computer models are not a subsitute for strategic thinking, however. They make it possible to carry out the wide consideration of issues under many circumstances. They are necessary for the calculation of the performance of the facilities under different loads. They are not, however, sufficient to develop a good strategic plan (de Neufville and Odoni, 2003, p.86).

We believe that it is difficult for airport operators to make sure computer-based tools are used appropriately. Actually, also Odoni *et al.* (1997, p.149) acknowledge this fact. Even if airport operators are capable of appropriately using computer-based tools, the actual use of those tools and generating the relevant information for decisionmaking and planning from the tool outputs will be a huge effort. This effort might get in the way of strategic thinking, because there is not enough time left or too much effort is spent on tool-related issues.

Our opinion is that the major fundamental cause of the problems discussed in Section 1.2 is the dispersion and fragmentation[2] of people (and their knowledge), data and information, and tools within the organization of the airport operator and its stakeholders (Figure 2.2). Resources cannot be easily integrated, consolidated, and focused on producing effective strategies for developing the airport of the future. People, data and information, and tools cannot quickly be deployed for analysis and subsequent synthesis so that the relevant information for decisionmaking becomes quickly available. Inherently, this fragmentation leads to an inefficient problem-solving process that is not able to support the creation of strategies for an airport's development that are acceptable to all stakeholders.

[2] In general, the 'force of fragmentation' is a cause of serious concern related to addressing wicked problems (Conklin, 2005).

## 2.5 Summary and conclusion

This chapter provided and justified a broad perspective on strategic planning by looking at it from both a management and an airport perspective. By doing so, we answered Research Question 1: 'How should the concept of strategic planning be understood within the airport decisionmaking and planning context?'

Originally, strategic planning was developed as a general management system that could help matching business opportunities with organizational resources. Since the concept was introduced, it has been strongly debated whether it is a key factor to a company's success or not.

We avoided that discussion by defining strategic planning as a broad concept that needs to be tailored for a specific context. Tailoring the strategic planning concept to a company's specific approach has to make sure that *strategic thinking* is constantly evoked. The approach to strategic planning should allow for divergent, creative thinking (Section 2.1.4) about the uncertain future, and the potential strategies for dealing with them.

The disadvantages of the Master Planning process are well-known. It is unlikely that the recent update to the Federal Aviation Administration Advisory Circular (AC) for Master Planning is able to overcome those disadvantages. The updated AC only suggests involving stakeholders earlier, which does not ensure that all the stakeholders will truly be involved (Problem Area I). Master Planning also remains an approach to strategic planning that is unable to deal with the uncertain future (Problem Area II).

The 'Other approaches' to airport strategic planning are limited in that they do not provide any means to involve the stakeholders (Problem Area I). It is however essential that the stakeholders are meaningfully involved in the strategic planning process. Stakeholder involvement is important because it results in a much richer set of strategies to choose from. It is also crucial for successful implementation of the selected strategies.

In our opinion, a good starting point for improving stakeholder involvement is to conceptualize an airport as a *socio-technical system* instead of a purely technical system. The next chapter describes an airport in such a way, explicitly discussing the technical and social perspective previously introduced in Figure 1.1.

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CHAPTER 3

# The Airport as a Socio-technical System

> It is no coincidence that in no known language does the phrase '*As pretty as an airport'* appear.
>
> DOUGLAS ADAMS (1952–2001), English humorist & science fiction novelist

The previous chapter concluded that current approaches to airport strategic planning do not provide a way to involve all stakeholders. This is problematic because engaging stakeholders is crucial for successfully discovering and formulating a rich set of strategies and implementation of the strategies.

Figure 1.1 implicitly shows there are two perspectives to look at an airport. There is the *technical* perspective concerned with the physical structure and efficiency of the system, i.e. the match between capacity and demand and the resulting delays. There is also the *social* perspective concerned with the economic, environmental, and land-use effects of the airport's infrastructure and operation.

Traditionally, airport planning uses a technical perspective of an airport. In the conclusion of the previous chapter we argued that a social perspective needs to be used if one wants to meaningfully involve all stakeholders.

Airports need to treated as *socio-technical* systems, because of the dual nature of technical artifacts, as put forward by Kroes, Franssen, van de Poel, and Ottens (2006, p.806):

> The function of a technical artifact is grounded on the one hand in its physical structure and on the other hand in a context of (intentional) human action. So the idea that the function of technical artifacts can be understood by looking only at their physical make-up has to be rejected.

The function of an airport is even constantly *changing*, as a result of different forces. There are forces internal to the aviation industry (e.g. airline mergers and low cost carriers) and forces external to the aviation industry (e.g. terrorist threats and environmental regulations), which affect the airport's performance in many different ways. An airport operator has to act upon these forces to make sure that the airport's performance meets (long-term) objectives.

So, formulating plans from a purely technical point of view, describing how demand is to be accommodated, is not sufficient anymore. Because of the multi-stakeholder context of airport planning and decisionmaking, the airport should be investigated as a socio-technical system.

This chapter first describes the airport from a technical point of view in Section 3.1. Section 3.2 describes the airport from a social perspective. Bringing the two perspectives together is discussed in Section 3.3.

## 3.1 The technical perspective

Airport infrastructure has been extensively described by de Neufville and Odoni (2003); Wells and Young (2004); and Horonjeff and McKelvey (1993), among others. Their work includes descriptions of the airport's infrastructure in terms of subsystems and components describing their characteristics and explaining their role.

This technical perspective of the airport is presented in this section using a description in terms of a collection of smaller systems within the airport system (based mainly on Wells and Young, 2004). Each element of the broader system is described as a system itself, and the relationships among the systems are identified. Figure 3.1 provides a conceptual view of the systems of an airport and their relationships. An airport is divided into an *airside* and a *landside*, defined as:

**Airside.** The part of the airport that facilitates the movement of aircraft around the airport as well as to and from the air, including adjacent areas and buildings or parts thereof.

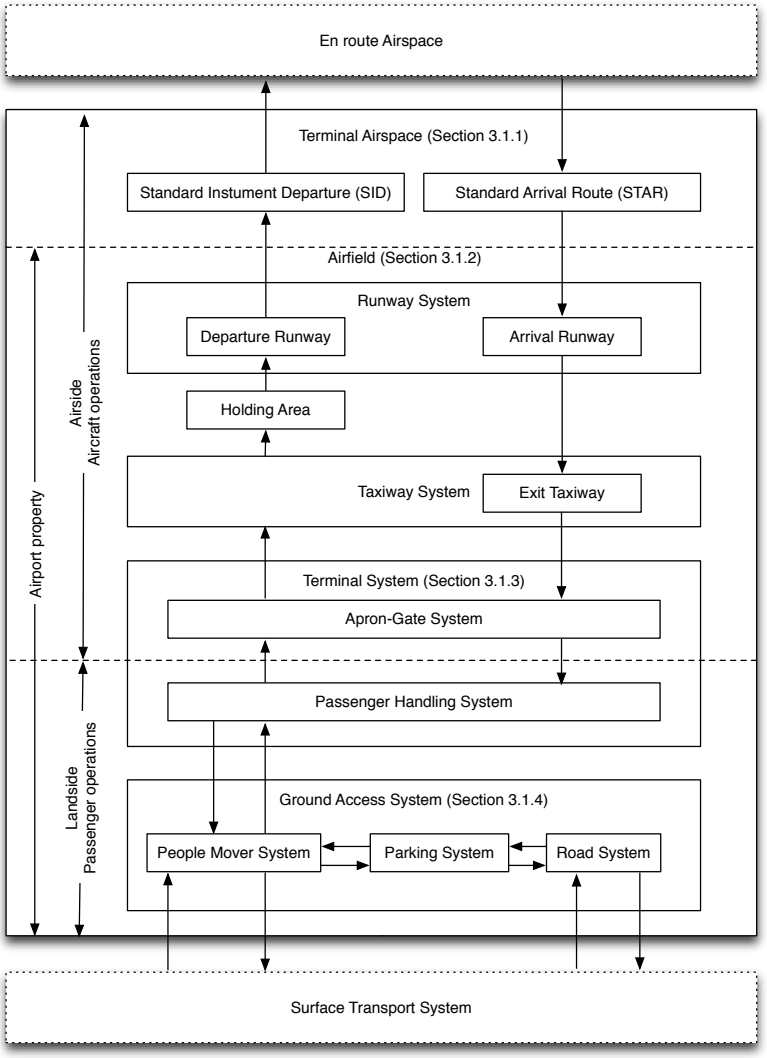



Figure 3.1: The airport described from a technical perspective. Source: adapted from Wells and Young (2004).

The airside can be further decomposed into the *airspace* (Section 3.1.1) and the *airfield* (Section 3.1.2). The airfield includes all the facilities (runways, taxiways, gates, stands, and ground handling equipment) located on the physical *property* of an airport to facilitate aircraft operations. The airspace is the area, off the ground, surrounding the airport where aircraft maneuver, after takeoff, or prior to landing, and pass through on their way to another airport.

**Landside.** The part of the airport that is not part of the airside and includes all the public facilities. The landside accommodates the movements of passengers and cargo.

The landside can be further decomposed into the *terminal* system (Section 3.1.3) and the *ground access* system (Section 3.1.4). The terminal system facilitates the movement of passengers and luggage from the landside to aircraft on the airside. Figure 3.1 shows the unique position of the terminal system within the airport system: it is the *interface* between landside and airside. The ground access system accommodates the movement of ground-based vehicles from the surrounding area (through the surface transport system), as well as between buildings on the airport property.

It should be noted that some airport operators define landside and airside differently. For example, they might define the customs checkpoint as the boundary between landside and airside, making a distinction between the flying and the non-flying public.

Although airports fulfill different roles within the air transportation system, every type of airport is composed of the systems described above, whose purpose is to facilitate the efficient movement of people and cargo through the air from one place to another. Viewed from the perspective of the transportation system, an airport is simply a node in the overall transport network. However, compared to a node in, for example, the road network, it is much more complex. Whereas a node in the road network (e.g. a crossing, roundabout, or flyover) only separates and organizes flows of cars, an airport needs to be capable of handling flows from different sources (i.e. road, rail, and air), processing the passengers and/or cargo from those flows, and converting them back into new flows.

### 3.1.1 The airspace

Airspace is divided into *en-route* airspace and *terminal* airspace. En-route airspace is divided into sectors, which contain air routes. The traffic within the sectors is controlled by air traffic controllers located at an Area Control Center (ACC).

The airspace around an airport is called Terminal Maneuvering Area (TMA) and the aircraft within this airspace are controlled by radar approach control. For each airport, there is an Aeronautical Information Publication (AIP) that includes information and charts with departure and arrival procedures and routes for each

of the runways (see for example Air Traffic Control the Netherlands (2008)). A departure route is called a Standard Instrument Departure (SID); an arrival route is called a Standard Arrival Route (STAR).

In order to enhance and/or sustain the capacity of an airport, air traffic controllers are supported with technology, such as the Central TRACON Automation System (CTAS) in the United States (Erzberger, 1992). Besides already existing technology, new technology and also new Air Traffic Management (ATM) concepts are being developed to increase the capacity of the ATM system (Bernabei, 2001; Wells and Young, 2004, pp.167-189). These new technologies and concepts determine to what extent airport capacity can be increased, although both the timing of their implementation as well as the expected benefits are subject to some degree of uncertainty (Zellweger, 2003).

### 3.1.2 The airfield

The airfield of an airport includes two major systems—the *runway system* and the *taxiway system*—as shown in Figure 3.1. These systems are described in more detail in the next two subsections.

Besides these systems, there are specific functional areas on the airfield as well, such as *holding areas* and bays. A holding area is an area where aircraft can be temporarily parked; bays are areas for parking ground support equipment. These areas may not seem to be that relevant at first. But, they might actually be enablers for solving planning problems. An example is Virgin Airlines announcing they would want to use tugs (i.e. trucks used to pushback aircraft from the gate) to move aircraft from the gate to so-called *starting grids* at the departure runway in order to reduce emissions (Virgin Atlantic, 2006).

*Runway system*

The runway system is composed of *runways*. The orientation of distinct runways is mainly determined by the prevailing wind conditions at the airport. The location and orientation of the runways is chosen in such a way that during most of the year, aircraft can take-off and land under safe conditions, i.e. without too severe crosswind and/or tailwind.

The majority of airports in the world have one or more runways in the main wind direction, possibly supplemented with a runway in another direction to cope with off-nominal wind conditions. Airports that have to deal with highly variable wind conditions have therefore more complex runway systems (e.g. those of Boston Logan Airport or Amsterdam Airport Schiphol).

The design and planning of the runway system should take into account the characteristics of each of the runways, i.e. their orientation, location, dimensions, and pavement so that they can accommodate the aircraft operations appropriately. These aspects determine how and when the runway system can be used for handling aircraft.

The capacity of a runway system depends on a large number of factors. The factors can roughly be subdivided into five categories: the physical elements of the runway system, the characteristics of the ATM system, the demand characteristics, the operational conditions (e.g. weather) and a number of other limiting factors such as noise considerations (de Neufville and Odoni, 2003, p.376–400). Several factors are now discussed in more detail:

**Runway configurations.** Runway configurations are unique combinations that describe which runways of the runway system are simultaneously active and in which mode they are operated. It is the number of simultaneously active runways that is the primary factor in determining airfield capacity. Therefore, the physical layout and the degree of dependence of simultaneously active runways plays an important role. Figure 3.2 shows eight different configurations used for handling the traffic under various conditions at Amsterdam Airport Schiphol during peak periods. Building a new runway increases the number of possible combinations of active runways and as such the runway configurations that can be used to handle demand.

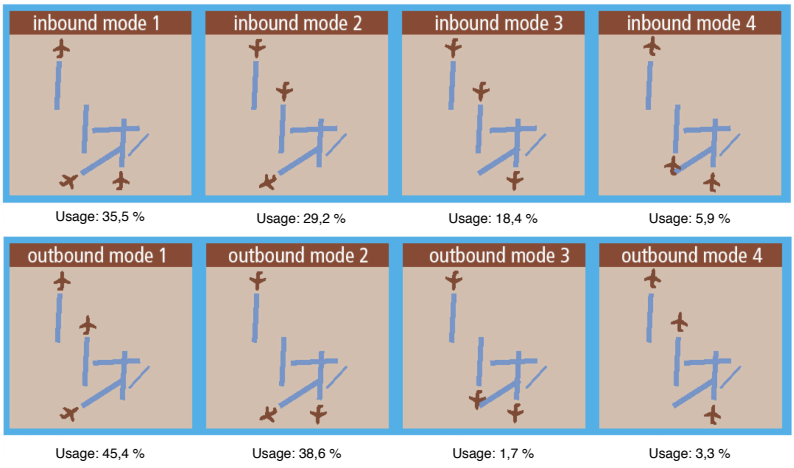



Figure 3.2: Primary runway configurations used at Amsterdam Airport Schiphol. Source: Schiphol Group (2003).

**Location and type of runway exits.** The location and type of runway exits determines the Runway Occupancy Time (ROT), which is defined as the time between touchdown and the moment that the aircraft is at the runway exit. Conventional runway exits are placed near the runway ends, perpendicular to the runway. Additional high speed exits can reduce the runway

occupancy time and thus possibly improve the runway capacity (Hobelka, Dona, and Nam, 1987; Read and Yoshikawa, 1962).

**State and performance of the ATM system.** The airport capacity obviously depends on the ATM equipment (e.g. its human-machine interface, and ergonomics) and the personnel (e.g. skill and experience). Air traffic controllers remain the fundamental element in ATM systems, but efficiency and safety can be enhanced by implementing new technologies to support them. Every ATM system specifies a set of required minimum separation distances or times for safety reasons, consisting of the following:

- Separation requirements for aircraft operating to/from the same runway. Each set of requirements gives the minimum separation time that must be maintained at all times between two aircraft operating successively (i.e. arrival-arrival (A-A), arrival-departure (A-D), departure-arrival (D-A), departure-departure (D-D)) on the runway;
- Separation requirements for aircraft operating to/from parallel runways. The critical parameter is now the distance between the centerlines of the runways. Additional separation requirements may be applied for closely-spaced parallel runways;
- Separation requirements for aircraft operating on intersecting, converging or diverging runways. The applicable operating procedures and separation requirements may vary, e.g. depending on the location of the intersection, the angles between the centerlines, or the mix of aircraft movements (ICAO, 1996). New aircraft technology, and ATM concepts and technologies could have a substantial impact on these separation standards.

**Aircraft type mix.** A relatively homogeneous mix of aircraft types is preferable to a non-homogeneous mix to optimize runway throughput capacity. In addition, the former simplifies the work of air traffic controllers. In case of non-homogeneous traffic, air traffic controllers often attempt to segregate traffic, by assigning aircraft from specific weight class to a particular runway. For this reason, the combined capacity of two independent parallel runways can be significantly higher than twice the capacity of a single runway.

**Movements mix.** The mix of movements for a given period of time, i.e. arrivals versus departures, also plays an important role in determining the airfield capacity. Departure capacity is generally higher than arrival capacity. Therefore, especially at hub airports, the total capacity varies with different time periods over the day. Air traffic controllers often prefer to use separate runways for arrivals and departures, simplifying aircraft flows to and from the airport. However, this approach usually does not result in the highest capacity. In case of an overflow of either arrivals or departure, mixed operations on a runway may reduce the imbalance. A mixed

mode of operation exploits the use of 'free departures', i.e. departures are scheduled between two consecutive arrivals without disturbing the string of arrivals. Sequencing of movements may influence the runway capacity as well. Typically, arrivals are given higher priority than departures due to safety considerations. Other than that, usually the first-come-first-serve principle is used. Air Traffic Control (ATC) controllers may prefer a string of arrivals followed by a string of departures.

**Wind direction and strength.** Runways can only be used when crosswinds and tailwinds are within prescribed limits (typically around 20 respectively 5 knots). The combination of the active runways, therefore, highly depends on the direction and strength of the prevailing winds at any time. Generally, when wind speeds are less than 5 knots, any runway configuration in a given direction can be used. In that case, other criteria, such as noise considerations, may be the determining factor.

**Visibility, ceiling, and precipitation.** Weather conditions have a great impact on the airfield capacity. More conservative separation requirements can be the result of bad weather conditions. In general, Visual Meteorological Conditions (VMC) allow higher capacity, while for example precipitation, snow, and ice may severely affect the capacity due to poor visibility and poor braking action.

**Noise considerations.** Environmental considerations, especially noise impacts, are becoming increasingly important in determining the order in which runway configurations are used and thus the runway capacity that is provided. Especially in off-peak hours, runway configurations that minimize the environmental impacts are often used, i.e. the so-called Preferential Runway Advisory System (PRAS). The modes shown in Figure 3.2 indicate the preferred use of runway configurations due to noise considerations at Amsterdam Airport Schiphol (AAS) (Schiphol Group, 2003).

In practice, single runways have a capacity of 20–60 movements per hour, while the total airfield capacity may range from 20 movements up to 250 movements per hour. Depending on the above factors, the airport has a particular expected capacity level.

Weather conditions and the demand characteristics are typically the principal factors that determine the operational capacity at a given time, as the other factors are more or less fixed for a particular airfield. However, most of these factors can be affected by implementing specific strategies, such as building a new runway, upgrading ATM technology, or adding high-speed exits. So, an airport's physical capacity is an important indicator when quantifying the effect of strategies. Specific capacity indicators, their evaluation, and implications for planning are therefore discussed in more detail in Section 3.1.5.

*Taxiway system*

Taxiways provide aircraft the ability to move to and from the runways and other areas of the airport. Busy airports with complex taxiway systems (e.g. taxiways that cross an active runway) that are prone to low visibility conditions may implement Advanced Surface Movement Guidance and Control Systems (A-SMGCS) to improve efficiency (Piazza, 2002). The efficiency of taxi operations can potentially be improved by fine-tuning taxi plans through optimization (Roling, 2004).

Designing the taxiway system requires attention to a number of aspects. Landing aircraft should not interfere with aircraft taxiing to take off. Taxiways should preferably be planned so that they do not cross an active runway, in order to avoid runway incursions and taxi delays (FAA, 1989; ICAO, 2004). If these aspects are not appropriately considered, the taxiway system might become the determining factor for the airport's overall capacity.

The taxiway system of LAX is an example of this. The original design of the taxiway system causes an increased risk of runway incursions (Los Angeles Times, 2008). The first project executed as a result of the 2005 Master Plan is aimed at fixing this design mistake (FAA, 2005).

### 3.1.3 The terminal system

The terminal system of an airport includes two major systems—the *apron-gate system* and the *passenger and baggage handling system*—as shown in Figure 3.1. These systems are described in more detail below.

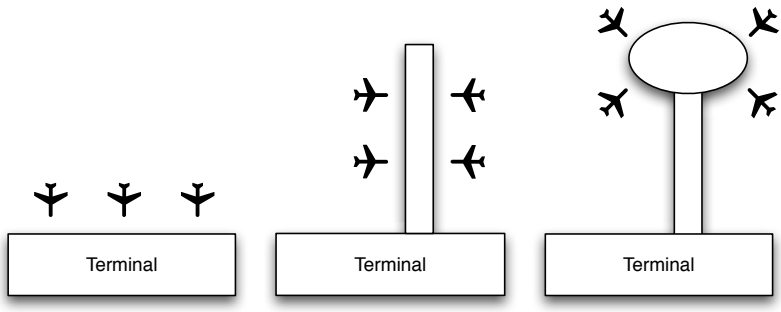
Many different configurations of the terminal system can be observed across airports around the world. There are airports with a linear terminal (Figure 3.3(a)), a curvilinear concept, pier finger terminals (Figure 3.3(b)), pier satellite (Figure 3.3(c)), and remote satellite terminals. At many airports, hybrid terminal geometries can be observed as a result of changes made to accommodate the ever increasing demand.

Because of uncertainty about both the growth as well as the character of the demand (e.g. origin/destination versus transfer traffic, or new large aircraft), planning and designing the future terminal system is quite difficult (Odoni and de Neufville, 1992; Tosic, 1992).

*The apron-gate system*

The apron-gate system is used for loading and unloading of aircraft passengers and cargo, as well as servicing and preflight preparation of aircraft before they enter the airfield and airspace. The area required for individual gates and apron parking spaces is mainly determined by aircraft size.

The size of the parking area is also determined by the aircraft parking type, which refers to the orientation in which aircraft will park. There are five major




(a) Linear design (b) Pier finger design (c) Pier satellite design

Figure 3.3: Different terminal designs.

aircraft parking types, namely nose-in, angled nose-in, angled nose-out, parallel parking, and remote parking. Depending on the parking type, an aircraft might need to be maneuvered in and out of its parking space by aircraft tugs or on its own power.

Planning and managing the apron is challenging, because the number of aircraft parking areas, or gates, that are required for efficient operations depends on many factors. Among these factors are: the number and type of aircraft scheduled to use a gate, each aircraft's scheduled turnaround time (or gate occupancy time), and the type of gate usage agreement that an airline has with the airport. Gate planning is therefore a problem that is subject to study by many operation researchers, either to improve our understanding of the problem, solve the problem through optimization, and/or to support airport operators through expert systems (Yan and Tang, 2005).

*The passenger handling system*

The passenger-handling system is a series of systems that facilitate the transfer of passengers between aircraft and one of the nodes of the local ground transportation system (i.e. road and rail). Specific processes are the flight interface, passenger processing, and access interface.

The flight interface provides the link between the aircraft gates and passenger processing facilities. Airport elements such as gate lounges and service counters, moving sidewalks, loading facilities (i.e. loading bridges, and air stairs), and facilities for transferring between flights are all part of the flight interface.

Passenger processing facilities are used for the major processing activities related to departure and arrival, as shown in Figure 3.4. There are facilities to prepare departing passengers for use of air transportation (ticketing, baggage

check, boarding card, security, and passport control, and boarding). Similarly, there are facilities to prepare arriving passengers to leave the airport for ground transportation to their ultimate destinations (deboarding, passport control, baggage reclaim, customs, and immigration).

The access/processing interface provides facilities to coordinate the flow of passengers between ground transportation and the terminal building. Activities taking place at this interface are the loading and unloading of passengers and baggage from vehicles at the curb and transit stations, and pedestrian circulation from vehicle parking facilities. This interface also includes the vehicular drive and terminal curb, sidewalks, shuttle buses, automated people movers, and bus stops, taxi stands, and rail stations.

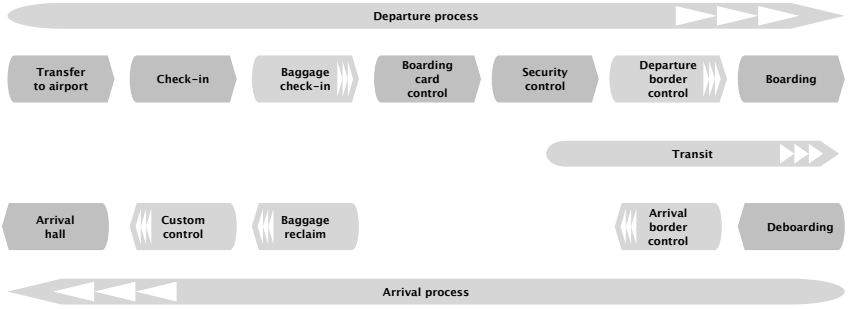



Figure 3.4: Passenger handling processes. Source: Kohse (2003)

### 3.1.4 The ground access system

The ground access system is an integral part of the overall passenger and baggage processing system of the airport (not explicitly shown in Figure 3.1; the figure only shows the part of the passenger handling system within the terminal system) and provides access to and from the airport from the surrounding community.

The access/egress link includes all the ground transportation facilities, vehicles, and other modal transfer facilities to move passengers to and from the airport. Included in the access/egress link are highways—elements of the larger *road system*, intercity and metropolitan rail service, autos, taxicabs, buses, shuttles, limousines, and transfer stations, including off- and on-site parking sites and rail stations.

Technology can help to improve the efficiency of the ground access system. An example is an Automated People Mover (APM)[1] system consisting of

[1]Walt Disney invented this term when he and his Imagineers were working on the new 1967 Tomorrowland at Disneyland as a working title for a new attraction, the PeopleMover.

automated, electric-powered, driverless vehicles operated singly or in multi-car trains. APM systems provide a high quality of service and are capable of moving between 2,000 and 25,000 passengers per hour per direction. Many airports include people movers as an integral part of their infrastructure for moving passengers between the different components (e.g. between terminals and parking facilities). The 2006 Master Plan for LAX even proposes to implement people mover technology as part of meeting their objective for improved security (Jacobson, 2005).

Ground access to the airport should be considered during Master Planning (DOT, 2000). In practice, the ground access system is usually considered in the final planning stage, after planning the airside and landside. Such a phased approach could result in a major problem: the ground access system becomes the weakest link, causing serious congestion and environmental problems (Humphreys *et al.*, 2005; Rhoades *et al.*, 1994). An example of an airport facing this problem is Brisbane airport in Australia (Brisbane Airport Corporation, 2008).

Planning of the ground access system should therefore be done within the broader regional context, involving regional planners as well (Stevens, Baker, and Freestone, 2007). The study on ground access to airports, prepared for the California Department of Transportation, seems to be a good attempt to do so (Landrum and Brown Team, 2001).

### 3.1.5 Physical capacity

Each of the systems just described is a link within a larger system. So, the airport as a whole is as strong as its weakest link. For the entire airport to be efficient in handling the traffic *demand*, each of the systems needs to be carefully dimensioned such that its *capacity* enables an overall flow without incurring excessive *delay* for a given period of time. The need for analyzing and planning these systems together has long been recognized (Block, 1969), but appears to be difficult in practice.

Capacity is an important performance indicator for an airport, because it determines the maximum number of flights (or number of passengers) that can be handled per unit of time during given circumstances. With growing demand for air transport, more and more airports are operating close to their maximum capacity. Some airports have been able to expand, increasing their capacity to meet the demand requirements. Other airports could not be expanded due to space limitations or noise considerations (Adams and Cidell, 2001; Caves and Gosling, 1999; Dempsey, 1999).

Airfield capacity can be limited by any of the systems discussed in Section 3.1.1 through Section 3.1.4. In general, the runway system of an airport is typically the most limiting factor that determines the airfield capacity. Runway

capacity is therefore an important outcome of interest. It is therefore useful to discuss the relation between capacity, demand, and delay and its implication for airport planning. Tse (2006) provides more detailed information about how to quantify and evaluate runway capacity in airport strategic planning studies. The physical capacity of the other systems will not be discussed any further.

*The relation between runway capacity, demand, and delay*

Figure 3.5 shows the relation between runway capacity, demand, and delay for an airport's runway system. Simply speaking, delay can be considered as the result of a 'mismatch' between capacity and demand. If demand is much lower than the maximum capacity, delays remain relatively small. When the demand/capacity or utilization ratio increases, delay increases as well. For utilization ratios close to one, delays rise exponentially. The dynamic characteristics of airport delays are much more complex and difficult to predict accurately, as shown by the dots in Figure 3.5, which reflect real-world examples. But, as a practical rule, runway systems should not be operated at more than 85–90% of the total capacity over an extended period of time.

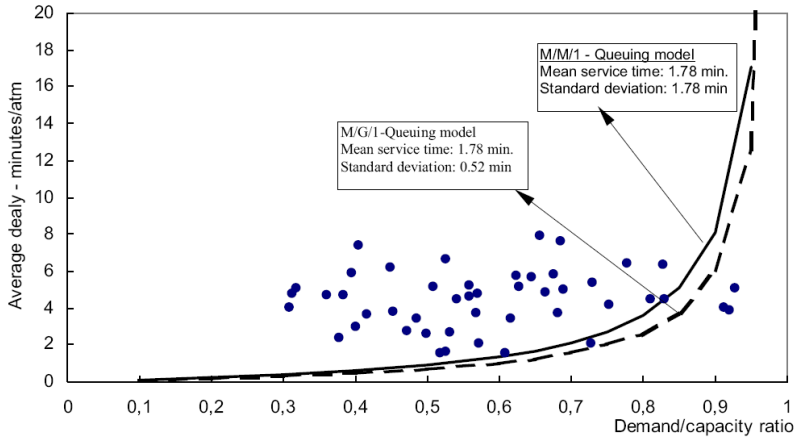



Figure 3.5: Expected time in queue with increasing demand. Source: Janic (2004)

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Furthermore, when a runway system operates at high utilization ratios, small changes in demand may result in large changes in delays and queue lengths. Thus with increasing utilization ratio, the system becomes more sensitive to changes in demand. When an airport is operated at a high utilization ratio, a

small increase of utilization ratio causes a high increase in delay, while a small decrease of utilization ratio reduces the waiting time tremendously. Finally, the probability of large delays is of interest, especially to the airlines, because it is an indication about the reliability with which the daily flight schedule can be carried out.

Matching demand with capacity on a daily and annual basis—through operational control decisions—and making sure there is a match on the longer term as well—through management control and strategic planning decisions—is, therefore, very important, as illustrated previously in Figure 1.1.

*Matching capacity and demand*

A solution to accomodate future demand is to distribute demand over multiple airports (de Neufville, 1995). Examples of metropolitan areas where demand is distributed over a system of airports are Los Angeles (LAX, John Wayne, LA/Ontario International, Bob Hope, and Long Beach Airport), Paris (Charles de Gaulle, Orly, Le Bourget, and Beauvais Airport), and London (Heathrow, Stansted, Gatwick, and Luton Airport). Recently, the same has been proposed for Amsterdam, using Schiphol, Lelystad, and Rotterdam Airport (Raad voor Verkeer en Waterstaat, 2008). Another option to deal with the capacity crunch is to build completely new *reliever* airports (ACI-Europe, 2007).

Another way to match capacity and demand is to change the demand pattern (Fan and Odoni, 2001), but this is often not considered at (hub) airports, although it can be very effective. Typical demand management strategies are congestion pricing, slot coordination, or depeaking. Depeaking is an airline logistics concept that smoothes out airline operations at hub airports, removing the peaks and valleys in aircraft operations. American Airlines (AA), for example, depeaked their entire annual flight schedule after being successful in depeaking their schedules at Chicago O'Hare ORD and Dallas Forth Worth (DFW) Airport (Shifrin, 2004). By doing so, American Airlines was able to improve their financial performance through increased aircraft utilization, fuel savings, and more efficient use of air crews (Franke, 2004). Also, they were able to improve customer satisfaction, because passengers experience less drastic delays or flight cancellations through improved punctuality of the schedule (Reed, 2006).

The most obvious strategy for increasing capacity is to expand the runway system to accommodate more flights. However, such a strategy is often difficult to implement due to other constraints, which most of the time tend to be related to social aspects. We therefore turn to the social perspective on the airport system in the next section.

## 3.2 THE SOCIAL PERSPECTIVE

Although we argued that an airport should be investigated as a socio-technical system in the introduction of this chapter, the conceptualization of an airport as such is not straightforward. Ottens *et al.* (2006, p.144) state that:

> The notion of a social element is far from clear. Laws, regulations, policies, economic, and organisational structure might be conceptually too different to capture in a single notion of the social element.

Wells and Young (2004, p.47) point to some social elements when they mention that problems of an airport are always related to *images* resulting from *collective opinions* of the public. These images are directly related to concrete problems the public encounters, like accumulated experience with noise, failing governmental policy, getting to the airport, lack of parking space, waiting lines, and other inconveniences.

Also, de Neufville and Odoni (2003, p.33) identify several social and cultural aspects that play a role when designing different parts of the terminal (i.e. the configuration of check-in desks and apron and gates). In both cases, different social elements are emphasized. In this section, we explore social elements that are appropriate for *our purpose*.

We choose to use the environmental impacts noise, emissions, and third-party risk as the elements that form our social perspective. This choice is motivated by the fact that many stakeholders, now and in the future, are affected by these environmental impacts and the extensive public discussion and policy debate that is the result. Sections 3.2.1–3.2.3 discuss these three impacts in some more detail (partly based on Visser *et al.* (2008)). Section 3.2.4 uses these impacts to form the notion of *environmental capacity* (as opposed to the physical capacity discussed in Section 3.1.5).

### 3.2.1 Noise

Aircraft noise has been subject of intensive study and policy debate since the 1970s. Today, both the noise problem as well as ways to mitigate the problem are fairly well understood. Still, noise issues and the ways to deal with them are at the heart of many conflicts related to airport planning.

Airport operators have various means at their disposal to mitigate noise impacts. The balanced approach to noise mitigation from International Civil Aviation Organization (ICAO) defines four key areas that should be explored to address airport noise problems (defined by ICAO's Committee on Aviation Environmental Protection (CAEP) (Andrade, 2001):

**Reduction at the source.** New aircraft technologies have brought significant noise reductions throughout the years. These reductions were partly driven by ICAO noise certification standards—Volume 1 of the Annex 16 (ICAO, 2008)— but mostly by the need of airlines to reduce fuel costs. It is also clear that the potential for additional noise reductions is low, without the emergence of some breakthrough technology (e.g. anti-noise or airframe noise reduction technology). It is therefore quite risky to assume that similar reductions can be achieved in the next 20 years (Casalino *et al.*, 2008).

**Land-use planning and management.** Planning instruments such as zoning and easements, and mitigation instruments such as building codes and noise insulation programs are needed to ensure that noise reduction gains are not offset by inappropriate noise sensitive developments around airports.

**Noise abatement procedures.** Standard or customized Noise Abatement Procedures (NAPs) can be used to reduce airport noise problems. Specific examples are the Continuous Descent Approach (CDA), changing SIDs and STARs, and Precision Navigation Instrument Departures (PNIDs) (Clarke *et al.*, 2004; Erkelens, 2002; In't Veld *et al.*, 2004).

Most of these NAPs depend and exploit the capabilities of new airborne and ground systems for approach, navigation, and flight management (for example Microwave Landing System (MLS), Global Positioning System (GPS), Area Navigation (RNAV)[2], and Cockpit Display of Traffic Information (CDTI)).

**Operating restrictions.** These are measures that can limit or control the access of an aircraft to an airport. Examples are denied access of specific aircraft types during the night, or higher landing fees for aircraft types that only marginally meet ICAO Annex 16 Chapter 3 standards. Another example to control access to the airport is to entirely close the airport at night.

The objective of a balanced approach to airport noise is to reduce noise impact through a program that balances solutions within each of the above areas. The goal is to achieve maximum environmental benefit most cost-effectively. A number of CAEP working groups are involved in research into each of the areas, but it is left up to ICAO member states to implement a program and decide among its elements. Upham *et al.* (2004) found that most aviation stakeholders are frustrated about the lack of a framework for global harmonization (see also van Zuijlen, 2004).

[2]Area Navigation is a generic term that refers to any instrument navigation performed outside the traditional routes defined by ground-based navigational aids (Wells and Young, 2004, pp.183-184).

Although there is not yet a global framework, airport operators have implemented a range of measures to manage noise impacts. Examples of such measures are noise abatement procedures (Erkelens, 2002; Reynolds *et al.*, 2005), noise charges (Hsu and Lin, 2005; Morrell and Lu, 2000; Nero and Black, 2000), operating quotas, and restrictions for ICAO Annex 16 Chapter 2 and 3 aircraft.

It is important to realize that noise annoyance is determined not only by acoustic factors. There also many social, economic, cultural, and attitudinal factors that affect people's perception of what is an acceptable level of annoyance (Hume *et al.*, 2003; Jue *et al.*, 1984; Stallen, 2004). Broer (2006), for example, showed that there is a relationship between noise policies and noise annoyance.

Unfortunately, at the present time, there are no quantitative methods in use that relate the level and acceptability of the perceived disturbance to socio-economic, cultural, and other non-acoustic factors. It is for this reason that acoustic indicators of noise exposure remain the primary regulatory indicators for noise disturbance. In the near future, current research that aims to develop a causal model of aircraft noise annoyance might be of use to better take into account non-acoustic factors and use that information to define more effective strategies to mitigate noise annoyance (Kroesen *et al.*, 2008).

At the same time there are many more noise effects than annoyance, such as effects on health (Franssen *et al.*, 2002; Rabinowitz, 2005), learning of children (Haines and Stansfeld, 2003; Haines *et al.*, 2002), sleep disruption, speech interference, rattle and vibration (caused by low-frequency noise), and the ecology (Trimper *et al.*, 1998). In order to better deal with these effects, more effective metrics and tools need to be developed (Eegan, 2007; Waitz *et al.*, 2004).

### 3.2.2 Emissions

Aircraft emissions, local air quality, and its relation to public health is receiving more and more attention (Whitelegg and Williams, 2000). So far, this issue is not yet fully understood: long term health effects of air pollutants are difficult to measure and poorly understood by medical science. Aircraft emissions might therefore well become the focus of environmental controversy in the years ahead.

With respect to emissions, two types of analysis can be distinguished, viz. inventory and dispersion analysis (CSSI, Inc., 2010). Inventory analysis computes the amount of pollutants emitted, usually for an entire year. Dispersion analysis computes the concentration levels of pollutants for a given area and time frame. Dispersion analysis is used to assess the impact of emission sources on local air quality. Dispersion contours represent concentrations and thus they also indirectly indicate the potential impact on human health at specific locations.

Many airports around the world are committed to reducing aircraft emissions through reducing ground delays and gate holds, optimizing aircraft movements, reducing Auxiliary Power Unit (APU) operational and engine idle time, early

shutdown of engines after landing, and towing aircraft instead of taxiing (Virgin Atlantic, 2006). Reducing non-aircraft emissions also receives attention through regular maintenance of vehicles, planning shorter vehicle routes, avoidance of vehicle idling, removing unnecessary weight from vehicles, using more fuel-efficient vehicles, using alternative energy sources (Miller, 1999), improving public access to airports, and encouraging sharing of ground support equipment. Yet, there is a lack of a strategic framework to assess whether these measures are effective in improving air quality (GAO, 2003).

### 3.2.3 Third-party risk

Airport communities are exposed to the risk of an aircraft crash during take-off and landing operations at an airport (Ale and Piers, 2000; de Bruijn, 2003). Individual risk is the risk of getting killed if a person is assumed to permanently remain at one and the same location. This assumption is a hypothetical one and it is used to compute risk contours that quantify the potential risk that people would be exposed to. Group risk quantifies the expected number of casualties due to airport operations and depends on the population density in the airport area (VROM, 1998).

In the Netherlands, the former Ministries of Housing, Spatial Planning and the Environment and Transport, Public Works and Water Management have jointly developed the external safety policy related to aviation, essentially setting construction limits or bans within certain areas with an increased risk. At present, the $5\text{x}10^{-5}$ per annum individual risk contour is used as the limit of the demolition zone. Homes within this zone must be demolished no later than 2015 (Hale, 2002).

Risk contours define areas of land around runways within which development is restricted in order to control the number of people on the ground at risk of death or injury in the event of an aircraft accident on take-off or landing. Risk contours should be of sufficient size to allow for possible future growth in the number of aircraft movements, without affecting unnecessarily large areas of land.

### 3.2.4 Environmental capacity

Airport operators obviously address the environmental impacts, discussed in the previous sections, when managing their day-to-day airside and landside operations. Within their planning processes, environmental impacts are also addressed, although mostly to comply with environmental rules and regulations through a formal Environmental Impact Statement (EIA).

It would be better to integrate the assessment of environmental impacts in strategic planning studies, because these impacts are a *real* constraint on the physical capacity of an airport (Thomas *et al.*, 2004; Waitz *et al.*, 2004). They

should also be adequately addressed in order to gain support from the airport stakeholders for specific plans (as previously discussed in Section 1.2.1).

A construct for better addressing environmental impacts is through the notion of *environmental capacity*. Different definitions of environmental capacity and an attempt to operationalize a definition are discussed in the next two subsections.

*Definitions*

One definition of environmental capacity brought forward is the following (Raper, 2002):

> The extent to which the environment (and the local community) is able to receive, tolerate, assimilate, or process outputs derived from air activity.

Although most stakeholders tend to agree about such a definition, there is still a clear dichotomy of opinions and interpretations with respect to the meaning of environmental capacity. Industry stakeholders mainly focus on mitigation of environmental impacts of aviation growth, while Non Governmental Organizations (NGOs) call for measures to manage demand and restrict growth (Raper, 2002).

Upham *et al.* (2004) also confirm the wide range of interpretation and understanding by different airport stakeholders.

One of the definitions of environmental capacity presented in their paper is:

> The level of an airport's operational capacity at which those deciding an airport's future agree that the adverse environmental and social disbenefits arising from its development and operation outweigh the benefits that the airport would otherwise have brought.

This definition is quite comprehensive in the sense that is refers to decision-making related to trading off multiple objectives against another. It also directly shows the problem: it is not easy to consistently quantify the benefits and disadvantages for each of the alternative strategies that might be considered for further development of the airport. It is even more difficult to come to an agreement within the multi-stakeholder context in which decisions about airport development have to be made.

*Operationalizing a definition*

It is clear that environmental capacity is too broad a concept to capture in a single metric. This is in clear contrast with physical capacity (Section 3.1.5), for which a metric can be selected more easily. Operationalizing a definition

for environmental capacity is not straightforward. In practice this will have to be done through *ongoing dialogue* among all airport stakeholders. Here, we provide a general attempt. Table 3.1 operationalizes environmental capacity by distinguishing three aspects—physical, physiological, and social—for the different environmental impacts—noise, emissions, and third-party risk—discussed in Sections 3.2.1–3.2.3. These aspects are discussed in the next subsections.

*Physical aspects.* The physical aspects of an environmental impact can be quantified by using a variety of well-defined metrics (such as metrics for cumulative noise load, pollutant concentrations, and individual risk). Although there are well-defined metrics available, choosing the most appropriate one can still be difficult. For example, dealing with annoyance and health effects from low-frequency noise requires metrics based on C-weighting of noise levels instead of the now commonly used A-weighted metrics.

Surprisingly, A-weighting was originally intended only for the measurement of low-level sounds (around 40-phon) (Pierre and Maguire, 2004). But, today A-weighting is commonly used for the measurement of environmental noise and industrial noise, which are obviously much louder. Metrics based on A-weighting are also used to assess potential hearing damage and other noise health effects at all sound levels. In order to make comparisons between different noise sources, metrics based on A-weighting are commonly used to assess noise impacts from transportation, including airports. By doing so, especially the effects of low frequency noise are devalued.

In addition, a metric might be well-defined in a mathematical sense, but that makes it difficult to communicate its meaning to the public. It is therefore commonly recognized that more meaningful metrics for engaging in a public dialogue about environmental impacts are required (Department of Transport and Regional Services, 2000; DOTARS, 2002; Eegan, 2007).

*Physiological aspects.* The physiological aspect of an environmental impact is much harder to quantify, because it involves laboratory or field experiments with real people, who are all different. Nevertheless, research has been done into quantifying sleep disturbance as a function of noise levels (FICAN, 1997), stress and hypertension as a function of long-term exposure to noise (Black *et al.*, 2007; Franssen *et al.*, 2002), and cardiovascular injury (Simkhovich *et al.*, 2008) and increased hospitalization rates (Westerdahl *et al.*, 2008) as a result of air pollution. Loss of life related to aircraft crashes is captured through statistical functions.

Nowadays, airport operators mostly focus on quantifying the physical aspect of environmental impacts and try to mitigate them in order to utilize most of their physical capacity. The physiological aspect of environmental impacts is not

Table 3.1: Aspects of environmental capacity

| **Aspect** | **Environmental impact** | | |
|---|---|---|---|
| | Noise | Emissions | Third-party risk |
| Physical | Noise load, vibration, and rattle | Polutants emitted, concentrations | Individual and group risk |
| Physiological | Sleep disruption, hypertension, cardiovascular disease, loss of hearing | Cardiovascular and respiratory disease | Loss of life, other casualties |
| Social | Operating restrictions, Annex 16 (Vol.1), noise zones, landing fees | Operating quota, Annex 16 (Vol.2), landing fees | Demolition of houses, zoning restrictions, construction limits |

directly addressed in airport planning. An exception are restrictions on aircraft operations or the required use of advanced noise abatement procedures during the evening or night-time period in order to avoid sleep disruption.

*Social aspects.* The social aspect of an environmental impact is about standards and regulations that are in place to protect the general public from adverse physiological effects due a particular physical aspect of an environmental impact.

With respect to noise and emissions, ICAO sets certification standards for aircraft respectively aircraft engines. National, regional, or local authorities define the norms that are to be used for compatible land use in the airport's vicinity and the insulation of houses. Historically, a noise level of 65 dBA has been used as the norm in most countries. That value is fairly high taking into consideration that the World Health Organization (WHO) recommends a value of 50 dBA (Schomer, 2001). Currently, many airport stakeholders seem to be in favor of a norm of 55 dBA or even lower (Cohney, 2009).

In the European Union, regulations with respect to local air quality in general already exist (European Commission, 1999). Some airports have already introduced local rules, such as Zurich Airport (Zurich Airport, 2010).

In the UK, the Health and Safety Executive has recommended that third parties should not be exposed to risks over $10^{-4}$ per year. In addition, it has been recommended that the UK base so-called Public Safety Zones (PSZs) around

airports on the $10^{-5}$ per annum individual risk contour. New or replacement development, or changes of use of existing buildings, are not permitted within Public Safety Zones. Similar regulations exist in the Netherlands as previously mentioned in Section 3.2.3.

In many countries, strong public debate and discussion takes place about the appropriateness of current standards and regulations in light of health, environmental, and ecological threats at different temporal (short- to long-term) and spatial (local, regional, and global) scales (Whitelegg and Williams, 2000). Sooner or later, these discussions will lead to revision of current standards and regulations, and completely new regulations.

The next section discusses the need to better consider environmental capacity and a way to do so.

## 3.3 Bringing the perspectives together

The airport strategic planning process needs to address physical and environmental capacity, because addressing both is key to *sustainable* airport development. Current airport strategic planning does not cater for a comprehensive way of dealing with all of the physical, physiological, and social aspects as described in Section 3.2.4. Most Master Planning studies mainly identify capacity requirements to accommodate future demand. Only after the Master Plan is more or less complete are environmental impacts quantitatively evaluated through an EIA. Such EIAs are merely in support of the chosen alternative rather than a serious investigation of new alternatives. Therefore, EIAs hardly affect the decisionmaking process (Deelstra *et al.*, 2003; Soneryd, 2004).

Environmental impacts would be better addressed if EIAs were integrated into the airport planning process. Apparently, such integration is not obvious. Also in other sectors, such as for example the oil and gas sector, environmental management and strategic planning are not so well integrated (Magrini and dos Santos Lins, 2007).

Sustainable development in general, and that of transport infrastructure in particular, does require an *integrated approach* to environmental management and strategic planning. Section 3.3.1 explains the need for an integral view on airport performance. The conceptualization of an airport as a socio-technical system that is required to provide this integral view is presented in Section 3.3.2.

### 3.3.1 The need for an integral view on airport performance

Environmental impacts such as noise, emissions, and third-party risk should be simultaneously addressed, since, to a large extent, they determine how the stakeholders are affected by and respond to the proposed strategies for developing the

airport. It is clear that the environmental impacts discussed in Sections 3.2.1—3.2.3 are important. Not only are each of these impacts an important aspect of the airport's performance in its own right, mitigation of one impact through the implementation of a particular strategy will most likely affect one or more of the other impacts.

Similarly, strategies that address environmental problems strongly affect the airport's physical capacity (Section 3.1.5), and vice versa. So, in most cases it will be difficult to find a strategy that improves one aspect of airport performance without affecting other aspects of airport performance.

This can be illustrated with some examples. Noise abatement procedures such as Continuous Descent Approachs reduce noise impact, but also reduce the arrival capacity of an airport. Air traffic controllers increase aircraft separations because of fluctuations between inter-arrival times (Huemer *et al.*, 2004). Waitz *et al.* (2004, p.19) observe this in more general terms:

> Noise, local air quality, and climate effects of aviation result from an interdependent set of technologies and operations, so that action in one domain can have negative impacts in other domains.

To illustrate this, they refer to a study of the Society of British Aerospace Companies (2001) that found that operational and technological measures to reduce noise can result in greater fuel burn, thus increasing aviation's impact on climate change and local air quality. Another example is the increasing temperature at which combustion takes place in aircraft engines. This is beneficial for fuel consumption, but also increases $NO_x$ emissions (GAO, 2003).

Therefore, Waitz *et al.* (2004) state that a win-win situation is not possible: there's always a trade-off between one or more aspects. In order to improve such a problem situation, a comprehensive approach is needed that integrates technology, policy, and operational aspects.

Another example of the trade-off between noise and emissions is the new runway at Schiphol that became operational in 2003 and was built to increase airport capacity and shift noise impacts from densely to less populated areas. Because of its remote location, average taxi time for the entire airport operation increased, thus potentially increasing emissions. The new runway did actually not result in the intended effect: the technical analysis predicted that noise load would be reduced, but a number of *physiological* aspects had been overlooked. People who live in rural or fairly low-noise environments, are much more sensitive to new noise events (Schomer, 2001). The noise impact analysis should have added a 5–10 dB penalty to the computed noise impacts in order to account for this. It is therefore not surprising that noise complaints went sky-high after the opening of the new runway (Telegraaf, 2006).

More than other companies, an airport operator's approach to strategic planning needs to rely on various computer tools (see also Section 4.1) for providing information about these many aspects of an airport's performance.

Throughout the years many efforts have been undertaken to design and build systems that would provide an integral view on airport performance by integrating tools used for airport performance analysis (addressing Problem Area III (Section 1.2.3)). These systems and whether they contribute to improved airport strategic planning will be discussed in Chapter 4.

### 3.3.2 The airport as a socio-technical system: Conclusion

This chapter provided and justified a broad perspective on an airport system by looking at it from a technical and a social perspective. By doing so, we structured knowledge about an airport system so that later it can be used to model and implement the airport system within our decision support system.

Effective airport strategic planning requires a holistic view on the airport system. Both technical and social aspects of an airport's performance need to be considered. The examples given in the previous section imply that a comprehensive conceptualization of an airport is required to capture the interpendencies between an airport's physical and environmental capacity. Figure 3.6 presents such a conceptualization, based on the technical (Section 3.1) and social perspective (Section 3.2) of the airport system.

The technical perspective identifies the different systems (i.e. airside, landside, and lower level systems, see Figure 3.1) that make up the airport as a whole. Each of these systems should be planned such that there is a match between capacity and demand, providing for an efficient flow of aircraft, passengers, and cargo. So, the technical perspective is required for evaluating airport performance in terms of physical capacity (Section 3.1.5).

The social perspective requires the identification of different systems of the airport environs (i.e. population, housing) and is required for evaluating airport performance in terms of environmental capacity (Section 3.2.4).

Besides integrating the technical and social perspective within one system representation and linking that to both physical and environmental capacity, it is also necessary to explicitly consider the *two different forces* that change the airport system and hence affect its overall performance. On the one hand, there are many *social conditions*—economic (demand, among others), regulations, technology, and demography that affect the airport system. These social conditions are *external factors* which cannot be controlled by airport decisionmakers. On the other hand, decisionmakers can control the airport performance through the implementation of *strategies* that change the infrastructure, operation, or management of the airport system (both forces were previously shown in Figure 1.1).

We realize that a comprehensive and structured approach that captures each of the elements shown in Figure 3.6 is needed in order to adequately address airport planning problems. Therefore, such an approach needs to be one of the

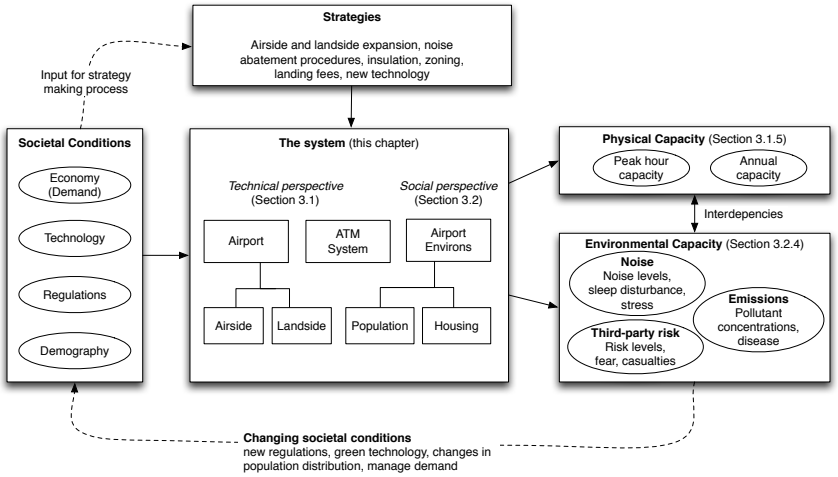


Figure 3.6: The need for a comprehensive view on airport performance

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key principles driving the design of the decision support, which will be presented in the Part II of this dissertation.

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CHAPTER 4

# Computer-based Systems for Airport Performance Analysis

> There can be as much value in the blink of an eye as in months of rational analysis.
>
> *Blink: The Power of Thinking Without Thinking*
> MALCOLM GLADWELL

Within an airport strategic planning study a wide variety of concerns needs to be addressed (Section 1.1). Typically, many organizations, each dealing with a single aspect of the airport infrastructure and/or operation, are involved in providing quantitative data (Section 2.4). All these data have to be integrated and aggregated such that the *relevant information for decisionmaking* becomes available.

The concerns about *integration* of data and analysis results have initiated many research projects, primarily sponsored by the European Commission (EC). One of the major objectives of all of these projects is to provide decision support for airport planning by improving the efficiency of airport *analysis*. As such, all of these projects focused on designing and building computer-based systems that provide an *integrated set of tools* for airport performance analysis.

Section 4.2 briefly describes the systems that were developed. An analysis of the functionality of those systems and the problems with that functionality is presented in Section 4.3.

But first, tools for analysis of different airport performance aspects are briefly discussed in the next section. The airport performance aspects—capacity, delay,

noise, emissions, and third-party risk—with a focus on planning, have already been discussed in the previous chapter.

## 4.1 Tools for airport performance analysis

Many tools have been developed for the analysis of different aspects of an airport's performance. These tools have been discussed and reviewed for different purposes and by different authors (OPAL, 2003; SPADE consortium, 2004; THENA, 2002). Odoni *et al.* (1997) provide a quite comprehensive and detailed survey, and also reflect on strengths and weaknesses of existing models and tools.

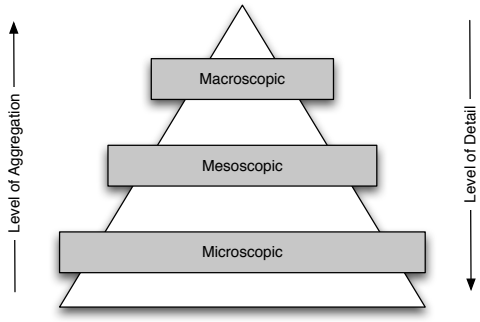


Figure 4.1: Level of detail and aggregation

When discussing tools, it is useful to use some sort of classification. A particularly useful classification is one related to the level of detail and the level of aggregation of tools, as shown in Figure 4.1. Three classes of tools can be defined: macroscopic, mesoscopic, and microscopic. From microscopic to macroscopic, the level of detail used to model the real-world decreases and the level of aggregation increases.

Macroscopic tools typically use analytical expressions to model and study airport operations at a fairly high level of aggregation, providing a global picture of a system, but with a crude level of detail. These tools need a moderate amount of input data to provide information about, for example, airport capacity and delay for a given situation. Mesoscopic tools for capacity and delay would use traffic flow models (e.g. aircraft flows). And microscopic tools for the same purpose typically use simulation methods and are used to investigate individual aircraft or passenger movements. It is important to realize that microscopic tools do not necessarily provide more accuracy in terms of modeling the real world. They just provide more level of detail for investigating the airport operation.

Tools that deal with capacity and delay, noise, emissions, and third-party risk are introduced in the next subsections.

### 4.1.1 Capacity and delay

Throughout the history of aviation one of the major issues has been the provision of airport capacity. As a result, a large number of tools for capacity and delay analysis have constantly been under active development. Examples are the Cranfield methodology, LMI Runway Capacity Model (LMI, 1998), the FAA Airfield Capacity Model (Swedish, 1981), MACAD and SLAM (Andreatte *et al.*, 1998), SIMMOD, TAAM, RAMS Plus, and CAMACA (Eurocontrol, 1998). For each class of tools—macro, meso, and micro—Figure 4.2 provides an example.

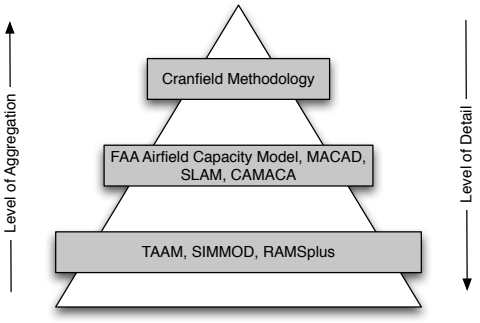


Figure 4.2: Capacity and delay analysis tools

The FAA Airfield Capacity Model is an analytic computer model which calculates the (maximum throughput) capacity of a runway system given continuous demand. Given data on the runway configuration and operating procedures in use, it estimates the hourly capacity for 15 common airfield configurations ranging from a single active runway to four active runways. The model was initially developed in the late 1970s by a consortium that included Peat, Marwick, Mitchell and Company and McDonnell Douglas Automation and further modified by the FAA with support from the MITRE Corporation. It was last modified in February 1981. The model approximates single runway capacity using logic based on the fundamental concepts of the classical Blumstein model and its extensions. For more complex configurations it uses models that extend the analysis. Combinations of these base models are then used for even more complex configurations. The FAA Airfield Capacity Model can be used for policy-level studies that require quick approximate estimates of the sensitivity of airfield capacity to various changes in the most common operating parameters of airports (number and configuration of runways, aircraft mix, separation requirements, runway occupancy times, etc.).

### 4.1.2 Noise

For the purpose of noise analysis, a standard methodology has been developed by the Society of Automotive Engineers (SAE) Society of Automotive Engineers (1986). The methodology documented by the European Civil Aviation Conference (ECAC, 2005) is basically the same, but differs in detail (e.g. with respect to atmospheric attenuation). The latest version of Integrated Noise Model (INM), version 7.0b, is compliant with both methodologies (ATAC Corporation, 2007). Other, nationally developed, software is available for noise impact assessment (such as the Dutch noise calculation model ENVIRA, developed by the Dutch Aerospace Laboratory, see Montrone *et al.*, 2001), but the INM is the most widely used tool.

The FAA INM can be used for evaluating aircraft noise impacts in the vicinity of airports. INM has many analytical uses, such as assessing changes in noise impact resulting from (1) new or extended runways or runway configurations, (2) new traffic demand and fleet mix, (3) revised routing and airspace structures, (4) alternative flight profiles or (5) other operational procedures. The INM has been the FAA's standard tool since 1978 for determining the predicted noise impact in the vicinity of airports.

INM utilizes flight track information, aircraft fleet mix, standard and user defined aircraft profiles and terrain as inputs. The INM model produces noise exposure contours that are used for land use compatibility maps. The model also calculates predicted noise at specific sites such as hospitals, schools or other sensitive locations. For these grid points, the model reports detailed information for the analyst to determine which events contribute most significantly to the noise at that location. The model supports a large number of predefined noise metrics that include cumulative sound exposure, maximum sound level and time above metrics from both the A-Weighted, C-Weighted and the Effective Perceived noise level families.

### 4.1.3 Emissions

To quantify the impact of pollutant emissions computer databases and models have been developed. There are two types of analysis: (1) emissions inventory, to assess the total mass of emissions released into the environment resulting from all air traffic operations, ground service equipment, ground vehicular traffic and stationary sources during a specified period of time; and (2) dispersion modeling of pollution concentrations, to assess concentrations of various pollutants at specified locations in the vicinity of the airport for ambient atmospheric conditions.

In the United States, for example, the FAA requires the use of the Emissions and Dispersion Modeling System (EDMS) for conducting air quality analyses of aviation emission sources from proposed airport projects (CSSI, Inc., 2010).

The EDMS can be used to create an emissions inventory for any individual airport emission source, or combination of emission sources. For dispersion analyses, EDMS generates input files to be processed by its module AERMOD, which essentially implements a steady-state plume model for specified weather patterns. The EDMS includes emission indicators for the various airport sources. For example, it incorporates all aircraft engine emissions data contained ICAO Exhaust Emissions Data Bank (ICAO, 2008), representing nearly two-thirds of EDMS's aircraft engine emissions data. The remaining aircraft engine emission data originate from other sources, including engine manufacturers.

### 4.1.4 Third-party risk

Airport communities are exposed to the risk of an aircraft crash during take-off and landing operations at an airport. Both the United Kingdom (Cowell, 1997) and the Netherlands (Piers and Loog, 1993) use risk assessment methodologies that broadly follow a similar approach. In both countries, it was concluded that the most appropriate metric for calculating third party risk around airports is individual risk. Individual risk is generally defined as the chance per year that an individual residing permanently at a particular location will be killed as a result of an aircraft impact; it is expressed in units per year (de Bruijn, 2003).

The concept of societal risk, being the chance that in a single aircraft crash a certain number of victims is killed, is also used in the Netherlands. It is expressed as the relationship between the number of people killed and the chance per year that this number is exceeded (Ale and Piers, 2000).

In the Netherlands a model to quantify third-party risk, called TRIPAC, has been developed by the Dutch Aerospace Laboratory (Pikaar *et al.*, 2000). In the UK, a model has been developed by the National Air Traffic Services (NATS) (Foot, 1997).

### 4.1.5 Limitations of tools for use in strategic planning studies

The tools just discussed are of limited direct use in airport strategic planning studies (see also the description of Problem Area III: Efficiency of problem solving, in Section 1.2.3). Since each of the tools are related to a single airport performance aspect, it is labor-intensive to provide an integral view on airport performance. An integral view is also complicated to produce, because the tools use different data and assumptions (e.g. related to aircraft performance, or engine characteristics).

Tools also have to be used many times in order to provide a picture of airport performance as a function of time within the planning period that is considered. Typically, a tool can only be used to address one given situation at a time. This is not only true to the temporal dimension, but for also for the airport system

dimension. A particular study with a tool is mostly restricted to one specific airport configuration and operation.

So, analysis of other situations, and periods of interest, requires setting up different studies. INM 7.0's functionality improved somewhat in this respect: It now uses a three-tier Study/Scenario/Case input data structure. Scenarios are a collection of separate cases for each airport operating configuration (ATAC Corporation, 2007, p.16). Previous versions of INM only had a Study/Case structure to organize input data, which only dealt with different airport operations.

The lack of an integral view is partly addressed by the Aviation Environmental Design Tool (AEDT) and Aviation Environmental Portfolio Management Tool (APMT) (Transportation Research Board, 2005, 2011). However, these tools only provide an integral view on noise and emissions (by integrating INM and EDMS).

Many other projects tried to provide an integral view by developing computer-based systems for airport performance analysis. These projects are described in the next section.

## 4.2 Projects to develop computer-based systems

The previous section discussed a subset of the many tools to evaluate different airport performance aspects. As previously mentioned when we discussed Dynamic Strategic Planning (Section 2.2), the problem with airport strategic planning is not a lack of tools. According to de Neufville and Odoni (2003, p.88), the problem is the *appropriate use of computer-based tools*. More specifically, the question is: 'Which tools should be selected and how should they be used?' According to Odoni *et al.* (1997, p.149), the selection of the appropriate tools/models is a significant problem:

> One of the most common and costly mistakes is selecting models which are not appropriate for investigating the problem at hand. For example: a highly-detailed model, like SIMMOD or TAAM is used to determine the timing of investments for expansion of an airport's capacity. Such a question is a 'macroscopic' policy question which typically looks 10–20 years into the future. Answering such a question should be done with the help of an approximate, fast and easy-to-use model, not one that requires a detailed layout of the airport, the construction of highly detailed scenarios, which are subject to great uncertainty, and a (totally speculative) flight-by-flight demand schedule for the distant future.

During the past decade or so, not much has improved in this respect. Still, not enough thought is given to the tool selection process. One example is the attempt

to support strategic decisionmaking for AAS with Total Airspace and Airport Modeler (TAAM) (Offerman, 2001). The TAAM model that was developed has, however, never been used by decisionmakers.

The lack of misperception about the appropriate level of aggregation for addressing a problem, actually appears to persist, unintentionally, with both tool developers as well as tool users. This situation cannot be easily resolved because: (1) tool developers are not directly involved in airport strategic planning studies (see also Figure 2.2); and (2) the tool users are not directly familiar with the underlying methodology of the tools or the entire range of functionalities offered by a particular tool. Luers and Moser (2006, p.45) provides a good rule of thumb for making the selection:

> The [level of detail] of models should be inversely related to the decision time horizon.

Microscopic tools and models are therefore not appropriate for the analysis of airport strategic planning problems. Strategic planning problems should be investigated with macroscopic and/or mesoscopic models and tools.

Airport strategic planning is about identifying, evaluating, and comparing many different strategies using a range of evaluation criteria, for a range of futures. An analyst and/or planner should be able to quickly define how those strategies change the airport system and present the effect of those strategies on different aspects of the airport's performance—capacity and delay, noise, emissions, third-party risk, financial and/or socio-economic. Macroscopic and mesoscopic tools are especially well suited for this because they do not require highly-detailed input data and require less computational resources.

The need to quickly and easily evaluate the effect on various airport performance aspects due to changes to the airport system and/or operation has led to many projects to design and build systems for airport performance analysis. The goal of those projects was twofold: (i) to remove the burden of users having to select the appropriate tools, and (ii) to provide an end-user with an integrated view on airport performance for different situations. As such, the projects focused on *integrating tools* in a single computer-based system for airport performance analysis. We discuss some of these projects below.

### 4.2.1 TAPE

The Total Airport Performance Evaluation (TAPE) project was a project within the EC's Fourth Framework Programme, aimed at identifying the factors affecting airport *efficiency* and *capacity* in a broad sense, including passenger and ground handling, ramp and apron services, airport access and information, with

the final objective of modeling all of these to assess potential improvements (TAPE, 1998).

The major objective was to develop a computer aided capability for *evaluating the impact of the entire airport alternatives* for increasing airport capacity and efficiency, both in the air and on the ground. This capability was implemented in the form of a multi-layered toolkit consisting primarily of analytical models, as well as of a few carefully selected simulation models, managed through a set of utility programs.

The TAPE concept and prototype gained wide acceptance within the airport authority that operates Linate and Malpensa airports in Milan. However, the literature does not provide any reference to TAPE's practical application within this airport operator's organization. Based on what is published about TAPE, it seems that only specific modules (e.g. the Simple Landside Aggregate Model (SLAM) model, and a database with the flight schedule data) have been used in practice.

The TAPE prototype has not been further developed, although the evaluation process recommended a number of specific issues that should be addressed. The models in the toolkit should be further integrated, database centralization should be improved, preparation and modification of inputs should be simplified, animation functionality should be added, functionality to address environmental issues (noise and air pollution) should be added, and the SLAM model should be refined.

### 4.2.2 OPTAS

Optimization of Airport Systems (OPTAS) was a research study within the EC's Fourth Framework Programme. Two studies, denoted A and B, were conducted. The objectives of part A of this project were to use and evaluate a suite of *airside* and *landside* simulation tools and to evaluate the applicability of using techniques from System Dynamics (SD) to develop a fast runtime, high level *modeling* tool that integrates the airside and landside of an airport (Dux, 2000a).

The main objective of part B was to achieve a comprehensive overview of the current state-of-the-art research into airport *capacity* (Dux, 2000b). The initial goal of the project was to integrate airside and landside tools at the software level, but this goal was set aside, mainly because there were major technical obstacles. Instead, three separate models of the same airport were implemented in parallel.

In addition, a prototype of a macroscopic tool based on SD was developed. It was found that the SD approach did not make this tool usable for modeling the all different airport subsystems and therefore the tool could only be used for a limited scope of problems. No further uses of the OPTAS results have been reported.

### 4.2.3 OPAL

Optimization Platform for Airports, including Landside (OPAL) was a research project within the EC's Fifth Framework Programme. OPAL offers a facility for total airport performance analysis (van Eenige, 2002). The platform enhances the ability of existing airside and landside *tools* to cooperate, providing a unified and integrated facility for modeling and evaluating total airports. The term *total airport* is an OPAL specific term, related to the fact that the project focused on analysis of both the airside as well as the landside.

The OPAL architecture is shown in Figure 4.3. OPAL is built around a central communication infrastructure (not shown) that interfaces with the various *tools* and *databases*. Each tool module has its own local database (not shown either). A centralized database is used to share data among the different tools. The data in the database are organized through the use of the so-called Scenario[1] Manager, which is responsible for manage the input of all the underlying tools.

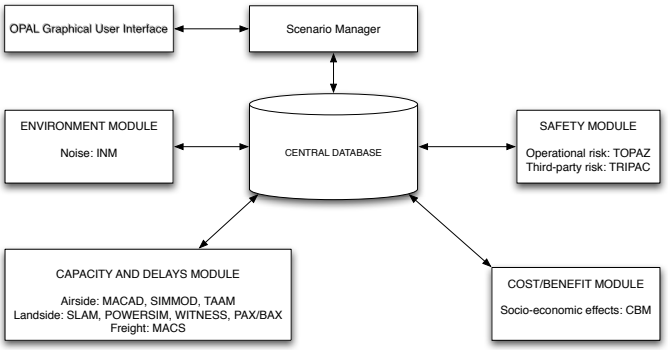


Figure 4.3: The OPAL architecture. Source: adapted from Zografos *et al.* (2005).

The OPAL Graphical User Interface (GUI) is the interface to the user, and provides functionality to manage the scenarios and control the workflow of the tools. OPAL is the follow up of the TAPE project and as such addresses a number of the TAPE recommendations. A central database has been designed within OPAL, tools for environmental issues have been included, and capacity and delay tools have been improved (particularly SLAM and Mantea Airfield Capacity and Delay (MACAD)).

[1]Scenario is not strictly defined within the OPAL project, but should be interpreted as a set of input data for a number of tools. This is quite different from the definition of scenario used in a policy analysis or a managerial context as we will discuss later.

### 4.2.4 SPADE

The SPADE project was an EC Sixth Framework Programme project. It aimed to develop a seamlessly integrated computational platform that will *support policy and political decisions* relating to airport development, planning and operations. The platform intended to provide integrated impact analysis. It also intended to support challenging airport decisionmaking problems with strong interdependencies and often conflicting objectives.

The SPADE design was driven by the assumption that solving a planning problem boils down to the workflow presented in Figure 4.4. A problem is identified, a set of input parameters is prepared, more data are collected if necessary, several tools/models are executed, the output of the tools are post-processed and the results are presented. SPADE's functionality has not been designed to help *formulating* the planning problem. Instead, the SPADE user selects a pre-defined planning problem that best resembles the actual problem at hand (called a so-called Frequently Asked Question).

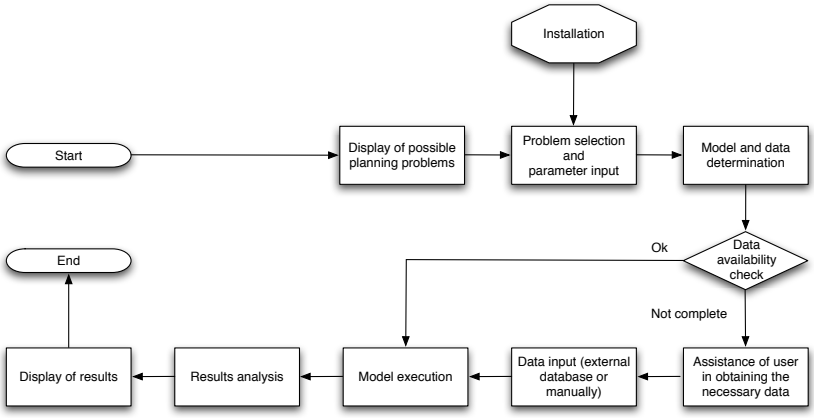


Figure 4.4: The SPADE workflow. Source: SPADE 2 consortium (2006).

Based on a pre-defined set of planning problems, SPADE's functionality is designed such that it provides (i) a user interface for specifying the required set of input data, (ii) controls to execute a pre-defined workflow of tools, and (iii) displays for reviewing the integrated results of the tools. Each type of functionality is provided by a distinct component—the Input Component (IC), the Computational Component (CC), and the Output Component (OC)—as shown in Figure 4.5.

Besides those components, SPADE's architecture also features a data model that describes the airport system. The data model is physically supported by a Relational DataBase Management System (RDBMS). The architecture is implemented using Java 2 Enterprise Edition (J2EE) technology, making SPADE a component-based and network-enabled application. The SPADE application server hosts the computational component and data model, which are accessed by multiple clients incorporating the input and output component. The computational component does not include the tools themselves. The tools are supposed to be executed on separate nodes (i.e. PCs or workstations) in the network. Through the use of a so-called Tool Wrapper, the SPADE platform interfaces with the tools through the computer network.

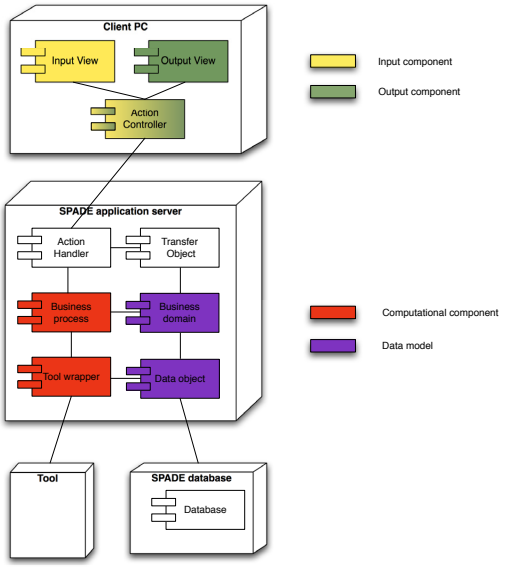


Figure 4.5: The SPADE architecture. Source: SPADE 2 consortium (2006)

### 4.2.5 Airport Business Suite

The Airport Business Suite (ABS), which was developed at the Delft Airport Development Center[2], was designed to be a computer-based system for decision support that enables its users to obtain, through a graphical user interface, consistent information about all facets of the airport's business now and for future

[2]The Delft Airport Development Center is now known as the Delft Centre for Aviation (DCA). More information can be found at `http://dca.tudelft.nl`

situations at the desired level of aggregation (Walker *et al.*, 2003). Its overarching objective was to improve the effectiveness and efficiency of producing information for airport strategic decisionmaking.

ABS' target users were the advisors of decisionmakers involved in airport strategic planning, since they were expected to benefit most from the analytic capabilities offered by the ABS. The ABS was designed as an Organizational Decision Support System (ODSS), following the general ODSS architecture suggested by Carter, Murray, Walker, and Walker (1992). The general architecture is presented in Figure 4.6.

Although a multi-user system was envisioned, ABS' current implementation is that of a single-user system. The Dialogue Generation Management System (DGMS) allows the user to interact with both the database (through a Database Management System (DBMS)) and an interlinked system of models (through a Model Base Management System (MBMS)). A case management system keeps track of the models and data that are used.

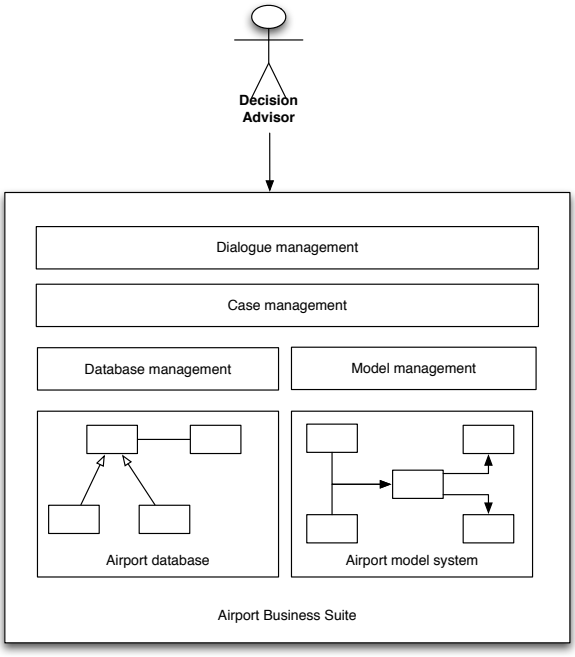


Figure 4.6: The ABS architecture. Source: Walker *et al.* (2003)

The current implementation of the ABS enables a user to conduct capacity and delay analysis for different uses of the runway configurations and passenger ter-

minal on a daily basis (based on a user-selected peak-day). Input data and computational results are stored and managed by the case management system in so-called peak day and yearly cases. The peak-day cases can be combined into a yearly case that is used to evaluate airport performance on an annual basis (only noise impact). The GUI provides an export function for data that can be used for further Cost Benefit Analysis (CBA) outside the ABS.

## 4.3 Problems with existing computer-based systems

None of the systems developed thus far (and which were reviewed in Section 4.2) has ever been deployed and used by airport operators themselves. Some of their components have been used (e.g. the TAPE flight schedule module, SLAM) to support some tasks within airport planning studies, but it is not clear to what extent its use supported the decisionmaking process. OPAL has been tested in a number of case studies and was used to provide an analysis of capacity and delay for Athens International Airport, but it does not seem to have been used by airport planners themselves (Andreatta, Brunetta, and Righi, 2007; Zografos and Madas, 2006). ABS was marketed to the users (Walker and Keur, 2003), but up to now it is only used by students in a course on airport strategic planning (Roling, Visser, Wijnen, and Hebly, 2007).

Although each of these systems claimed to be a decision support system, why are airport executives, planners, and managers not using any of them for airport strategic planning? We will investigate this by looking at the level of decisionmaking support that is provided by the systems (Section 4.3.1). After that, a thorough analysis of the specific problems with the functionalities of these systems is carried out (Section 4.3.2).

### 4.3.1 Levels of decisionmaking and support

Before we identify a number of specific problems that resulted in the systems *not* being adopted by airport operators, it is useful to first discuss the term decision support system. The term Decision Support System (DSS) was first coined by Gorry and Scott-Morton (1971) in an article that makes a distinction among strategic planning, management control, and operational control and classifying decision problems as highly structured, semistructured, or unstructured.

There is a direct relation between the type of managerial activity on the one hand, and the class of decision problem and the level of support needed on the other hand (Sage, 1991, p.2–5). As shown in Figure 4.7, each of the managerial activities, as defined by Anthony (1965), can be supported by a computer-based system. Conceptually, a distinction between a Management Information System (MIS), Predictive Management Information System (PMIS), and DSS can be made (based on Sage (1991, p.5–6); it should be noted, however, that other definitions besides these exist):

**Management Information System (MIS).** Provides reporting functionality related to some question. A classic MIS only needs to be able to respond to queries with reports. For example: it would provide detailed information about the current yearly flight schedule of all the airlines, or a specific airline operating at an airport. The system would search a database to obtain this information and subsequently present it to the user in one form or another. The system is focused on data processing and structures data flows at an operational level, providing summary reports to the user. An example of an MIS is the Official Airline Guide (OAG) Max product[3], which provides functionality to analyze (global) airline flight schedules in detail.

**Predictive Management Information System (PMIS).** Just like an MIS, this type of system provides some sort of functionality for formulation of an issue, or problem at hand, accompanied with functionality to do some analysis. Basically, the user is able to ask '*what if?*' questions, with the system being able to respond with an '*if then...*' answer, and hence the analysis capabilities of this system are more extensive than those of an MIS.

**Decision Support System (DSS).** This system is obtained when the PMIS is extended with model-base management. However, that is only part of the functionality that needs to be provided. Zachary (1998) identifies six generic needs that a DSS needs to fulfilll: (1) projecting into the future despite uncertainty; (2) making trade offs among competing goals, which implies that different alternatives can be evaluated and compared; (3) managing large amounts of information simultaneously; (4) analyzing complex situations within constraints on time and resources; (5) visualizing and manipulating those visualizations; and (6) making heuristic judgments, even if they are only qualitative.

Conceptually, the differences between the systems and their use within the managerial context are clear. However, in practice these differences tend to blur, which leads to classifying a system as a DSS while in fact its not. From a technical point of view, a system may have characteristics similar to that of a DSS (e.g. model-based, the ability to manage large amounts of data). But, from a user point of view, these systems lack essential features required for supporting problem-solving of unstructured problems at the strategic planning level.

The systems for airport performance analysis reviewed in the previous section are a typical example of this: none of the systems are able to meet all of the needs identified by Zachary. The systems have hardly any functionality to project into the future, besides extrapolating a flight schedule. They do not directly provide functionality for comparing alternatives among each other and with the objectives of the decisionmaker, so decisionmakers cannot directly use

[3]More information about this product can be found at `http://www.oagmax.com`.

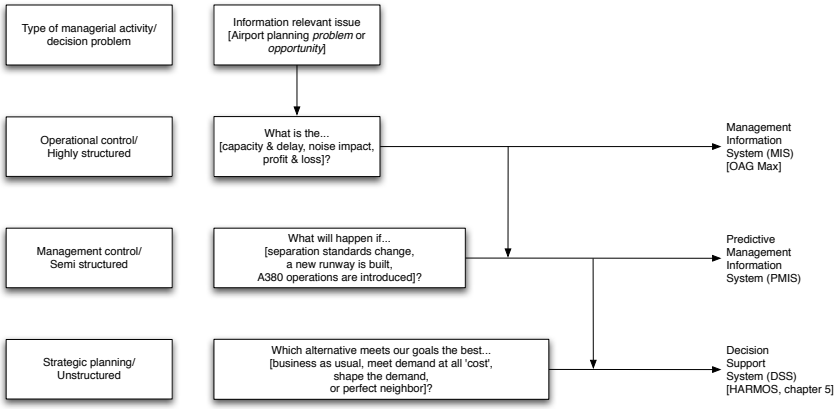


Figure 4.7: Decisionmaking levels and support. Source: Adapted from Sage (1991, p.5–6).

the results for making trade-offs. Finally, the planning problems that can be analyzed with the systems are limited.

Although there are a number of specific problems with the systems for airport performance analysis that have been developed so far, each of these problems results from the purely technical perspective that has been used to design and build the system. Even within DSS research, a strong tool-orientation as opposed to a problem-orientation has been identified as a major problem (Brown, 2006).

The strong focus on tools and models results in systems that support only the *analysis* phase of the problem-solving process. The systems hardly provide any functionality to support the *formulation* and *interpretation* phases of problem-solving. Support for the problem formulation phase is important, because during this phase potential problems or opportunities that an airport operator will be facing or can take advantage of are identified.

The interpretation phase needs to be supported as well, because during that phase all the different potential strategies for developing and managing the airport are to be discussed with all the airport stakeholders.

More specific problems with the systems are now discussed in more detail.

### 4.3.2 Discussion of specific problems

This section discusses some more specific problems with computer-based support for airport strategic planning in more detail.

**Decision environment is not defined.** In all previously described systems, the decision environment in which the systems are to be used is not clear.

The users (both direct and indirect) have not been explicitly defined. The decisionmaking process that is to be supported is hardly described. A DSS design effort that intends to support a decisionmaking process should first describe and analyze that process so that it is clear which steps within the decisionmaking process and which people are to be supported by the computer-based system.

The ABS did identify a user, namely the decision advisor, which is the person that advises decisionmakers. Unfortunately, this user, and more specifically his/her needs, have not been explicitly used to drive the ABS design, although the high-level user needs were documented at the start of the project (Hengst and Lang, 2001)

A major problem in DSS development projects is the fact that the context in which decision support is to be realized (as described for airport strategic planning in Chapter 2) is often forgotten (Dodson *et al.*, 2006). As a result, it is not clear what the DSS being designed is trying to support and what functionality it should provide, So, after the DSS has been developed, it is not used in practical applications (Arnott and Pervan, 2005; Briggs and Arnott, 2004; Poon and Wagner, 2001).

**Focus on capacity and delay analysis.** Early projects that were carried out, such as TAPE and OPTAS, focused exclusively on capacity and delay (or throughput efficiency).

The tools integrated were related to capacity and delay analysis, although they addressed different components of the airport system (airside and landside). The OPAL project can be considered a milestone in that respect. Within the OPAL project, the integration of MACAD and SLAM (previously developed within the TAPE project) became very mature. The term 'total airport' was even introduced in order to stress that now airside and landside could be concurrently analyzed.

The OPAL architecture included tools for the evaluation of other airport performance aspects: INM for evaluating noise impacts, the Cost Benefit Model (CBM) from ECORYS (an economic consultancy company) for socio-economic impacts, and TRIPAC (developed by the Dutch Aerospace Laboratory) for third-party risk. It is however not clear whether the integration of those tools provided any added value, beyond a proof of concept for integration at the software level. Capacity and delay analysis is mostly done on a daily basis, and because of OPAL's focus on capacity and delay, the noise analysis functionality seems to be limited to providing noise contours on a daily basis as well (Zografos *et al.*, 2005). Planners, however, require such information to be available on a yearly basis for the purpose of land-use planning and insulation projects. Additionally, regulators enforce limits on the annual noise impact.

**Strong focus on tools/models.** Each of the projects is *tool-oriented* as opposed to *problem-oriented*.

The projects define the decision support in terms of the capabilities of the tools that are available instead of gaining an understanding of the support that is needed from a decisionmaking and planning perspective. Especially for planning purposes, it is needed to look beyond the features that are provided by the tools (see also Section 4.1.5). One should not rely on the default features or data that a tool or model provides.

For example: an airport operator definitely would want to evaluate the effects on the airport operation resulting from a new fleet mix that includes new large aircraft. However, the such an aircraft might not yet have been defined in the aircraft database of the INM. The system should either provide a user the ability to define the noise characteristics of these new aircraft themselves, or model such aircraft in some alternative way. The literature does not discuss such functionality at all.

**The problem space is constrained.** TAPE, OPTAS, OPAL, and ABS were more concerned with integrating tools into a single system than with designing and building functionality that could readily support airport planning problems.

The OPAL facility has been tested together with airport operators, but it turned out the system could not easily be used to address a planning problem. Moreover, a considerable effort was needed to collect and prepare data, before OPAL could actually be used (Zografos and Madas, 2006).

SPADE attempts to address this issue by using a design philosophy that defines the system's functionality based upon a set of frequently asked questions derived from interviews with airport planners, managers, and other airport stakeholders. However, the problem with such a design approach is the turbulent nature of aviation which constantly changes the airport planning context. Today's frequently asked questions will be different from tomorrow's. A system design exclusively driven by a fixed set of frequently asked questions might become obsolete rather quickly.

One of ABS' design principles is to provide support for different user-defined situations (although it did not provide functionality to easily define those situations). So, the ABS design did not constrain the problem space that can be investigated. However, the lack of problem-orientation within ABS makes exploring the problem space very inefficient. A user has to create different studies if changes to the airport system (e.g. related to runway expansion) or changing external factors (e.g. improved ATM technology that reduces separation standards) need to be considered (Wijnen and Roling, 2004; Wijnen, 2004).

**Software development process.** Odoni *et al.* (1997, p. 147) make an important statement related to the software development process:

> Development of airport models to date have been primarily done by ATM and airport specialists for whom software development has been a secondary consideration. As a result, the usability, robustness, and user interfaces of many existing models are severely deficient. Much improved software engineering practices should be expected and are very much required.

Unfortunately, the airport specialists that develop tools are also the ones that develop the systems for airport performance analysis. This might explain why systems such as TAPE, OPAL, and ABS have not been used in practical applications.

## 4.4 Summary and conclusion

This chapter provided and justified a broad perspective on DSS and its development by looking at it from a tool-oriented and a problem-oriented perspective. By doing so, we answered Research Question 2: 'What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?'

A large number of tools for airport performance analysis have been developed. For each of the major airport performance aspects—capacity, delay, noise, emissions, and third-party risk—mature tools are available. Any approach to airport strategic planning has to rely on these tools for quantitative analysis. Configuring these tools and integrating and aggregating the generated results is, however, a cumbersome and time-consuming process. During the past decade or so, many projects have been carried out to design and build computer-based systems for airport performance analysis. The goal of these systems is to improve the efficiency of airport performance analysis and, as such, to support the airport (strategic) planning process.

A decisionmaker involved in strategy making mainly needs support for synthesis, i.e. integrating and aggregating the results from analysis into a consistent overall picture. Although most of the projects claim to provide such high-level support to decisionmakers, it seems that within the projects hardly any effort was spent to comprehensively understand the generic strategic planning process (as discussed in Chapter 2). Due to their explicit focus on tools, the systems typically only provide functionality for analysis. The systems do not support synthesis, which is confirmed by the lack of support for the formulation and interpretation phases of the problem-solving process.

The development of systems for airport performance analysis has been ongoing for quite some time now. Some of the developed components seem to have been used in consultancy work by the tool developers. However, none of the systems has ever been used by airport operators themselves for strategic planning.

Based on the analysis in this chapter, we conclude that the technical perspective that has been used to design and build systems for airport strategic planning does not result in systems that qualify as decision support systems (following Turban's definition in Section 1.3 and Zachary's needs in Section 4.3).

We will use this information as lessons learned during our DSS design and development effort that is presented in Part II.

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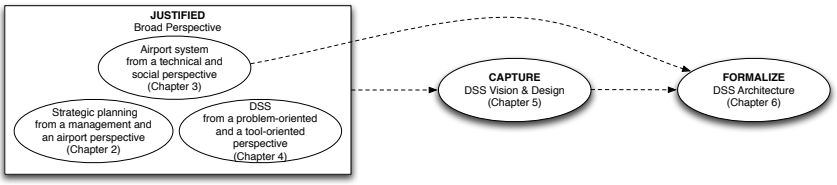
# Summary Part I




In order to design decision support that can address all three problem areas identified in Section 1.2, a broad perspective is needed. This first part of the dissertation provided and *justified* (the second stage of the MOKA Life Cycle as shown in Figure 1.2) a broad perspective on strategic planning, an airport system, and DSS development.

The concept and practice of strategic planning have been explored in Chapter 2 from a management and airport perspective. This chapter answered Research Question 1: 'How should the concept of strategic planning be understood within the airport decisionmaking and planning context?' We looked at strategic planning as a business activity and various approaches to airport strategic planning were discussed.

Chapter 3 described an airport as a socio-technical system providing both a technical as well as a social perspective of the system and its performance. We concluded that a structured approach is needed which brings these perspectives together.

Chapter 4 discussed previous efforts building computer-based systems for airport performance analysis. So, this chapter answered Research Question 2: 'What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?'. The insights gained from this chapter provide important lessons for our DSS design effort, which is presented in Part II of this dissertation.

# Part II

# Decision Support Design

# Overview Part II




Part I concluded that none of the computer-based systems for airport performance analysis developed so far, which are mainly *tool-oriented*, fully supports airport operators in their strategic planning efforts.

We argue that a paradigm shift is needed in the approach used to design systems that aim to support airport strategic planning. Our approach to designing decision support for airport strategic planning is therefore *problem-oriented* (justified in Chapter 4) and is presented in detail in this part of the dissertation.

The three problem areas of airport strategic planning *identified* in Section 1.2 are the high-level requirements that drive the design of our solution to decision support. Part I *justified* a broad perspective on strategic planning, an airport system, and DSS development in order to support airport strategic planning such that the three problem areas are addressed.

This part of the dissertation *captures* ((the third stage of the MOKA Life Cycle as shown in Figure 1.2) the knowledge from Part I to arrive at our solution to decision support for airport strategic planning. The detailed argument for a DSS is provided in Chapter 5, which also presents the key design principles and our approach to DSS development. The DSS vision and conceptual design presented in Chapter 5 is input for the design of the DSS' software architecture in Chapter 6. The software architecture *formalizes* our DSS vision and concept.

So, this part addresses Research Question 3: 'How can airport strategic planning be supported through a DSS and how should the decision support system be designed?'

CHAPTER 5

# What is Needed?

We go where our vision is.

JOSEPH MURPHY (1898-1981)
Prosperity writer extraordinaire

The guidelines for Master Planning, Dynamic Strategic Planning and the other approaches to strategic planning, and the computer-based systems for airport performance analysis, presented in Part I of this dissertation, offer support for airport strategic planning. However, each of them is limited in its approach to decision support. Each addresses only one of the problem areas that exist with airport strategic planning today.

The recent update of the FAA advisory circular on Master Planning (Section 2.2) is now more concerned with the problem of involving the stakeholders (Section 1.2.1). Dynamic Strategic Planning and the other approaches to strategic planning (Section 2.2) deal mainly with the inadequate approach for dealing with the future (Section 1.2.2). And, the systems for airport performance analysis (Section 4.2) target only the problem with the efficiency of problem-solving (Section 1.2.3), albeit with a specific focus on tool-based airport performance analysis (Section 4.3).

We conclude that these approaches to decision support are limited in improving the practice of airport strategic planning. Something more is needed! The practice of airport strategic planning can only be substantially improved if all three problem areas are addressed concurrently. This chapter presents such a solution.

We start by presenting our vision on decision support, which (1) illustrates the high-level goals of airport operators in Section 5.1.1; (2) clearly defines the problem in Section 5.1.2; and (3) leads to our proposed solution in Section 5.1.3.

The key principles that drive the design and implementation of our solution are presented in Section 5.2. We discuss the selection of the software development approach for realizing our solution in Section 5.3. The scope of the development effort is set in Section 5.4. A summary is given in Section 5.5.

## 5.1 Vision about decision support

A vision about decision support is required in order to identify what is needed to improve the practice of airport strategic planning. The vision identifies the high-level goals of decisionmakers, states the problem to be solved, and presents a potential solution to that problem. These items are discussed in the following three sections.

### 5.1.1 High-level goals

Anthony (1965) identified four types of management decisions: (1) strategic planning decisions; (2) management control decisions; (3) operational control decisions; and (4) operational performance decisions. Previously, we introduced the first three types of decisions in Figure 4.7, when we discussed the computer-based systems for airport performance analysis (see Section 4.3.1).

Figure 5.1 shows these decisions again, related to their added value potential to an airport organization, as a function of the planning interval. The most added value potential, strongly related to strategic planning decisions, is at the left end of the planning spectrum. *Strategic planning* decisions are decisions related to setting high-level objectives, choosing strategies, and associated resource allocations.

By strategic thinking, decisionmakers from the airport operator should identify the role of the airport and services to be delivered such that the most value, *preferably for all stakeholders*, is added. In order to do that, a divergent, *intuitive* and creative mode of thinking is required leading to a *vision* for the airport of the future (see also Section 2.1.4, 'Strategic thinking').

A next step is to identify all the potential *strategies* that might help realizing this vision. After these strategies have been evaluated, all the strategies are assessed through comparison among each other and against the objectives of the airport operator, and its stakeholders. The comparison either results in a strategy to be selected for *implementation* or in a request for more analysis, evaluating variations of a strategy, or completely new strategies. These activities are related to an analytical and convergent mode of thinking, eventually resulting in action, i.e. implementation of strategy (see also Section 2.1, 'Strategic planning').

The implementation of a strategy is related to *Management Control* decisions, which are decisions made for the purpose of assuring effectiveness in the

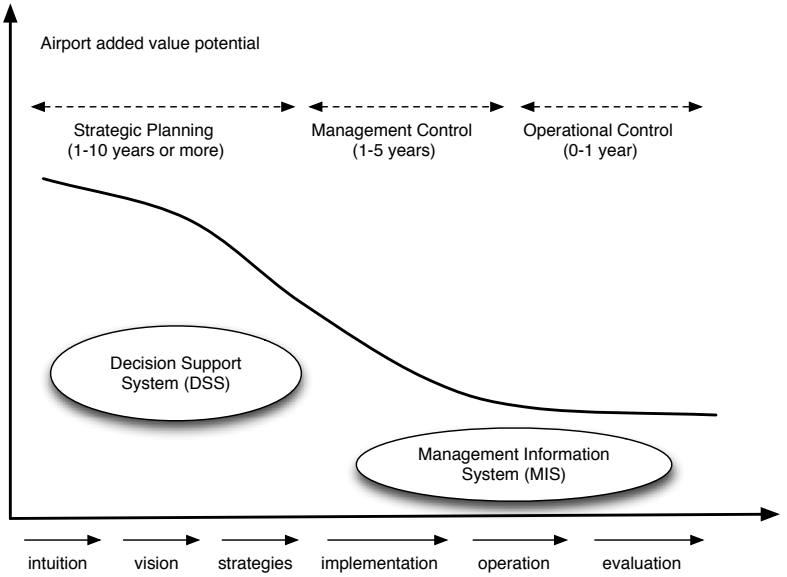



Figure 5.1: Added value potential as a function of the planning interval. Source: Personal communication with a former strategic planner at Amsterdam Airport Schiphol.

acquisition and use of resources. The implemented strategies result in a different *operation* of the airport.

The effect of the changes to the airport operation should be monitored, i.e. an *evaluation* of the real-world airport performance should be carried out to assess whether the objectives of the intended strategies are truly met. If not, corrective actions should be taken at the operational level. These actions are *Operational Control* decisions, which are decisions made for the purpose of assuring effectiveness in the performance of operations..

Another possibility is to formulate completely new strategies, or even start over with a complete new vision, making the process, shown on the horizontal axis in Figure 5.1, an iterative and cyclic process.

Managing the day-to-day operation does not provide many opportunities to substantially change the rules that govern the airport operation, let alone change the airport's infrastructure. Therefore, its potential to add value is low. Managers and other staff not directly involved in organizing the daily operations can and should *take the time* to think through how the business could be developed on

the longer term (van der Heijden, 1999, p.2). Because these people are not completely occupied with the realization of short-term, operational goals, they have the time to *study* plausible futures for the airport and the strategies to face those futures. Since many plausible futures and strategies are conceivable, especially if a planning study spans a period of 10 years or more, it is clear that conducting such a study is very challenging. But, the added value potential that results from strategic planning decisions based on such studies is very high. The added value potential of strategic planning decisions can, however, only be realized if an airport operator and its stakeholders are appropriately supported.

Our survey and analysis in Chapter 4 makes clear that Decision Support Systems (DSSs) that support formulating a vision, exploring the future, and identifying, evaluating, and comparing strategies, do not exist as yet. This is not necessarily true of decision support for management control and operational control decisions: for these type of decisions, airport operators usually have some sort of MIS in place[1] as shown as well in Figure 5.1. These are usually developed in-house.

### 5.1.2 Problem statement related to decision support for airport strategic planning

Airport operators are not very well supported in making strategic planning decisions, which results in a number of problems. Summarizing each of the three problem areas, which were discussed in detail in Section 1.2, leads to the following problem statement:

> Airport decisionmakers cannot realize the full potential of an airport to add value because they, and the planners and experts that support them, have difficulties to fully understand the system, its problems and the potential strategies for addressing these problems.
>
> Airport decisionmakers find it difficult to understand how proposed strategies affect their own objectives and those of its *stakeholders*. As a result they are not able to formulate strategies that are *effective* in satisfying both. Essentially, the decisionmakers are suffering from a lack of information that is relevant to their decisionmaking in the multi-stakeholder context (Section 1.2.1).
>
> Decisionmakers, planners, and experts are not fully aware of how uncertainty about the future would affect the airport's performance. They lack a method to adequately and quantitatively take into account the inherently uncertain developments in demand, technology, regulations, and demography (Section 1.2.2).

[1] Personal communication with Manager Environmental Capacity at Amsterdam Airport Schiphol.

> Although the people that support the decisionmakers try to come up with the relevant information, they are hardly able to do so in a timely manner. Planners and experts do not have the means to execute a systematic problem-solving process that *efficiently* handles (collecting, generating, processing, and interpreting) the large amounts of data and information from the various sources within and outside the airport organization (Section 1.2.3)

This problem statement is the starting point for defining a software solution in the next section. The DSS should be able to address all three problem areas in order to fulfill the specific needs of airport decisionmakers and the people that support them. Besides these generic needs, it is important to make sure the generic needs defined by Zachary (1998) are also met (mentioned before in Section 4.3.1).

### 5.1.3 HARMOS: A DSS for airport strategic planning

The underlying cause of the problems, as just summarized in the problem statement, is the dispersion and fragmentation of resources within the organization of the airport operator and those of its stakeholders (as shown before in Figure 2.2). Current airport strategic planning involves many common, repetitive activities, executed by many people, which is very time-consuming and error-prone.

It would make a lot of sense to coordinate the use of these resources—the data and information, and tools—through a Decision Support System (DSS) that supports the people involved in a strategic planning effort in their activities. By doing so, decisionmakers, planners, consultants, and experts can work more efficiently and effectively in analyzing problems, thereby unlocking their creative powers, rather than spending large amounts of time on activities that a DSS can do faster and better. The DSS integrates the problem-solving process, data and information, and tools so that solving a new strategic problem does not require starting from scratch every time one arises.

Our proposed solution, which we call the HARMOS[2] decision support system, enables an airport operator to deploy its resources—people (knowledge), data and information, and tools—more efficiently, resulting in an improved understanding of the airport system, its problems and potential strategies for airport development. The system explicitly facilitates the involvement of stakeholders in the planning process. A graphical representation of HARMOS, and how it is positioned in the decision environment, is shown in Figure 5.2.

The HARMOS DSS becomes the centerpiece of the planning effort. The DSS provides *coordination* of the data and information, and tools, so that consistent

[2] HARMOS is the Greek root for harmony and the act of bringing people, concepts and objects together. Asian philosophy calls this *aiki*, which is the key principle of the Japanese martial art aikido (practiced by the author for about 14 years now).

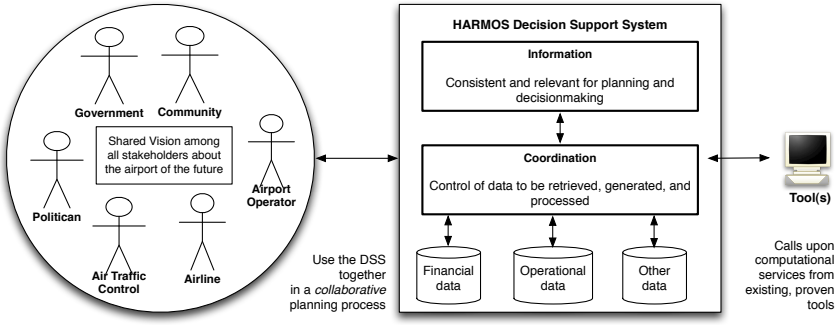



Figure 5.2: HARMOS—bringing people together.

and relevant *information* for planning and decisionmaking is obtained. As such, HARMOS significantly reduces the huge coordination effort that currently needs to be taken by airport staff and consultants. Instead of spending their time on this coordination effort, planners, consultants, and experts can use their valuable time to more extensively explore planning problems given the uncertain future, and the potential strategies that address those problems.

The uncertain future can be adequately addressed by using the DSS to develop multiple scenarios. Functionality for developing scenarios also provides a direct means to actively engage stakeholders (Patel *et al.*, 2007).

HARMOS enables airport staff *and* stakeholders to effectively share information and work together on their problems so that they gain an understanding of each other's perspectives, perceptions, values, and objectives. Only when there is a mutual understanding is it possible to look for strategies that are satisfactory to all parties involved (see the left side of Figure 5.2). As a result, an airport operator and its stakeholders can realize a *shared vision* for the future airport. The proposed DSS design is about enabling collaborative authoring of outcomes as envisioned by Humphreys and Jones (2008).

Our solution, the HARMOS Decision Support System, has the potential to improve the practice of airport strategic planning. Designing and implementing the envisioned DSS is not a trivial task. Many of the problems with computer-based systems for airport performance analysis (as discussed in Section 4.3) are more generally observed in the DSS field—particularly, the technical focus on tools and technologies, and the lack of identification of users and their needs (Brown, 2006; Dodson, Arnott, and Pervan, 2006).

During our DSS design and development effort, we have to avoid these problems. In order to do that, two things are needed: (1) a set of key design principles; and (2) an appropriate DSS development process. The DSS development

process in general and the specific development process we have selected is discussed in Section 5.3. We discuss the key design principles in Section 5.2.

## 5.2 KEY DESIGN PRINCIPLES

This section presents the key principles that drive the HARMOS design and implementation. Besides these principles, the design and implementation is driven directly by user requirements (as described later in Section 6.3). The key design principles help to *formalize* the domain of airport strategic planning. Formalization of the domain is necessary for turning the conceptual solution, presented in Section 5.1.3, into a software system.

By adopting these key design principles, we are able to effectively deal with the complexity of airport strategic planning and capture this into a so-called *Domain Model*. A Domain Model is a system of abstractions that describes selected aspects of a domain and can be used to solve problems related to that domain (see Section 5.3.2). The Domain Model is the heart of the DSS and will be presented in detail in Chapter 7. The key design principles for designing the Domain Model (and hence the DSS) are:

**Policy Analysis.** The policy analysis approach, according to Walker (2000a), is used as the basis to design the problem-solving functionality of the DSS. The DSS is thus based on a well-defined and systematic methodology for problem-solving, which is an important requirement for software to support strategic planning at the management level (Wagner, 2004).

**Integration.** As already pointed out, the fundamental cause of the problems in current airport planning is a fragmentation of data, tools, information, and knowledge within the organization of the airport operator and its stakeholders. An integrative approach toward the deployment of people, data and information, and tools is taken to address that fragmentation.

Section 5.2.1 discusses policy analysis in detail. Integration is discussed in detail in Section 5.2.2.

### 5.2.1 Policy analysis approach

Policy analysis (Miser and Quade, 1988) is a systematic, well-defined, complete, and comprehensive approach for problem solving and decisionmaking that evolved out of operations research and systems analysis (Davis, Kulick, and Egner, 2005, p.33). It is widely accepted for analyzing a diversity of problems, and generic enough for addressing the wide range of airport planning problems (Walker and Fisher, 1994). Policy analysis explicitly recognizes that problems caused by systems affect many stakeholders, and hence finding solutions needs to be done by involving all those stakeholders (van de Riet, 2003; Stigson *et al.*,

2009; White and Lee, 2009). Policy analysis also recognizes that there is *uncertainty* about the future and provides different methods to deal with uncertainty (Walker, 2000b; Walker and Marchau, 2003).

Policy analysis studies usually adopt well-known methods and tools from operations research and management science (for an overview of such methods, see, for example, Daellenbach and Mc. Nickle, 2005). The acknowledgement of uncertainty and the way scenarios are used and developed (see for example The RAND Corporation, 1997) within the policy analysis process is similar to scenario planning/thinking (van der Heijden, 1999; van der Heijden *et al.*, 2002).

The nature of airport strategic planning—the multiple effects of a potential strategy on airport performance, uncertainty about the future, and a multi-stakeholder setting—makes a comprehensive approach to structure the problem and a systematic problem solving process an absolute must. Also, the majority of problems in airport planning are due to the lack of stakeholder involvement and the lack of a method to account for an uncertain future. Policy analysis is therefore ideally suited for supporting airport strategic planning problems.

The policy analysis approach according to Walker (2000a) is such an approach. Walker defines a framework to structure a strategic problem and a process for systematically addressing strategic planning problems. Below, we will now discuss the framework and the process. We also discuss the comparison and selection of strategies (the final step of the policy analysis process) within the multi-stakeholder context in more detail.

*The policy analysis framework*

Figure 5.3 presents the policy analysis framework, according to Walker (2000a). The framework is an integral system description of a policy domain. The framework is subdivided into the *decisionmaking* domain and the *system* domain. Both the system and decisionmaking domain are described below.

*The decisionmaking domain.* The decisionmaking domain explicitly identifies the decisionmakers, stakeholders, and their objectives. An objective is a system outcome desired by a decisionmaker or stakeholder. Objectives might be related to a vision about the future state of system. A decisionmaker is defined as:

> A person or organization that perceives the current or projected future state of the system as problematic and *can* make changes in the system through the implementation of strategies.

A stakeholder is defined as:

> A person or organization that has an interest in the system and *may* have the power to make changes to that system directly or indirectly.

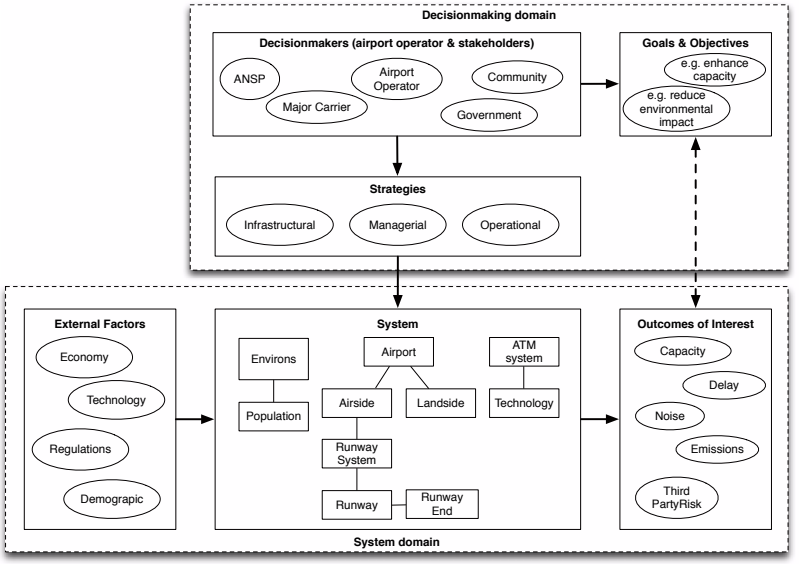



Figure 5.3: The policy analysis framework. Source: Adapted from Walker (2000a).

Stakeholders are concerned about or affected by the outcomes of the system, since they have something to win or lose; their interest is at stake when the operation, structure, and management of the system changes.

Our DSS concept motivates collaboration among decisionmakers of the airport operator and its stakeholders. As a result, the decisionmaking process becomes a collective effort of the airport operators and its stakeholders. Therefore, Figure 5.3 does not separate decisionmakers from stakeholders (which is the case for the framework originally defined in Walker, 2000a).

Decisionmakers of the airport operator and its stakeholders typically have different worldviews, explaining conflict among them, as discussed in Section 1.2.1. Worldview, a loose translation from the German word *Weltanschauung*, is a concept that captures personal factors such as our upbringing, cultural and social background, education, practical experience, and values and beliefs of an individual (Daellenbach and Mc. Nickle, 2005, p.24). Hall, Guo, and Davis (2003), among others, mention that someone's worldview defines the primary perspective that an individual or organization (van der Heijden *et al.*, 2002) uses to make sense of a new problem situation and generate solutions. So, the worldview of decisionmakers of an airport operator and its stakeholders affects their

perception of the problem situation, their objectives, and the identification, assessment, and selection of strategies.

*The system domain.* The system domain defines the *system*, the *outcomes* from the system, and the forces acting upon the system. Two sets of forces act on the system: *External factors* outside the control, and *strategies* under the control of the actors in the decisionmaking domain. Both sets of forces affect the infrastructure, operation, and management of the system and, hence, the outcomes of interest, which may or may not match the objectives of the decisionmakers of the airport operator and its stakeholders.

The system[3] sits at the heart of the policy analysis framework upon which strategies are imposed, and external factors act, and from which outcomes are produced.

The system can be defined as those aspects and parts of the real world that are most relevant for the stated problem and that are able to be directly affected by strategies implemented by one of the decisionmaker(s). Chapter 3 showed that for effective strategic planning the system needs to be defined from a technical (Section 3.1) as well as a social perspective (Section 3.2). Also, the need for a framework that brings these perspectives together was identified (Figure 3.6 and Section 3.3). The policy analysis framework presented here is such a framework.

Within a policy analysis study, the system should be modeled at the appropriate level for the problem situation at hand. For that purpose, a representation of the system has to be developed. The system representation is a model of the system capturing the system structure (the elements and relationships among them), and the operational and managerial aspects of importance for the problem under investigation.

The outcomes of interest are categories of system outputs intended for evaluating, assessing, and choosing a strategy. An outcome indicator is a measurable factor related to one of the outcomes of interest that is a proxy for one of the objectives of the decisionmakers. That is, an outcome indicator is a specific quantitative measure used to assess the degree to which a strategy meets a particular objective.

*The policy analysis process*

Figure 5.4 presents the policy analysis process. The process generally involves performing the same set of logical steps, which are not necessarily performed

[3] A system is a human conceptualization of the real world and as such a system can not be described objectively, because the way it is described depends on the personal interest of the observer (Daellenbach and Mc. Nickle, 2005, pp.23-24). Even if two people are viewing the same system with the same purpose in mind, they may form different conceptualizations of the system, because the individual view is affected by personal factors (i.e. their worldview).

in the same order, while there is usually feedback among the steps. More general information about the individual steps in the process is described in detail by Miser and Quade (1985, Chapter 4). The steps, again according to Walker (2000a), but made specific for airport strategic planning are:

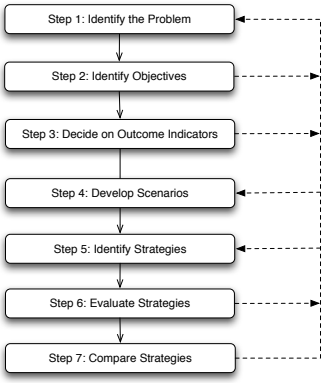



Figure 5.4: The policy analysis process. Source: Adapted from Walker (2000a).

**Step 1: Identify the problem.** Identify the planning problems (this also covers the need to identify new opportunities), clarify constraints on possible strategies, identify the airport stakeholders, and discover the major operative factors.

This step could turn out to be difficult, because the airport operator and its stakeholders perceive the problem situation differently, because of their different worldviews. This is characteristic for wicked problems.

**Step 2: Identify objectives.** Identify the objectives from the airport operator, and the objectives of stakeholders, so that later during the planning study it can be determined if (1) a strategy addresses the problem situation or seizes the opportunity, and (2) to what extent the strategy meets the objectives of the various stakeholders (see Figure 5.3, box 'Goals and Objectives').

**Step 3: Decide on outcome indicators.** Identify the outcome indicators to determine the quantitative or qualitative effects of a strategy. The outcomes indicators are directly related to the objectives (see Figure 5.3, box 'Outcomes of Interest').

It is essential to have an integral view of the airport's future performance (Section 3.3.1) so that bottlenecks and adverse effects of a specific strategy on the airport's overall performance can be correctly identified.

**Step 4: Develop scenarios.** Define the future contexts within which the problems are to be analyzed and the strategies will have to function.

In this step, several plausible scenarios are developed. A scenario is a specification of the development of external factors—economic, technological, regulatory, and demographic—influencing the system (see Figure 5.3, box 'External Factors').

**Step 5: Identify strategies.** Specify the strategies, in terms of infrastructural, operational, and managerial changes to the system, whose effects are to be estimated (see Figure 5.3, box 'Strategies').

It is important to include as many strategies as stand any chance of being worthwhile ('think the unthinkable'). If a strategy is not included in this step, it will never be examined, so there is no way of knowing how good it may be. The current strategy—Business as Usual (BaU)— should be included too (often referred to as the 'base case'), in order to determine how much of an improvement can be expected from the other strategies.

**Step 6: Analyze strategies.** Determine the effects that are likely to follow if the strategy is actually implemented in each of the scenarios, where the effects are measured in terms of the outcome indicators chosen in Step 3.

In order to do this, a representation of the system capturing the elements in the system domain needs to be available. The system representation essentially quantifies how the system (see Figure 5.3, box 'System') is affected by external factors and strategies in terms of the outcomes of interest and as such serves as an experimental laboratory for testing strategies for different developments in the external factors (consistently captured in the scenarios developed in Step 4).

**Step 7: Compare strategies.** Examine the effects of the strategies in terms of the outcome indicators for each of the scenarios, making tradeoffs among them, and choosing a preferred strategy (or combination of strategies), which is robust across multiple futures.

If none of the strategies examined so far is good enough to be implemented (or if new aspects of the problem have been found, or the analysis has led to new strategies), return to Step 1, 4, or 5.

Steps 1–3 are related to problem *formulation*, Steps 4–6 are related to *analysis*, and Step 7 is about *interpretation*. Strategies are designed to change the system such that the airport's performance (measured in terms of the outcome indicators) meets the decisionmaker's objectives. The objectives of the decisionmakers of the airport operator and its stakeholders are explicitly identified early on in the policy analysis process (Step 3). This evokes strategic thinking about the problem and the potential strategies that might address the problem.
Keeney (1996) refers to such an approach as value-focused thinking, as opposed to alternative-focused thinking. Most decisionmaking usually focuses directly

on choice among alternatives[4], which is a limited way to think about decision-making problems. The policy analysis process is value-focused too. The policy analysis process does not start identifying strategies until the problem has been defined (Step 1), objectives from the airport operator and the stakeholders have been identified (Step 2), and indicators to quantify the effects of strategies have been selected (Step 3). Several iterations might however be required to arrive at an appropriate problem definition (again, because of the wickedness of airport strategic planning problems).

Another important observation is that the policy analysis process is very similar to the steps that are conducted in Master Planning (see Section 2.2). The advisory circular on Master Planning from the FAA is actually based on a systems analysis approach (FAA, 2007). Hence, the resemblance in steps is not surprising, since policy analysis evolved from systems analysis (Davis *et al.*, 2005, p.32). The resemblance in steps is important, because the new way of doing things—i.e. using a DSS—partly fits the current way of doing things, which increases DSS acceptance (Sage, 1991).

*Our method for comparing and selecting strategies*

The final stage of a policy analysis study is about selecting one or more strategies from a large number of potential strategies—preferably one (or more) that is (are) acceptable to all stakeholders. Many approaches have been developed for this purpose. We briefly revisit the discussion by Walker (2000a) here, because he clearly identifies the theoretical and practical problems associated with these approaches in a multi-stakeholder context.

Many policy or strategy choice approaches are aggregate approaches, such as cost-benefit analysis, multi-criteria analysis, or multi-objective optimization. Walker has a critical attitude towards this, which we fully support:

> In an aggregate approach, each impact is weighted by its relative importance and combined into some single, commensurate unit such as money, worth, or utility. Decisionmakers then use this aggregate measure to compare the alternatives.
>
> However, there are drawbacks to using an aggregate approach. First, the aggregation process loses considerable information. Second, any single measure of worth depends strongly on the weights given to the different effects when they were combined and the assumptions used to get them into commensurate units. Unfortunately, these crucial weights and assumptions are often implicit or highly speculative. They may impose a value scheme

[4]Alternative, solution, policy, and strategy are used interchangeably here. Throughout the remainder of the text, we use the term strategy, because it better fits the terminology used by airport decisionmakers.

> on the decisionmakers that bears little relation to their concerns.[5] Third, the aggregate techniques are intended to help an individual decisionmaker choose a single preferred strategy—the one that best reflects his/her values (importance weights).
>
> Serious practical and theoretical problems with aggregate approaches arise when there are multiple stakeholders and multiple decisionmakers. The practical problems include the need to answer the following questions: whose values get used (the issue of interpersonal comparison of values), and what relative weight does the group give to the preferences of different individuals (the issue of equity)?
>
> The theoretical problem associated with these questions is that it has been proved that there is no rational procedure for combining individual rankings into a group ranking that does not explicitly include interpersonal comparison of preferences (Arrow, 1950). To make this comparison and to address the issue of equity, full consideration of the complete set of impacts is essential.

To avoid such problems, Walker proposes to use a disaggregate approach in which the impacts of the strategies (or policies) are presented in the form of tables called scorecards. Each column of a scorecard represents an impact and each row represents a strategy. An entire row shows all of the impacts of a single strategy; an entire column shows each strategy's value for a single impact. Numbers or words appear in each cell of the scorecard to convey whatever is known about the size and direction of the impact in absolute terms—i.e., without comparison between cells. Coloring the cells can be used to make comparison easier. For example: blue for the best strategy for this impact, yellow for intermediate and red for worst. Scorecards that summarize the effects of a strategy for a specific impact could also be created (e.g. a noise scorecard). Walker further states that:

> In comparing the strategies, each stakeholder and decisionmaker can assign whatever weight he/she deems appropriate to each impact. Explicit consideration of weighting thus becomes central to the strategy choice process itself, as it should be. Prior analysis can consider the full range of possible outcomes, using the most natural description for each outcome. Therefore, some effects can be described in monetary terms and others in physical units; some can be assessed with quantitative estimates (e.g. noise and pollutant emissions) and others with qualitative comparisons (e.g. 'a particular stakeholder's acceptability for this strategy is high').

[5] For example, traditional cost-benefit analyses implicitly assumes that a Euro's worth of one kind of benefit has the same value as a Euro's worth of another; yet in many public decisions, monetarily equivalent but otherwise dissimilar benefits would be valued differently by different stakeholders.

An example of a scorecard is shown in Table 5.1. We will exclusively use scorecards for supporting the comparison of strategies.

Table 5.1: An example scorecard for comparing strategies

| **Strategy** | **Delay [min.]** | **Noise [houses]** | **Emissions [tons]** | **3rd Party Risk [people]** | **Profit [mln]** |
|---|---|---|---|---|---|
| Business as Usual | 7.5 | 20,000 | 1,500 | 4,000 | 170 |
| Build New Runway | 4.0 | 17,000 | 2,000 | 4,500 | 160 |
| Noise Abatement | 4.8 | 18,000 | 2,000 | 4,000 | 140 |
| Manage Demand | 3.5 | 16,000 | 1,500 | 3,000 | 120 |

### 5.2.2 Integrating resources

As already pointed out in Section 2.4.4, the fundamental underlying cause of the problems in current airport strategic planning is a dispersion and/or fragmentation of people (and their knowledge), data and information, and tools within the organization of the airport operator and its stakeholders:

1. Many people with different roles are involved, who conduct fundamentally different activities;
2. A huge amount of data and information is needed and generated;
3. Different tools need to be deployed and used.

Based on these observations, we identified three categories of resources: people, data and information, and tools. A concrete planning study involves specific resources from the airport operator and from its stakeholders. Currently, those resources are not embedded in a unified structure, which makes it difficult to use them efficiently (Problem Area III, Section 1.2.3). An integrative approach toward the deployment of people, data and information, and tools is needed to address this problem. We discuss the integration of these three types of resources below.

*People*

Many people are involved in airport strategic planning, both from inside and outside the organization. Each of them plays a different *role* and conducts specific

tasks, either throughout the entire duration of the planning study or at specific times. In order to achieve an integration of resources, it is necessary to identify the different roles of these actors.

In order to be successful as an organization, strategic planning should be a collective effort of both the people within the airport operator's organization and its stakeholders. Therefore, both groups should be able to use the DSS. A further division can be made with regard to the roles of the people involved in a study. Conceptually, those roles are schematically shown in Figure 5.5, including the main sources of information that people with these roles use or have available. This is a very schematic representation. In reality, each of the roles and sources of information is interlinked with one another. Also, strategies come not only from the decisionmaker, but can be put forward by people with any of the other roles as well (so-called emergent strategies as put forward by the Learning School as discussed in Section 2.1.3).

There are three major roles in the planning process, which are performed by one or more persons, depending on the size of the airport operator's organization:

**Decisionmakers.** The persons that have the decision power to develop and implement strategies for the airport's development, operation, and management.

Strategies are developed such that they meet the business goals associated with the vision about the airport of the future. Decisionmakers usually do not make direct use of (analytical) computer tools. The sources these people use are very diverse—newspapers, meetings with airport staff and stakeholders, laymen, intuition[6]—and include their own mental models and input from their advisors.

**Decision Advisors.** The persons that advise the people that make the actual decisions.

Decision advisors explore the strategies that could be implemented for meeting the objectives set by the decisionmakers. In order to accomplish this task, they hire external consultants, use in-house computer tools, and consult domain experts.

**Domain Experts.** The persons that have specific knowledge of the airport system (e.g. of the airside, landside, ground access infrastructure) and its operation.

[6]The role of intuition by decisionmakers should not be ignored. As stated by Sloan (2006, p.164): 'Intuition within the context of strategic thinking has to be balanced with deliberate, rational analysis. But rational analysis can never substitute for intuition within the process of strategic thinking'. So, intuition and analysis are complementary within the strategic thinking process. Actually, intuitive decisions tend to improve if decisionmakers are provided with relevant information for the decision problem at hand (Dijksterhuis and van Olden, 2006; Duijksterhuis, 2006; Khatri and Alvin, 2000).

Domain experts use various tools to provide quantitative information about the (future) airport performance (e.g. capacity and delay, environmental impacts, and financial results).

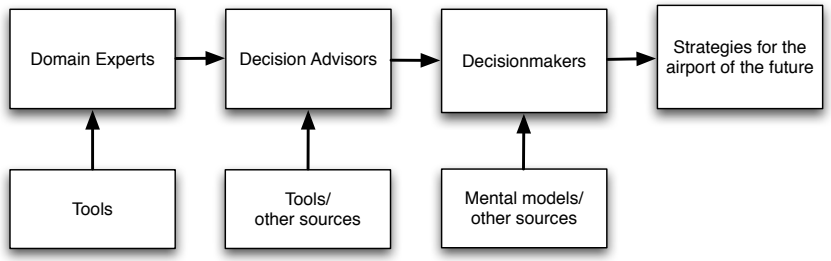



Figure 5.5: Roles of the people involved and their information.

In order to meet the different needs of people with each of these roles, the design of the DSS' functionality starts with identifying *functional* requirements. These are identified in Section 6.3 of Chapter 6, which presents the architecture of the HARMOS DSS.

*Data and information*

Integrating data and information helps reduce the coordination effort required for making sure that the decision advisors, domain experts, and external consultants use a consistent set of data and assumptions. It also makes data, such as current information about the airport infrastructure and operation, airlines and their flight schedules and networks, aircraft and their noise and emissions characteristics, and demographics (e.g. population densities, housing projects) available for easy retrieval, analysis, and reuse.

Moreover, it makes sure that the information is valid and consistent (and remains so) and that it can be easily shared. The aforementioned policy analysis framework can help in structuring the data and information in a clear manner. Categorization according to the policy analysis framework provides the means to effectively deal with all the data and information and reason about strategic planning problems. The most important advantage of structuring data and information according to the policy analysis framework is that there are clear distinctions among data and information that are related to the system, the external factors, the strategies, and the outcomes of interest for the problem at hand.
Table 5.2 through Table 5.5 provide concrete examples for each of the four categories of data and information[7]. A bottom-up approach to data modeling has

[7]Table 5.2 through Table 5.5 are not intended to provide an exhaustive overview of the data and information that need to be collected for each of the categories.

been applied in all of the projects discussed in Section 4.2. This approach results in a single enormous data model, which is hard to set up from scratch, maintain, difficult to understand, and is poorly connected to the problem context.

Table 5.2: Examples of external factors

| **Category** | **External factor** |
|---|---|
| Economy | Traffic demand and mix (regional jets, new large aircraft). |
| | Growth rates. |
| | Type of demand: business, leisure, transfer. |
| | Market share low cost carriers and other airlines. |
| | Aviation market conditions: deregulation, liberalization, globalization, competition, privatization. |
| Technology | New modes of transport. |
| | Air Traffic Management. |
| | New aircraft designs. |
| | Noise reductions: engine & airframe. |
| | Emission reductions. |
| Regulations | Noise certification standards. |
| | Emission standards. |
| | New government regulations. |
| | Rules for slot allocation. |
| Demographics | Demographic growth and distribution. |
| | Effect of noise impact and third party risks on population (distribution) and housing developments. |

*Tools*

The dispersion of tools (a number of them have been introduced previously in Section 4.1) both within and across organizations leads to inconsistencies in the assumptions and input data used for airport performance analysis.

Using these tools for planning studies is very time-consuming as previously mentioned in Section 4.1.5. For example: INM is a tool that is frequently used for land-use compatibility planning (ATAC Corporation, 2007; FAA, 1983) and for determining the effect of forecasted airport operations within the airport Master Planning context. In order to use INM, an expert needs to first create and set up an INM study, which means selecting, checking, and setting up the INM default data for the specific airport under consideration. Next, an expert needs to input data about the airport infrastructure (runways and tracks) and the airport operation, prepare noise metrics and other computational settings, run the computations,

Table 5.3: Examples of strategies.

| **Objective** | **Strategy** |
|---|---|
| Increase Airside Capacity | Additional infrastructure: runways, taxiway system design. |
| | New operational concepts and technology. |
| | Change in aircraft mix. |
| Reduce Environmental Impact | Reorganize departure (SID) and arrival (STAR) routes. |
| | Noise abatement procedures (NAP). |
| | Ban or curfews on noisy aircraft. |
| | Taxiing with one engine out. |
| | Insulation of houses. |
| | Runway allocation strategies. |
| Increase Landside Capacity | Additional landside infrastructure: new pier, terminal. |
| | New check-in procedures. |
| | Different security procedures. |
| Increase Revenues | Real estate development. |
| | Expand shopping areas. |
| | Parking services. |
| | Increase concession fees. |
| | Meeting facilities (golf course, conference centre). |

Table 5.4: Examples of system elements.

| **System** | **Elements** |
|---|---|
| Airport Airside | Runway system: runways, configurations, tracks. |
| | Taxiway system: taxiways, holding bays and areas. |
| | Apron. |
| Airport Landside | Terminal system: terminals, people movers. |
| | Parking areas and garages. |
| | Roads (circular drive). |
| Environs | Population and housing. |
| | Industry parks. |
| | Schools. |
| | Wild-life. |
| Other Systems | Air Traffic Management system. |
| | Train station. |
| | Access roads. |

Table 5.5: Examples of outcomes of interest and outcome indicators.

| **Outcome of interest** | **Outcome indicator** |
|---|---|
| Airport capacity | Runway system, gate, and terminal capacity for a peak day. |
| | Annual airport capacity. |
| Airport delay | Annual or daily delay statistics for the overall airport. |
| | Delay statistics for different airport components, such as the runway and taxiway system, apron, gates, and terminal. |
| Noise impact | Noise levels at specific locations. |
| | Noise contours. |
| | Population (annoyance) and houses affected. |
| | Effect of noise on public health. |
| | Effect of noise impact (level) on annoyance. |
| Third-party risk | Individual risk contours and group risk. |
| | Houses and population affected. |
| Emissions | Inventory of pollutant emissions. |
| | Concentration levels of pollutants (air quality). |
| Financial | Costs and revenues (e.g. used to create airport balance sheet, or to conduct cost-benefit analysis). |
| | Return on investments. |

and finally interpret the results. If another situation needs to be assessed, this process or parts of it need to be repeated.

Because of this effort, detailed Environmental Impact Statement (e.g. the analysis of noise and emissions) is usually postponed until it is more or less clear which infrastructural developments are to be included in a strategy. If all of the tools for all of the analyses are coordinated by a DSS, an integral assessment of all relevant effects of a plan can be carried out at the same time. These observations, and the need for consistent assumptions across all of the analyses, make it clear that it is more efficient and effective if all of the tools are controlled centrally.

## 5.3 DSS DEVELOPMENT PROCESS

The process that is used to develop a DSS is crucial for meeting the decision support needs. Apparently, the selection and adoption of the appropriate development process remains a problem, given the fact that most DSS development efforts fail to deliver the right DSS (Arnott and Pervan, 2005; Poon and Wagner, 2001). One of the causes is the traditional approach to DSS development, which has its roots in systems engineering. This approach does not encourage DSS developers to take a *user* and *problem* perspective.

Since the 1990s, the *Software Engineering* discipline has been growing fast, resulting in a number of software development processes, methods, and best practices that focus on adding value for the potential users. Collectively, this is called the *Agile approach* to software development[8].

An agile approach starts from the problems of the client, which we expressed in the Vision in Section 5.1, and builds the software from there. The next two sections elaborate on this by discussing both the traditional approach (Section 5.3.1) and the modern software engineering approach (Section 5.3.2).

### 5.3.1 Traditional approach

The interest in supporting human decisionmaking with computer-based systems dates from the late 1960s and early 1970s. One of the drivers that further developed the field was the availability of computing power at reasonable cost during the 1980s (Power, 2002, p.2). During that time, the ideas and concepts developed earlier were tried and tested in business applications intended to support decisionmaking.

Most DSS development efforts start from the generic design presented in Figure 5.6 as discussed in Sage (1991, p.7) and Carter *et al.* (1992, p.18), among others. The traditional DSS design features three components: (1) a Database Management System (DBMS); (2) a Model Base Management System (MBMS); and (3) a Dialogue Generation Management System (DGMS). Furthermore, an appropriate decision support system design framework is supposed to consider each of these components and their interrelations and interactions.

Sage (1991, p.163–164) suggests a systems engineering approach to DSS development, shown in Figure 5.7, which is similar to what Power (2002, p.62) calls the System Development Life Cycle (SDLC). The approach defines the following phases: (1) requirements analysis; (2) conceptual design; (3) logical design and architectural specification; (4) detailed design and testing; (5) operational implementation; (6) evaluation and modification; and (7) operational deployment. The phases are executed sequentially, but iteration and feedback *should* be applied throughout the lifecycle.

Unfortunately, on a real project with time constraints and fixed budgets, there is usually a *big-bang* approach, which tries to capture all the requirements at once, continues with a big up front design effort (also know as the anti-pattern Big Design Up Front (BDUF)), followed by one single, large implementation effort, instead of an *iterative* approach that *would* result in learning at the meta-level throughout the project (as shown in Figure 5.7). The software development process falls back on a traditional *waterfall* process, which is known to be flawed (Larman, 2003). As a result, the DSS that is developed does not satisfy the true needs of the user, and hence the DSS does not get used in practice.

[8]The agile manifesto, available at `www.agilemanifesto.org`, marks the formal start of this movement (2001).

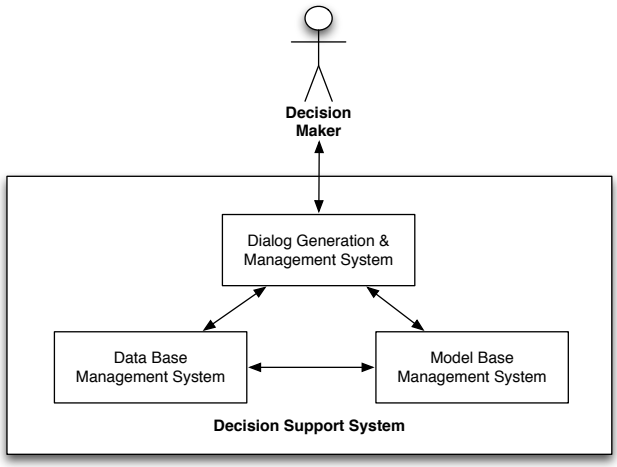



Figure 5.6: Generic design of a DSS. Source: Adapted from Sage (1991).

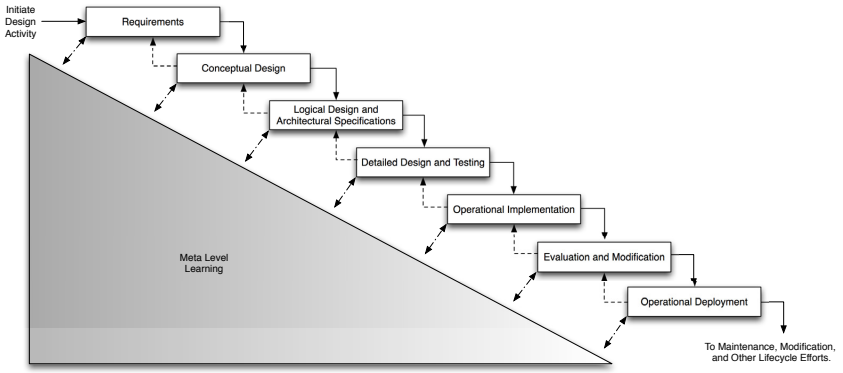



Figure 5.7: The DSS development process. Source: Sage (1991).

Recently, some new approaches to DSS design and development have been discussed. Zhang and Goddard (2005) discuss an approach that combines formalized architectural design with a component-based framework for implementation of a Web-based DSS. Klashner and Sabet (2006) present a new DSS Design Model for complex, mission-critical decisionmaking situations in the domain of electric power systems.

These new approaches are more and more based on modern software engineering practices and methods. Adopting principles and methods from the

software engineering discipline is important for more success with DSS development, but they seem to only slowly enter the DSS field.

### 5.3.2 Modern software engineering

The heart of software should be its ability to solve domain-related problems for its users, and this is exactly the goal of an agile approach to software development during the entire development lifecycle. The same goal should apply to software development that intends to provide decision support. Although software systems are usually perceived to be highly complex, it is actually the client's problems that the software tries to solve that are complex.

The challenge of complexity is not in the technical dimensions of the software, but in the domain itself, and the activity or business of the user (Evans, 2004, Section 'The Challenge of Complexity', p.xxi of the Preface). Mostly, the difficulty in the software development effort is to adequately model complex domains that have never been completely formalized before. Modeling the domain is crucial to be able to cope with a software system's complexity. Such an approach to software design is known as *Domain-Driven Design* (Evans, 2004). The core artifact created is a so-called *Domain Model*, which Evans defines as follows:

> A *system of abstractions* that describes *selected* aspects of a domain and can be *used* to solve problems related to that domain[9].

A Domain Model is actually the most sophisticated form of a *Domain Logic Pattern* (see Fowler, 2003, p.26 and p.116)). The Domain Model documents and expresses the software design in a way the potential users can directly understand because the terminology from the domain and business is used. A limited example is given in Figure 5.8: Here it is described how Traffic Demand—in terms of Airline Flights—are allocated to the Runway Ends and associated Tracks of an airport's Runway System according to the Operational Plan that specifies Runway Configurations.

Using a Domain Model means inserting a whole architectural layer, i.e. the Domain Layer. The *Domain Model* becomes the core artifact throughout the entire software development cycle. Designing and implementing a Domain Model is a very labor-intensive activity, as the Domain Model needs to capture all the relevant aspects of the domain and the business activities.

The Domain Model should be based on a *shared understanding* among developers and potential users of the system; it can thus be used to communicate about the ongoing design and implementation of the software system.

[9]Note that a Domain Model is similar to the System Model used within Policy Analysis. The System Model describes selected aspects of a policy field to come up with effective policies that address the policy problem.

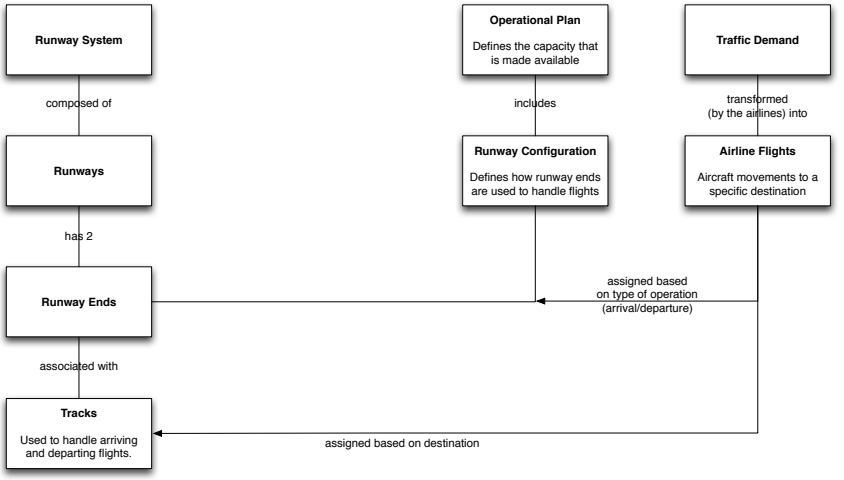



Figure 5.8: An example of a (limited) Domain Model for an airport.

A shared understanding goes hand in hand with a *common* and *shared language*, which Evans recognizes as the UBIQUITOUS LANGUAGE pattern (Evans, 2004, p.24). Defining—through the use of a Glossary (ours is partly covered by the List of Definitions in this dissertation)—and consistently using such a language is crucial for the success of a software development project.

A Domain Driven Design approach goes hand in hand with an *iterative* development process (as discussed later, see also Figure 5.9). There are many different iterative development processes, such as Extreme Programming (Beck and Andress, 2004), the Rational Unified Process (Krol and Kruchten, 2003), and Scrum.

We adopted an agile approach to the Rational Unified Process (RUP)[10] (Rational Software Corporation, 1998) as described by Larman (2005) or Ambler (2008), who calls it the Agile Unified Process (AUP)[11]. The AUP describes a simple, easy to understand approach to developing software using agile techniques and concepts, yet still remaining true to the RUP. Our adoption of this approach has earlier been described in Wijnen (2006a).

Figure 5.9 depicts the lifecycle of the AUP, showing its two dimensions. The horizontal axis shows how the process is organized along time, visualizing the dynamic aspect of the process (phases, iterations, and milestones). The vertical

[10]Rational Unified Process is a trademark or registered trademark of Rational Software Corporation in the United States and in other countries.

[11]See also `http://www.ambysoft.com/unifiedprocess/agileUP.html`

axis shows how the process is organized along content, visualizing the static aspect of the software development process. The serial nature is captured in its four phases:

**Inception.** The goal of this phase is to identify the initial scope of the project, specify a potential architecture for the software system, obtain initial project funding, and stakeholder acceptance (only the first two items apply here due to the academic nature of the project).

The initial scope of the DSS has been determined in Section 5.1. We arrived at a potential architecture by experimentation: first we built a HARMOS version without paying much attention to architectural design. Through an ad-hoc approach, we designed and implemented a HARMOS version that only focused on the design and evaluation of two distinct strategies, through the use of optimization techniques (Hebly and Wijnen, 2005; van Loo and Wijnen, 2005; Wijnen, 2004, 2005c). With this ad-hoc architecture, it turned out that it was difficult to extend the DSS so that it would provide the functionality needed to support a broad class of airport strategic problems. At that time, we decided to adopt the domain driven design approach just mentioned (see also Section 11.2 for a reflection on this).

**Elaboration.** The goal of this phase is to *prove* the architecture of the system.

This is the major goal of our DSS development effort. The HARMOS architecture in general is described in the next chapter; the HARMOS Domain Model is described in detail in Chapter 7.

**Construction.** The goal of this phase is to build working software on a regular, incremental basis that meets the *highest-priority* needs of the project stakeholders.

During this phase, *most* of the development work is done, capitalizing on the *stable architecture* that resulted from the Elaboration phase. The work to be done here requires many different skills and therefore requires a *dedicated team* of software engineers, *and* the potential users themselves. Hence, this phase is not part of our research effort. However, we discuss the global plan for executing this phase in Section 11.1.1.

**Transition.** The goal of this phase is to validate and deploy the software system in the production environment. This phase is not part of our research effort either.

As just mentioned, the disciplines are performed in an iterative manner, defining the activities that development team members perform to build, validate, and deliver working software that meets the needs of their stakeholders. The engineering disciplines are:

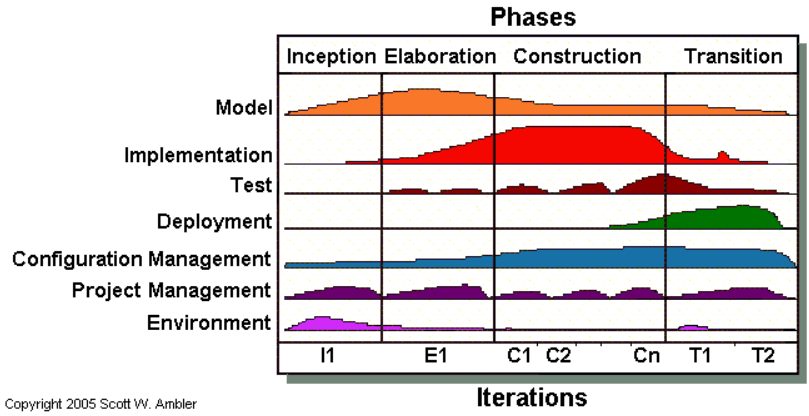



Figure 5.9: Iterative software development process. Source: Ambler (2008).

**Model: Business Modeling, Requirements, Analysis and Design.** The goal of this discipline is to understand the business of the organization (Chapter 1 and 2), the problem domain being addressed by the project (Chapter 2, 3, and 4), and to identify a viable solution in terms of software to address the problem domain (Section 5.1 and 5.2, this chapter). One of the artifacts started is the Software Architecture Document (SAD) (Wijnen, 2006e), which describes the software's architecture (see Chapter 6). The Domain Model itself is another very important artifact started during this discipline (see Chapter 7).

**Implementation.** The goal of this discipline is to transform the Domain Model into executable code and to perform a basic level of testing, in particular unit testing. The result of this discipline is the software system itself. What the DSS looks like to a user is presented in Chapter A. How the DSS is used for addressing the problems in each of the three problem areas (Section 1.2 will be discussed in Chapter 8.

**Test.** The goal of this discipline is to perform an objective evaluation to ensure quality. This includes finding defects, validating that the system works as designed, and verifying that the requirements are met. In an agile project, testing is not a separate activity. Implementation of the code is test-driven. As such, testing is built into the development process, instead of being an afterthought.

**Deployment.** The goal of this discipline is to plan for the delivery of the system and to execute the plan to make the system available to end users.

**Configuration Management.** The goal of this discipline is to manage access to the project artifacts (i.e. documentation, source code, memos, test data,

etc.). For this project, every artifact (even the LaTeX source code of this dissertation) is controlled by the Subversion[12] versioning control system.

**Project Management.** The goal of this discipline is to direct the activities that take place on the project. Within this discipline, a Software Development Plan (SDP) (Wijnen, 2006f), and Iteration Plans (Wijnen, 2005a,b, 2006b,c,d) are written. The SDP is a plan that globally describes what will be done in each of the iterations, and who is doing what. The SDP is updated regularly. The Iteration Plan (IP) is a plan that describes the activities to be executed in detail; a new Iteration Plan is written at the end of each iteration.

**Environment.** The goal of this discipline is to support the rest of the software development effort. This discipline includes setting up the software development environment, a website for sharing information among developers, among other things.

Throughout a number of iterations, the domain is explored, crunching the knowledge about the domain into the Domain Model. So, during the software development effort, the Domain Model is constantly *refined*. Instead of executing tasks in the various engineering disciplines—business modeling, requirements, analysis, design, implementation, test, and deployment—in a linear process, the software development process is divided into a number of time-boxed *iterations*. During each of these iterations, tasks in each of the disciplines are executed, resulting in a partial build of the software system at the end of the iteration (as opposed to the 'big bang' approach in which software is delivered all at once).

In the DSS field, the adoption of an iterative development process does not seem to be common practice (Kwakkel, 2006), despite the fact that many researchers have discussed such a process (Keen, 1980). Carter *et al.* (1992, p.15) is one of the few examples that describes the use of an iterative, evolutionary, and adaptive DSS development process (it was used to develop a personnel planning and management system for the United States Air Force).

The lack of using iterative development processes in the field is very unfortunate, because as a result the DSSs being developed are not very relevant to practitioners.

## 5.4 Scope of the HARMOS development effort

We discuss the scope of the DSS development effort using the elements of the system domain of the policy analysis framework (Figure 5.3):

[12] More information about the Subversion versioning control system can be found at `http://subversion.apache.org/`

**External factors.** The external factors are modeled as changes to airline flight operations (in terms of their network and fleet), changes to aircraft separation standards, changes to population (size and distribution), and changes to environmental standards. Although the (air) transport network itself is not modeled in detail, the demand by mode of transport is taken into account as an external factor. Obviously, if an airport serves as a hub in a multi-modal transport system, the fact that demand is handled by other modes of transport (e.g. train) should be accounted for.

**Strategies.** The DSS is designed such that a broad range of strategies can be evaluated. However, for providing the proof of concept for the DSS the focus is on strategies that change the infrastructure, operation, and management of the airside of an airport. Strategies related to the airside of an airport are also the most interesting in the multi-stakeholder context, because these strategies (e.g. building a new runway, introducing new noise abatement procedures) affect most of the stakeholders in a significant way.

**System.** The system representation that will be developed will be flexible, easily customizable, and covers both the technical perspective and the social perspective as shown in Figure 3.6.

The technical perspective will model the runway system in detail, including the characteristics of the individual runways and flight tracks. The taxiway system will not be considered. Neither will the terminal system be included. For the ground access system, we consider those elements of the ground access system (roads and parking lots) that are on the airport property and hence part of the airport's landside. Airport access and egress is not included in the system representation.

The social perspective will model the environs in terms of population, dose-response relationships for aircraft noise (annoyance and awakenings), and (statistical) functions describing the risk of getting killed by an aircraft crash. Also the weather is part of the environs system.

**Outcomes of interest.** The outcomes of interest considered are those related to physical capacity (Section 3.1.5), and those related to environmental capacity—noise, emissions, and third-party risk (Sections 3.2.1–3.2.3). The outcome indicators will be chosen such that the stakeholders can have a fruitful discussion about strategies related to their objectives. So, with respect to, for example, the noise outcome of interest, not only noise contours are used, but also population counts, people annoyed, people highly annoyed, and awakenings (see Table 3.1).

Other environmental impacts, such as waste, or ecological impacts will not be considered. The reason for this is that strict laws are usually already in place to regulate these impacts (Wells and Young, 2004, p.359–361). But, if needed such impacts could readily be included during the customization process of the DSS.

> Although it is important for decisionmaking, we do not consider the economic or financial implications of strategies. The reason to exclude these effects is the fact there is no generic way of evaluating the financial implications of a strategy. The financial evaluation of investments is highly dependent on the type of organization and the decisionmaking style (Akalu, 2003; Carr and Tomkins, 1996). Traditional CBA for airport investments (FAA, 1999; ICAO, 2006) could be useful when assessing strategies that involve investments in infrastructure. CBA—according to FAA or ICAO guidelines—or cash-flow analysis—according to the airport operator's accounting and project appraisal practices—would then provide additional outcome indicators (i.e. columns in the scorecard), such as Net Present Value (NPV), Return On Investment (ROI), payback period, or Internal Rate of Return (IRR). However, quantifying these indicators requires many assumptions, and determination of cost and revenue centers, which depends on the way an airport operator is making money and funding its investments (de Neufville and Odoni, 2003, p.247-257). Therefore, adding economic/financial performance as an outcome of interest should be done as part of the customization effort for a specific airport operator. Besides this, in traditional strategic planning the focus is almost exclusively on financial performance, which did more harm than good to the strategy making process (see also the discussion in Section 2.1).

Daily airport operations are not the primary subject of this thesis, but they are important to consider. The rules used in operational planning are highly important input for strategic planning studies. The rules used for the day-to-day operations define in detail how the different systems within the airport system are used for processing traffic units, i.e. the passengers, cargo, and aircraft. These so-called *production rules* are important input, because they explain how the airport is managed today, and as such those rules can be used as a starting point for defining strategies for managing the airport of the future. This is why the role of domain expert (i.e. managers and staff involved in the day-to-day operations) has been identified as a user for the DSS. The production rules are also used to define the business as usual strategy, which is used as a reference when comparing strategies.

Our DSS development effort focuses on the design of functionality that covers all three phases of problem solving—formulation (Step 1–3 of the policy analysis process), analysis (Step 4–6 of the policy analysis process), and formulation (Step 7 of the policy analysis process).

We also recognize that supporting the problem solving needs to facilitate both a divergent mode of thinking (i.e. when thinking about different plausible futures to be captured with scenarios, or when identifying objectives, and strate-

gies) as well as a convergent mode of thinking (i.e. when identifying outcome indicators, evaluating and comparing strategies).

The result of the development effort will not be a fully featured business application. A proof of concept will be provided for the HARMOS DSS (see also Section 1.6). The proof of concept is demonstrates how the HARMOS architecture is able to address specific problems in each of the three problem areas. The proof of concept coincides with the Lifecycle Architecture Milestone (LCA) in Figure 5.9. From there, the DSS can be grown further into a business application for a specific airport operator and its stakeholders.

## 5.5 Summary and conclusion

This chapter *captured* the knowledge that has been brought together in Part I of this dissertation and translated that into a vision and conceptual design for the DSS. We also presented a modern, problem-oriented approach for developing the DSS, as opposed to the tool-oriented approach described in Chapter 4.

In addition to Section 1.3 'Motivation for a decision support system', this chapter provided a more detailed motivation for a DSS as a way to improve airport strategic planning . The key design principles driving the design of the DSS have also been presented in detail.

The main reason to propose a DSS is because only a computer-based system can provide coordination of resources and execution of repetitive tasks to involve improve the efficiency the problem-solving process (Problem Area III). However, it is important to design the DSS such that it also addresses the other two problem areas with airport strategic planning, i.e. the inadequate approach for dealing with the future (Problem Area II) and the lack of involvement of stakeholders (Problem Area I). This requirement can be met by adopting the policy analysis approach as a key design principle for the DSS. Policy analysis provides both the framework and process needed to explicitly deal with uncertainty and multiple stakeholders.

The second principle that is used for the DSS design is the integration of resources, explicitly dealing with people, data and information, and tools. Both principles have been put into practice during the agile software development process, resulting in the DSS architecture discussed in the next chapter.

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CHAPTER 6

# Architecture of the HARMOS DSS

Who needs an architect?

MARTIN FOWLER

In order to improve the current approach to airport strategic planning, all three problem areas (discussed in Section 1.2) needs to be addressed concurrently. The previous chapter identified a DSS as a solution to meet this requirement (Section 5.1.3), and presented the key principles used for designing the DSS.

The first design principle is the policy analysis approach as a basis for conducting strategic planning studies (Section 5.2.1). The policy analysis *framework* structures the planning problem from a *systems point of view*, making a clear distinction between forces *outside* the control of decisionmakers (external factors, captured by a *scenario*) and forces *under* the control of decisionmakers (structural, operational, and managerial changes to the system, represented as a *strategy*). The framework also provides explicit consideration of *objectives* from not only the airport operator, but the airport *stakeholders* as well. The policy analysis *process* structures problem-solving; it provides a number of logical steps for *formulation*, *analysis*, and *interpretation* of a strategic planning problem.

The second design principle is the integration of resources from a broad perspective (Section 5.2.2). People (and their knowledge), data and information, and tools are embedded in a unified structure so that they can be readily deployed to work on strategic planning problems. With respect to people, we have introduced a conceptual model that dintinguishes among people with the *roles* of decisionmaker, decision advisor, and domain expert. The HARMOS DSS supports

each of these roles in coordinating data and tools and organizing information within the context of the strategic planning problem.

This chapter describes how the design principles drive the design of the Software Architecture (SA) of the HARMOS DSS. Architecture is an important design artifact, which can be created and described in many ways. Section 6.1 briefly presents how we define architecture, and which approach we used for documenting it. Sections 6.2 and 6.3 describe two views on the HARMOS architecture itself. A summary is provided in Section 6.4.

## 6.1 SOFTWARE ARCHITECTURE

We adopt the definition for Software Architecture (SA), given by Medvidovic *et al.* (2007)

> A software system's architecture is the set of principal design decisions about the system.

Design decisions encompass every aspect of the system under development, such as (1) system structure, (2) behavioral or functional requirements, (3) interaction among system elements, (4) non-functional requirements, (5) the system's development itself, and (6) the system's business position (i.e. how does the software fit into the market for decision support solutions).

The importance of architecture has increasingly been recognized since the 1990s. Early software engineering research and software development focused primarily on technological aspects of architecture. Only recently has the need to also address domain aspects and business aspects been recognized (Medvidovic *et al.*, 2007). Figure 6.1 shows each of the three aspects: technology, domain, and business. Each of them needs to be covered when designing the architecture of a software system.

Within this research, we are dealing with: (1) aviation in general, and airports specifically as the domain, including the scientific disciplines to investigate them (i.e. aeronautical engineering and policy analysis are also part of our domain); (2) strategic planning as the business activity; and (3) DSS engineering concepts, object-orientation, and the PYTHON programming language (Chun, 2007; Hetland, 2005), as the technology.

Obviously, these areas overlap. Airport strategic planning is at the cross-section of domain and business. Therefore, we looked at strategic planning from both the business point of view (Section 2.1) and the airport domain point of view (Section 2.2), in order to understand how the concept should be understood

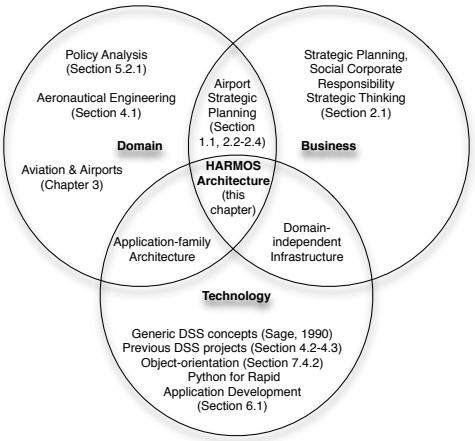


Figure 6.1: The overlapping areas of domain, business, and technology aspects. Source: Adapted from Medvidovic *et al.* (2007).

(Research Question 1, see Chapter 2). The other cross-sections are not very relevant here[1].

It is essential that all three aspects are covered when designing the architecture of a DSS, positioning DSS architecture in the center of Figure 6.1. Actually, we focused mainly on the domain and business aspects, because these aspects bring forward the complexity that should be tackled by the architectural design.

The latest technology is not needed to address the problems with airport strategic planning. New software technologies usually have a large appeal on DSS researchers, but these technologies do not solve problems. Yet, much DSS research focuses more on the use of new technology than on the needs of decisionmakers. Or, as Bui (2008) stated at the 2008 International Conference on Collaborative Decision Making (CDM08): 'We are good at playing with new technology'.

It is much more important to have a deep understanding of the aviation and airport domain and the strategic planning activity, and iteratively embed this understanding in the DSS and Domain Model under development.

A strong focus on technology is just the reason why the development of computer-based systems to support airport strategic planning has not been very successful (as was shown by our analysis in Section 4.3). Because of this, we

[1]The cross-section between domain and technology is about application-family architecture (Rosel, 1998). The cross-section between business and technology is about domain-independent infrastructure. Information technologies for financial planning and control are examples of this.

selected PYTHON[2] to implement the DSS. PYTHON is an object-oriented programming language, which provides many modules that can readily be used for realizing parts of the functionality of the DSS (e.g. modules for dealing with a DBMS, the wxPython[3] framework for building the GUI, and more).

In order to describe the DSS architecture, a method for presenting and documenting a software system's architecture is needed. We use the approach from Kruchten (1995), who uses five concurrent views to present and document software architecture. These views are:

**Logical View.** This view describes the structure of the system. The overall structure of the HARMOS DSS is presented in Section 6.2. The heart of the HARMOS DSS, the Domain Model, is presented separately in Chapter 7.

**Process View.** Describes the design's concurrency and synchronization aspects. We use it to describe the interaction between the DSS and each of the tools, which are different computer processes (see Tse (2006)).

**Development View.** Describes the software's static organization in its development environment. This view is shown in Figure 6.2.

**Physical View.** Describes the mapping of the software onto the hardware reflecting its distributed aspect. This view is not used.

These four views are supplemented by a fifth view—the Functional View—which describes the functionality of the DSS. The Functional View is the central view that drives the design, implementation, and testing of the architecture. It is presented in Section 6.3.

## 6.2 LOGICAL VIEW OF THE ARCHITECTURE

The Logical View of the HARMOS architecture is presented in Figure 6.3, which shows the structure of the DSS, its users, and the interface between the DSS and existing resources.

The DSS has a layered design based on the Layers pattern (Larman, 2005, p.202), with each layer partitioned into modules (also known as packages, see the description of the MODULE pattern in Evans, 2004), each of which has a

[2] PYTHON is a fully object-oriented scripting language, used from system's administration to application development. More information can be found on `http://www.python.org`. An example of a company using PYTHON is Industrial Light & Magic, the visual effects company that created STAR WARS. They use PYTHON to glue together the thousands of computers and hundreds of software components used in its computer graphics production pipeline.

[3] wxPython is the PYTHON port of the wxWidgets GUI framework. More information can be found on `http://www.wxpython.org`.

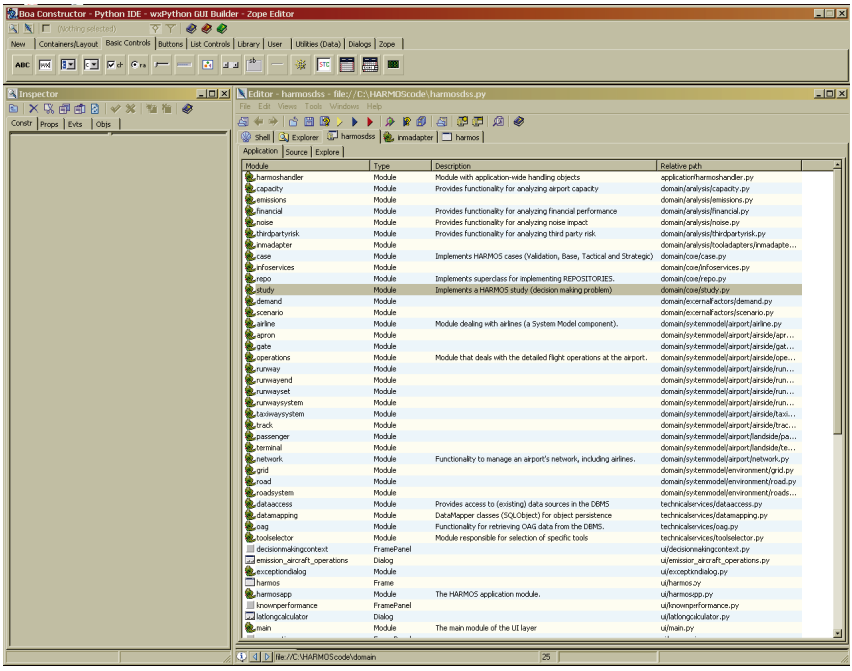


Figure 6.2: Screenshot of the Boa Constructor Integrated Development Environment

clear responsibility[4]. Within the modules there is a further partitioning into submodules and classes so that the design is truly modular, making the DSS easy to maintain, extend, and customize for a specific airport organization (more on that in Section 11.1.1). Three layers have been designed:

**Graphical User Interface Layer.** This layer is the interface between the DSS and its users. The DSS users are directly related to the roles defined in the conceptual model (previously discussed in Section 5.2.2 and shown in Figure 5.5). So, decisionmakers, decision advisors, and domain experts are the users of the DSS.

**Domain Layer.** The Domain Layer provides the domain and business related functionality of the DSS. The Domain Layer incorporates the Domain Model, introduced earlier in Section 5.3.2.

[4]Responsibility-Driven Design was conceived in the 1990s as a shift from thinking about objects in terms of data and algorithms, to thinking about objects as roles and responsibilities (Wirfs-Brock and McKean, 2002).

**Technical Services Layer.** The Technical Services Layer incorporates lower-level, more generic services used by the higher-level layers.

As shown in the Logical View in Figure 6.3, the HARMOS DSS is not intended to be a stand-alone system. A stand-alone system is a software system that does not depend and/or interact with any other software or Information Technology (IT) infrastructure within a company. Software that is designed as a stand-alone system (although it might need a specific need) is often not used, because it does not fit well into the business process and IT infrastructure (Fowler, 2003).

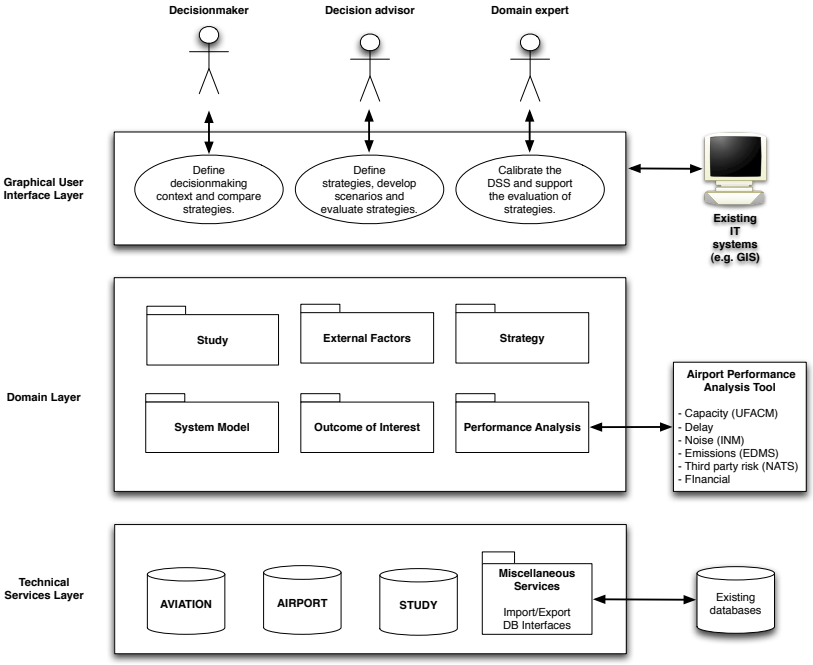


Figure 6.3: Logical view of the HARMOS architecture.

HARMOS can be customized so that existing IT systems interact with the DSS. For example, Geographic Information System (GIS) (Keenan, 2003) already in use at the airport operator's organization could be connected to HARMOS for visualization of the airport's infrastructure (e.g. taxiways, runways, tracks, roads and terminal buildings) or for presentation of geographical information, such as population densities, noise impacts, emissions, and third-party risks (Li, 2006).

Figure 6.3 also shows how the DSS integrates the resources involved in a strategic planning effort. The architecture of the HARMOS DSS provides differ-

ent ways to integrate and coordinate the resources within the airport operator's organization and its stakeholders (Section 5.2.2):

- The GUI exposes functionality for all the roles—decisionmaker, decision advisor, and domain expert—of the *people* involved in an airport strategic planning effort (Section 2.4.1);
- Multiple databases are used to organize the *data* needed within the strategic planning study (Section 2.4.2). An interface to existing database management systems is also provided for the retrieval of company-specific data that are to be used within strategic planning studies;
- The policy analysis framework structures the strategic planning problem and as such organizes the *information* that is relevant to the strategic planning problem (Section 2.4.2);
- Tool Adapters, included in the Performance Analysis module, provide access to the *tools* for airport performance analysis (Section 2.4.3) already available within the organization or the default set of tools provided with the DSS.

If we compare the HARMOS architecture to the OPAL, ABS, or SPADE architectures (Section 4.2), two observations can be made: (1) each layer of the HARMOS architecture is primarily focused on organizing the strategic planning problem instead of organizing data and tools; and (2) the HARMOS architecture extends beyond providing functionality for airport performance analysis supporting only a manager or expert (see also the narrow scope of most DSS development projects in Section 4.3).

The architectural layers are further discussed in the next sections. Chapter 7 discusses the Domain Model in much more detail.

### 6.2.1 Graphical User Interface Layer

The GUI layer is the interface between the DSS and its users. The HARMOS users are related to the roles defined in the conceptual model presented previously in Figure 5.5 (Section 5.2.2).

Decisionmakers, decision advisors, and domain experts are the users of the DSS. The people adopting these roles can be from the airport operator's organization or its stakeholders (and may all be the same people). Through the GUI, the users conduct the following tasks:

- **Decisionmakers** define the decisionmaking context and disseminate and share information related to decisionmaking. Decisionmakers from the airport operator and its stakeholders compare the business as usual strategy with other strategies that have been evaluated so that they can determine which strategy is collectively preferred for implementation;

- **Decision advisors** develop scenarios describing different plausible futures, identify strategies that potentially solve the problem or seize an opportunity, and assess the strategies in terms of the airport's performance within each of the scenarios;
- **Domain experts** support the decision advisors in the preparation, execution, and evaluation of quantitative analyses of the airport's performance in terms of capacity, delay, noise, emissions, and third-party risk.

The current GUI implementation is based on the wxPython GUI framework and was developed with Boa Constructor, which is an Integrated Development Environment (IDE). Most of the GUI code itself has been generated from the GUI builder that Boa Constructor provides. The GUI builder provides a WYSIWYG ('What You See Is What You Get') editor for laying out the different GUI elements, such as menus, frames, panels, buttons, listboxes, and other widgets.

The GUI layer itself is not discussed any further. The version of the GUI that finally resulted from the implementation of this layer is presented in later Chapter A.

### 6.2.2 Domain Layer

The Domain Layer provides the domain-specific functionality of the software system. The Domain Layer provides an object-oriented model, i.e. the Domain Model, providing support to conduct efficient and effective airport strategic planning studies. The Domain Layer is divided into modules, each having a clear and focused responsibility.

The definition of the modules is not made from the developer's point of view—most likely resulting in a structure that nobody else can understand—but is inspired by the domain (Evans, 2004, p.109). In order to identify modules, the concepts from the domain need to be discovered and defined consistently. A *Glossary* is therefore an important artifact within the software development process (see the List of Definitions).

Six modules have been defined such that a HARMOS user is able to solve a broad class of airport planning problems. These six modules and their responsibilities are:

**Study module.** Its primary responsibilities are capturing the context of a planning problem (i.e. the stakeholders and their objectives) and to keep track of the scenarios and strategies that have been defined. The module also provides services for obtaining general information needed by other modules (e.g. information about airlines and aircraft types). Its second responsibility is to translate information from the problem space to the tool space so that strategies can be evaluated in terms of the outcomes of interest for a specific period of interest.

**External Factors module.** Responsible for providing support for building scenarios. The module provides functionality for organizing the information needed to define the scenario space that is to be considered for the study. It also provides functionality for capturing qualitative and quantitative data about the external factors related to specific economic, technological, demographic, and regulatory developments used within each of the developed scenarios.

**Strategy module.** Responsible for keeping information related to strategies i.e. changes to the airport's infrastructure, operations, and management.

**Outcomes of Interest module.** Responsible for organizing a collection of outcome indicators for a specific aspect of the airport's performance—capacity and delay (Section 3.1.5), noise (Section 3.2.1), emissions (Section 3.2.2), and third-party risk (Section 3.2.3).

**System module.** Responsible for providing a representation of the current airport system, including both a technical perspective (Section 3.1) and a social perspective (Section 3.2) as illustrated in Figure 3.6.

**Performance Analysis module.** Responsible for computing the airport's performance (including pre- and post-processing) in terms of specific outcome indicators, using tools for airport performance analysis.

Most of the module definitions (i.e. the external factors, strategy, system, and outcomes of interest module) are based on the policy analysis framework (Figure 5.3) as to organize the information within a strategic planning study.

The study module has been defined to organize the planning effort as a whole. The performance analysis module has been defined to provide computational services using external tools for airport performance analysis.

### 6.2.3 Technical Services Layer

The Technical Services Layer incorporates lower-level, more generic services used by the higher-level layers, mainly providing functionality for disclosing data needed for setting up a study or permanently storing the user-generated information within a study. Three types of databases are incorporated:

**Aviation database.** Includes generic data, such as the world's airlines based on industry data as provided by FlightGlobal (2006), aircraft characteristics (e.g. flight performance, noise and emissions data), International Air Transport Association (IATA) and ICAO codes, and latitude/longitude coordinates for airports around the world.

**Airport database.** Includes airport-specific data, such as traffic demand data (based on the OAG format and data[5]), historic wind data, and general data related to the external factors.

[5]This data is based on the OAG Max product.

**Study database.** Includes data and information related to a specific study (i.e. the decisionmaking context, scenarios, strategies, the system, and the results of strategy evaluations).

Another module that is included in this layer provides miscellaneous services, such as data import and export functionality and functionality to interface with existing databases within the airport operator's organization. The Technical Services Layer is not further discussed.

## 6.3 FUNCTIONAL VIEW OF THE ARCHITECTURE

In order to define the user-specific HARMOS functionality, *use cases* have been written. Writing use cases is a very effective method for identifying the actors, and identifying and specifying the functional requirements of a software system (Cockburn, 2001). Use cases describe the *interaction* between a software system and its actors and are *goal-oriented*.

For a software system, typically three categories of actors can be distinguished: primary, supporting, and off-stage actors. The primary actors are those actors that have their goals fulfilled through using services of the system. They need to be identified because through them the user goals, which drive the use cases, are found. The primary actors follow directly from our conceptual model in Figure 5.5 (presented in Section 5.2.2) and are the decisionmaker, decision advisor, and domain expert (already shown in Figure 6.3. Besides these three primary actors, there is a fourth primary actor, namely the Application Manager, who is the IT expert with specific installation and maintenance experience with the DSS (not further discussed).

A supporting actor provides a service to the system. This is often a computer system, but it can also be an organization. The most important supporting actors for HARMOS are the tools for airport performance analysis.

An off-stage actor is an actor that has an interest in the software system, but is not directly using it. Depending on the organizational structure of an airport operator, a decisionmaker could actually be an off-stage actor.

The goals of the primary actors that we identified are listed in Table 6.1, which also shows the sections that describe the DSS-user interactions that attain these users goals.

In most cases, the goals are used as the titles for a use case. These use cases are so-called *black box* use cases and describe what a system will do, not how it will be done. However, the use cases *Execute Performance Analysis* and *Specify System Characteristics* are not user goals, but subfunctions that are indirectly used by domain experts. These are so-called *white box* use cases, which document the internals of the system (Cockburn, 2001, pp.40–41). The

Table 6.1: Actor-goal list

| Actor | Goal | Section |
|---|---|---|
| Decisionmaker | Define Decisionmaking Context | 6.3.1 |
| | Compare Strategies | 6.3.8 |
| Decision Advisor | Define Decisionmaking Context | 6.3.1 |
| | Develop Scenarios | 6.3.4 |
| | Define Strategy | 6.3.5 |
| | Evaluate Strategy | 6.3.6 |
| Domain Expert | Calibrate Study | 6.3.2 |
| | Specify System Characteristics (subfunction) | 6.3.3 |
| | Execute Performance Analysis (subfunction) | 6.3.7 |
| | Develop Scenarios | 6.3.4 |

use case Execute Performance Analysis, for example, describes how the tools for airport performance analysis interact with the HARMOS DSS.

Both are included here because of its architectural importance. The Execute Performance Analysis subfunction because it provides an interface between the DSS and tools for airport performance analysis (e.g. the ones mentioned in Section 4.1). The Specify System Characteristics subfunction because it provides the basis for specifying an airport system in a way that is familiar to the people involved in planning studies.

The collection of use cases is called a Use Case Model (UCM). The use case diagram shown in Figure 6.4 is a graphical presentation of the Use Case Model (Cockburn, 2001, p.128). However, a use case diagram provides only a high-level overview of the DSS functionality. A use case diagram is not that useful for requirements analysis, because a diagram cannot capture the user-DSS interactions in enough detail.

The next sections present the use cases briefly in textual form (see the third column in Table 6.1). Within the HARMOS software development process, use cases in fully dressed format have also been written (2 to 3 pages of text, see Tse (2006) and Vreeswijk (2007) and Cuijpers (2008)).

### 6.3.1 Define Decisionmaking Context

Airport management needs to revisit its strategies from time to time in order to evaluate whether the strategies are still adding value to the company, its customers, and its stakeholders. In order to do that, the effect of strategies on the airport's performance need to be assessed against multiple plausible futures and compared to the objectives of the decisionmakers of the airport operator and its stakeholders.

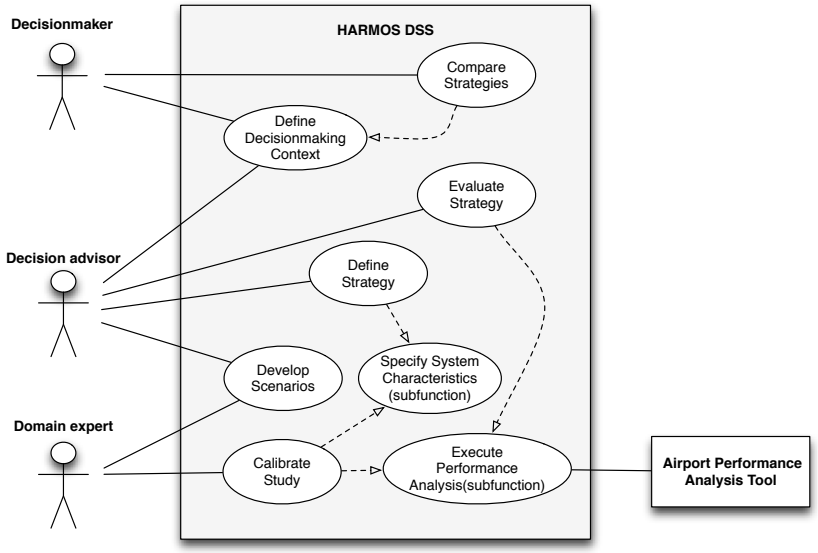


Figure 6.4: Functional view of the HARMOS architecture.

The actual assessment of strategies is done within a specific decisionmaking context. Decisionmakers from the airport operator and its stakeholders discuss this context. More specifically, the *problem* at hand or *opportunity* to be seized is tentatively defined, the *objectives* of the decisionmakers of the airport operator and the stakeholders are identified, the *outcome indicators* to be used for quantifying the effects of the strategies is discussed.

Based on the results of the discussion among decisionmakers, the decision advisors create and set up a new *study* within the HARMOS DSS. Within the newly created study, a decision advisor:

1. Defines the planning period;
2. Documents the problem or opportunity;
3. Specifies the objectives of the airport operator and its stakeholders;
4. Selects the outcome indicators to be used for the assessment of strategies.

The functionality described in this section supports the formulation phase of problem-solving and is directly related to Steps 1–3 of the policy analysis process—identify the problem, identify objectives, and decide on outcome indicators.

### 6.3.2 Calibrate Study

A decision support system needs to be trustworthy, i.e. the results it provides should be trusted by its users and have an accuracy that is appropriate for the decision problems it intends to support (Sage, 1991). Obviously, design choices affect the trustworthiness of a DSS.

However, the data and information that are used within the DSS play an equally important role. Two categories of data and information should be distinguished here: (1) data and information that are used to set up the system model that describes the airport, its environs, and the ATM system, and (2) data and information that are created and generated when investigating a particular planning problem.

The first category of data and information should be selected such that the airport performance *computed* with the HARMOS DSS is within the same order of magnitude of the *known* airport performance. Because this data and information are used as the basis for an entire planning study, it is very important to perform a calibration.

Right after a new study is created (see Section 6.3.1), domain experts calibrate the study using a past year, which is called the *calibration year*. Calibration involves the following steps:

1. Specifying the characteristics of the system (this is a separate use case described in the next section), the annual demand for the calibration year, and the operational plan that defines how airport capacity is used to handle this demand;
2. Decision advisors and domain experts collect existing information about the airport's performance for the calibration year, using HARMOS to store that information;
3. Domain experts compute the airport's performance in terms of capacity, delay, noise, emissions, and third-party risk for the calibration year including some specific days of interest within that year;
4. Decision advisors compare the *computed* performance (Step 3) with the *known* performance (Step 2). If they are close enough, the calibration process is successful. If not, the domain experts should carefully review the data and information that was used for characterizing the system, adjust tool settings, and check the information about known performance.

The calibration process is not explicitly defined as a step in the policy analysis process (see Figure 5.4); it is usually an activity conducted only once by the analysts and modelers involved in a policy analysis study (van Daalen *et al.*, 2002). The DSS, however, needs to support calibration by default, since calibration is needed every time a new strategic planning study is started.

### 6.3.3 Specify System Characteristics

This is Step 1 of the calibration process (see Section 6.3.2). In this step, the characteristics of the system—the airport, the airport environs, and the ATM system—which are required for quantifying airport performance, is specified. The HARMOS DSS automatically creates the structure of the system representation, which captures the relevant elements from the socio-technical system described in Chapter 3. HARMOS presents this structure to the domain expert, who specifies each of the specific elements and their characteristics (for examples, see Table 5.4). Domain experts and/or decision advisors specify:

1. General information, such as the airport's name, origin, elevation, and opening hours;
2. Detailed characteristics of the airside, such as runways, tracks, taxiways, aprons, aircraft stands. For example: For a runway very specific data needs to be specified, such as its designators, designator coordinates, informal name, width, surface type, lighting equipment, slope, and navigation aids;
3. Detailed characteristics of the landside, such as passenger and freight terminals, people movers, parking facilities, test-run facilities, and roads;
4. Detailed characteristics of the airport environs, such as the long-term average meteorological conditions, wind conditions, population distribution, residential, rural, and undeveloped areas;
5. Aircraft separation standards for different meteorological conditions, representing the state of the ATM system.

The functionality described here is not explicitly mentioned in the steps of the policy analysis process (see Figure 5.4). Developing a system representation is, however, an essential activity within a policy analysis study (van Daalen *et al.*, 2002; Walker, 1981).

### 6.3.4 Develop Scenarios

Scenarios are used to test the strength and robustness of the strategies. Building scenarios is not directly supported by HARMOS because it is a creative and interactive process among decisionmakers and scenario planners that cannot and should not be automated (van der Heijden, 1999).

A decision advisor (experienced in scenario planning) facilitates the creative process of building the scenarios. The steps, according to van der Heijden *et al.* (2002), of the scenario building process are: (1) identify the major uncertainties the decisionmakers are facing in the context of the planning study; (2) identify the driving forces (and their impacts) within the (business) environment (3) organize the driving forces in higher level clusters; (4) position the clusters within the so-called uncertainty/relevance matrix; (5) take the two clusters that are most relevant and uncertain to define the dimensions of the scenario space; (6) define

the scenario space (four scenarios), which are characterized using extreme states of the driving forces; and (7) name the scenarios uniquely and write the storylines. Decision advisors store the information generated during each of these steps within the DSS, so that it is available for later use.

Next, the decision advisors and domain experts quantify each of the scenarios. Decision advisors use the data used for calibration of the study as a starting point for quantifying the external factors for each of the four scenarios. The following information is combined consistently into a specific scenario: (i) economic developments that drive traffic demand; (ii) technological developments affecting ATM system performance, aircraft performance, noise and emissions, and aircraft accident rates; (iii) demographic developments, specifying the density and distribution of people living in the vicinity of the airport; (iv) regulatory developments, imposing constraints on some of the aspects of an airport's operation.

The functionality described in this section is directly related to Step 4 of the policy analysis process—developing scenarios.

This use case has been improved and refined by Cuijpers (2008). The purpose of his work was to: (i) better understand the driving forces of airline behavior—one of the major future uncertainties that an airport operator has to deal with—in general and for Brisbane Airport specifically, and (ii) create a more detailed design of the HARMOS Scenario Builder—the GUI component that exposes this functionality to the users (later discussed in Section A.4).

### 6.3.5 Define Strategy

Implementing strategies that add value to the organization as well as its stakeholders is essential for any business. Strategies that are identified typically fall in one of these three categories:

**Expand capacity** e.g. extend a runway or build a new runway, or improve the performance of the ATM system.

**Manage demand** e.g. set curfews, ban noisy carriers, introduce pricing policies, or prohibit night flights.

**Revisit operations** e.g. introduce noise abatement procedures, use alternative fuels for ground support equipment, place noise barriers, redesign take-off and landing procedures, or change the use of runway configurations.

So, there are many strategies to choose from (for examples, see Table 5.3). Each specific strategy will have a different effect on the airport's performance, and hence be more or less satisfying to a particular stakeholder. It is therefore important to explore as many strategies as possible.

Decision advisors use HARMOS to specify those strategies so that their effect on airport performance can be evaluated (described in the next section) for each of the scenarios that have been developed (as described in the previous section).

The decision advisors define a strategy within the DSS by giving it a unique name and specifying how it affects the infrastructure, operations, and management of the airport. Domain experts might help with specifying the details of a strategy. For example: suppose a decision advisor identifies a strategy *build new runway*. Domain experts would then specify the characteristics of the new runway (location, tracks, type of landing system used, etc.) and its planned operational use.

Decision advisors also specify all the necessary details related to the strategy's implementation. The most important detail is obviously the specific point of time within the planning period when the changes to the system as defined by the strategy come into effect (e.g. the new runway becomes operational on August 31, 2015).

One strategy that is included by default by HARMOS is the Business as Usual strategy. This strategy defines changes to the system for the entire planning period according to a strategy that is not fundamentally different from the airport's current strategy. The business as usual strategy is used as a reference for assessing new strategies.

The functionality described in this section is directly related to Step 5 of the policy analysis process—define strategies.

### 6.3.6 Evaluate Strategy

Each strategy defined within a study (described in the previous section) needs to be evaluated for all the scenarios (see Section 6.3.4). Without such an evaluation, the airport operator and its stakeholders cannot truly make reasonable assessments about the effectiveness of a strategy in addressing a problem or seizing an opportunity.

The lack of quantification of specific strategies proposed by either an airport operator or one of its stakeholders often causes gridlock during the implementation of a chosen strategy. Airport stakeholders usually oppose a strategy whose effects have not been discussed with them, because the effects cannot be valued in terms of their objectives (Problem Area I, Section 1.2.1).

Decision advisors, therefore, evaluate each strategy defined within the study against all of the scenarios that have been developed. For each strategy, the decision advisor selects the appropriate indicators for each outcome of interest—capacity, delay, noise, emissions, and third-party risk.

The decision advisor selects specific periods of interest (either a year or a day) within the planning period and runs a performance analysis for each of the outcomes of interest.

The HARMOS DSS executes the specific performance analysis, calling upon the computational services of the appropriate tools for the airport performance analysis (described in the next section). The decision advisor or domain experts

use HARMOS to execute tools for capacity, delay, noise, emissions, and third-party risk analysis, so that the results in terms of the outcome indicators can be evaluated.

The functionality described in this section is directly related to Step 6 of the policy analysis process—evaluate strategies.

### 6.3.7 Execute Performance Analysis

When a decision advisor is evaluating a strategy (see previous section), the airport's performance for a given outcome of interest—capacity and delay, noise, emissions, or third-party risk (see Table 5.5 for concrete examples)—needs to be quantified for each of the periods of interest selected by the user.

HARMOS converts the information from the problem space—the state of the system as a result of the external factors (consistently specified by the scenario) and the strategy for the period of interest that is being investigated—to input data for one or more tools, executes the tools, processes the output data from the tools, and returns the results to the decision advisor.

Returning to the example of conducting a noise analysis with the INM, as previously mentioned in Section 5.2.2, the sequence of events is the following:

1. HARMOS retrieves the outcome indicators (e.g. noise contours and areas, population counts) that have been selected by the decision advisor;
2. HARMOS checks whether all the input data required to quantify the selected outcome indicators are available;
   a) If all the input data are available, HARMOS proceeds to step 3;
   b) Some input data are missing (e.g. census data, departure/arrival tracks), HARMOS notifies the user so that he/she can add the appropriate data (probably with the help of domain experts).
3. HARMOS performs the noise analysis:
   a) HARMOS automatically creates an INM study, retrieves the appropriate data from the system representation, and converts the data into specific input for INM (pre-processing);
   b) HARMOS initiates INM, sends it a message to start the actual computations, and shuts it down when it is finished (tool execution and control);
   c) HARMOS retrieves the results from INM, and converts the results into the appropriate format for presentation within the problem context. When noise contours and population counts have been requested, the contours are plotted on a background map, and calculations are made to determine the number of people inside those contours (post-processing).

HARMOS executes similar steps to obtain information about other performance aspects (capacity, delay, emissions, and third party risk). Tse (2006) specified this use case for executing capacity analysis. Vreeswijk (2007) specified this use case for executing emissions analysis.

So, HARMOS takes care of many of the repetitive activities that are usually done manually. This functionality is related to activities conducted within Step 6 of the policy analysis process—evaluate strategies.

### 6.3.8 Compare Strategies

Once all of the strategies have been evaluated for all of the scenarios (see Section 6.3.6), the results need to be presented to the decisionmakers of the airport operator and its stakeholders. The numerous and diverse effects of a strategy on the airport's performance need to be summarized and presented in a way that facilitates the comparison and ranking of the strategies.

HARMOS uses a disaggregate approach to presenting its results (as previously motivated in Section 5.2.1), in which the effects of the strategies are presented in the form of tables called *scorecards*. An example of a scorecard has been previously shown in Table 5.1.

HARMOS generates a scorecard for each scenario presenting the effects on the airport's performance for each of the strategies. The scorecards are then used as a means for discussion between the decisionmakers of the airport operator and its stakeholders in order to make a choice for the preferred strategy or strategies to be implemented.

The decisionmakers of the airport operator and its stakeholders might also decide to ask for more analysis, either because none of the strategies that have been evaluated can satisfactorily meet their objectives or there is the need to evaluate strategies not thought of before.

This functionality is directly related to Step 7 of the policy analysis process—compare strategies.

## 6.4 SUMMARY

This chapter *formalized* knowledge by turning our DSS vision and conceptual design into a Software Architecture.

The Software Architecture of the HARMOS DSS was presented by discussing both the Logical and Functional View. The Logical View showed how the DSS is structurally organized and how it interfaces with its users and tools for airport performance analysis. The Functional View identified the HARMOS users and identified their goals. Based on the user's goals, use cases have been written that describe the user-HARMOS interaction.

Both the Logical and Functional View illustrate how policy analysis and integration (Section 5.2, 'Key design principles') drove the design of the HARMOS DSS. The Logical View makes clear how the people, data and information, and the use of tools have been integrated. The design of the Domain Layer in terms of modules shows how the policy analysis framework has been used to organize a strategic planning problem. The Functional View shows how the steps defined in the policy analysis process have been incorporated into the user functionality of HARMOS.

The black box use cases presented here describe only the actions performed by the user and the DSS ('what is done'), not how they are actually *realized*. The next chapter describes how the HARMOS Domain Model has been designed in detail, showing how the HARMOS DSS realizes the functionality that has just been described.

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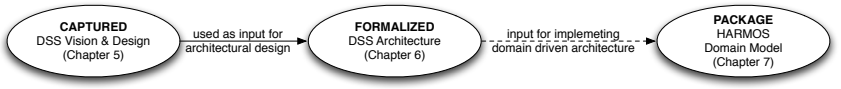
# Summary Part II




This second part of the dissertation answered Research Question 3: 'How can airport strategic planning be supported through a DSS and how should the decision support system be designed?'

Chapter 5 *captured* (the third stage of the MOKA Life Cycle as shown in Figure 1.2) the knowledge needed to arrive at a decision support design and development process for implementing the design. Our vision for decision support was presented in Section 5.1. We presented the high-level goals, summarized the three identified problem areas for airport strategic planning in a problem statement, and the concept for the HARMOS DSS was presented. The key principles required for turning the DSS concept into software—policy analysis and integration— were discussed in detail in Section 5.2. The rationale for using a modern software development process instead of the traditional DSS development process was given in Section 5.3. The scope for the development process was set in Section 5.4.

The architecture for the DSS, which formalizes our DSS vision and concept, was presented in Chapter 6. First, we discussed the need to address the business and domain aspects as opposed to the usual focus on technological aspects. Our way to describe the architecture has been introduced as well, with a focus on the Logical View and Functional View. The Logical View—defining the structure of the DSS, its users, and interfaces between the DSS and existing resources—has been defined in Section 6.2. The Functional View—defining the user functionalities—has been defined in Section in 6.3.

The next part of this dissertation shows how all the previous knowledge is *packaged* into the Domain Model in order to realize the user functionality (Chapter 7).

# Part III

# Implementation of the HARMOS Architecture

# Overview Part III




Part II *captured* our vision on decision support for airport strategic planning and the approach to DSS development and *formalized* the vision and concept through the architecture for the HARMOS DSS. Chapter 5 presented the concept for the HARMOS DSS and the approach for its development. The key principles—policy analysis and integration—required for turning the DSS concept into software were discussed. Chapter 6 presented the architectural design in terms of the Logical View—the structure of the DSS—and the Functional View—the user requirements to be realized by the DSS.

In Chapter 5 we argued that a Domain Model is needed to realize the functional requirements of the HARMOS DSS. The Domain Model crunches or *packages* (the fifth stage of the MOKA Life Cycle as shown in Figure 1.2) the domain knowledge from Part I into software modules and classes based on the language from the domain. The Domain Model is described in detail in Chapter 7.

The Domain Model is an executable artifact, which is *used* in Chapter 8 to provide a proof of concept for the HARMOS DSS. The proof of concept will show how the HARMOS DSS is able to address specific problems within the three problem areas *identified* in Chapter 1. The proof of usefulness will show what potential users think about the DSS.

So, this part of the dissertation answers Research Question 4 ('How is the architecture to be implemented such that the DSS requirements are realized and a solid foundation for growing HARMOS into a business application is created?') and Research Question 5 ('How can a proof of concept and a proof of usefulness be provided?').

CHAPTER 7

# The HARMOS Domain Model

> When we set out to write software,
> we never know enough.
>
> *Domain Driven Design (p.15)*
> ERIC EVANS

The previous chapter presented part of the Software Architecture of the HARMOS DSS. The Logical and Functional View were presented in order to show how the key design principles—policy analysis and integration, which were discussed in Section 5.2—have been applied. The Logical View showed how the HARMOS DSS provides integration of people, data and information, and the use of tools; it also showed how the policy analysis framework is used to structure the planning problem. The Functional View showed how the activities within airport strategic planning are supported (each of the use cases has a clear user goal), and how the policy analysis process provides the functionality for engaging in a systematic problem-solving process.

These architectural views, and Part I of this dissertation, clearly show that the aviation and airport domain and the business activity of strategic planning is complex. It is also clear that it is difficult to understand and subsequently deal with this complexity when building computer-based systems that intend to support airport strategic planning (see Section 4.3). None of them have yet been adopted by airport operators.

We argued that the use of a Domain Model (introduced in Section 5.3.2) is a necessary requirement for designing and building a DSS for airport strategic planning. Using a Domain Model means inserting a whole architectural layer—the Domain Layer—as discussed in Section 6.2.2. The iterative design, implementation, and testing of the Domain Model is driven by user requirements, as captured by the use cases described in Section 6.3.

Use cases describe *what* is done by the users and the DSS; they do not provide any details on *how* it is done. The object-oriented design, in terms of the Domain Model, that *realizes* the HARMOS functionality—the how—is described in detail in this chapter.

The Domain Model is the heart of the DSS and provides all the functionality needed to support airport strategic planning. In this chapter, we present the architectural elements of the Domain Model. The next section first describes the HARMOS development process in some more detail. Section 7.2 provides a high-level overview of the Domain Model. The sections that follow describe each of the modules of the domain layer in detail (see also the Logical View in Figure 6.3). A summary is given in the final section.

## 7.1 THE HARMOS SOFTWARE DEVELOPMENT PROCESS

In designing the Domain Model, we followed an object-oriented analysis and design approach (Larman, 2005), combined with an agile approach to the Rational Unified Process (Ambler, 2008; Larman, 2005). The choice for this software development process was motivated in Section 5.3.2. The activities carried out in each of the disciplines are described in the next section. The iterative character of the development process is discussed in Section 7.1.2. Explaining the design requires a way to visualize the design, which is described in Section 7.1.3.

### 7.1.1 Activities carried out within the disciplines

The disciplines defined by the agile approach to the RUP have been introduced in general in Section 5.3.2. The activities we conducted are:

**Business Modeling.** Identifying the scope and high-level requirements for the system, i.e., who will be using the software system, and what will they use it for?

We identified both in Section 5.1, where we presented the problem statement (Section 5.1.2) and the concept of the HARMOS DSS (Section 5.1.3). The users of the DSS—decisionmaker, decision advisor, and domain expert—were explicitly identified in Section 6.2.1; their goals were specified in Table 6.1.

**Requirements.** Describing the interactions between the user and the DSS, i.e. what actions does the user perform and how does the DSS respond to those actions in order to realize the goal of that user?

These interactions have been specified through the use cases included in the Functional View presented in Section 6.3.

**Analysis and Design.** Assigning responsibility for meeting the goals of the users to the most appropriate *objects* in the software system.

In order to do this, we combined the generic object-oriented analysis and design approach (Larman, 2005) with domain driven design (Evans, 2004) (as mentioned before). The result of that is the *Domain Model*, which is described in detail in this chapter.

**Implementation.** Once the objects involved and their collaborations in order to meet the goals of the users are known, the related code can be implemented.

Objects are implemented as *classes*, which provide the blueprint for the objects that exist in the software system when it is running. The architecturally significant classes that have been implemented are discussed in detail in this chapter.

**Testing.** Testing should be done at all times, including unit-testing and functional testing. Based on these tests, the code is refactored to improve its implementation. We only did functional testing.

As previously discussed in Section 5.3.2, these disciplines are not executed in a linear fashion. Instead the disciplines have been executed within short periods of time—a time-boxed iteration—as to be able to reflect on and learn from the implementation, building the software incrementally (see Figure 5.9). The next section briefly discusses these iterations.

### 7.1.2 Iterations

A common problem with software development is trying to do the analysis and design for the entire system before any coding begins (this is for example the approach followed in the SPADE project, as described by Kwakkel, 2006)). Such an approach is often referred to as BDUF, previously mentioned in Section 5.3.1), resulting in a product that does not meet the real needs of the users. In the BDUF approach, each of the above disciplines is executed in a linear fashion, as previously illustrated in Figure 5.7.

As mentioned in Section 5.3.2, we did not execute the disciplines in a linear fashion. Instead, the disciplines were executed over and over again in an iterative process (see Figure 5.9). By doing so, the functionality of the DSS grew incrementally.

During early iterations of the HARMOS development effort, the focus was on the use cases: (i) Calibrate Study (Section 6.3.2); (ii) Specify System Characteristics (Section 6.3.3); and (iii) Execute Performance Analysis (Section 6.3.7).

During later iterations, we included other use cases as well, with a primary focus on Evaluate Strategy (Section 6.3.6). At all times, the implementation effort was driven by user requirements with the goal to arrive at a stable architecture for the DSS. This point is referred to as the Lifecycle Architecture Milestone, as shown in Figure 5.9. About seven iterations were executed, resulting in a stable architecture, of which the Domain Model discussed in this chapter is the most important result.

### 7.1.3 Visualizing the design

In order to explain the Domain Model in this chapter, some aspects of the Unified Modeling Language (UML) need to be introduced. The UML is used for visual modeling during software development efforts. UML can be used for conceptual and software modeling. When using a software perspective, the elements of the UML map directly to elements in a software system. With the conceptual perspective, the UML represents a description of the concepts of a domain of study (Fowler, 1999, p.5).

In this research project and the associated development effort, we have used UML for sketching in both conceptual and software perspectives. The diagrams that are used to present the Domain Model in this chapter are in between the conceptual and software perspectives.

UML provides many diagrams for describing structural (e.g. the class, package, deployment, and component diagram) and behavioral (e.g. the activity, use case, sequence, state machine, and communication diagram) aspects of a software system.

We need only a few of them to explain our Domain Model. As a matter of fact, we have already presented some of these UML diagrams. The Logical View is a *package* diagram (see Figure 6.3), which showed how the HARMOS DSS is structured in terms of packages or modules. A *use case* diagram—providing a high-level overview of the requirements—was shown in Figure 6.4. A deployment diagram—showing how different components are distributed over different computing nodes within a computer network—was shown in Figure 4.5. We will use the *activity* diagram in Figure 7.2, for describing a series of steps in a workflow.

The most widely used UML diagram in general, and also in this chapter, is the class diagram (Fowler, 1999, p.35):

> A class diagram describes the types of objects in a system and the various kinds of static relationships that exist among them. Class diagrams also show properties and operations of a class and the constraints that apply to the way objects are connected.

The class diagrams we present are rather conceptual: they show the responsibilities of each of the classes and relationships among the classes.

The *operations* are not included in our diagrams, but presented separately through tables (see, for example, Table 7.1). In that way, it is easier to discuss the *behavior* of the classes in more detail. Behavior is a crucial feature of a Domain Model. A Domain Model that has no or only poor behavior is what is called an Anemic Domain Model. The Anemic Domain Model is a Domain Model that looks like the real thing, featuring classes named after the concepts

in the domain. However, a closer look reveals that it lacks behavior and only captures data (Fowler, 2003).

Besides the class diagram, we also sketched *sequence* diagrams. A sequence diagram is a diagram that describes how groups of objects collaborate in some behavior. Typically, a sequence diagram shows a number of example objects and the messages that are passed between these objects (typically within a use case, such as the ones in Section 6.3).

We now continue with presenting a high level overview of the Domain Model in Section 7.2. The sections that follow discuss in more detail how the modules within the Domain Model are designed so that each of the individual user goals, as specified in Table 6.1 and detailed in Sections 6.3.1–6.3.8, are met.

## 7.2 High-level overview of the Domain Model

This section provides a high-level overview of the Domain Model. The next section presents the core classes, representing the concepts that structure a strategic planning problem, based on the policy analysis framework (discussed in Section 5.2.1). Section 7.2.2 presents the workflow that organizes the problem-solving process for a strategic planning problem, based on the policy analysis process (discussed in Section 5.2.1 as well).

### 7.2.1 Core classes

The modules and core classes of the Domain Model involved in the workflow for a strategic planing effort are shown in Figure 7.1. The **Study** class is responsible for organizing the strategies and the scenarios against which the strategies are to be evaluated. The Study class is associated with the **Context** class, which holds information about the context of a decisionmaking problem, in a one-to-one relationship.

The typical planning problem of matching traffic demand with airport capacity, given a number of constraints (e.g. environmental and financial), requires many potential strategies ($n$) to be evaluated against *four* scenarios. Hence, there is a one-to-four relationship between the Study class and the **Scenario** class and a one-to-$n$ relationship between the Study class and the **Strategy** class.

The evaluation of a single strategy against a scenario involves repetitive computations that quantify the airport's performance in terms of the *outcomes of interest* for various *periods of interest* (selected by a user) within the *planning period* (specified by a user).

The evaluation of a strategy against a scenario is the responsibility of the **Case** class. The number of cases associated with a study is 4*$n$+1. The additional case (+1) is used for calibration of the planning study as described in

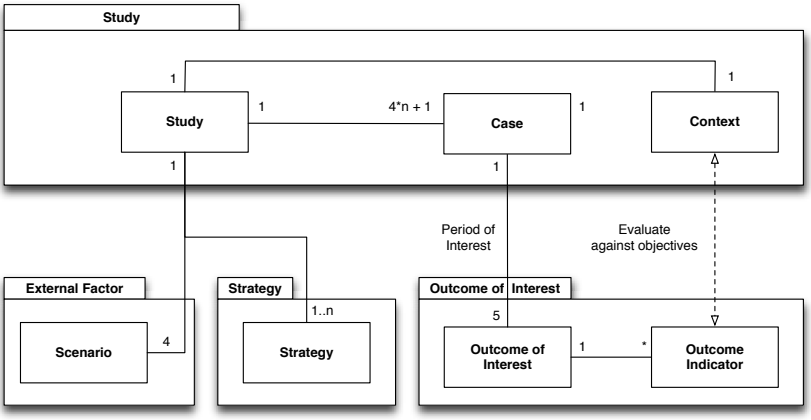



Figure 7.1: Package diagram presenting the core classes of the Domain Model

Section 6.3.2; it is a special case that contains the results of an airport performance analysis for a known year, called the calibration year.

For each strategy, the airport's performance is evaluated in terms of five categories of outcomes: capacity, delay, noise, emissions, and third-party risk. So, for each period of interest there is a one-to-five relationship between a Case class and the **Outcome of Interest** class.

Specific outcome indicators related to each of the five categories of outcomes (for examples, see Table 5.5) are used to assess whether the strategies are able to meet the objectives of the decisionmakers. Hence, the one-to-many relationship between the Outcome of Interest class and the **Outcome Indicator** class. The overall workflow when executing a planning study is described in more detail in the next section.

### 7.2.2 Workflow

The activity diagram shown in Figure 7.2 depicts the workflow of the users when working with the DSS. The workflow can be summarized as follows, indicating how each of the modules of the Domain Model is involved (see also the Domain Layer in Figure 6.3):

1. A decisionmaker identifies an opportunity that could be seized or a problem that needs to be addressed;
2. A decision advisor creates a new study for investigating the opportunity or the planning problem, and *defines the decisionmaking context* based on input from the decisionmakers (described in Section 6.3.1 and supported by the **study** module);

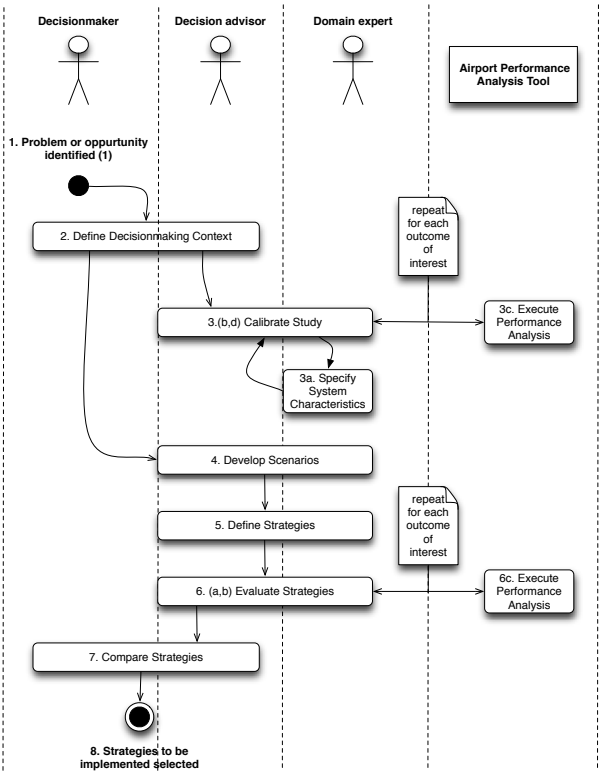



Figure 7.2: Activity diagram showing the HARMOS workflow

3. The decision advisor and the domain experts *calibrate the study* (described in Section 6.3.2):
   a) The domain experts *specify the characteristics of the airport system* (described in Section 6.3.3 and supported by the **system** module);
   b) The domain experts collect information about the known performance of the airport of each of the outcomes of interest—capacity, delay, noise, emissions, and third-party risk;
   c) The domain experts *execute an airport performance analysis* for each of the outcomes of interest (described in Section 6.3.7 and supported by the **performance analysis** module);
   d) The domain experts and the decision advisor compare the computed performance with known performance. The previous three steps will be repeated if the match between computed and known performance is not good enough.

4. The decision advisors and domain experts *develop four scenarios*, describing different plausible futures (described in Section 6.3.4 and supported by the **external factor** module);
5. The decision advisors *define different strategies* (described in Section 6.3.5 and supported by the **strategy** module);
6. The decision advisors and domain experts *evaluate the strategies* against each of the four scenarios for specific periods of interest within the planning period. For each period of interest:
   a) The effect of the external factors, captured by the scenario representing forces outside the control of decisionmakers, on the system is determined (supported by the **external factor** module);
   b) The effect of the strategy, which is under the control of the decisionmakers, on the system is determined (supported by the **strategy** module);
   c) The domain experts and decision advisors evaluate the airport's performance in terms of the outcomes of interest (described in Section 6.3.6 and supported by the **performance analysis** and **outcomes of interest** module);
7. The decision advisors present the results of the strategies that have been evaluated to the decisionmakers from the airport operator and its stakeholders, so that *strategies can be compared* and discussed (described in Section 6.3.8 and supported by the **strategy** module);
8. The decisionmakers come to an agreement about the strategies preferred for implementation. If there is no agreement, (part of) the workflow is started again.

The modules within the Domain Model and their responsibilities were introduced in Section 6.2.2, when we discussed the Logical View. Although many classes are defined within each module, only a couple of them are *architecturally significant*. Our implementation effort was mainly focused on these classes. Growing the DSS into a fully featured and working business application requires a more substantial implementation effort related to the Domain Model, as will be discussed in Section 11.1.

Each of these architecturally significant classes will be described for each of the modules in the next sections.

## 7.3 Study Module

The study module realizes the functionality described in Section 6.3.1—Define Decisionmaking Context, part of the the functionality described in Section 6.3.2—Calibrate Study, and part of the functionality described in Section 6.3.7—Execute Performance Analysis.

The study module has two responsibilities: (1) creating, opening and deleting studies within the HARMOS DSS; and (2) structuring a planning problem within a single study. The most important classes within the study module are shown in Figure 7.3.

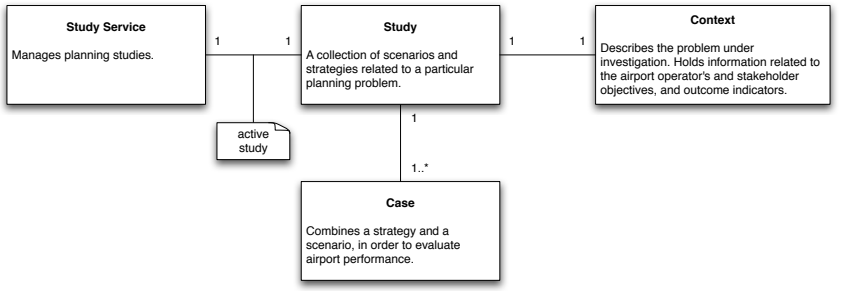



Figure 7.3: Class diagram showing the classes within the study module

The **Study Service** class is responsible for study management. The **Study** class is responsible for organizing a strategic planning problem (as already mentioned in Section 7.2.1). The Study class is associated with the **Context** class, which captures the description of the planning problem, the objectives of the airport operator and its stakeholders, and the outcome indicators used for determining whether the strategies under evaluation meet the objectives of the airport operator and its stakeholders.

The **Case** class combines a strategy and a scenario so that the strategy can be assessed quantitatively against the scenario in terms of the outcomes of interest. Each of these classes are discussed in more detail in the next sections.

### 7.3.1 Study Service

The Study Service provides services for managing strategic planning studies. The Study Service class can be used for creating new studies, opening existing studies, and deleting studies. As such, the Study Service class realizes the functionality related to *creating a new study* as described in Section 6.3.1.

### 7.3.2 Study

The Study class realizes part of the functionality described in Section 6.3.1 and related to: *defining the planning period*; it also realizes the overall functionality for defining and investigating a planning problem. The Study class maintains a list of scenarios to be used to evaluate the strategies against, and holds information related to the strategies being evaluated within the study. The Study class has a one-to-one relationship with the Context class (Section 7.3.3).

The study collaborates with the case (see Section 7.3.4), so that a strategy can be quantitatively evaluated against a scenario in terms of the outcomes inidcators (using the tools for airport performance analysis as discussed in Section 7.8). The Study class has the behavior specified in Table 7.1.

Table 7.1: Operations of the Study class

| **Operation** | **Behavior** |
|---|---|
| Get Name | Return the name of the study (uniquely defined by the user). |
| Get Planning Period | Return the planning period for the study (defined by the user). |
| Update Decisionmaking Context | During planning studies, the decisionmaking context is likely to change. This operation takes care of updating the decisionmaking context defined by the airport operator and its stakeholders. |
| Get Scenarios | Retrieve the scenarios associated with the study. |
| Add Scenario | Add a specific scenario to the study. |
| Get Strategies | Retrieve the strategies associated with the study. |
| Add Strategy | Add a specific strategy to the study. |
| Add Case | Add a case to the study. A case is created when a strategy is selected for evaluation against a scenario. |

The Study class itself is not responsible for creating scenarios or strategies. Scenarios are created by the user through the **Scenario Service** (see Section 7.5.1). Strategies are created by the user through the **Strategy Service** (see Section 7.6.1).

How the functionality of the study module is exposed to the user through the GUI is discussed in Section A.2. The use of part of this functionality for addressing a specific problem in one of the problem areas is discussed in Section 8.3.1 in Chapter 8.

### 7.3.3 Context

The Context class realizes the part of the functionality described in Section 6.3.1 related to the steps: (2) documenting the problem or opportunity; (3) specifying the objectives of the stakeholders and airport operator; and (4) selecting the outcome indicators. The Context class holds information about the planning problem, the objectives of the airport operator and its stakeholders, and outcome indicators.

During the formulation phase of problem solving, the planning problem is identified. However, identifying a problem is not a one-shot process; a number of

iterations are usually required to come up with a well-defined problem situation (Daellenbach and Mc. Nickle, 2005, p.56). Similarly, identifying the problem perspectives, and objectives of the decisionmakers of the airport operator and its stakeholders is an iterative process. So, even if a shared planning problem, the objectives, and outcome indicators have been defined, each of them need to be updated because of information and insights acquired during problem analysis or interpretation, which is characteristic to wicked problems. This is also why the policy analysis process includes a number of feedback loops as indicated in Figure 5.4.

As previously mentioned, there is only one context associated with a study. The context of a planning problem is very important for decisionmaking. Therefore, the HARMOS DSS provides functionality to define the context through the behavior described in Table 7.2 covering the formulation phase of problem-solving.

Table 7.2: Operations of the Context class

| **Operation** | **Behavior** |
|---|---|
| Define Planning Problem | Add the initial problem definition to the decisionmaking context. |
| Update Planning Problem | Add a revised problem definition, including the date of the revision. |
| Add Stakeholder | Add a stakeholder to the decisionmaking context, providing a unique name and a description. |
| Set (Get, Update) Objectives | Specify (return, update) the objectives and related targets of the airport operator or one of the stakeholders. |
| Set (Get) Outcome Indicators | Specify (return) specific outcome indicators for each of the outcomes of interest. |

How the functionality for defining the decisionmaking context is exposed to the user through the GUI is presented in Section A.2.

### 7.3.4 Case

The Case class realizes the functionality related to selecting a specific *period of interest* (either a year or a day) within the planning period (as described in Section 6.3.6) and running a performance analysis for each of the outcomes of interest (as described in Section 6.3.7) for that period.

A case is the interface between the planning problem and the airport performance analysis. So, a case is responsible for bringing together all the information that is needed to quantitatively evaluate airport performance throughout the planning period for a specific strategy and scenario. A case combines a strategy

Table 7.3: Operations of the Case class

| Operation | Behavior |
|---|---|
| Get Name | Return the name of the case. A case is uniquely defined by combining the name of the strategy and the scenario. |
| Add Period of Interest | The period of interest can be selected by a user when evaluating a strategy, or can be added indirectly because of: (1) an event that is defined in the scenario (see Section 7.5.2); or (2) the date of implementation of the strategy (see Section 7.6.2). |
| Delete Period of Interest | Delete the period of interest and all the computational results that are associated with that period of interest. |
| Set Period of Interest | Set the period of interest, either a year or a day, for which a strategy is to be evaluated. |
| Prepare Analysis | Prepare the airport performance analysis by: (1) creating a **System** representation; (2) retrieving the **Traffic Demand** from the scenario (see Section 7.5.2); and (3) retrieving the **Operational Plan** from the strategy (see Section 7.6.2). |
| Create System Representation | Create a system representation for the selected period of interest. This system representation is generated on the fly and created by copying the baseline system representation and modifying it according to the strategy and scenario (which model the forces that change the system). |
| Execute Performance Analysis | Run a performance analysis for a specific outcome of interest—capacity, delay, noise, emissions, or third-party risk—by collaborating with the **Analysis Service** (see Section 7.8.1) of the Performance Analysis module. |
| Get, Save, Load Outcomes of Interest | Return the outcomes of interest associated with the case for a specific period of interest. The save and load operations store and retrieve the outcomes of interest for a specific period of interest by collaborating with the outcome of interest module. |

and a scenario, so that the effect of both of these forces on the system can be determined (see Section 7.4), and the airport performance in terms of the outcome indicators can be evaluated for a specific period of interest. The Case class has the behavior specified in Table 7.3.

The Case class has dedicated operations—save and load outcomes of interest—for persistent storage of the data, related to the outcomes of interest. This is done

for improving the performance of the DSS. The computational results for a specific period of interest within the planning period are only loaded (or saved) when a user is actually investigating that particular period of interest.

## 7.4 System Module

The system module realizes the functionality described in Section 6.3.3—Specify System Characteristics. The representation of a system was previously discussed in Section 5.2.1, as part of the policy analysis framework. The system representation is some kind of model that clarifies the system by defining its boundaries, and defining its structure—the elements, and the links, flows, and relationships among them. Approaches to modeling are briefly described in Section 7.4.1. Our approach to modeling is explained in Section 7.4.2.

### 7.4.1 Modeling the system

Different types of models exist, such as mathematical models, material models, and fictional models (Frigg and Hartmann, 2006). Our model of the system is a fictional model describing the real-world system—an airport—in a way that is appropriate for the purpose of supporting airport strategic planning. For the purpose of airport strategic planning, we need to create a model that is able to reflect the airport as a socio-technical system (as described in Chapter 3).

In a regular policy analysis study, system representations are usually not developed from scratch. Most of the time, the research team uses existing models that are tailored for the policy analysis study. Sometimes, policy analysts develop so-called fast and simple models that encompass the entire system domain shown in Figure 5.3 (see for example SUMMA, 2005).

Such a fast and simple model hard codes pre-specified external factors, strategies, a high-level representation of the system, and computational rules so that the outcome indicators for each of the outcomes of interest can be computed directly. Even these fast and simple models quickly become complex and difficult to deal with in terms of the software engineering effort, if one wants to be able to take into account a range of external factors, strategies, and outcomes of interests.

Developing a fast and simple model is therefore not the approach we use. For reasons of maintainability, flexibility, and adaptability, each of the elements of the policy analysis framework need to be kept separate in the software implementation. For the same reason, the computational functionality needs to be separate as well.

Object orientation is used to build our system representation. It must be noted that the system representation is used for descriptive purposes. The system representation should capture data and behavior relevant for airport strategic

planning. For instance, the overall system representation should include a representation of the runway system including its runways and tracks (data). This representation of the runway system must also feature the ability to add, change, or delete a runway object (behavior).

### 7.4.2 Exploiting object orientation

The system representation needs to incorporate *data* for descriptive purposes, as well as *behavior* so that the system representation is sensitive to the forces—external factors and strategies—that drive system change. Object-orientation is the ideal approach for creating a system representation that exhibits these features, because by definition, objects include both data and behavior. Another important benefit is that the object paradigm can be used to reflect the real-world system in an elegant and natural way.

For airport systems, some object-oriented modeling has been done in the field of simulation to support ATM research (Zhong, 1997). Also, Eurocontrol developed the Aeronautical Information Exchange Model (AIXM), whose objective is to harmonize the exchange of aeronautical information related to airports, runways, and terminal procedures (EEC, 2007). Currently, Eurocontrol is investigating how to extend the AIXM with more airport specific features (EEC, 2007). However, each of these models are fairly detailed models, and as such not usable to represent the airport system within the HARMOS DSS.

We, therefore, developed an object-oriented representation of the system from scratch, as shown in Figure 7.4. At the top level, the system representation consists of three systems—airport, airport environs[1], and ATM system. Hence, the one-to-one association of the **System Model** class to the **Airport**, **Environs**, and **ATM System** classes. Each of these systems in itself is a collection of systems as well:

**Airport.** The Airport class is a composition of the relevant elements of the landside and airside of the airport, as previously described at the beginning of Section 3.1. So both an **Airside** and **Landside** class have been defined. The Airside class is associated with the following classes in a one-to-one relationship:

**Runway System.** Models the runway system described in Section 3.1.2. It is associated with the **Runway** class in a one-to-many relationship, modeling the runways of an airport. The runway is modeled as a composition of two runway ends. Hence, the one-to-two association with the **Runway End** class. For each runway end, tracks are defined: SIDs for departing flights; STARs for arriving flights

[1]The area surrounding an airport that is considered to be directly affected by the presence and operation of that airport (MEAD & HUNT, 2009).

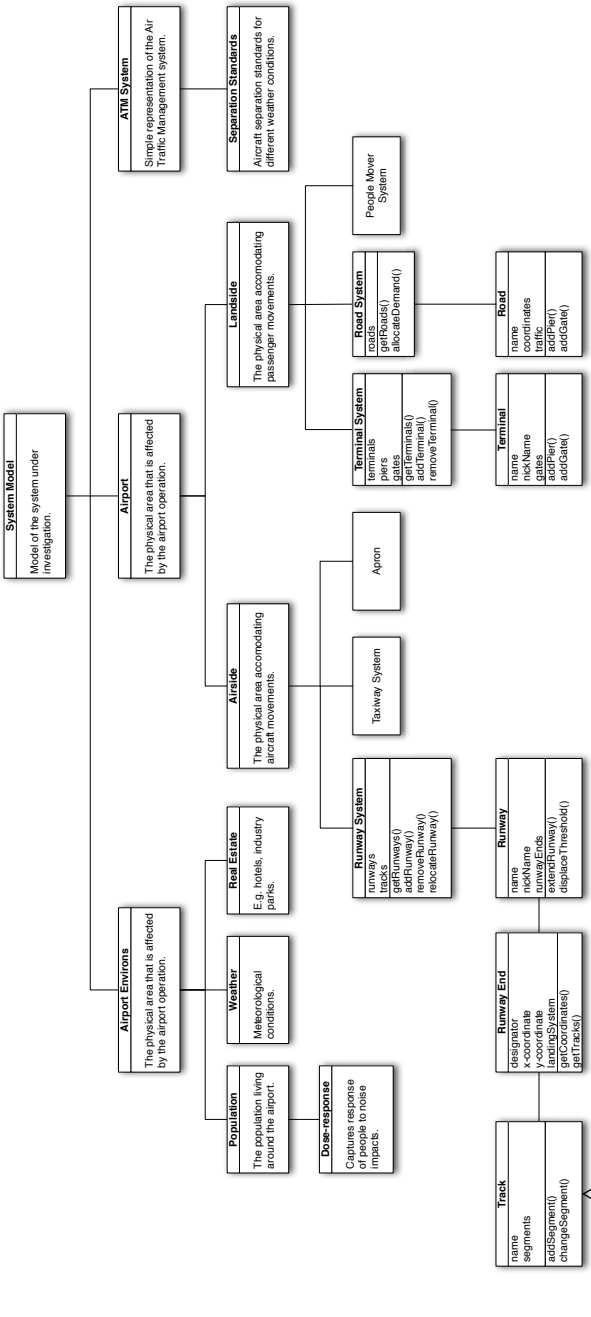



Figure 7.4: Classes within the system model module

(see for example the Dutch AIP Air Traffic Control the Netherlands, 2008)). Therefore, a **SID** and a **STAR** class have been defined as derived classes from the **Track** class.

**Taxiway System.** Models the taxiway system described in Section 3.1.2 at a very high-level of aggregation. Taxiways have not been modeled at the moment, since taxi operations are outside the scope of the current research effort (usually the capacity of the taxiway system is not a bottleneck at an airport). A more detailed representation of the taxiway system could easily be added to the System Model.

**Apron.** Models the apron described in Section 3.1.3 at a very high-level of aggregation. The Apron class is only a placeholder; it does not have any data or behaviour at the moment.

The Landside class is associated with the following classes in a one-to-one relationship:

**Terminal System.** Models the terminal system, described in Section 3.1.2, at a very high-level of aggregation. The focus of the modeling and implementation effort so far has mostly been on the airside and environs of an airport, since the effects related to these elements are usually more important to the stakeholders. We did however also start an effort that models the landside in more detail and the relationships between airside and landside as well (Balen, 2007).

**Road System.** Models the road system, briefly mentioned in Section 3.1.4, as the use of this part of the landside contributes significantly to the total emissions. The roads on the airport's property are modeled by the **Road** class through a one-to-many relationship.

**People Mover System.** Models the people mover system, also mentioned in Section 3.1.4, at a very high-level of aggregation. This class has not been implemented, as people mover systems are outside the scope of the research. However, it could readily be added as well.

**Parking System.** Models the parking system through the **ParkingLot** class, in order to quantify emissions from vehicular activity.

**Environs.** Models the environs of an airport with the purpose for environmental impact assessment of noise (Section 3.2.1), emissions (Section 3.2.2), and third-party risk (Section 3.2.3).

Hence, the classes associated with the Environs class capture the characteristics needed for environmental impact assessment. Hence, the one-to-one relationship with the following classes:

**Population.** Models the population, in terms of density (i.e. persons per square km), of the communities around an airport.

**Weather.** Models the weather at an airport, in terms of wind strength and direction for a 30 year period.

**Dose-response.** Models the dose-response relationships related to noise annoyance.

**ATM System.** Models the ATM system that manages and controls the aircraft operations at an airport. The performance of the ATM system is modeled through the **Separation Standards** class. The effect of new ATM technologies or ATM regulations can be quantified as changes in aircraft separation standards.

The representation of the system reflects the real system quite naturally through the use of object-orientation. At the same time, it provides a single and consistent *data* and *behavioral* model of the relevant airport systems, the airport environs, and the ATM system.

Our system model does not have computational capabilities. Our system model is not able to compute outcome indicators for each of the outcomes of interest directly. Doing so would not make sense because our DSS concept use *external* tools to quantify the effects of strategies for each of the scenarios. Additionally, it would violate the *Separation of Concerns* principle of good Object Orientation (OO) design: The resulting object oriented system would become bloated, i.e. having too much responsibility. Computational capability within the problem context is the dedicated responsibility of the Performance Analysis module, which is discussed in Section 7.8.

Because of the comprehensiveness of the representation of the system, only the behavior of one of its representative elements—the Runway System—will be presented in some more detail. Table 7.4 shows the behavior of the Runway System class.

Table 7.4: Operations of the RunwaySystem class

| **Operation** | **Behavior** |
|---|---|
| Get Runway | Return a runway by its identity (e.g. 06-24). |
| Add Runway | Add a runway specifying its physical characteristics. |
| Delete Runway | Delete a runway. |
| Get Tracks | Return the tracks. |
| Get RunwayEnds | Return the runway ends of all the runways. |
| Extend Runway | Change the length of a specific runway. |
| Displace Threshold | Displace the threshold of a specific runway end. |

How the functionality of specifying the characteristics of the system is exposed to the user through the GUI is described in Section A.3. The modification of the

system representation to reflect change to the system as a result of the strategy 'Add Runway' is illustrated in Section 8.4.2.

## 7.5 External Factor Module

The external factor module realizes the functionality described in Section 6.3.4—Develop Scenarios.

A scenario has been defined as follows (see Step 4 of the policy analysis process as discussed in Section 5.2.1):

> An assumed development of external factors producing an internally consistent description of a plausible future that forms the context for the strategic planning problem, describing what happens in the external world.

The external factor module is responsible for supporting the development of scenarios. The most important classes within the external factor module are shown in Figure 7.5.

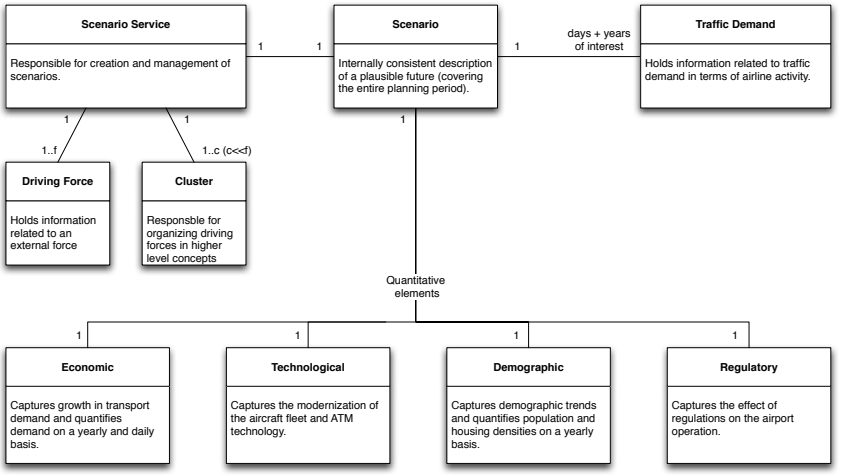



Figure 7.5: Class diagram showing the classes within the external factor module

The **Scenario Service** manages scenarios. The Scenario Service organizes the information needed to build scenarios, i.e. the driving forces and clusters that have been identified, and the scenario space that was defined.

The **Scenario** class holds information about the storyline and quantitative information related to the external factors—economic, technological, demographic

and regulatory. So, a scenario is associated with the **Economic**, **Technological**, **Demographic**, and **Regulatory** class, each of which captures developments related to these external factors.

A scenario is also associated with the **Traffic Demand** class, which captures traffic demand in terms of airline flight activity at the airport. Traffic demand needs to be captured for each year, and the days within that year, that a user wants to include in a scenario. The Scenario Service, Scenario, and Traffic Demand classes are discussed in the next three sections.

### 7.5.1 Scenario Service

The Scenario Service provides four services: (1) create a scenario; (2) retrieve an existing scenario; (3) save a scenario; and (4) delete a scenario. A new scenario is created by specifying a unique name and description.

### 7.5.2 Scenario

The Scenario class is responsible for holding information about the storyline that provides a narrative describing future developments and the associated quantitative information related to the external factors. The users that develop scenarios have to make sure that an internally consistent description of a plausible future is developed. The Scenario class is designed with the behavior specified in Table 7.5.

Critical to the assembly of the scenarios are the data and the assumptions that are used. A starting point for developing scenarios for airport planning are aviation forecasts by Boeing (Boeing Commercial Airplanes, 2008), Airbus (Airbus Industrie, 2007), or Airport Council International (ACI) (Airport Council International, 2007).

How this functionality is exposed to the user through the GUI is described in Section A.4. The use of this functionality is demonstrated in Section 8.4.

### 7.5.3 Traffic Demand

The Traffic Demand class holds information related to traffic demand in terms of *airline* activity at an airport. Within a scenario, traffic demand needs to be included both on a yearly as well as a daily basis, depending on the periods of interest selected by the users.

We use the OAG to extract information about current traffic demand (needed to calibrate the study as discussed in Section 6.3.2). The OAG timetable is also used to generate future traffic demands for either a day or a year. So, traffic demand is represented in terms of airline flight activity. This is important, because in order to be able to interact with the airlines during the planning process, their specific activities at the airport should be modeled. Hence, an **Airline** class

Table 7.5: Operations of the Scenario class

| Operation | Behavior |
|---|---|
| Get Name | Return the name (description) of the scenario (uniquely defined by the user). |
| Get Description | Return the description of the scenario. |
| Get (Set) Storyline | Return (Set) the narrative describing the future developments. |
| Add Event | Add the name, date, description, and characteristics of a specific event, occuring during the planning period. |
| Get Events | Return the events defined for the entire scenario or a specific year. |
| Get Economic (Technological, Demographic, Regulatory) | Return the economic (technological, demographic, regulatory) developments for the planning period. |
| Get (Set) Traffic Demand | Return (Set) the traffic demand for a specific period of interest. Setting the traffic demand requires elaborate processing for translating the events and developments included in the storyline into changes to airline networks and subsequently the traffic demand. |

has been defined associated in a one-to-one relationship with the **Network** class, which is determined from the OAG timetable.

An airline's network is a composition of routes with one (or possibly more) aircraft type operating on each route. So, the Network class is associated in a one-to-many relationship with the **Route** class. Each airline operates a fleet of aircraft, which leads to the definition of a one-to-many relationship between the Airline class and the **Aircraft** class. The Aircraft class in turn is associated with the Route class in a many-to-many relationship, because the same aircraft type could be operating on different routes.

The Aircraft class holds information about the number of arrivals and departures on each route. Arrival and departures are categorized by the hour of the day. A day can either be a real day (e.g. 31-08-2005), or a so-called *average day*, which creates a fictitious day of operations based on the annual aircraft operations.

By using this representation of demand two important information requirements are covered: (1) demand can be analyzed and modified in terms of airlines and their networks, which are important characteristics of the external world; and (2) aircraft operations are categorized by route, which is information that can be used to allocate flights to specific runways and tracks (see Section 7.6.3).

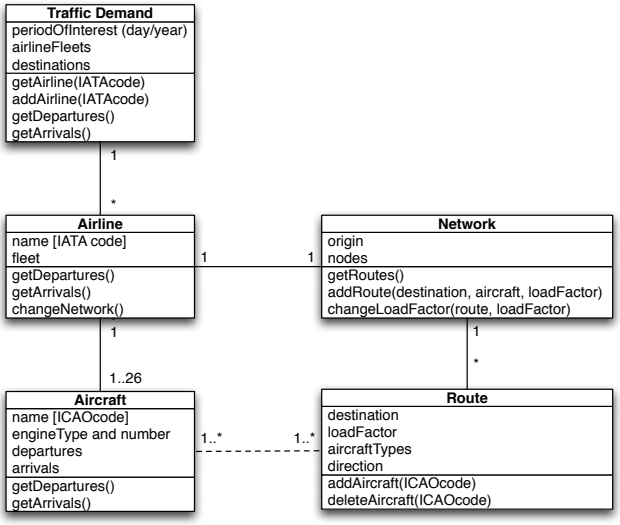



Figure 7.6: The Traffic Demand class

The traffic demand shown in the class diagram is actually modeled as an aggregation of the information in an OAG timetable. A traffic demand object does not include single flights anymore. Flights are categorized by airline, route, and aircraft, with the arrivals and departures summed by the hour of the (average) day.

For strategy assessments on an annual basis—required for noise impact, emissions, and third-party risk—such a demand representation is more convenient; otherwise a user would have to deal with hundreds of thousands of flights (for an average hub airport).

This aggregate demand representation is also convenient for designing functionality for building scenarios. A storyline of a scenario typically describes how airline networks evolve throughout the planning period. Based on the events and driving forces described in the storyline, the changes to the airline network and subsequently traffic demand can be quantified.

So, scenarios describe demand developments in terms of airlines: airlines merging, an airline going bankrupt, airlines downscaling or upscaling their network, airlines increasing or decreasing frequencies and/or load factors on their routes, etc. This behavior is modeled through a number of operations (e.g. ‘add Routes’ or ‘add Airline’) of each of the classes, as shown in the class diagram.

## 7.6 Strategy Module

The strategy module realizes the functionality described in Section 6.3.5—Define Strategy, and also the functionality described in Section 6.3.8—Compare Strategies.

A strategy is defined as (previously discussed in Section 1.6):

> A change to the airport's infrastructure, operations and/or management under the control of the decisionmakers.

Ideally, strategies need to be designed such that the objectives of both the airport operator and its stakeholders are met, addressing the planning problem, or seizing an opportunity. Decisionmakers have a large set of strategies to choose from to solve a problem or seize an opportuninty. A new runway could be build at a number of different locations. Demand management strategies could be implemented or changed. The terminal facilities could be extended or entire new terminals could be built. Noise abatement procedures could be implemented, and so on.

The strategy module is responsible for: (1) supporting the definition of strategies by decision advisors; and (2) holding information about the strategies themselves. Its most important classes are shown in Figure 7.7.

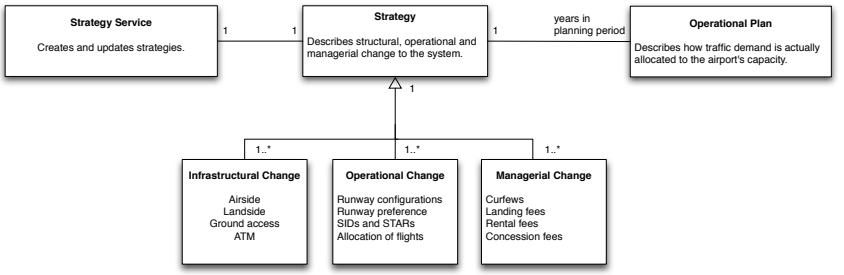



Figure 7.7: Classes within the strategy module

The **Strategy Service** supports the definition of strategies. The **Strategy** class holds information related to a strategy. A strategy captures infrastructural, operational, and managerial change to the system. Hence, the Strategy class is associated with the **Infrastructural Change**, **Operational Change**, and **Managerial Change** classes.

A strategy not only covers changes to the airport and related systems, but also specifies how traffic demand is allocated to the airport's capacity throughout the planning period. It is therefore associated with an **Operational Plan** for each year in the planning period. The Strategy Service, Strategy, and Operational Plan class are discussed in the next three sections.

### 7.6.1 Strategy Service

The Strategy Service allows a decision advisor to define a strategy. The default strategies that the Strategy Service provides are organized in three categories (although additional categories can easily be added):

**Expand Capacity.** Strategies related to expansion of the airport's physical and/or environmental capacity.

- **Relocate Runway.** Change the location of a runway to mitigate congestion problems due to runway incursions or environmental impacts.
- **Reinforce/Extend Runway.** Extend a runway so that heavier aircraft can use the airport.
- **Build New Runway.** Build a new runway at a location to be specified by the user.
- **Add High-speed Runway Exit.** Add a runway exit in order to reduce runway occupancy time or avoid the use of reverse thrust.
- **Build New Terminal.** Build a new terminal to accommodate more demand or attract new demand (e.g. low-cost airlines).
- **Upgrade ATM System Technology.** Introduce new ATM technology that reduces aircraft separation standards, which increases airside capacity.

**Manage demand.** Strategies that directly or indirectly affect demand or its characteristics.

- **Depeak Airline Schedule.** Depeak an airline schedule in order to reduce congestion during peak hours.
- **Curfews.** Introduce curfews for specific aircraft types or all operations.
- **Ban Charter Flights.** Allocate all demand for charter flights to another airport.
- **Restrict Night Flights.** Restrict night flights for noisy aircraft types or close the airport during specific night hours.
- **Restrict Low Cost Demand.** Allocate demand for low cost airlines to another airport.

**Revisit operations.** Strategies that change the airport operations.

- **Displace Runway Threshold.** Displace the runway threshold in order to mitigate noise impacts or remove interdependencies between runways.
- **Change Departure or Arrival Tracks.** Change the geometry of SIDs or STARs in order to address noise problems or optimize the use of the terminal airspace.
- **New Noise Abatement Procedure.** Introduce a new NAP for all airport operations, specific aircraft, or specific runways.
- **Alternative fuels.** Introduce alternative fuels for Ground Support Equipment (GSE).

**Change Runway Use.** Change the use of the runway configurations throughout the day or year.

A strategy that is included by default is *business as usual*, which describes the strategy that is currently implemented. This strategy is used as a reference when comparing strategies.

### 7.6.2 Strategy

The Strategy class realizes part of the functionality described in Section 6.3.5—Define Strategy. The users select a strategy through the Strategy Service; once a strategy is selected, the details of the system changes related to the strategy must be specified. A Strategy class is thus responsible for capturing data about a specific infrastructural, operational, and managerial change. The strategy is also associated with operational plans for each year in the planning period, which need to be specified as well.

Depending on the strategy that is selected, defining the details of a strategy can be a very small effort or substantial effort. In both cases, the decision advisor might be required to specify technical data that are not known to him/her. In such a case, a domain expert can easily be involved to provide these data. The strategy class has the behavior specified in Table 7.6.

How this functionality is exposed to the user is discussed in Section A.5. The definition of a strategy by the decision advisors and domain experts is demonstrated in Section 8.4.2.

### 7.6.3 Operational Plan

Previously, we mentioned that a strategy is associated with operational plans, one for each period of interest that a user is considering, which detail how traffic demand is allocated to the airport's capacity. Although the operational plan covers both airside and landside, we implemented only the part of the plan related to the airside of an airport, i.e. the allocation of flights to runways and tracks (see Section 5.4, 'Scope of the development effort').

In order to allocate flights to specific runway ends—defined within a runway configuration—and its tracks (SIDs and STARs), information about the airline, aircraft type, origin or destination, and arrival or departure time of a flight is required. The Traffic Demand class, previously discussed in Section 7.5.3, has been designed to hold this information.

We assume that flights are allocated to runway ends and tracks based on arrival or departure direction. However, different allocation rules might exist. These are not modeled within the HARMOS Domain Model at the moment. The Domain Model is, however, flexible enough to include different allocation rules

Table 7.6: Operations of the Strategy class

| Operation | Behavior |
|---|---|
| Get Name | Return the name of the strategy (uniquely defined by the user). |
| Get Description | Return the description of the strategy (defined by the user). |
| Get Category | Return the category of strategy, e.g. 'Expand Capacity'. |
| Set (Get) Implementation Date | Specify (retrieve) the date of the strategy's implementation, per type of change—infrastructural, operational, managerial—if needed. |
| Set (Get) Operational Plan | Specify (retrieve) the Operational Plan for a specific year. |
| Set (Get) Structural Change | Specify (retrieve) the structural change, e.g. the characteristics (designators, coordinates, etc.) of the runway and additional runway sets. |
| Set (Get) Operational Change | Specify (retrieve) the operational change, e.g. new runway configurations. |
| Set (Get) Managerial Change | Specify (retrieve) the managerial change, e.g. increased landing fees to recover higher operational cost. |

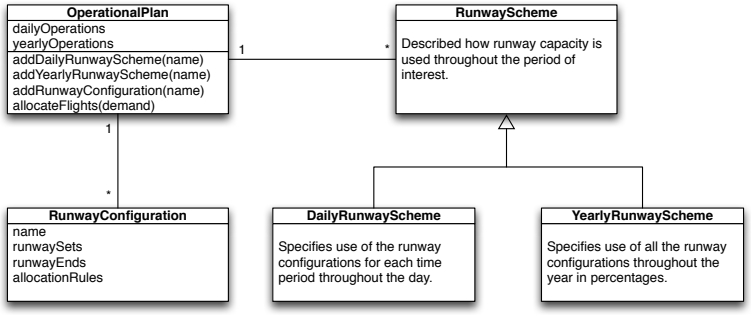



Figure 7.8: Class diagram showing the classes associated with the Operational Plan

during the customization of the DSS for a specific airport operator (again see Section 5.4; Section 11.1.1 discusses the customizing the DSS for a specific airport operator).

Figure 7.8 presents the class diagram related to the operational plan. The **Operational Plan** class holds information about how traffic demand is allocated

to runway ends and tracks on an annual or daily basis (depending on the period of interest that is selected by a user). Hence, it has a one-to-many relationship with the **Runway Configuration** class, which holds information about how runway capacity in terms of departure and arrival runways is made available.

Each runway configuration is associated with allocation rules for each runway end. The **Yearly Runway Scheme** class has been defined to hold information about how the runway configurations are used throughout the year, expressed as percentage (i.e. the number of days the runway configuration is used divided by 365). The **Daily Runway Scheme** class has been defined to hold information about the use of runway configurations throughout the day, specified for user-specified intervals (e.g. an hour, one-and-a-half hours, etc.). Both classes are actually derived from the generic **Runway Scheme** class.

### 7.6.4 Scorecard Service

The Scorecard Service realizes the functionality described in Section 6.3.8—Compare Strategies.

We use a disaggregate method for comparing and selecting strategies as previously discussed and motivated in Section 5.2.1. The way to present multiple strategies for comparison and selection for a given scenario is through a scorecard (see Table 5.1). The Scorecard Service provides the functionality to generate such scorecards.

For a user selected set of strategies, a set of outcome indicators (Section 7.7), and a scenario, this service produces a colored scorecard. There are two different types of scorecards that can be produced:

1. A scorecard presenting the effects of the strategies for a specific day or year in the future (e.g. 31-08-2015 or 2025). The Scorecard Service directly presents the effects of the strategies for the specific period of interest in terms of the outcome indicators in the cells of the scorecard;
2. A scorecard presenting the cumulative effect of the strategies throughout the planning period. In this case, additional processing of the effects of a strategy throughout the planning period is needed. The Scorecard Service needs to implement some logic and rules to aggregate the effects of the strategies to produce the values in the cells of the scorecard. For example: if the number of people highly annoyed has been selected as one of the outcomes indicators, the Scorecard Service could add up the numbers of people highly annoyed for each of the years evaluated within the planning period.

So, the first type of scorecard only requires implementation of functionality that formats the strategies and their effects in a table. For the second type of scorecard, an additional effort is needed to implement the rules and logic for aggregating the effects of a strategy throughout the planning period. How exactly

the aggregation is to be done is up to the airport operator and its stakeholders. Implementing this service is part of the customization process of the HARMOS DSS.

## 7.7 Outcome of Interest Module

The outcome of interest module realized part of the functionality described in Section 6.3.6—Evaluate Strategy.

Outcomes of Interest are defined as (previously mentioned in Section 5.2.1):

> Those outputs of the system that are of interest to the decisionmakers of the airport operator and its stakeholders, given a particular context for the planning problem.

This module is responsible for organizing the outcome indicators needed for quantifying the strategies in terms of the outcomes of interest. Each outcome of interest—capacity, delay, noise, emission, and third-party risk—is modeled separately. The most important classes in this module are shown in Figure 7.9.

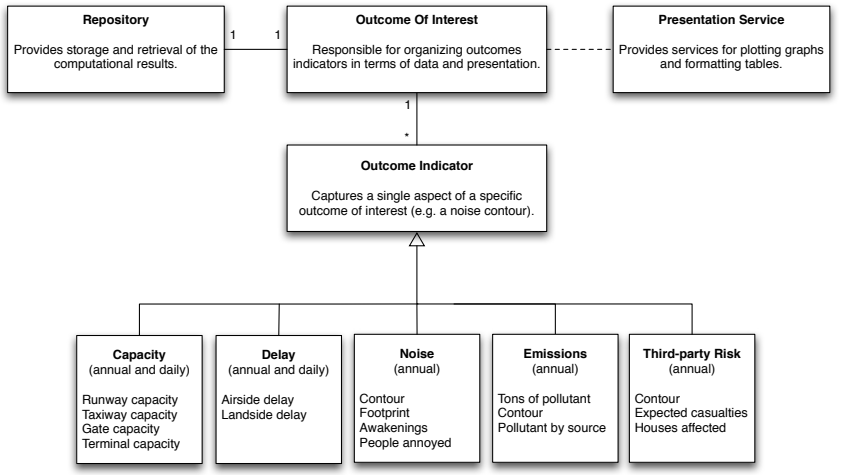



Figure 7.9: Class diagram showing the classes within the outcome of interest module

The **Outcome of Interest** class is responsible for organizing the outcome indicators, including their persistent storage and presentation. Each outcome of interest class has a one-to-one relationship with a **Repository** class that takes

care of loading and saving specific results for a period of interest, as requested by a user. The Outcome of Interest class collaborates with the **Presentation Service** class for the display of one or more specific outcome indicators.

The **Outcome Indicator** class is a class that includes behavior that is common for all outcome indicators. An outcome indicator is a specific and quantified aspect, related to an outcome of interest.

Most of the time, the outcome indicators cannot be made available directly by the tools that quantify the different airport performance aspects. The outcome indicators can only be presented through the GUI of the tool itself. This is why one of the responsibilities of the performance analysis package is post-processing the output data of the tools.

For example: INM can present noise contours, including population counts, to a user. However, delegating this responsibility to INM itself would not lead to a satisfactory user experience for the HARMOS DSS user. The ABS, discussed in Section 4.2.5, actually uses this approach; the results of the noise analysis have to be viewed in INM itself. A user thus needs to switch from ABS to INM and vice versa when evaluating results.

Within HARMOS, each of the outcome indicators is created, from raw tool output data, by the post-processing functionality of the Specific Analysis Service. Therefore, each outcome indicator needs to be implemented in an object-oriented way. By doing this, it is very easy to manipulate and display the outcome indicators and to facilitate different user needs with respect to the presentation of information in the GUI. Implementation of every possible outcome indicator is a large effort and has not been done. This should be done together with the airport operator for which HARMOS is being customized, in order to satisfy specific post-processing needs and specifc ways for presenting the information.

## 7.8 Performance Analysis Module

A DSS for airport strategic planning requires functionality for evaluating different strategies, as we have described in the use case *Evaluate Strategy* in Section 6.3.6. The performance analysis module plays an important role in realizing this functionality, since it is responsible for quantifying the effects of a strategy on airport performance (for a specific period of interest within the planning period). This overall responsibility is realized through three more specific responsibilities, namely:

**Pre-processing.** Converting information from the problem space—characteristics of the system resulting from the external factors and strategies, traffic demand, and the operational plan—to input data for a specific tool.

**Computing.** Executing the necessary runs with a specific tool.

**Post-processing.** Converting output data from a tool to information within the problem space (i.e. the outcome indicators as presented in Table 5.5 for example).

The analysis of the airport's performance is architecturally significant, which was the reason to include the subfunction *Execute Performance Analysis* in our Use Case Model (see Section 6.3.7). This use case provided a concrete example of the steps related to each of the responsibilities for a noise analysis with the INM. This example is also used here to make the following description a bit more specific.

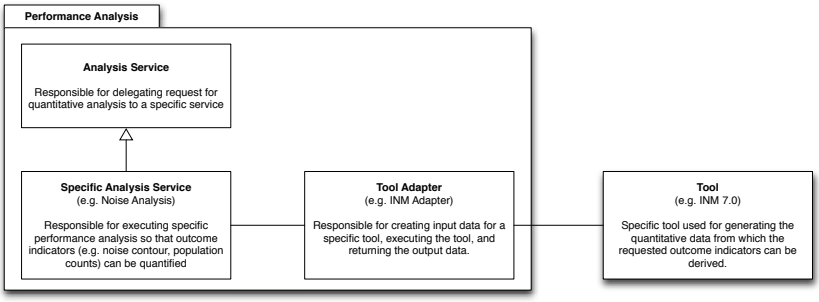



Figure 7.10: Classes within the performance analysis module

The most important classes of the performance analysis module are shown in Figure 7.10. The **Analysis Service** class provides the means for the case class (see Section 7.3.4) to interact with the performance analysis module. The analysis service delegates requests for analysis of a specific airport performance aspect to a **Specific Analysis Service**. The specific analysis service receives all the information needed—typically information about the system, traffic demand, and the operational plan—to perform the requested computation, determines which tool is to be used, and passes the information to the appropriate **Tool Adapter** (discussed in Section 7.8.2).

The design of the performance analysis module provides an abstraction of quantitative analysis with specific tools. Although it adds a significant amount of work with respect to implementation (as shown by Tse, 2006; Vreeswijk, 2007), this design choice is crucial, because the performance analysis functionality of the DSS is made independent from specific tools. As such, the tools are tailored to the strategic planning process and the people involved, instead of the other way around. Hence, airport operators can use the tools they already use and are familiar with. If a tool lacks certain computational features, those could be provided by the analysis services. Also, some commonly needed functionality,

such as plotting contours from grid-data, become part of the DSS' functionality. The Tool Adapters and Analysis Service are now discussed in more detail.

### 7.8.1 Analysis Service

In order to adequately address airport planning problems, an integral view of the different airport performance aspects needs to be provided (Section 3.3.1). So, the HARMOS DSS needs to provide information about different airport performance aspects, i.e. capacity, delay, noise, emissions, and third-party risk. The Analysis Service therefore provides the services specified in Table 7.7.

Table 7.7: Computational services provided by the Analysis Service

| Operation | Behavior |
|---|---|
| Capacity Analysis | Provides services for computing the airport's daily and annual runway capacity, and daily and annual terminal capacity. |
| Delay Analysis | Provides services for computing the airport's daily and annual runway delay, and daily and annual terminal delay (not implemented). |
| Noise Analysis | Provides services for computing footprints for single aircraft movements, footprints for specific SIDs or STARs, airport noise contours (in various metrics), population counts for contours, population annoyed, and awakenings. |
| Emissions Analysis | Provides services for computing the total amount of emissions for each of the pollutants $CO_2$, NO, PM-10, PM-5, and $SO_2$, by emission source (vehicles, aircraft, training fires, fuel storage), or in total. |
| Third-Party Risk Analysis | Provides services for computing individual risk contours, population counts for contours, and group risk (i.e. expected casualties). |

Except for the delay analysis service, each of the services has been implemented. Tse (2006) implemented the service for capacity analysis, which can be used to compute both daily and annual runway capacity.

Heblij (2004) and van Loo (2005) implemented the service for noise analysis (not compliant with the architecture, because it was built when we were experimenting with the architecture as previously mentioned in Section 5.3.2), which can be used to compute noise impact in terms of noise load, awakenings (based on the FICAN 1997 dose-response relationship (FICAN, 1997)), and people annoyed (based on dose-response relationship compiled by Miedema and Vos (1998)).

Vreeswijk (2007) implemented the service for emissions analysis, which can be used to compute $NO_x$, $CO_2$, $SO_x$, PM-5, and PM-2.5 emissions for both aviation (aircraft and ground support equipment) and non-aviation (cars, parking lots) related sources.

Heblij (2004) implemented the service for third-party risk analysis (not compliant with the architecture either), which can be used to compute individual risk and group risk (i.e. expected number of casualties).

### 7.8.2 Tool Adapters

In order to perform the required quantitative analysis of an airport's performance, the DSS *collaborates* with *third-party* analysis tools. Those tools could be purchased, already be in use by domain experts within the airport operator's organization, or made available by external organizations, such as research institutes or consultancy firms. The tools are not integrated into the DSS. Instead the DSS calls upon the required computational services of third-party tools through a so-called *Adapter*.

The DSS users are able to decide for themselves which tools to use, albeit that the tools should have a macro- or mesoscopic character (see our discussion about the level of detail and aggregation of tools in Section 4.2). Of course, such a design means that the system will have to be customized for a specific airport organization (if tools other than the default tools delivered with HARMOS are preferred), but it adds crucial business value. The design of the Tool Adapters could either be performed by the DSS development team or by a third party.

The following tool adapters have been implemented. Tse (2006) implemented an adapter for the FAA Airfield Capacity Model (see also Section 4.1.1). Vreeswijk (2007) implemented a tool adapter for the EDMS computational methodology (see also Section 4.1.3); the EDMS methodology was implemented from scratch as a stand-alone tool; a tool adapter for the Mobile6 model for computing vehicle emissions was also implemented. Heblij (2004) and van Loo (2005) implemented a tool adapter for the Integrated Noise Model (see also Section 4.1.2). Heblij (2004) implemented a tool adapter for the NATS computational methodology for third-party risk (see also Section 4.1.4); the NATS methodology was implemented from scratch as a stand-alone tool.

How the functionality of the analysis services is exposed to the users is described in Section A.6.

## 7.9 Summary and conclusion

This chapter crunched or *packaged* domain knowledge about airport strategic planning into a Domain Model, being the heart of the DSS. By implementing a Domain Model, we laid a solid foundation for growing the HARMOS DSS into a business application. So, this chapter answered Research Question 4: 'How is the architecture to be implemented such that the DSS requirements are realized and a solid foundation for growing HARMOS into a business application is created?'

The projects surveyed in Section 4.2 build computer-based systems for airport strategic planning through a data-driven and technology-driven approach. This approach does not result in systems that are capable of fully supporting airport strategic planning, and hence the systems are of little practical use.

A data- and/or technology driven approach for designing decision support for airport strategic planning fails, because such an approach is not able to deal with the complexity of the aviation and airport domain and the business activity of strategic planning. Airport strategic planning is not only about data and efficiently using tools for airport performance analysis. It is about mutual understanding among the airport operator and its stakeholders, taking into account each other's objectives, so that a shared vision can emerge. Once there is a shared vision, strategies need to be identified that potentially realize the vision. Next, these strategies need to be evaluated and compared, such that a collective decision can be taken about the strategies to be implemented.

An approach is needed that is able to tackle this complexity. Domain Driven Design is such an approach. By creating a Domain Model, for realizing the functionality of the HARMOS DSS, we have been able to formalize the airport strategic planning domain. Policy analysis according to Walker (2000)—one of the key design principles discussed in Section 5.2—drove the overall design of the HARMOS Domain Model.

The policy analysis framework (Figure 5.3) structures airport strategic planning problems in terms of the system, the forces that affect the system (external factors and strategies), the outcomes of interest, and the objectives of the decisionmakers. The structure of the policy analysis framework has been used to provide the main structure of the Domain Model (see the Domain Layer in Figure 6.3). Hence, the Domain Model features modules such as external factors, strategy, system, and outcome of interest. The study module has been designed to organize an airport strategic planning study as a whole; it thus provides functionality to capture the multi-stakeholder decisionmaking context. So, each of these modules has a clear responsibility in structuring the strategic planning study and associated strategic planning problem (Section 7.2.1, 'Core Classes').

The policy analysis process (Figure 5.4) organizes the problem solving effort through a logical number of steps that cover problem formulation, analysis, and interpretation. These steps provide the main user functionalities of the HARMOS DSS—Define Decisionmaking Context (Step 1–3), Develop Scenarios (Step 4), Define Strategy (Step 5), Evaluate Strategy (Step 6), and Compare Strategies (Step 7). Additional functionalities have been defined to make sure a study is set up correctly (Calibrate Study), the characteristics of the system are specified (Specify System Characteristics), and different airport performance aspects can be quantified (Execute Performance Analysis). Each of the modules is used to perform specific work within the workflow of the HARMOS DSS (Section 7.2.2, 'Workflow').

Table 7.8 provides an overview of how each of the user functionalities (Section 6.3) has been realized through the implementation of specific classes within each of the modules.

This chapter described the responsibility and behavior of each of these classes in detail. The implementation of these classes is not sufficient to provide for a fully featured and mature business application. However, the current Domain Model is complete and stable enough to further construct the functionality of the HARMOS DSS and grow HARMOS into a business application.

So, the development process within this research stops at the end of the Elaboration phase, meeting the LCA Milestone. The Domain Model is based on a number of explicit decisions that in our opinion add business value for growing the DSS into an airport operator's customized version during the *Construction* phase (discussed later in Section 11.1.1).

Table 7.8: Realization of the HARMOS functionality

| Functionality | Module | Class | Section |
|---|---|---|---|
| Define Decisionmaking Context (Section 6.3.1) | study | Study | 7.3.2 |
| | | Study Service | 7.3.1 |
| | | Context | 7.3.3 |
| | | Case | 7.3.4 |
| Calibrate Study (Section 6.3.2) | study | Case | 7.3.4 |
| Develop Scenarios (Section 6.3.4) | external factor | Scenario | 7.5.2 |
| | | Scenario Service | 7.5.1 |
| | | Traffic Demand | 7.5.3 |
| Define Strategy (Section 6.3.5) | strategy | Strategy | 7.6.2 |
| | | Strategy Service | 7.6.1 |
| | | Operational Plan | 7.6.3 |
| Evaluate Strategy (Section 6.3.6) | strategy | Strategy | 7.6.2 |
| | | Operational Plan | 7.6.3 |
| | study | Case | 7.3.4 |
| | external factor | Scenario | 7.5.2 |
| | | Traffic Demand | 7.5.3 |
| | outcome of interest | Outcome Indicator | 7.7 |
| Specify System Characteristics (Section 6.3.3) | system | Airport | 7.4.2 |
| | | Airport Environs | 7.4.2 |
| | | ATM System | 7.4.2 |
| | study | Case | 7.3.4 |
| Execute Performance Analysis (Section 6.3.7) | performance analysis | Case | 7.3.4 |
| | | Analysis Service | 7.8.1 |
| | | Tool Adapter | 7.8.2 |
| | study | Case | 7.3.4 |
| | strategy | Operational Plan | 7.6.3 |
| | external factor | Traffic Demand | 7.5.3 |
| | outcome of interest | Outcome Indicator | 7.7 |
| Compare Strategies (Section 6.3.8) | strategy | Strategy | 7.6.2 |
| | | Scorecard Service | 7.6.4 |

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CHAPTER 8

# Proof of Concept

This chapter provides a proof of concept for the HARMOS DSS. We define a Proof of Concept (PoC) as follows:

> The establishment of whether a system satisfies some aspect of the requirements, based on testing a partial solution, involving a small number of users acting in [business] roles (Wikipedia, 2012).

Because of the scope of this research (Section 1.6), we did not have direct access to users. But, we will explicitly show how users acting in business roles use the DSS. This proof of concept is organized around the three problem areas identified in Section 1.2:

I. Lack of involvement of the stakeholders (Section 1.2.1);
II. Inadequate approach for dealing with the future (Section 1.2.2);
III. An inefficient problem solving process (Section 1.2.3);

We show how the HARMOS architecture that has been designed and implemented addresses the specific problems within each of the three problem areas (we take these as the 'requirements' for the system). In this proof, the aspects of the requirements that are tested are the functional requirements defined in Section 6.3. The focus is on testing the HARMOS Domain Model, which was described in Chapter 7. The functionality of the Domain Model is tested for all three types of users—decisionmaker, decision adviser, and domain expert—who interact with HARMOS through the Graphical User Interface (see Appendix A). The test is carried out in the context of strategic planning for AAS.

The chapter is structured as follows. In Section 8.1, we show how the HARMOS architecture meets the high-level requirements for a DSS. A set of specific problems in each of the three problem areas is identified in Section 8.2.

Sections 8.3, 8.4, and 8.5 show how HARMOS addresses specific problems in respectively the first, second and third problem area. Section 8.6 compares the use of the DSS to Master Planning. The final section summarizes the chapter and draws conclusions related to the proof of concept.

## 8.1 THE HARMOS CONCEPT: CLOSING THE GAP BETWEEN DECISIONMAKING NEEDS AND DECISION SUPPORT

Our motivation for a DSS (Section 1.3) is based on the gap we identified between decisionmaking needs and current decision support (Section 1.3.3). We used the decisionmaking needs defined by Zachary (1998) as generic requirements for our decision support design (Section 5.1.2).

Our development effort has been primarily focused on meeting the specific need to deal with the three problem areas with airport strategic planning discussed in Section 1.2. As such we have been able to satisfy the needs defined by Zachary (1998) as well:

1. Lack of involvement of the stakeholders. The second part of Zachary's second need—comparing alternatives and making trade-offs among competing goals—is supported by the Strategy Comparator (Section A.7). The GUI as a whole (Appendix A) fulfills Zachary's fifth need—visualizing and manipulating those visualizations—as it presents the relevant information for decisionmaking in a graphical way.

   The Strategy Comparator also supports the sixth need—making heuristic judgments, even if they are only qualitative. The DSS users are able to test strategies against multiple futures, learn from the results they obtain, and try other strategies and scenarios.

   Section 8.3 demonstrates how HARMOS is able to deal with specific problems in this problem area.
2. Inadequate approach for dealing with the future. The Scenario Builder (Section A.4) meets Zachary's first need—project into the future despite uncertainty.

   The Strategy Evaluator (Section A.6) supports the first part of Zachary's second need: it provides functionality to evaluate different alternatives.

   Section 8.4 demonstrates how HARMOS is able to deal with specific problems in this problem area.
3. An inefficient problem solving process. The design of the Domain Model (Section 7), based on a policy analysis approach as the means to structure the planning problem and the problem solving process, meets the Zachary's third need—managing large amounts of information simultaneously.

The Strategy Evaluator (Section A.6) organizes information related to individual strategies. The Strategy Comparator (Section A.7) organizes information (albeit at a higher level of aggregation) related to all strategies that have been evaluated in the study.

The DSS as a whole meets Zachary's fourth need: analyzing complex situations within constraints on time and resources.

Section 8.5 demonstrates how HARMOS is able to deal with specific problems in this problem area.

The next section identifies specific problems in each of the three problem areas in order to demonstrate how each of them is addressed by the HARMOS DSS.

## 8.2 Specific problems related to airport strategic planning: Case of Amsterdam Airport Schiphol

This section looks at the strategic planning process for AAS from a multi-stakeholder point of view. This brings up the different visions and objectives of the stakeholders. We use this analysis to identify specific problems within each of the three problem areas to provide a proof of concept for HARMOS. The overall relationships between Schiphol Group and some of its stakeholders are visualized in Figure 8.1. The position of Schiphol Group in the middle is only because an airport typically initiates the airport strategic planning process (not because the airport operator is more important than the other actors). The actors are described in more detail below.

### 8.2.1 Schiphol Group

Schiphol Group's overall business strategy is focused on maintaining and reinforcing the competitive position of mainport Schiphol as an important intercontinental hub, which, in terms of its network of connections, is able to compete with London, Paris, and Frankfurt (Schiphol Group, 2007). Their corresponding objectives are:

1. Reinforce the mainport network of Schiphol;
2. Provide reliable capacity in order to prevent congestion during adverse wind conditions and peak periods;
3. Provide additional capacity from 2015 onwards in order to accommodate predicted demand (85 million passengers);
4. Improve the accessibility of the airport and increase its catchment area;
5. Reduce the environmental impact as much as possible.

Most of these objectives are related to the economic performance of either Schiphol Group or its surrounding region. Only the fifth objective is related to other aspects of the airport's operation. So, there is no integral view on the airport's

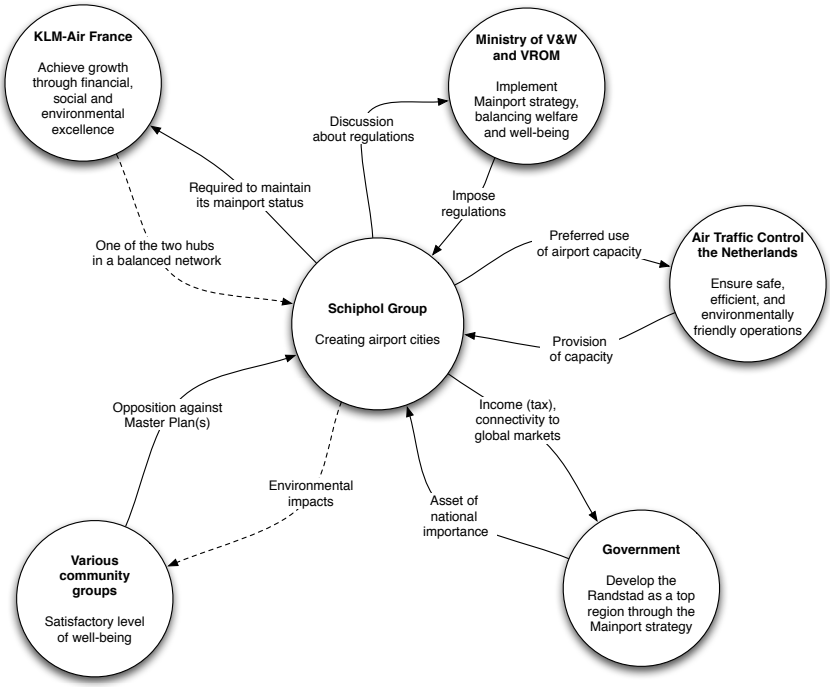


Figure 8.1: Multi-stakeholder Context for Amsterdam Airport Schiphol

performance (Problem Area III) nor is the airport's planning explicitly looked at from the perspectives of the different stakeholders (Problem Area I). The third objective reveals that uncertainty is not adequately addressed: a prediction based on past trends is used to determine future capacity requirements (Problem Area II). It is also interesting to see that the third objective is not an objective. It is a strategy for making sure future demand (whatever that will be (it is highly unlikely that it will be 85 million)) matches the capacity of the airport (Problem Area II).

### 8.2.2 Air France-KLM

As an industry leader, Air France-KLM holds itself responsible for achieving growth through financial, social, and environmental excellence (Air France-KLM, 2007). In the Corporate Social Responsibility report just cited, it is stated that 'the environmental impacts of airline activities call for in-depth dialogue with residents and local authorities'. Some of Royal Dutch Airlines (KLM)'s objectives are:

- Structurally discuss Schiphol's future;
- Reduce environmental impact and take into account trade-offs between noise and emissions (through improved procedures);
- Improve fuel efficiency and operating efficiency (through investments in a new fleet);
- Exploit opportunities afforded by the Open Skies Treaty;
- Invest in innovative and automated systems for improving safety and security;

Schiphol is one of the two hubs (Charles de Gaulle being the other) in Air France-KLM's (balanced) network. At the time of their merger (May, 2004), it was agreed that Schiphol should at least be connected with 42 important, international destinations for a period of five years (Raad voor Verkeer en Waterstaat, 2008, p.25). But, what will happen after this period? None of the thinking about Schiphol's long-term development is explicitly taking this into account (Problem Area II). It is also not clear how the in-depth dialogue with residents and local authorities will be organized (Problem Area III).

### 8.2.3 Air Traffic Control the Netherlands

In the first place, the Air Traffic Control the Netherlands (LVNL) is responsible for ensuring safe aircraft operations on the ground and in the TMA. Second, the LVNL is concerned about handling aircraft in an economically efficient way. Third, LVNL tries to reduce the environmental impact of aircraft operations. The LVNL's objectives are:

- Realize a strong position in the European ATM playing field;
- Contribute to the sustainable development of mainport Schiphol;
- Reduce costs.

The objective of sustainable development is not specific: no concrete outcomes of interest have been specified, nor any objectives related to specific environmental impacts (Problem Area III). These objectives do not show any intent of collaborating with airport stakeholders (Problem Area I).

### 8.2.4 The Government and Ministries

The former Ministries of Transport, Public Works, and Water Management and Spatial Planning and Housing shared the responsibility to design and implement government policies that maintain a balance between on the one hand opportunities for further development of Schiphol, and on the other hand the public safety, well-being, and land use in the Schiphol region. The results of their work are laws and regulations governing the use of Schiphol and the surrounding area (MinVW, 2003a,b). These laws and regulations have become quite complex. This complexity even contributed to a computational error that prevented the

new fifth runway from being used at its full capacity (todo: include reference). These governmental bodies would like to accommodate as much growth as possible, while keeping the environmental impact of the airport at acceptable levels. So, their objectives are:

- Provide opportunities for growth;
- Reduce environmental impact.

These objectives are very high-level, and therefore vague. They actually limit searching for strategies that favor a more sustainable development of the airport (Problem Area II). During public debates it is often strongly questioned whether both objectives can be met simultaneously. The first objective actually raises the question whether growth is really needed or even justified given the uncertain future (Problem Area II).

The complexity of the laws and regulations results in huge computational efforts for determining environmental impacts. It also makes stakeholder involvement more difficult, because public debate tends to revolve around the (computational) details of the laws and regulations instead of collective sensemaking and decisionmaking about strategies to be implemented (Problem Area I).

### 8.2.5 The Community

The community as such does not exist. However, different people and/or institutions have organized themselves in one form or another in order to be heard in discussions about Schiphol. These groups are usually composed of the people that have to deal with Schiphol's environmental impacts. These groups generally oppose plans presented by Schiphol (WRR, 2003).

The community does not favor an increase in noise annoyance. One of these groups is the Commissie Regionaal Overleg Schiphol (CROS), which organizes many local authorities and residential groups into a forum for discussion. Their objectives are:

- Reduce the noise impact and annoyance from activities at Schiphol;
- Improve local air quality and reduce odour annoyance;
- Provide employment;
- Provide a level playing field, and empower the community in planning and decisionmaking.

The fourth objective actually states that they want to be involved in the planning process (Problem Area I). The province of North-Holland recently stated that their objective is to limit the growth of Schiphol. They even conducted an extensive study evaluating many alternatives for the future of Schiphol. This is typical of the stakeholders that are in this group. They all conduct their own studies (Problem Area I), based on different data sets (Problem Area III).

### 8.2.6 Summary of the specific problems in each of the problem areas

As stated in the introduction of this chapter, our Proof of Concept is organized around the three problem areas in airport strategic planning as identified in Section 1.2: (I) a lack of involvement of the stakeholders, (II) an inadequate approach for dealing with the future, and (III) an inefficient problem solving process. From the analysis in the previous five subsections, we identified the specific problems for each of the three problem areas, as shown in Table 8.1.

Table 8.1: Specific problems within the three problem areas

| Problem Area | Specific Problem | Section |
|---|---|---|
| I: Lack of involvement of the stakeholders | Lack of collaboration | 8.2.2 8.2.3 |
| | Lack of trust among stakeholders | 8.2.5 |
| | No collective sensemaking or decsion-making | 8.2.4 |
| II: Inadequate approach for dealing with the future | Single view of the future | 8.2.1 8.2.2 |
| | Narrow set of strategies | 8.2.1 8.2.2 8.2.4 |
| III: Inefficient problem solving process | Computational errors due to complexity of laws and regulations | 8.2.4 |
| | Narrow perspective on airport performance | 8.2.1 |
| | Huge time investment for translating detailed computational results to an understandable presentation for decision makers | 8.2.4 8.2.5 |

The architecture of HARMOS has been designed so that the DSS is able to address these specific problems. The following three sections demonstrate how the functionality of the HARMOS DSS can be used to deal with the problems in each of the three problem areas. Each section describes in detail *who* is using the HARMOS DSS, *how* they use it, and *what* results can be obtained.

## 8.3 Problem Area I: Lack of involvement of the stakeholders

The first problem area that we have identified is a lack of involvement of the stakeholders. Section 8.2 identified the following specific problems in this problem area for the AAS case:

1. Lack of collaboration;

2. Lack of trust among stakeholders;
3. No collective sensemaking or decisionmaking.

We developed HARMOS with the vision that the airport operator and its stakeholders are able to work together on the development of the airport (see Section 5.1.3). Below, we demonstrate how HARMOS addresses these specific problems.

### 8.3.1 Define Decisionmaking Context

The **Decisionmaking Context Panel** of the HARMOS Study Manager (Section A.2) has been designed to document the decisionmaking context and update it throughout the planning effort if needed.

The decisionmakers of the airport operator and its stakeholder can specify their perspective on the problem situation and their objectives through the Decisionmaking Context panel previously shown in Figure A.1(b). The outcomes of interest are selected based on the objectives. So, all actors have to be explicit about their objectives and the outcome indicators needed to evaluate them. In addition, analysis of trade-offs between objectives (related to noise and emissions, for example) is decided at the start of the planning study, instead of being considered as an afterthought.

By having a single place to define the decisionmaking context, actors can *learn* about each other's perspectives and objectives. Eventually, this might even lead to a *shared* problem definition, which can be described in the **Shared Problem Definition** tab (right tab on the panel in Figure A.1(b)). The result is an improved *collective understanding* of the problem situation.

### 8.3.2 Compare Strategies

The HARMOS **Strategy Comparator** (Section A.7) supports decisionmakers of the airport operator and its stakeholders to compare strategies against each other and with respect to their objectives.

HARMOS generates a scorecard for each scenario, presenting the effects on the airport's performance for each of the strategies, as previously shown in Figure A.6. The rows of the scorecard are related to the strategies. The scorecard is used to assess individual strategies and compare them with each other and the Business as Usual strategy, which is included by default. The decisionmakers also use the Strategy Comparator to assess the effects of the strategies (in terms of the outcome indicators selected when defining the decisionmaking context, previously shown in Figure A.1(b)) in relation to their objectives.

The scorecards provide a means for discussion and dialogue between decisonmakers of the airport operator and its stakeholders in order to make a choice for the preferred strategy or strategies to be implemented. The decisionmakers might also collectively decide to conduct additional analysis, either because none of the strategies that have been evaluated can satisfactorily meet their objectives or to evaluate strategies not thought of before.

## 8.4 Problem Area II: Inadequate approach for dealing with the future

The second problem area that we have identified is the inadequate approach for dealing with the future. Section 8.2 identified the following specific problems in this problem area for the AAS case:

1. Single view on the future by predicting demand for a single year;
2. Narrow set of strategies (i.e. focus on growth).

We designed specific functionality for HARMOS to appropriately deal with the future and the uncertainties it brings (Section 6.3.4). Below, we demonstrate how HARMOS addresses these specific problems.

### 8.4.1 Develop Scenarios

This section describes how the HARMOS Scenario Builder (Figure A.3) is used to get a better grip on the future and the uncertainties it brings. As mentioned before, HARMOS supports the scenario building methodology from (van der Heijden *et al.*, 2002). This methodology provides decisionmakers and decision advisers an easy and structured approach to build four scenarios describing structurally different, but plausible futures for testing the strategies. How this methodology works and how the HARMOS Scenario Builder supports this methodology is described in detail by (Cuijpers, 2008). Scenarios provide an easy and structured way to quantify trends and developments for the relevant external factors. Decision advisers and domain experts quantify trends and developments so that these can be used for evaluating the effects on airport performance for each of the strategies (Section 8.5.2). Based on the HARMOS architecture, Kwakkel (2010) implemented 'generator objects', which allow for quantification of any external factor throughout the planning period. External factors for which these objects have been implemented are:

- Economic developments driving traffic demand;
- Technological developments affecting ATM system performance, aircraft performance, noise and emissions;
- Regulatory developments putting constraints on some of the aspects of an airport's operation;
- Demographic developments specifying the density and distribution of people living in the vicinity of the airport.

By building on top of the HARMOS architecture, Kwakkel (2010) could easily implement functionality for quantifying trends and developments for several external factors. By doing so, the quantified trends and developments could readily be used for computational experiments (based on the HARMOS code as well).

### 8.4.2 Define Strategy

The HARMOS Strategy Builder (Section A.5) supports the airport operator and its stakeholders to define a broad range of strategies.

The design and implementation of the HARMOS architecture is domain driven (Evans, 2004). This means that the HARMOS code is based on language and concepts that are used by the people in the airport strategic planning domain. We have already seen an example of this: the Decisionmaking Context Panel explicitly allows each actor to specify their problem perspective and objectives. This is also why strategy is a concept that is explicitly implemented.

We have used object orientation to implement the HARMOS architecture (Section 7.4.2). Hence, our representation of an airport system is also object oriented. The system representation captures data and behavior relevant for airport strategic planning. As such, our system representation includes a representation of the runway system, including its runways and tracks (data). The representation of the runway system features the ability to add, change, or delete a runway object (behavior).

A strategy is a change to the airport's infrastructure, operations and/or management under the control of the decisionmakers. The choice for an object-oriented representation of the system makes it very convenient for domain experts and decision advisers to define a broad range of strategies. It's a matter of defining a strategy object that describes how a strategy affects an airport's infrastructure, operations and management.

For example: the strategy 'Build New Runway' is an object that describes the physical characteristics of the runway (including its departure and arrival routes) and the new operational plan for using the expanded runway system. This information is used to change the part of the system model that represents the current airport infrastructure and operation. This is easily done by using the 'add runway' operation of the runway system class (Section 3.1.2). A screenshot of the Strategy Builder showing how the strategy 'Build New Runway' is defined was previously shown Figure A.4.

Since all the real-world elements of the airport system have been modeled this way, it is easy for domain experts and decision advisers to define a broad set of strategies (strategy objects) that change the airport system or its operation in various ways.

So, strategies are in fact just changes to the object-oriented system model that has been implemented that become effective at a certain point in time during the planning period. The changed system model contains all the data and information needed to compute an airport's performance for a specific situation (as described in Section 8.5.2). Kwakkel (2010) used the HARMOS Domain Model to conduct computational experiments in which a broad set of strategies was evaluated against a large number of scenarios.

## 8.5 Problem Area III: Inefficient problem solving process

The third problem area that we identified is an inefficient problem solving process. Section 8.2 identified the following specific problems in this problem area for the AAS case:

1. Computational errors due to the complexity of laws and regulations;
2. Narrow perspective on airport performance;
3. Huge time investment for translating detailed computational results to an understandable presentation for decision makers.

Below, we demonstrate how HARMOS addresses each of these specific problems.

### 8.5.1 Calibrate Study

The HARMOS Calibrator (Section A.3) ensures that a common and consistent dataset is used for executing quantitative performance analysis within a planning study.

The Calibrator guides a domain expert through the steps needed to work with consistent data about the current airport system and its performance. For a chosen baseline year, a single and consistent system model representing the current airport system and its operation is setup by domain experts (see also Section 6.3.2). After that, domain experts use the Calibrator to compute current airport performance (Execute Performance Analysis, mentioned in Section 6.3.7) and check whether this is comparable to the airport's known performance. If that is not the case, the domain expert should revisit the data used for setting up the system model and/or change computational parameters.

The results of the calibration provide a single source of data and information about the airport's performance, greatly improving the efficiency of the problem solving process. Also, all actors have access to the same information. This helps build trust among stakeholders (Section 8.3).

### 8.5.2 Evaluate Strategy

The HARMOS Strategy Evaluator (Section A.6) supports the airport operator and its stakeholders to evaluate the effect of a strategy on the airport's performance in terms of a wide variety of outcomes of interest. It allows domain experts and decision advisors to evaluate the quantitative effects of a strategy on airport performance, taking into account the quantified trends and developments for each of the scenarios (Section 8.4.1) that have been developed.

As an example, Figure 8.2 shows how capacity analysis is done with the DSS (previously, Figure A.5(b) showed the panel for noise analysis). First, a period of interest within the planning period (Part I in Figure 8.2) needs to be selected. Part II in Figure 8.2 shows the selected outcome indicators when the decisionmaking context was defined (see also Section 8.3.1).

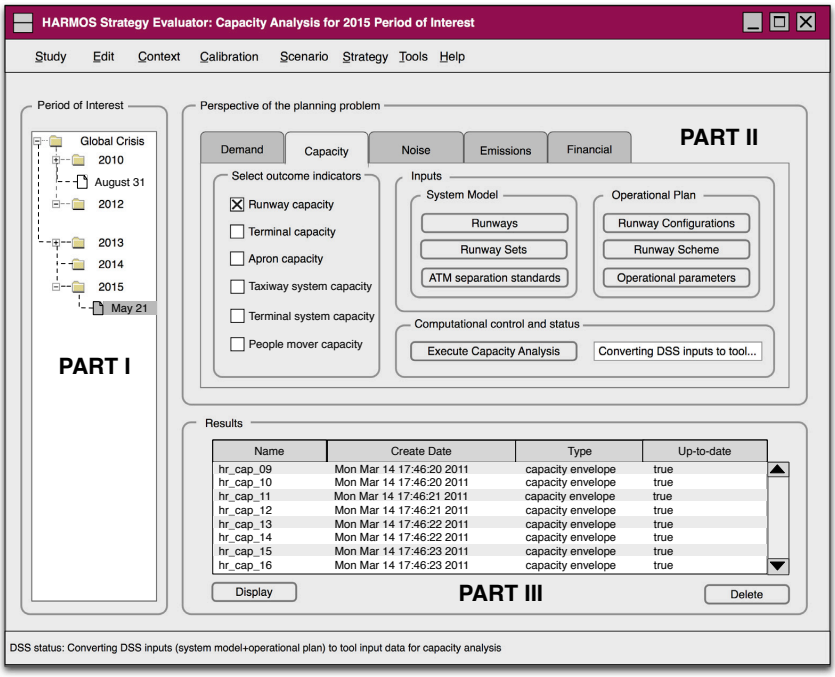


Figure 8.2: Strategy Evaluator providing an integral view on airport performance

Additional indicators can be selected from the panel if needed. Whenever an additional outcome indicator is selected, HARMOS checks whether the appropriate inputs have been specified. If input is missing, the buttons shown in Part II of the figure can be used to directly add the missing information to the relevant part of the system model.

When a domain expert (or decision adviser) activates the **Execute Capacity Analysis** button, the HARMOS DSS executes the specific performance analysis calling upon the appropriate tool. The results from the computations are presented in the lower half of the panel, i.e. Part III of the panel, as indicated in Figure 8.2.

## 8.6 Compatibility with Master Planning

As discussed in Section 2.2, the dominant approach to airport strategic planning is Master Planning. Although the HARMOS DSS has been primarily designed to deal with all three problem areas of current airport strategic planning it actually

Table 8.2: Master Planning versus HARMOS' functionality.

| **Master Planning** | **HARMOS' Functionality** |
|---|---|
| Pre-planning | Study Manager |
| Public Involvement | Study Manager, Strategy Comparator |
| Existing Conditions | Calibrator (has not been discussed) |
| Aviation Forecasts | Scenario Builder |
| Facility Requirements | Strategy Evaluator for Business as Usual |
| Alternatives Development and Evaluation | Strategy Builder, Strategy Evaluator |
| Environmental considerations | Strategy Evaluator |
| Financial Feasibility | Strategy Evaluator, Strategy Comparator |

encompasses all of the activities defined within Master Planning. This is not surprising, since policy analysis evolved from systems analysis, which is used as the analytical framework for Master Planning.

Table 8.2 presents a comparison of the Master Planning activities (see also Section 2.2) with specific HARMOS functionalities. Master Planning starts with identifying the need for a Master Plan. The need for a planning study could be based on existing or potential shortcomings in the existing plan or current airport system, or be driven by the vision or business plan for the airport.

We think that in today's rapidly changing world, there is a continuous need for an airport operator to monitor and adapt its strategies. At any time, the HARMOS Study Manager can be used to create a new planning study to investigate a problem or opportunity.

Public involvement is directly facilitated by HARMOS by using the the Study Manager to define the planning problem together (Section 8.3.1) and the Strategy Comparator for comparing and selecting strategies in a collaborative setting (Section 8.3.2). The ease with which different strategies can be defined with the Strategy Builder (Section 8.4.2) and evaluated with the Strategy Evaluator (Section 8.5.2) makes it possible to also assess strategies proposed by each of the stakeholders. The HARMOS DSS eliminates the coordination effort related to data and information, and tools, so that the time that becomes available can be used to interact more meaningfully with the stakeholders.

The evaluation of existing conditions at an airport is taken care of by the (required) use of the Calibrator after creating a new study. Aviation forecasts are replaced by scenario through the use of the Scenario Builder (Section 8.4.1), which in addition offers a way to deal with more external factors than demand alone. Facility requirements are dealt with through the use of the Strategy Evaluator for the 'business as usual' strategy.

The evaluation of that strategy does not provide the requirements for the airport facilities per se; it merely shows which airport facilities become bottlenecks at some point in the future. The development of alternatives is done with the Strategy Builder; their evaluation is covered by the Strategy Evaluator.

Environmental considerations do not have to be separately assessed, because the Strategy Evaluator provides the functionality to integrally assess the outcomes of interest. For the same reason, the assessment of the financial feasibility of a strategy is covered by the Strategy Evaluator.

In addition, the Strategy Comparator provides the means to provide financial information at a higher level of aggregation than when using the Strategy Evaluator (e.g. the return on investment, payback period), which is needed to be able to compare the financial feasibility of different strategies.

So, using the HARMOS DSS is not inconsistent with current airport planning practice. The DSS actually incorporates the procedures, tasks, and activities of Master Planning into a broader framework for problem solving and decision-making, to overcome the problems with current airport strategic planning.

## 8.7 SUMMARY

This chapter showed how the DSS is *activated* to address specific problems in each of the three problem areas. By doing so, we have answered Research Question 5: 'How can a proof of concept be provided?' We also compared using the HARMOS DSS with the current Master Planning process.

By describing and showing the use of various GUI components, we demonstrated how the HARMOS DSS is able to address the specific problems in each of the problem areas for the case of strategic planning at AAS. This is summarized in Table 8.3.

So, identifying specific problems for AAS in Section 8.2 allowed us to show that each of them can be addressed by the HARMOS DSS, as such providing a Proof of Concept. By providing the Proof of Concept, we have met the Lifecycle Architecture Milestone (LCA), shown in Figure 5.9.

We also showed that using the HARMOS DSS is compatible with the current Master Planning process. The next chapter describes what potential users think about the usefulness of the DSS.

Table 8.3: How HARMOS addresses the problems in each of the problem areas

| Problem Area | Specific Problem | How Addressed |
|---|---|---|
| I | Lack of collaboration in pre-planning phase | Study Manager for defining different perspectives on the planning problem |
| | Lack of trust among stakeholders | Strategy Comparator for integrated assessment of strategies against multiple futures |
| | No collective sensemaking or decisionmaking | Every part of HARMOS, but the Study Manager, Scenario Builder and Strategy Comparator in particular |
| II | Single view of the future | Scenario Builder for co-creating four scenarios |
| | Narrow set of alternative strategies | Strategy Builder for defining a wide range of strategies |
| III | Computational errors | Calibrator providing a single and consistent system model for extracting data to execute airport performance analysis |
| | Huge time investment for translating computational results to understandable format | Strategy Evaluator for integrated assessment of the outcomes for a single strategy |

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CHAPTER 9

# Proof of Usefulness of the HARMOS DSS

As explained in the previous chapter, we did not have direct access to users during DSS development. The previous chapter showed how users acting in the roles of decisionmaker, decision adviser, and domain expert would use the DSS, providing a proof of concept. A proof of usefulness is provided in this chapter. Section 9.1 explains the approach to testing the usefulness of the HARMOS DSS, based on a workshop with potential users. An analysis and discussion of the results of this workshop is given in Sections 9.3 and 9.3.4. Section 9.4 discusses implications for the practical use of the DSS. The final section draws conclusions about the usefulness of the HARMOS DSS.

## 9.1 APPROACH FOR TESTING DSS USEFULNESS

A DSS will be adopted only if it is perceived as useful for addressing the decision problems it is designed for. In the previous chapters, we showed that the HARMOS DSS is able to address specific problems in each of the three problem areas in the previous chapter, providing a proof of concept. This proof of concept, however, does not say anything about how potential users perceive the usefulness of the DSS. Therefore, the usefulness of the HARMOS concept and its functionality was tested by potential users through a one-day workshop.

We invited potential users of the DSS for testing the concept and promise of the HARMOS DSS. Directly asking potential users what they think about the functionality of the DSS is a good way to get insight into the perceived value of the DSS in a real-world setting.

### 9.1.1 Methodology and technology

We used Group Decision Room technology and tools (Kolfschoten and de Vreede, 2008) to facilitate the discussion among participants and structure the feedback process on HARMOS and its functionality. This technology makes it easy for an individual in a group to voice his or her opinion, and it facilitates open discussion. Therefore, the use of this technology allowed us to get the honest feedback we wanted from potential users.

### 9.1.2 Design of the workshop

The workshop was divided into three parts, each focused on getting feedback about various aspects of our research and the functionality of the HARMOS DSS. These three parts and the related questions for triggering feedback were:

**Part I: Open question about key challenges in airport strategic planning.** We asked the participants the question: 'What are the key challenges in airport strategic planning?'.

**Part II: Specific problems in each of the problem areas.** We asked the participants about specific problems they encountered and/or observed within the three problem areas identified in this research.

**Part III: Demonstration of specific HARMOS functionality.** We used the storyline of the Proof of Concept (Chapter 8) to demonstrate the HARMOS functionality to the potential users.

### 9.1.3 Potential users

Because usefulness is defined as 'being of practical use', we invited a number of people who are professionally involved in airport strategic planning. These people were associated with different organizations representing a number of stakeholders:

- A former Director Airport Development and a Manager Airport Planning from Amsterdam Airport Schiphol;
- An aviation consultant from Cap Gemini;
- A policy researcher from the PBL Netherlands Environmental Assessment Agency;
- A researcher from the Dutch Aerospace Laboratory;
- A consultant from aviation consultancy TO70;
- A program manager from Delft Infrastructures & Mobility Initiatives (DIMI);
- A former senior policy researcher from the Dutch Ministry of Transport;
- A PhD. student from the Faculty of Aerospace Engineering, involved in airport development.

## 9.2 WORKSHOP RESULTS

For each of the three parts of the workshop, Sections 9.2.1, 9.2.2 and 9.2.3 present the responses of the participants to the questions we asked during Parts II and Part III of the workshop.

### 9.2.1 Part I: Open question about key challenges in airport strategic planning

We opened the workshop by asking the participants the question: 'What are the key challenges in airport strategic planning?'. From the response to this question six different clusters were identified during the session:

**Stakeholder Management.** The first issue that was brought up was who the stakeholders exactly are. The participants talked about building consensus with stakeholders. Questions were raised about which scale consensus should be at (world-wide, European, or national), with whom (members of upper class or society as a whole?) and about what (definite plan, growth). Dealing with conflicting interests was discussed. Participants mentioned covering information needs and making sure that metrics are used that are understood by all stakeholders. It was also said that both benefits and disadvantages should be made explicit to the main stakeholders.

**Dealing with uncertainty.** The first issue that was mentioned was about being adaptive, i.e. being able to respond to (sudden) changes in the market. A number of questions were raised by the participants, such as: 'How to deal with the uncertainty in assumptions that are made? Do you really need to wait until all uncertainty is cleared? How can we cope with uncertainty?'. One participant said that it is not required to wait until all uncertainty is cleared, if the influence on the effects can be quantified and is accepted by the stakeholders.

**Interfaces, synchronizing different systems.** The participants had a discussion about the role of air transport compared to other modes of transport. They also raised the issues of dealing with the limitations of existing infrastructure. One of the participants wondered about how to translate these limitations into structural decisive criteria relevant for the Master Plan. Also having an integral view about issues such as environmental impact, consequences for charges, or the effects of a Emission Trading System (ETS) for non-aviation sources was raised.

**Environmental impact.** The participants raised the issue of how to address noise and emissions. Someone mentioned a much higher level problem, i.e. the tension between available and needed energy resources for different consumption requirements. Getting all the relevant data required for

the assessments on time and without error was also mentioned as a challenge. Similarly, modeling the (future) operation such that the impacts in terms of noise and emissions (both in the air as well on the ground) are explicit was mentioned as a challenge. Again, the need to explain the environmental impact and offset the negatives with something positive was brought up. One of the participants proposed to incorporate Corporate Social Responsibility into the planning cycle.

**Decision process.** A few remarks were made about the decision process. The participants mentioned the decision process is both slow and complex, because of multi-level governance. Dealing with process and content and combining them in a timely manner to come to decisions is difficult.

**Investments.** The specific challenges mentioned were having a clear view on future investments and getting your strategic goals right. Raising the required capital and having an economic regulation in place to fund capital-intensive projects was also mentioned. Another challenge that was brought up was dealing with the large buying power of your main stakeholders and getting approval from airlines.

The challenges that were raised by the participants cover a wide range of subjects, which is why the challenges were clustered during the session. The link between these challenges and the motivation of our research will be discussed in Section 9.3.1.

### 9.2.2 Part II: Specific problems in each of the problem areas.

During this part of the workshop we asked the participants for specific problems they encountered and/or observed within the three problem areas identified in our research. The responses to this question are listed below for each of the problem areas. These responses are direct quotes from the participants.

*Problem Area I: Lack of stakeholder involvement*

The specific problems within the first problem area as mentioned by the participants were as follows:

- *The level and type of involvement of the stakeholders should be defined. Also, the categories of stakeholders and their roles should be defined.*
- *Stakeholders should not be pampered, and their knowledge should be used.*
- *Stakeholders should be involved according to their different stakes and influence on the planning decision process.*
- *Possible problem areas and solutions are overlooked or underestimated because not all stakeholders are present.*

- *Stakeholders are limited in their effort to be sufficiently involved. Airlines often do not want to participate in research for financial reasons, although they have a high interest. Air Navigation Service Providers (ANSPs) are less interested in capacity increase because it might impact safety and workload.*
- *Often stakeholders are unable to judge complexity. Not all stakeholders are equally equipped with competences and tools to evaluate proposed options.*
- *Different stakeholders focus on different things. Municipalities have a different interest in the growth of the airport because of the impact on their plans. Airlines have a relative short time horizon of planning, and their focus is on investing in their core business, which is flying. Airport investment plans look 20-40 years ahead, while airlines and airline alliances may change their network strategy within 2-5 years.*

*Problem Area II: Inadequate approach to deal with the future*

The specific problems within the second problem area as mentioned by the participants were as follows:

- *Making assumption on assumption on assumption.*
- *Constraints are underestimated, environment and scarce resources are not yet visible in pricing.*
- *Often a long term focus and clear strategy is lacking or too ambitious and not feasible (supply dominated planning dominated by political goals).*
- *Decisions are too often focussed on time horizons with the most uncertainties and there are often no options built in for decisions on the fly.*
- *Plans are not designed in an adaptable way.*
- *Benefits should be considered against the current problem and new problems should be identified.*
- *Planners and decision makers ask for detailed plans and certainties, but you should present a global thematized plan with options open, allowing to make decisions at the appropriate moment.*
- *Try to hold a steady story line for the outside world (politicians, residents).*
- *No clear decision path and the built-in guarantees to involve those stakeholders along the process.*
- *Effects are usually expressed as a single number, but a bandwidth is needed.*

*Problem Area III: Inefficient problem solving process*

The specific problems within the third problem area as mentioned by the participants were as follows:

- *Not all information needs are covered.*
- *Data required for analysis is not available in a timely manner and without errors.*
- *Making assumption on assumption on assumption. Assumptions made were not agreed upon by all stakeholders.*
- *Metrics used are not understood.*
- *At the start [of the problem solving process] you should have a clear agenda and consensus about this agenda with all stakeholders involved. However, practice is muddling through.*
- *Mix up of content and process often hampers the decision process.*
- *Enlarge the scope of the process to find new solutions.*
- *Selected methods or models are not suited for 'the job'. Models are by definition inefficient.*
- *Development of advanced systems requires an open attitude to change. This is not always the natural attitude.*
- *I see this [an inefficient problem solving process] as an advantage, if different stakeholders do their own analysis, at least the spread of the problem becomes clear.*
- *Changes in the representatives of the stakeholders. The [new] people involved no longer have the same information or have different ideas.*
- *Often the technicals are all solved. It is the 'soft' side that is poorly managed.*
- *A long term strategy should take a strategic view on world development. But, airports are operating in a local context of interests. Most important is to have a shared vision with your stakeholders on the need to expand and all the problems related to this; too fast we go for solutions and models instead of formulating problems and alternatives.*
- *Dealing with the uncertainty of innovation.*

The similarities and differences between the specific problems identified by the participants and those identified in our research will be discussed in Section 9.3.2.

### 9.2.3 Part III: Feedback on specific functionality of the HARMOS DSS

During this part of the workshop we used the storyline of the Proof of Concept (Chapter 8) to demonstrate the HARMOS functionality (see Figure 6.4) to the potential users. We presented screenshots of the main components of the HARMOS GUI (see the Appendix). After presenting each of the screenshots, we asked the following three questions:

1. What is your current approach for executing the planning task supported by this functionality?
2. What do you think is the effect on [trust, collaboration, collective decisionmaking, time effort needed] when using this functionality?
3. Do you see other benefits and/or disadvantages?

The first question was used to get the participants to reflect on a particular activity within the strategic planning process from their own point of view and/or experience. The second and third questions were about using HARMOS to support these activities. The responses to the second and third question are presented below for each specific functionality.

*Problem Area I: Lack of Involvement of the Stakeholders*

Section 8.3 showed the specific functionalities of HARMOS that are used to address the lack of involvement of stakeholders. These functionalities—Define Decisionmaking Context and Compare Strategies—were presented to the potential users, asking for their feedback.

*Define Decisionmaking Context.* We presented Figure A.1(b) and explained how HARMOS is used to define the decisionmaking context for an airport strategic planning problem (previously described in Section 8.3.1). We then asked the following question:

> What do you think is the effect on collaboration, trust building and collective decisionmaking of using the demonstrated HARMOS functionality for defining the decisionmaking context?

The responses to this question were as follows:

- *A priori you must start with a situation of mutual trust, maybe starting first with stakeholders who are willing to collaborate.*
- *Do not know, depends on how the various stakeholders accept the tool. I have my doubts if the general public will trust the tool. It is a black box to them. To me even-so.*
- *Trust building works fine until you discover that one stakeholder has a plan B, that does not fit.*

- *I guess HARMOS will have a positive effect on collaboration and collective decision making. I doubt the model will contribute to trust building.*
- *From the first screen, I would say that potentially the tool improves collaboration and collective decision as all stakeholders adopt the same decision framework, data, tools, and analysis. Unsure about trust building, I think it that depends mainly on the people you work with.*

The participants mentioned the following benefits related to this functionality:

- *All parties involved are able to express their interest direct and unconstrained.*
- *It is helpful to make an inventory of undiscussed pro's and contra's and thereafter to structure them stepwise.*
- *It helps in structuring the discussions. However, HARMOS has to be flexible to accommodate new things that come up in the discussions.*
- *It helps to speak a common language.*
- *It helps if the structuring of arguments leads to an agreed structuring of the problem, but it is not evident who ultimately determines this agreed structure.*
- *At least you'll start with identifying the problem in stead of diving into solutions.*

The following disadvantages were raised:

- *There might be an unbalanced dominance of arguments.*
- *It seems difficult to introduce an ordering in the discussion due to a changing vision and/or objectives in time, the proposed method suggests a two-step process.*
- *HARMOS assumes all stakeholders are actually willing to negotiate. How do you prevent strategic behavior? And how do you deal with discussions between stakeholder A and B in which stakeholder C does not play a role?*
- *HARMOS provides a framework to structure the decisionmaking. However, I doubt whether it provides sufficient level of detail to sketch the decisionmaking context. For example, specification of the outcome indicators at a too high level.*

*Compare Strategies.* We presented the Strategy Comparator (Figure A.6) and explained how HARMOS is used to compare strategies (previously described in Section 8.3.2). We asked the following question about using HARMOS for defining the decisionmaking context:

> What do you think is the effect on collaboration, trust building and collective decisionmaking of using the demonstrated HARMOS functionality for comparing strategies?

The responses to this question were as follows:

- *Show the effects of different perspectives and interests. That should be the input for further and open discussion.*
- *Help on the advisory level in order to negotiate with stakeholders.*
- *Introduce all different visions without a built-in appraisal process.*
- *Facilitate the comparison. However the trust in the system is depending on the trust people have in models that the scorecard is based upon.*
- *A more neutral comparison of statements may allow to build a more reflection-based decisionmaking process.*
- *Trust building will increase by making visible the interests of each stakeholder.*
- *Improved collaboration and decisionmaking because the information is available to all stakeholders.*

The participants mentioned the following benefits:

- *It could illustrate the effects of different strategies within different scenarios.*
- *The advantage is that you all agree on what you consider as the 'real truth' (at least at a specific moment in time).*
- *The advantage of getting weighted Key Performance Indicators and comparable entities leads to better overall judgement.*
- *Benefit is that all effects for all scenarios are available instantly if the metrics are defined correctly and the tools and analysis is supported by all stakeholders.*

The following disadvantages were raised:

- *Would the system capture all relevant factors and are all needed metrics/data available?*
- *Options to compare scenarios and check against performance objectives can be improved.*
- *The potential disadvantage lies in the fact that* HARMOS *implies a sequential process. I think that due to discussion, stakeholders will find it very hard to comply with the rules of the game (in which* HARMOS *is 'the game').*
- *Decisionmaking is based on scores and drives out the dominance of one controversial issue. Maybe that controversial issue is decisive after all.*
- *The black box character of the system.*

*Problem Area II: Inadequate Approach for Dealing with the Future*

Section 8.4 showed which specific functionalities of HARMOS are used to deal with the future. These functionalities—Develop Scenarios and Define Strategy—were presented to the potential users, asking for their feedback.

*Develop Scenarios* . We presented the Scenario Builder (Figure A.3) and explained how HARMOS is used to develop scenarios (previously described in Section 8.4.1). The question we asked about using HARMOS for developing scenarios was:

> What do you think is the effect on (collective) understanding and insight into the future and the uncertainty it brings of using the demonstrated HARMOS functionality for developing scenarios?

The responses to this question were as follows:

- *It could create awareness of several scenarios. Usually people have preferred solutions without any consideration of the viability or context.*
- *HARMOS enables the stakeholders to collectively agree about the starting point [scenario].*
- *The HARMOS system might bring a sort of neutral analysis, and might help to exclude emotions from analyzing the differences of interest.*

The participants mentioned the following benefits:

- *An agreed starting point of the discussion.*
- *The perception of stakeholders that they have something to say.*
- *A single data room.*
- *It provides overview and structure of an appraisal of a scenario.*
- *It provides an overview of the scenarios, sources used, assumptions made.*

The following disadvantages were raised:

- *There is an agreed truth which may limit the potential for stakeholders (what is in it for me here?), so they might leave the discussion.*
- *All stakeholders have the perception that they are (equally) important.*
- *It may emphasize the ultimate conflicts of interest that remain.*
- *It is helpful if a decomposition of a scenario is supported by any form of analysis that makes clear if there is consistency, and if there are possibly uncertain and controversial issues.*
- *Developing scenarios is almost a professional task. The pitfall of model aided scenario design is the easy way in which you come to a result.*

*Define Strategy.* We presented the Strategy Builder (Figure A.4) and explained how HARMOS is used to define strategies (previously described in Section 8.4.2). The question that was asked about using HARMOS for defining strategies was:

> What do you think is the effect on the quantity and quality of the formulated strategies when using the demonstrated HARMOS functionality for defining strategies?

The responses to this question were as follows:

- *It enlists at least all possible strategies.*
- *They are accessible to all stakeholders (both an advantage as well as a disadvantage). I think that you end up with a lot more strategies than in the traditional process. It is difficult to predict the effects on quality: since you want to be treated seriously as a stakeholder (also in the future), you better make sure you come up with realistic strategies.*
- *It is as good as the underlying model/tools.*

The participants mentioned two benefits: (1) stimulates to collect all strategies, and (2) providing an overview of all strategies that have been identified. One participant mentioned that the advantages are in most cases also potential disadvantages. For example, sharing strategies can help the discussion, but it can also harm the discussion, since stakeholders may misuse them to develop anti-strategies. No specific other disadvantages were reported.

*Problem Area III: Inefficient problem solving process*

Section 8.5 showed the specific functionalities of HARMOS that are used to address the inefficiency of the problem solving process. These functionalities—Evaluate Strategy and Execute Performance Analysis—were presented to the potential users, asking for their feedback.

*Evaluate Strategy.* We presented the Strategy Evaluator (Figure A.5) and explained how HARMOS is used to evaluate strategies (previously described in Section 8.5.1 and 8.5.2). The question about using HARMOS for defining strategies was:

> What do you think is the effect on computational errors, the view on airport performance and time investment of using the demonstrated HARMOS functionality for evaluating strategies?

The participants' responses were not direct answers to this question. They replied with generalities, such as 'garbage in = garbage out', systems and processes should incorporate learning effects, and any model is a proxy of reality. They

also mentioned that the calculations done by HARMOS are difficult to understand and that it might not be clear what data had been used.

The participants mentioned the following benefits: an increase in efficiency (time and costs), working with results based on common data, the ability for users to do their own analysis, and showing causal relationships between objectives and outcomes.

*Execute Performance Analysis.* We did not present this functionality with a screenshot, because it is a subfunction of the DSS (see Figure 6.4). We did briefly explain that this functionality is called upon several times when users evaluate a strategy (see Section 6.3.6 and Figure 7.2).

The participants mentioned the following two benefits: an average user being able to control the tools, and agreement on what you are going to calculate. As a disadvantage, the black box nature of this functionality was mentioned. One participant stated: 'Is the transparency of the system sufficient for all users?'.

## 9.3 Response to the workshop results

The results of the workshop are analyzed following the three part structure of the workshop. These three parts were (Section 9.1):

**Part I: Open question about key challenges in airport strategic planning.** We asked the participants: 'What are the key challenges in airport strategic planning?'.

**Part II: Specific problems in each of the problem areas.** We asked the participants about specific problems they encountered and/or observed within the three problem areas identified in this research.

**Part III: Demonstration of specific HARMOS functionality.** We used the storyline of the Proof of Concept (Chapter 8) to demonstrate the HARMOS functionality to the potential users.

The results from Part I are analyzed in Section 9.3.1, showing the link between the challenges in airport strategic planning perceived by the participants and the motivation of our research. Section 9.3.2 analyzes the results of Part II from the workshop, focusing on differences and similarities in specific problems for each of the problem areas as identified by the participants and during our research (Section 1.2). The feedback of the potential users on specific HARMOS functionality is analyzed in Section 9.3.3. Section 9.3.4 concludes with an overall discussion of the results.

### 9.3.1 Part I: Open question about key challenges in airport strategic planning

Below is a brief discussion of the clusters that were defined during the discussion among the participants (Section 9.2.1):

**Stakeholder Management.** The overall idea that emerged was managing stakeholders as opposed to fully engaging them. In our opinion, a planning process that does not fully engage all stakeholders will not be efficient nor be effective because of the airport being a socio-technical system (Chapter 3).

**Dealing with uncertainty.** It is interesting to see that some participants accept uncertainty as a given, while the other participants talked about about controlling uncertainty in one way or the other. We also accept uncertainty. In addition, we provide a structured approach to use uncertainty to inform decisionmaking and identify better strategies. Our approach for dealing with uncertainty is based on scenario thinking (Section 6.3.4).

**Interfaces, synchronizing different systems.** The airport system itself was perceived as a challenge. The discussion here was about understanding the system as a whole. We did not identify the airport system as a challenge, but more as an underlying cause of what makes airport strategic planning complicated. We found that the complexity of the airport system often leads to a narrow, mostly technical view of the system when dealing with airport strategic planning problems. That is the reason that we conceptualized the airport as a socio-technical system (Chapter 3). This allowed us to understand the domain of airport strategic planning from a broad perspective and turn this understanding into a Domain Model (Chapter 7) as the heart of the HARMOS DSS.

**Environmental impact.** The proposal from one of the participants to include Corporate Social Responsibility in the planning cycle appeared to be more about a means to communicate environmental impact to stakeholders. Corporate Responsibility, according to our definition, is about finding out what is important for your stakeholders and making sure their objectives are satisfied too (Section 3.3).

**Decision process.** From the discussion it seemed that there is not a clear view of the decision process itself, nor the content that is required or produced by the process. This supports our conclusion that the current process of interacting with each other is fairly ad-hoc and fragmented in terms of resources (Section 2.4.4).

**Investments.** The importance of financial information for making investment decisions was put firmly on the foreground (hence a separate cluster). We agree that financial aspects of developing an airport are important, but decided to leave it outside the scope of our research effort (for the reasons listed in Section 1.6).

There is a similarity between the clusters and the problem areas we identified. The cluster *Stakeholder management* is similar to Problem Area I: Stakeholder involvement (Section 1.2.1). The cluster *Dealing with uncertainty* is similar to

Problem Area II: Inadequate approach for dealing with the future (Section 1.2.2). Problem Area III (Inefficient problem solving process) did not show up as a cluster in itself. The cluster *decision process* is, however, closely related to this problem area, and the participants made several remarks related to quantification and qualification of outcomes of interest (cluster *Environmental impact*).

It is also clear that there is a fundamental difference between the cluster *Stakeholder management* and Problem Area I. The participants mainly talked about the challenge of informing stakeholders. We talk about stakeholders differently. Our intention is to involve and fully engage stakeholders, not manage them.

It seems that two challenges—decision process and interfaces, synchronizing different systems—arise because there is (1) no common conceptualization of the airport system, (2) a lack of structure to study a strategic planning problem, and (3) not a good way to organize the problem-solving process within a multi-stakeholder context.

This is precisely what motivated our research (Section 1.3) and this is why HARMOS addresses these challenges *by design*. The airport system has been conceptualized as a socio-technical system (Chapter 3), which covers elements and aspects of the airport system related to the interests of all stakeholders. Adopting a policy analysis approach (Section 5.2.1) as a key design principle provides a proven way to structure the airport strategic planning problem and organize the problem-solving process within the multi-stakeholder context.

### 9.3.2 Part II: Specific problems in each of the problem areas

Below, we discuss similarities and differences between the specific problems identified by the participants (Section 9.2.2) and those identified in our research.

*Problem Area I: Lack of stakeholder involvement*

Two interesting things can be observed from the specific problems mentioned by the participants (Section 9.2.2):

1. There seems to be a need to control the involvement of the stakeholders. The participants mentioned that the level and type of involvement should be defined. It was even mentioned to involve stakeholders depending on their stake or influence. We find this need for control problematic: at the start of the planning process it will not be known what the stakes are and how much influence a particular stakeholder can or will exert on the decision process.
2. The participants came up with explanations for the lack of involvement of the other stakeholders, such as no willingness or a difference in interest. Our research looks at stakeholder involvement in a different way. Because of the socio-technical nature of the airport system (Chapter 3), we state

that it is required to truly engage stakeholders and work together with them on the development of the airport. We were not interested in explaining why involving stakeholders failed in the past. We focused on coming up with a vision of decision support that engages stakeholders throughout the entire strategic planning process (Section 5.1).

*Problem Area II: Inadequate approach to deal with the future*

From the discussion among the participants (Section 9.2.2) it becomes clear that everyone is well aware of the lack of adaptability in plans and the inadequate approach for dealing with the future. One participant even mentioned that he did not see a problem here and simply suggested: 'to develop different future scenarios and design an adaptive policy plan'.

Conceptually, everybody understands that uncertainty should be taken into account and that a plan should be adaptable. Unfortunately, in reality this is easier said than done, which was confirmed by the other participants. We also concluded that, based on the literature, there are various approaches available to deal with uncertainty, but these are hardly ever adopted (Section 2.3).

*Problem Area III: Inefficient problem solving process*

Three issues were brought forward here.

1. There is a lack of structure for dealing with a strategic planning problem. The participants mentioned difficulties in dealing with information, methods and tools, the process, and defining the problem. This lack of structure is exactly the reason why we adopted the policy analysis approach as a key design principle. The policy analysis framework structures the planning problem and the policy analysis process organizes the problem solving process (Section 5.2.1).
2. There are two clashing mindsets that are brought to the planning process. On the one hand, it was suggested to be open to change; on the other hand, a number of participants worried about competition with other airports (such as Dubai). We realized as well that being open to change is essential. Strategic thinking is required to come up with a rich set of strategies that creates value for both the airport operator as well as its stakeholders (Section 2.1.4). Holding on to business as usual strategies (e.g. expanding the airport) in the hope that you can win the battle for demand is very fragile. Such a strategy is about being (a little bit) *better* than other airports, and that is a weak strategy. Successful brands and companies do not waste their resources in trying to be better. They focus on being *different*.
3. Airport strategic planning generally adopts a technical perspective. This is why we conceptualized the airport as a socio-technical system (Chapter 3) as the basis for the Domain Model (Chapter 7) that we implemented as the heart of the DSS.

### 9.3.3 Part III: Feedback on specific functionality of the HARMOS DSS

Below, we discuss the feedback on specific functionality of the HARMOS DSS (Section 9.2.3).

*Define Decisionmaking Context*

The participants had reservations about the collaborative use of HARMOS itself and collaboration in general. Obviously, HARMOS will be effective only if there is a genuine desire for the airport operator and stakeholders to work together.

What can be observed from the feedback is that the potential users see that HARMOS produces a positive effect on collaboration and collective decisionmaking, but no direct effect on trust building. This observation is consistent with our vision on decision support (Section 5.1). We have not designed HARMOS as a system for building trust. Just as the desire to work together, trust is a prerequisite for using HARMOS together.

It is clear from the list of disadvantages that there is an implicit need for a facilitator who oversees the engagement of all stakeholders and manages the specification of information (e.g. making sure outcome indicators are specified at the appropriate level).

*Compare Strategies*

Overall, the response to this question shows that HARMOS is expected to make comparing strategies in the multi-stakeholder context easier and more transparent.

Two issues are raised here by the potential users:

1. The availability of data and information to make a good comparison. This will not be a problem because HARMOS has been designed to manage data and coordinate tools in such a way that the relevant information for decisionmaking is available.
2. HARMOS being a black box enforcing a particular process. HARMOS in itself is not a black box. Each use case (i.e. specific functionality) has a clear user goal. For the use case 'Compare Strategies' the goal is (1) presentation of the effects on airport performance of a particular strategy (given a specific scenario) and (2) objective comparison of each of the strategies. As such, each use case delivers specific value to the users. Likewise, the specific functionalities combined offer comprehensive support for addressing airport strategic problems.

*Develop Scenarios*

The feedback reveals that scenarios are seen as a good way to explore the future together. This was reflected in the comment: 'It prevents people from jumping to solutions and brings differences of interest together'.

Some of the disadvantages that were raised had to do with the stakeholder involvement: there is a fear that stakeholders might leave the process or conflicts will remain. Actually, a well facilitated scenario process does not leave room for this to happen. The facilitator will emphasize that the future is the same for all stakeholders and that they are supposed to come up with multiples pictures of what the future could possibly bring.

The last two disadvantages—inconsistent scenarios and the creation of scenarios —are related to the process of developing scenarios. The scenario development process has indeed to be executed by a professional facilitator. HARMOS does not have functionality to enforce consistent and well-developed scenarios.

*Define Strategy*

The participants tended to agree that a richer set of strategies will be formulated by using HARMOS.

Some of the participants raised the issue of stakeholders leaving the collaborative planning process that HARMOS supports. Again, we emphasize that there has to be a commitment from the airport operator and all its stakeholders to think and work together. Certainly, differences in perspectives, objectives, and worldviews will surface. However, we believe that it is much better to share these differences and to work on a win-win for everyone involved, as opposed to playing out those differences in a win-lose game.

*Evaluate Strategy*

Some of the participants had trouble answering our questions related to this functionality. They wanted to know more about the internal workings of this functionality. Hence, they probed for more details about the exact way HARMOS DSS coordinates tools and turns data into relevant information.

One of the concerns was the traceability of data: which data will be used for which computation that is the basis for providing the relevant information to the users of the DSS. Because we implemented a Domain Model, the data used by HARMOS can always be traced back to a specific element of the airport system. The main disadvantage that was raised was that non-experts miss relevant input or misinterpret results. Of course, this can happen (even with experts). However, a non-expert will not be looking at the results of a strategy evaluation by himself. He will be supported in understanding the computational results by a Domain Expert.

*Execute Performance Analysis*

The feedback on this subfunction also shows that the participants wanted to have more information about the internal workings of the system before they could make up their minds about the usefulness of HARMOS. We agree that during

a first-time encounter with HARMOS it is difficult to grasp the architecture and inner workings of the DSS.

We deliberately did not explain the exact mechanism HARMOS uses to interact with tools for airport performance analysis. We presented the subfunction *Execute Performance Analysis* as a black box to the potential users in order to stay focused on the user goal that this subfunction supports, i.e. evaluating strategies. So, we explained that HARMOS uses one single source (the Domain Model, Chapter 7) for storing and retrieving information about the airport system. Data about different subsystems of the airport system are extracted from the Domain Model and translated into input data for specific tools. The execution of the tools is controlled by HARMOS, but the tools themselves are not integrated within the DSS.

Still, there was some skepticism about the quality of the information in the Domain Model and the reliability of converting this information into data for the tools. It was also said that the 'black box' nature of this functionality might be problematic for some users.

The Domain Model has not been fully implemented yet, so potential users can get involved in the next development stage.

### 9.3.4 Discussion of the workshop results

This section discusses the results of the workshop. The analysis of the results from Part I of the workshop clearly shows that people involved have a wide variety of challenges to deal with. It also seems that these challenges arise from a lack of structure for working together, defining strategic problems, dealing with uncertainty, and organizing the problem solving process. As such, the motivation for our research aligns well with the challenges raised by airport planning professionals.

The results from Part II of the workshop show that the specific problems mentioned by the participants have also been identified in some way or another in our research (Section 1.2). From the discussion of these results, we have shown that each of those specific problems have been used to drive the design of the HARMOS concept, software architecture, and functionality.

The analysis of the results from Part III of the workshop reveals that the potential users:

- see value in how HARMOS provides structure to defining the problem in the broad sense;
- see value in how HARMOS supports comparison of strategies;
- agree that using scenarios to describe different futures provides structure and consistency to the discussion. They also see the use of scenarios as a mechanism for starting an engaged discussion;
- state that a richer set of strategies will be formulated by using HARMOS.

It was also stated that these functionalities have a positive effect on collaboration and collective decisionmaking, increases insight into the uncertain future, and provides a broader set of strategies. So, with respect to the functionalities for defining the decisionmaking context, developing scenarios, and defining and comparing strategies potential users find HARMOS useful.

The potential users were not clear about the usefulness of HARMOS in evaluating strategies. They did appreciate the approach to data and tools, mentioning that it improves the efficiency in problem solving and allows users to conduct their own analyses.

We agree that it is difficult to form an opinion about this part of the functionality because it is indeed fairly complicated. Since, we were aware of this, this subfunction has been included as an architecturally significant use case (Section 6.3.7). Its realization within HARMOS' architecture is documented in Section 7.8. Two dedicated projects (Tse, 2006; Vreeswijk, 2007) have been executed to implement specific parts of this subfunction.

## 9.4 Implications of the workshop results for using HARMOS

This section reflects on the use of HARMOS in a multi-stakeholder context. From the results of the workshop a number of implications for the further development and actual use of the HARMOS DSS can be derived. There implications are:

**Collaborative planning.** The HARMOS concept of collaborative planning was questioned several times by the potential users, which was a good thing. It made us realize that collaboration in general, and a collaborative planning process specifically, might not be the preferred way for some organizations to meet their goals. The structure imposed by HARMOS is meant to support a collaborative planning process. In that sense, HARMOS imposes a specific structure focused on sharing and exchanging information in an open way. Of course, potential users have to be comfortable with that in the first place. They also have to share the belief that a planning process that does not fully engage all stakeholders will not be efficient nor be effective because of the airport being a socio-technical system (Chapter 3).

**Structure provided by HARMOS.** The potential users found the structure that HARMOS provides for addressing strategic planning problems in a multi-stakeholder context useful. They were however concerned about imposing a too rigid structure, forcing them to follow a prescribed process. HARMOS' functionality is based on basic steps that have proven their usefulness in planning and policymaking for a wide range of issues (from military planning to water management). These steps are fairly basic, high-level steps that have to be taken anyway to tackle a planning problem systematically. The steps do not require the people involved to conform to

a specific way of thinking. So, it is important to emphasize that HARMOS users are free, and indeed required, to bring their own thinking to the collaborative planning effort.

**Requests for specific or additional functionality.** During the session, one of the potential users made a request for additional functionality with respect to specific outcome indicators. Such a request can easily be accommodated during the Construction phase of the development process (Section 11.1.1). During this phase, all the different types of users (domain experts, decision advisers, and decisionmakers) will be involved themselves. That is when they can discuss and decide about additional functionality and any other aspects of the DSS they would like to customize.

**Getting the data and the tools right.** Potential users were concerned about the use of data and tools. This is a valid concern. Obviously, it is necessary that the Domain Model is carefully implemented. Therefore, the potential users need to get involved to make sure the elements of the Domain Model are consistent with their (real world) representation of those elements (see our recommendation about this in Section 11.1.2). By having users (i.e. domain experts) involved, the mechanism for translating information about the system into data for tools can also be implemented correctly. At the same time, the developers and users can document the implementation so that other users (i.e. decision advisers and decisionmakers) can understand what is going on (if they want to).

**Facilitator for using HARMOS and developing scenarios.** Several times, the participants had concerns about the group process that is needed for using HARMOS. Having an efficient and effective group process requires a facilitator that observes and manages the interaction between the airport operator and its stakeholders. This facilitator should also lead the development of scenarios.

These implications for the further development and use of HARMOS can easily be addressed during the next development stage and the promotion of the DSS for addressing airport strategic planning problems in a multi-stakeholder context.

## 9.5 Conclusions about the usefulness of the HARMOS DSS

From the analysis and discussion of the results of the workshop, we draw the following conclusions about the usefulness of the HARMOS DSS.

There is a clear need for bringing structure to the practice of airport strategic planning. Without a well-defined structure, it is difficult to exchange information among an airport operator and its stakeholders. We chose the following approach for making sense of all the knowledge, information, and data that is involved in airport strategic planning studies:

- We treated an airport as a socio-technical system (Chapter 3), taking into account both the technical aspects (i.e. airport capacity) as well as social aspects (i.e. environmental capacity) of an airport. The Domain Model (Chapter 7) that we implemented as the heart of the DSS is based on this conceptualization of an airport;
- We adopted the policy analysis approach from (Walker, 2000) for structuring the airport strategic planning problem, making a clear distinction between the system itself, the external factors that affect it (but cannot be controlled by decisionmakers), and strategies that change the system in order to achieve a desired outcome. The policy analysis approach also provides a well-defined, yet flexible approach to problem solving, which has been used as the basis for the DSS' functionality.

The potential users found that the functionality of the HARMOS DSS, based on the choices above, useful as a way to bring structure to airport strategic planning studies.

One of the issues that surfaced is the need for potential users to better understand and provide input the design of specific functionality of the DSS. Based on our analysis of previously developed systems for airport performance analysis, we expected this to come up. It is the reason why we used an agile software development process up to the point of the Lifecycle Architecture Milestone. The architectural significant elements of the DSS have been implemented and proved to address specific problems in the three problem areas (Chapter 8). During the next development phase of the DSS, we require the potential users to get involved in the further development of the DSS (Chapter 11). By having the potential users on the software development team, it is ensured that additional functionality is tailored to the needs of the users. In that way, a truly useful DSS will be delivered at the end of the entire software development process.

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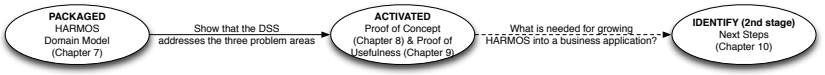
# Summary Part III




This part of the dissertation first answered Research Question 4: 'How is the architecture to be implemented such that the DSS vision are realized and a solid foundation for growing HARMOS into a business application is created.'

Chapter 4 showed that building decision support through a data-driven and technology-driven approach does not result in a system of practical use. Such an approach fails, because it is not able to deal with the complexity of the aviation and airport domain and the business activity of strategic planning. Domain Driven Design is an approach that is meant to tackle complexity in the heart of software. By creating a Domain Model, for realizing the functionality of the HARMOS DSS, we have been able to formalize the airport strategic planning domain and crunch or *package* (the fifth stage of the MOKA Life Cycle as shown in Figure 1.2) knowledge about airport strategic planning into a software system.

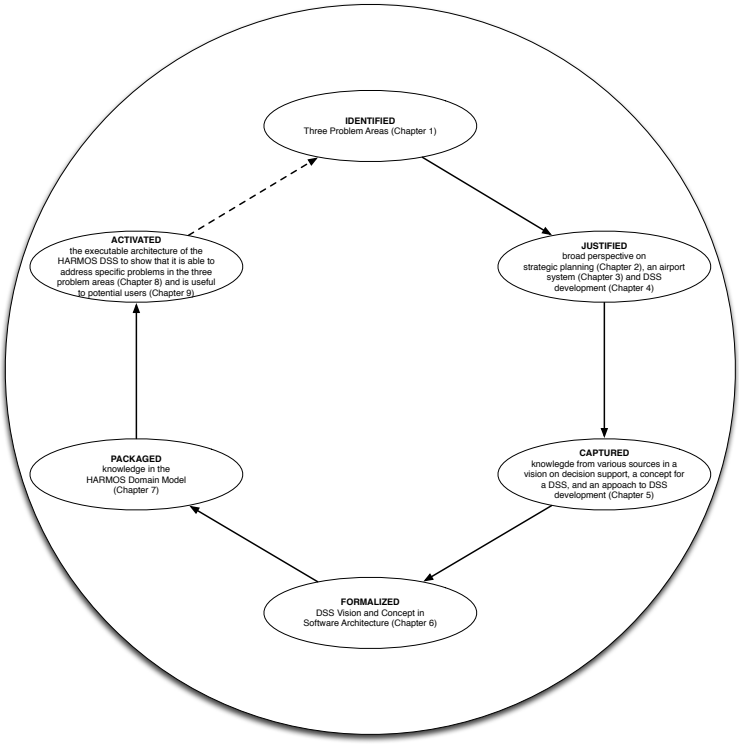
Chapter 7 showed how the implementation of the HARMOS architecture based on a Domain Model realizes the user functionalities defined in Section 6.3. We did this by describing the responsibilities and behavior of the modules and classes of the Domain Model in detail.

This part of the dissertation also answered Research Question 5: 'How can a proof of concept and a proof of usefulness be provided?'. Chapter 8 showed how the functionality of this Domain Model is *activated* to address the three problem areas. For specific problems within each of the problem areas, we explicitly showed how the airport operator and its stakeholders are using the functionality of the DSS. Chapter 9 described and discussed what potential users think about the usefulness of the DSS. We also showed what the user feedback implies for using HARMOS and its further development.

# Part IV

# Epilogue

# Overview Part IV




This dissertation addressed the three identified problem areas (Chapter 1) with airport strategic planning through the development of a DSS. We used knowledge

from different fields and disciplines (Part I) to arrive at the design of the DSS (Part II) and to implement its architecture (Part III).

Knowledge from *management science*, in particular the strategic planning and strategic management literature, was explored to better understand the concept and different aspects of strategic planning and thinking. *Policy analysis* was used to investigate airport strategic planning problems in a holistic way, dealing with the complexity of the system, the uncertain future, and the multi-stakeholder context. Knowledge from *aeronautical engineering*, in particular experience with a range of tools for airport performance analysis, was used to find out how to generate the appropriate information for decisionmaking. *Software engineering* principles and best practices were applied to specify the requirements, design the DSS' architecture, and implement that architecture.

The above figure shows the different stages from the MOKA Life Cycle we went through. We first *identified* three problem areas with airport strategic planning (Section 1.2). Secondly, we *justified* a broad perspective on strategic planning, an airport system and DSS development (Chapters 2-4 in Part I). Then we *captured* the knowledge from Part I and combined it into a vision on decision support, a concept for a DSS, and an approach to DSS development (Chapter 5). The fourth stage *formalized* our vision and conceptual design of the HARMOS DSS into a Software Architecture (Chapter 6). The fifth stage packaged the knowledge into an executable Domain Model (Chapter 7). The sixth and final step *activated* the executable architecture of the DSS to show that it is able to address specific problems in each of the three problem areas (Chapter 8). Included in this step was feedback from potential users (Chapter 9, which feeds into the second phase of DSS development).

This epilogue is structured as follows. The answers to the research questions are summarized in Chapter 10. Next steps and a reflection are presented in Chapter 11.

CHAPTER 10

# Answering the Research Questions

> Imagination is more important than knowledge.
>
> ALBERT EINSTEIN

Chapter 1 discussed the need for a more comprehensive airport strategic planning and decisionmaking process. The strategic planning process should involve all airport stakeholders, explicitly deal with the uncertain future, and become more efficient in problem solving.

The term airport strategic planning is used in different ways without being explicitly defined. We used the broad definition provided by Wells and Young (2004):

> Strategic planning is the activity that encompasses all other planning activities [facility, economic, financial, organizational, and environmental planning] into a coordinated effort to maximize the future potential of the airport to the community (Wells and Young, 2004, p.368).

This definition does not imply a specific approach. Simply speaking, an airport operator needs to match the capacity of the airport system with demand, taking into account environmental and financial constraints. Doing so is difficult because the airport in essence is a socio-technical system, which is affected by different social conditions—the state of technology, potential demand, regulations, and demographics. And, the economic, environmental, and land-use effects that are produced by the airport system affect many stakeholders. Any

change to the system that an airport operator proposes is therefore scrutinized and publicly debated to a great extent (see Figure 1.1).

An airport being conceptualized as a socio-technical system reveals that the planning problems associated with it are wicked problems. Dealing with wicked problems is difficult. Current airport strategic planning therefore faces a number of problems, which we organized in three problem areas:

I. Lack of involvement of the stakeholders;
II. An inadequate approach for dealing with the future;
III. An inefficient problem solving process.

We proposed a DSS as a way to simultaneously address all three problem areas, because current approaches to airport strategic planning—Master Planing and Dynamic Strategic Planning—mainly focus on only one of the problem areas.

The identified problem areas, and the envisioned DSS to address them, directed this research effort, leading to the following five research questions (Section 1.4):

1. How should the concept of strategic planning be understood within the airport decisionmaking and planning context?
2. What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?
3. How can airport strategic planning be supported through a DSS, and how should the decision support system be designed?
4. How is the architecture to be implemented such that the DSS vision is realized and a solid foundation for growing HARMOS into a business application is created?
5. How can a proof of concept and a proof of usefulness be provided?

The next five sections summarize the answers to each of these questions and, as such, show our contribution to knowledge in the field of airport strategic planning and decision support systems.

## 10.1 Research Question 1: How should the concept of strategic planning be understood within the airport decisionmaking and planning context?

This question was answered in Chapters 2 and 3. The concept of strategic planning within the airport decisionmaking and planning context should be understood as:

- A broad concept instead of a purely analytical activity (Section 2.1.4, ‘Strategic thinking’);
- Supplement to strategic thinking and corporate social responsibility (Section 2.1.5, ‘Social corporate responsibility’);

- Inclusive, not exclusive, i.e. a way to address the fragmentation of resources—people, data and information, and tools (Section 2.4.4, 'Underlying cause of the problems with current airport strategic planning');
- A facilitator for other ways of looking at an airport and its development: the airport as a socio-technical system (Section 3.3.2).

## 10.2 Research Question 2: What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?

This research question was answered in Chapter 4. The lessons we learned from past and currents projects are:

- Serious attention should be paid to the decision environment in which it is to be used, before designing a DSS (Section 4.3, 'Discussion of specific problems');
- Focus should be on the DSS users, not on the tools and models that are envisioned to be included in the design;
- A DSS should be built on an understanding of all three phases of the problem solving process—formulation, analysis, interpretation. A DSS for airport strategic planning should support all three phases.

## 10.3 Research Question 3: How can airport strategic planning be supported through a DSS, and how should the decision support system be designed?

This research question was answered in Part II of this dissertation. Designing a DSS for supporting airport strategic planning requires the following:

- A strong vision for the DSS design is needed, throughout the entire development process (Section 5.1);
- The DSS needs to be built upon a well-defined and systematic methodology for problem solving and decisionmaking. We used the policy analysis framework and process (Section 5.2.1);
- The DSS design needs to integrate resources—people, data and information, and tools—in an elegant way. We defined the roles of people involved in strategic planning efforts as the DSS users. We decided that the DSS should provide those users with relevant data and information. The DSS is responsible for interfacing with tools for airport performance analysis, *external* to the system.
- The needs of the users should drive the DSS design in terms of specific functionalities (see Section 6.3);
- A software development process based on agile principles is needed to come up with executable versions of the DSS on a frequent basis. We used the Agile Unified Process (Section 5.3.2).

## 10.4 Research Question 4: How is the architecture to be implemented such that the DSS vision is realized and a solid foundation for growing HARMOS into a business application is created?

This question was answered in Chapter 7. The structure of the DSS' architecture should be based on design patterns. Because of the complexity of airport strategic planning, we decided to use a Domain Model as the heart of the architecture to realize the user functionalities. The Domain Model includes all the functionality for supporting airport strategic planning. The added value of the Domain Model can be summarized as follows:

**Problem-oriented.** The framework according to Walker (2000) defined a large part of the Domain Model. The policy analysis framework provided a way to structure data and information.

**Natural representation of the system.** The System Model is a natural way of specifying and presenting the real world system.

**Independent of tools.** The introduction of the Performance Analysis module realizes an important separation of concern. The DSS becomes independent of the third-party tools used to quantify airport performance.

**Extendability.** The modules in the Domain Model can easily be extended to accommodate changing or new user-requirements.

**Scalability.** The functionality included in this module also scales very well. If the System Model is extended to include more elements (e.g. roads outside the airport property), the analysis services can be extended to provide quantification of outcome indicators related to those elements as well.

These qualities of the Domain Model brings business value and paves the way for commercialization.

## 10.5 Research Question 5: How can a proof of concept and a proof of usefulness be provided?

This question was answered in Chapter 8 and Chapter 9. Through designing and implementing the GUI for the HARMOS, the functionality of the Domain Model is exposed and presented to the users. The working implementation of the GUI Layer and the underlying Domain Layer and Technical Services Layer made it possible to show how HARMOS would be used to address specific problems in each of the problem areas, using Amsterdam Airport Schiphol as an example. By showing the use of various GUI components, we demonstrated how the HARMOS DSS is able to address the specific problems in each of the problem areas (Table 8.3). So, identifying specific problems within each of the three problem areas

allowed us to show that each of them can be addressed by the HARMOS DSS, as such providing a proof of concept.

By inviting potential users to a workshop, we received valuable insights into the usefulness of the DSS. Overall the users confirmed that the HARMOS DSS improves collaboration and collective decisionmaking between the airport operator and its stakeholders.

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CHAPTER 11

# Next Steps and Reflection

> To break a mental model is harder
> than splitting the atom.
>
> ALBERT EINSTEIN

The previous chapter summarized our answers to each of the five research questions. This chapter presents the next steps with respect to the development of the HARMOS DSS (Section 11.1). We also reflect on the research itself (Section 11.2).

## 11.1 NEXT STEPS

Chapter 8 concluded that the HARMOS DSS is compatible with Master Planning, because the underlying framework for decisionmaking and planning we used (a policy analysis approach) evolved out of systems analysis, on which Master Planning is based.

The HARMOS DSS is, however, not a business application yet. It is not ready to be deployed and used by airport operators and their stakeholders. A stable architecture has been designed and implemented, on top of which the full functionality for a specific airport (as summarized by the Functional View presented in Figure 6.4) has to be further realized. We intentionally stopped the development process at the point of meeting the Lifecycle Architecture Milestone (see Figure 5.9). The proof of concept provided in Chapter 8 showed that we have met the LCA. Meeting this milestone is the starting point for successfully growing the HARMOS DSS into the business application that we envisioned in Section 5.1.

Chapter 9 showed that potential users are positive about the usefulness of the DSS. There were some reservations about using the DSS and specific functionalities, but these can be addressed when the potential users get onboard during the next phase of the (agile) development process. The next phase in the development process is the *Construction* phase—focusing on building the business application, which requires many resources and skills to successfully realize the full functionality of the HARMOS DSS. The most important resources that are required are an environment for software development facilitating agile development, and a team of software developers with the many skills required to build business applications (Section 11.1.2). It is obvious that these requirements can never be met by a single researcher, but require a professional software development team.

### 11.1.1 Growing the HARMOS DSS

By focusing on a subset of user requirements during each iteration within the development process, a stable architecture has been developed. A stable architecture is an architecture that provides a solid foundation for implementing the functional requirements. The architecture is flexible and extendable, so that during the *Construction* phase (see Figure 5.9) specific airport operator requirements can be realized, resulting in a business application that an airport operator and its stakeholders will actually use.

Part II of this dissertation described the implementation of the architecture of the HARMOS DSS in detail. We argued that the lack of a problem-oriented architectural design is the primary reason for the lack of adoption of decision support systems by high-level decision makers. We followed a Domain Driven Design (DDD) approach combined with an iterative software development process that should result in a more usable and useful DSS. The HARMOS architecture that resulted from this approach is stable and provides a good and consistent basis to further develop the application for a specific airport operator.

In order to fully realize the functionality described in Section 6.3, the Domain Model (Chapter 7) needs to be further developed. We suggest the following approach for doing this: (i) ask potential users for feedback on the DSS concept; (ii) ask the users for feedback on the functionality; (iii) rewrite the use cases with the users if needed; (iv) show the users the initial design of the GUI components and ask for their feedback; (v) implement the revised use cases by building op top of the existing implementation of the HARMOS architecture; and (vi) redesign the GUI based on the feedback of the users. This approach can be designed similar to the workshop executed for the Proof of Usefulness (Chapter 9, but needs to go into more depth with potential users that are committed to collaborative planning supported by HARMOS.

Below, we review what needs to be developed further in terms of the functionalities that have been defined (see also Figure 6.4).

**Define Decisionmaking Context.** This functionality has to be further implemented in terms of managing the perspectives, objectives, and outcomes of interest of the airport operator and its stakeholders. This is directly related to implementing the Context class as described in Section 7.3.3 and redesigning the **Decisionmaking Context Panel** of the Study Manager (Section A.2).

**Calibrate Study.** This functionality has to be further implemented in terms of managing information about the known performance of a specific airport. Functionality for easily comparing the known performance with computed performance has to be designed and implemented. This also implies that the Calibrator (Section A.3) is redesigned.

**Develop Scenarios.** The detailed design of the Scenario Builder (Section A.4) has to be implemented.

**Define Strategy.** This functionality has to be further implemented in terms of defining specific strategies. The general functionality for defining a strategy has been implemented: the system model that we have implemented allows for flexible and easy definition of a broad set of strategies. Again, Kwakkel (2010) used the system model we have implemented to quickly and easily define strategies for subsequent quantitative evaluation. The Strategy Builder (GUI component described in Section A.5) needs to be implemented so that Domain Experts and Decision Advisers can work together on defining strategies.

**Evaluate Strategy.** This functionality has been implemented in general. The evaluation of a strategy in terms of its effect on airport airside capacity has been implemented by Tse (2006). The same has been done by Vreeswijk (2007) for emissions. The Domain Model code that has been created in both of these projects does not fully adopt object orientation. In order to consistently integrate the code they have written, substantial refactoring[1] is required. For reasons of consistency, the GUI design and implementation created in these two projects also needs some work.

**Compare Strategies.** Functionality needs to be implemented that enables the comparison through scorecards of the strategies that have been evaluated. The scorecards need to be presented for the different scenarios, and their color coding—which shows to which degree their objectives are met by each strategy—needs to depend on the actor that is using the system (i.e. the airport operator or one of its stakeholders). So, a flexible way to manage the information defined during the process of defining the decisionmaking context (objectives and outcomes of interest), and generated during the evaluation of strategies, needs to be designed and implemented. Based

[1] Refactoring is restructuring code to increase extendability and readability and reduce complexity without changing its functionality.

on this functionality, the Strategy Comparator (Section A.7) needs to be further designed and implemented.

**Execute Performance Analysis.** This functionality has been developed for performance analysis in terms of capacity (Tse, 2006), noise (Heblij, 2004; van Loo, 2005), emissions (Vreeswijk, 2007), and third-party risk (Heblij, 2004). As mentioned before, the code from these projects does not fully adopt object orientation. Some of the code has already been refactored by Kwakkel (2010), but more work is needed to integrate this code with the existing code base of the HARMOS architecture.

These steps for growing the DSS will only result in a useful and effective DSS if the agile development approach discussed in the next section is in place.

### 11.1.2 Adopting agile development

During the DSS development effort, we have applied agile practices to a limited extent (Smith and Sidky, 2009; Younker, 2008) (the practices we used are shown in italics in the following text). *User stories* (in the form of use case briefs) were used to document the functionality of the DSS (Section 6.3). The *System metaphor*, based on the policy analysis approach, was used to talk about the design in a consistent and unambiguous way, supported by continuously maintaining a *Glossary* as an artifact during the development process. *Simple design* allowed us to focus on fulfilling the requirements and nothing more. The DSS design, implementation, and testing were driven by the use cases at all times.

*Continuous reflection* was used to make sure both the DSS design as well as the development process was regularly discussed and revisited. *Iterations* were used to make sure the implementation was focused and manageable. *Documentation* was written to communicate the concept of the DSS (Vision), lay out the overall plan for developing the DSS (Software Development Plan), provide consistent terms and definitions (Glossary), capture user requirements (Use Case Model), and present the architecture of the DSS (Software Architecture Document).

In order to deliver a useful and effective DSS, these practices need to be maintained within the software development team working on growing the HARMOS DSS into a business application for a specific customer. Additionally, it is important to introduce other agile practices as well. These are:

**Pair programming.** Two developers working together on the same code produces better quality code.

**On-site customers.** Including the customer in the development team makes sure the Domain Model is correct and provides the functionality that the users truly need.

**Unit tests and test-driven development.** Testing each class of the software through unit testing improves code quality, and test-driven development increases satisfaction of a developer's task. It also ensures that quality is addressed continuously, not just as an afterthought.

**Refactoring.** Changing the internal working of the code simplifies the implementation to improve readability, extendability, and maintainability.

**Collective code ownership.** Each developer is familiar with and takes responsibility for the code as a whole.

**Continuous integration.** Code and other artifacts (e.g. databases) are continuously integrated to package the final product and test it on a non-developer's machine from scratch.

Without adopting these practices it will be very difficult to grow the HARMOS DSS in an efficient and effective way. The software development process will be inefficient because of the need to carry out many development tasks manually and lack of understanding of the code base. The process will also be ineffective because the DSS will not be able to satisfy customer requirements. That is why a well qualified team of software professionals is needed: they know how to apply these principles.

## 11.2 REFLECTION

In this section we reflect upon the research presented in this dissertation. Our participation in two other DSS development projects is discussed in Section 11.2.1. Other applications envisioned for the HARMOS DSS are proposed in Section 11.2.2. The approach we took to learn software engineering is described in Section 11.2.3.The changes to our mental model throughout this research are presented in Section 11.2.4.

### 11.2.1 Involvement in other DSS projects

We have been involved in two other DSS development projects that influenced the development of the HARMOS DSS.

The first project is the development of the Airport Business Suite (ABS) at the Delft University of Technology (previously described in Section 4.2.5). This computer-based system has been reviewed in Section 4.2.5. We concluded that the ABS did not turn out as we envisioned at the start of the project. Actually, the ABS project had a quite compelling vision and identified the decision adviser as the specific user. The vision was, however, not enforced throughout the project. This resulted in a system that is hard to maintain. Both versions of the ABS were only fully understood by the lead developer. The code was hard to read and understand by other developers. Despite this, the ABS has been used successfully by many students, who enrolled in a course on airport strategic planning. But,

the students have been using the ABS as domain experts, not as the decision adviser as we had intended.

The second project we have been involved in is the development of SPADE, a DSS development project that was sponsored by the European Commission (previously described in Section 4.2.5). Through this project, we were actually introduced to iterative software development. Within the project, it was decided to adopt the Rational Unified Process (RUP). We got acquainted with this broad framework for software development, but quickly noticed that the framework was not being used as it was intended. The focus within the project was on technology (J2EE as a means to integrate tools) instead of tackling the complexity of the domain and meeting the needs of the potential users. By being involved in this project, we learned what can go wrong with adopting an iterative development process.

We learned many lessons from the ABS and SPADE projects, which have been applied throughout the development of HARMOS.

### 11.2.2 Other applications for the HARMOS DSS

An airport is just one example of a large-scale system that is difficult to plan. There are many other examples of such large-scale systems, such as seaports, rail stations and infrastructure, road networks, heliports, and industry parks. The problems that planners and decisionmakers face with respect to strategic planning for each of these systems are similar to those in airport strategic planning. At a later stage, it would therefore be interesting to explore other application fields for the HARMOS DSS.

### 11.2.3 Learning approach to software engineering

Our involvement in the two projects discussed in the previous section pointed us to valuable resources, which covered the essentials of modern software engineering (Ambler, 2008; Cockburn, 2001; Evans, 2004; Fowler, 2003; Krol and Kruchten, 2003; Larman, 2005). We studied those resources in depth in order to understand what is needed to successfully develop software (architecture). Most of the material covered by those resources has been applied in this DSS development project. Basically, we trained ourselves 'on the job'. Our choice for PYTHON as the programming language has been very helpful. Because PYTHON does not have a steep learning curve, the concepts, principles, techniques, and patterns we read and learned about could readily be applied when writing the code for the DSS.

### 11.2.4 Changes to our mental model

A nice way to reflect on the research is by looking at our own mental model and how and why it changed throughout the execution of the research. The definition of a mental model is:

> A mental model is an explanation of someone's thought process about how something works in the real world. It is a representation of the surrounding world, the relationships between its various parts and a person's intuitive perception about their own acts and their consequences. Our mental models help shape our behavior and define our approach to solving problems (akin to a personal algorithm) and carrying out tasks (Wikipedia, 2011b)

Our mental model changed several times during the course of the research. At the start, our model was optimization-based. Halfway through the research, our model was policy-based. And, at the end of the research our model was people-based. Each of these models is described below.

*Optimization-based mental model*

Our background is in aeronautical engineering with a specialization on optimizing aircraft departure trajectories in order to minimize noise impact. The results of this work were promising. So, we expanded the scope of this work by looking at arrival trajectories and including various different metrics in the objective function (Visser and Wijnen, 2001). We started questioning ourselves about implementation of these optimized noise abatement procedures in an airport's future operation. What would be the effect on airport capacity? What is the trade-off between noise and emissions? What technology would be required to enable such Noise Abatement Procedures (NAPs)?

These questions led to the idea to create a DSS that uses hierarchical optimization to solve this strategic planning problem. The development of functionality for an early HARMOS version for optimizing departure and arrival operations by van Loo (2005) fits with this idea. Additionally, Heblij (2004) developed an optimization model for allocating flights to runways and tracks in order to minimize noise impact and third-party risk. We explored using dynamic programming for optimally planning new runways (Wijnen, 2005).

However, turning a strategic planning problem into an optimization problem is not straightforward. Many assumptions need to be made in order to come up with a robust mathematical formulation of a strategic planning problem. These assumptions are related to rules that govern the airport operation, future developments of technology, and preferences of decisionmakers for alternative courses of action.

For a strictly technical problem, such as the allocation of flights to runways and tracks, an optimization approach can still be explained to decision advisers and decisionmakers. An optimization approach is very beneficial for such a problem, because it quickly finds the best way for using an airport's resources. If, instead, a simulation approach would be used, much more time would be required, because the best solution has to be found through trial and error.

So, there is certainly value to an optimization perspective for representing part of the world. However, we discovered its limitations as well, which led to our adoption of a policy-based mental model.

*Policy-based mental model*

An optimization approach does not work very well in a multi-stakeholder context in which there is uncertainty about the future. It is just not possible to turn all the strategies that could be considered against multiple futures into a consistent mathematical formulation. What is needed is a way to structure a strategic planning problem from a decisionmaker's perspective. Decisionmakers and their advisers need to be able to understand how the performance of the airport system is affected by external factors (outside their control) and strategies (under their control).

Once we realized this, we adopted another mental model—one that represents the world from a *policy* (or strategy) point of view. This mental model is of a higher order than the optimization-based mental model. The policy-based mental model provides a richer representation of the surrounding world, because it allows for (i) acknowledging different views (from each of the stakeholders) on a strategic planning problem and (ii) taking into account future uncertainty.

Our mental model changed in a way that is similar to how policy analysis evolved from systems analysis and operations research, as shown in Figure 11.1. Policy analysis emerged because the mathematical methods from operations research were not sufficient to deal with problems related to (the emerging) socio-technical systems.

*People-based mental model*

The structure and process that policy analysis provides to deal with airport strategic problems is very effective and efficient. It is absolutely a solid foundation for building a DSS. But, in the end, it is *people* that have to adopt the structure provided by policy analysis and the DSS for working together in a collaborative planning process that produces creative solutions to the strategic planning problem at hand.

Actually, the need for people to work together on these types of problems has always been clear to us. Trying to convince other actors of one's opinion or plan might work and even provide benefits on the short term. But, in the long term, a collaborative approach brings every actor and the general public the most benefits. Therefore it is no coincidence that HARMOS stands for 'bringing people together'. The inspiration for this idea comes from our aikido experience. Through aikido, we learned to *embody* the benefits of collaboration[2]. It is nice to

[2]Our aikido experience and how it shaped the way we look at the world is a good example of *embodied cognition*. Embodied cognition is an emerging research field states that the nature of the human mind is determined by the form of the human body (Wikipedia, 2011a).

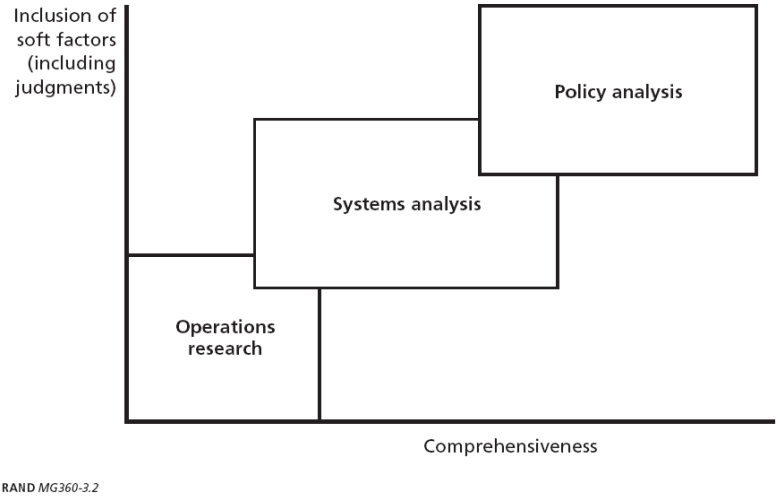


Figure 11.1: The evolution of policy analysis. Source: Davis *et al.* (2005).

see that the benefits of a collaborative planning approach has also been proven from a planning theory point of view (Innes and Booher, 2000) and a business point of view (Sisodia *et al.*, 2007).

Although we advocate the use of methods and techniques from policy analysis to structure strategic planning problems, we also learned that the mindset and attitude of people is crucial. People need to be open-minded, aware of their changing environment, and willing to change themselves and take (collective) action. Awareness and willingness to change and act do not come from using a method or technique. These qualities are to be developed through informal learning, i.e. by learning from all sorts of life's experiences and the ability to transfer the lessons learned to a business or strategy context (Sloan, 2006). By adopting a people-based mental model, we have been able to understand people's needs in developing their strategic thinking qualities—imagination, broad perspective, ability to juggle, awareness of no control, and a desire to win—so that we can support them to deal with a world of change. We also discovered that facilitating dialogue among people is essential for effectively working together on wicked problems, such as airport strategic planning problems. Dialogue is the only way to exchange mental models and understand each other's worldview, and truly learn from one another.

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# Part V

# Appendix on the HARMOS Graphical User Interface

APPENDIX **A**

# Graphical User Interface

The complexity of the airport domain and the business activity of strategic planning motivated the use of a Domain Model as the heart of the HARMOS DSS. The Domain Model is the most sophisticated form of a Domain Logic pattern. We argued that without it, it is not possible to realize the functional requirements described in Section 6.3 and thus adequately support airport strategic planning.

Through the presentation of the GUI, this chapter discusses how the functionality of the Domain Model (Chapter 7) is *exposed* to the DSS users. First, Section A.1 provides an overview of the GUI in terms of its components and briefly discusses how these components have been developed. Section A.2 through Section A.7 present a description of the individual components of the GUI. A summary is given in the final section.

## A.1 Overview of the Graphical User Interface

The GUI has been realized quite independently from the Domain Model, which could be done because of the Layered design of the architecture (see the Logical View in Section 6.2). The GUI presented in this chapter (i.e. a traditional windows-based GUI) can therefore readily be replaced by an alternative implementation, e.g. a Web-based GUI, if so desired.

The current GUI is composed of a number of different components, each related to a different part of the functionality of the Domain Model. Section A.1.1 introduces these components. The menu structure of the DSS is described in Section A.1.2.

### A.1.1 Components

The GUI is organized in terms of *components*, each of which is directly related to the functionality described by the use cases in Section 6.2. More specifically, six components have been designed:

**Study Manager** Exposes the functionality to manage the studies created within the HARMOS DSS. It is used to create new studies, delete studies, and open and work with existing studies (Section 6.3.1). This component is discussed in Section A.2.

**Calibrator** Exposes the functionality for calibrating a new study (Section 6.3.2). This component is described in Section A.3.

**Scenario Builder** Exposes the functionality for developing scenarios (Section 6.3.4). This component is described in Section A.4.

**Strategy Builder** Exposes the functionality for specifying strategies (Section 6.3.5). This component is described in Section A.5.

**Strategy Evaluator** Exposes the functionality for evaluating the effects of a strategy on the airport's performance for one or more scenarios (Section 6.3.6). This component is described in Section A.6.

**Strategy Comparator** Exposes the functionality for comparing one strategy versus another for each of the scenarios (Section 6.3.8). This component is described in Section A.7.

So, the GUI components logically follow from the functional requirements. The components are available to each type of user—decisionmaker, decision advisor, and domain expert—although the actual use of the components will vary per type of user. Most of the components are directly accessible from the Study Manager by using buttons (as discussed in Section A.2). Besides that, a menu structure is provided to access the components. This menu structure is discussed in the next section.

### A.1.2 Menu structure

All the GUI components can be accessed through menus of the main window of the HARMOS DSS (see the menubar as shown in Figure A.1(a)); this is also the window that is presented to the user at startup. The pull-down menus provided are:

**Study.** Includes the menu items: (1) **Open**, for opening an existing study; the title bar of the main window then shows the name of the study; (2) **New**, for creating a new study; (3) **Overview**, which provides the starting point for working with the scenarios and strategies in a study (Figure A.1(a)); (4) **Print**, for printing specific information; (5) **Close**, which closes a study; (6) **Exit**, which shuts down the DSS.

**Edit.** Provides the standard items **Copy**, **Cut**, and **Paste** for copying, cutting and pasting information within the application.

**Context.** Used for specifying the decisionmaking context. This menu includes the items: (1) **Planning Problem**, for describing the planning problem and selecting outcomes of interest (Figure A.1(b)); (2) **Airport Operator**, for

specifying general information and the objectives of the airport operator; and (3) **Stakeholders**, which provides access to a submenu including all of the stakeholders for specifying general information and their objectives.

**Calibration.** Used for calibrating the study. This menu includes the items: (1) **System Model**, for specifying the system model (as described in Section 6.3.3); (2) **Known Performance**, for specifying the known airport performance; (3) **Traffic Demand**, for analyzing traffic demand; (4) **Operational Plan**, for specifying how demand is allocated to the airport's capacity (see also Section 7.6.3); (5) **Compare**, for comparing the computed performance, presented within the Strategy Evaluator (see also Section A.6), to the known performance.

**Scenario.** Used for developing scenarios. This menu includes the items: (1) **Forces**, for specifying driving forces that have been indentified during the research effort within the scenario building effort; (2) **Clusters**, for naming the clusters of driving forces; (3) **Scenario Space**, for defining the scenario space; and (3) **Quantify**, which provides access to a submenu with the scenarios that are defined; selecting a scenario brings up the Scenario Builder to quantitatively develop the scenario (Section A.4).

**Strategy.** Used for defining, evaluating, and comparing strategies. This menu includes the items: (1) **Define**, which brings up the Strategy Builder for defining strategies (Section A.5); (2) **Evaluate**, which brings up a submenu for selecting strategies to be opened with the Strategy Evaluator (Section A.6); and (3) **Compare**, which brings up the Strategy Comparator for comparing strategies (Section A.7).

**Tools.** Includes the items (1) **Airline Manager**, for working with information about airlines; (2) **Aircraft Manager**, for working with information about aircraft types; (3) **Database Server**, for specifying settings related to the underlying DBMS; and (4) **Third-party Tool Settings**, for specifying settings related to specific tools for airport performance analysis.

**Help.** Includes items for accessing documentation.

The GUI components, as introduced in Section A.1.1, are either accessed directly through the menu items or from the Study Overview panel of the Study Manager, as shown in Figure A.1(a).

The users can navigate through the HARMOS GUI whatever way they like. This idea of *non-linear navigation* was also the basis for the ABS design (Section 4.2.5; see also Walker *et al.* (2003)). During the planning effort, the users are not constrained to a predefined way of using the GUI. The users are in control. Only at the start of the planning effort, during the calibration of the study, is it required to follow steps in a predefined sequence (enforced by the DSS)in order to make sure that everything is set up correctly to engage in the planning effort.

## A.2 STUDY MANAGER

The Study Manager exposes the Domain Model functionality related to: (1) creating new studies, opening studies, and deleting studies (realized through the Study Service as described in Section 7.3.1); and (2) organizing the planning problem being the subject of study (realized through the implementation of the Study class as described in Section 7.3.2). As such, the Study Manager implements that part of the GUI that exposes the functionality described in Section 6.3.1—Define Decisionmaking Context. The Study Manager has three panels, two of which are shown in Figure A.1:

**Study Manager Panel.** This panel is actually the main window (not shown), used for managing studies within the DSS. The panel shows an overview of previously created strategic planning studies and general information about those studies.

**Study Overview Panel.** Provides an overview of the scenarios and the strategies within a study. The panel is shown in Figure A.1(a). The Study Overview panel is the starting point for working with strategies and scenarios. The top of the panel contains an overview of general information about the study, including its name, a short description of what the study is about, the planning period covered by the study, and a **History** button for viewing the editing history of a study. The lower left side of the panel provides an overview of the scenarios that have already been defined in the study. Below the list, three buttons are provided for working with scenarios:

**New.** Used to create a new scenario by bringing up the Scenario Builder (described in Section A.4).

**Edit.** Brings up the Scenario Builder for the selected scenario.

**Delete.** Deletes the selected scenario from the study.

Similarly, the lower right side of the panel provides an overview of the strategies that have already been defined in the study. Below the list, five buttons are provided for working with strategies:

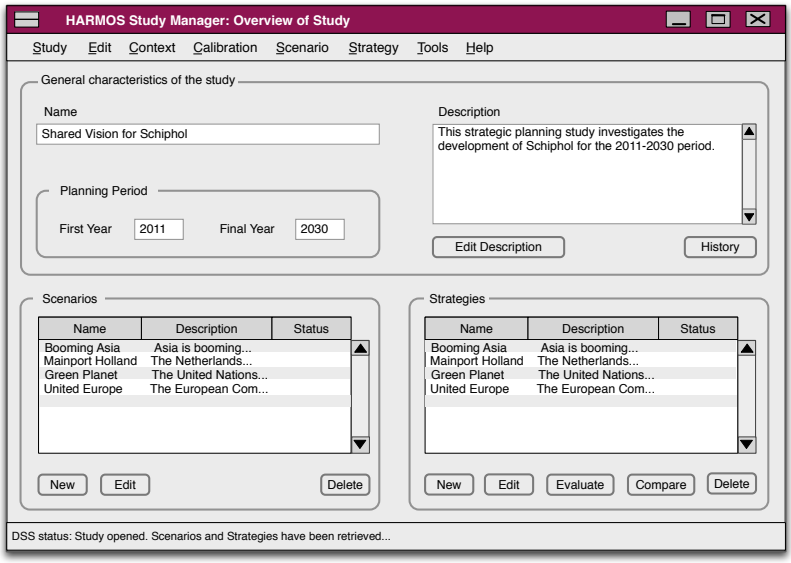
**New.** Used to define a new strategy by bringing up the Strategy Builder (described in Section A.5).

**Edit.** Brings up the Strategy Builder for working on a previously defined strategy.

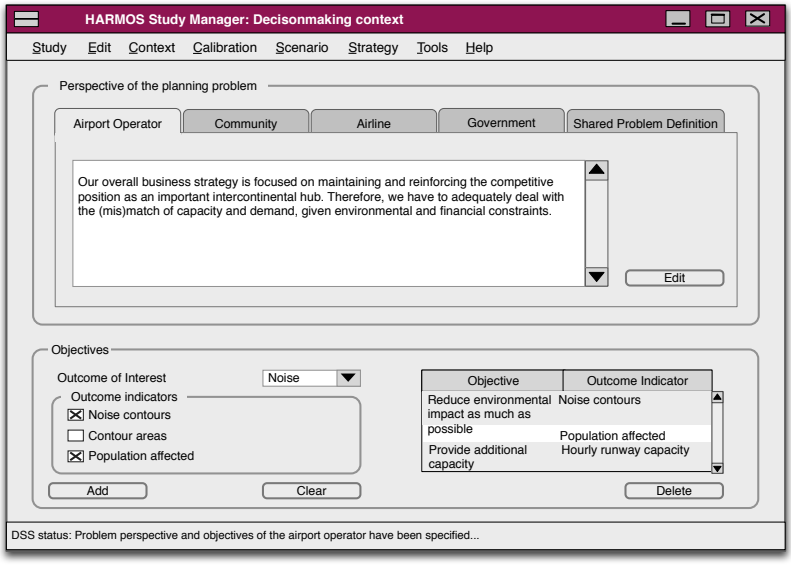
**Delete.** Deletes the selected strategy from the study.

**Evaluate.** Brings up the Strategy Evaluator for the selected strategy (described in Section A.6).

**Compare.** Brings up the Strategy Comparator so that the selected strategies can be compared (described in Section A.7).




(a) Study Overview Panel




(b) Decisionmaking Context Panel

Figure A.1: The panels of the Study Manager

**Context Panel.** Provides an overview of the decisionmaking context. The panel is shown in Figure A.1(b) and is used for defining and updating the decisionmaking context. It provides a notebook with at least these three pages:

**Shared Problem Definition.** Used to document a shared problem definition.

**Airport Operator.** Used to specify the problem perspective, objectives, and outcomes of interest of the airport operator.

**Stakeholder.** Used to specify the problem perspective, objectives, and outcomes of interest of a stakeholder. For each stakeholder that is involved in the planning efort, a tab is added to this notebook.

For each stakeholder that is involved in the planning effort, a page is added to the notebook for specifying general information and their objectives. As an example, Figure A.1(b) includes pages for the airlines, ATC authority, the community, and regulators.

Scenarios or strategies can only be created after the calibration of the study has been successfully carried out. After calibration, scenarios and strategies can be added to the study as needed. Obviously, the list with strategies grows during the course of the planning effort.

## A.3 CALIBRATOR

The Calibrator exposes the Domain Model functionality related to the calibration of a study. As such, the Calibrator implements that part of the GUI that exposes the functionality described in Section 6.3.2—Calibrate Study. The Calibrator has four panels shown in Figure A.2:

**Known Performance Panel.** Used for entering information about the known airport performance. The panel features a notebook with a page for specifying general textual information about airport peformance, a button **Annual Report** for accessing the airport's annual report, a quantitative summary of the airport's performance, and a button **Display** for displaying the airport's performance. For each of the outcomes of interest, a page is provided to specify detailed quantitative information.

**System Model Panel.** Used for specifying the characteristiscs of the System Model. The panel features a notebook with three pages related to the three subsystems of the system model—airport, environs, and ATM system. Each page provides buttons for accessing dialog windows for specifying the characteristics of specific elements, such as runways, roads, terminals, population, etc. (some of them will be shown and discussed in Chapter 8). The panel is shown in Figure A.2.

**Traffic Demand Panel.** Used for analyzing the traffic demand in terms of flights and passengers.

**Operational Plan Panel.** Used for specifying the operational plan, which describes how traffic demand is allocated to the airport's capacity.

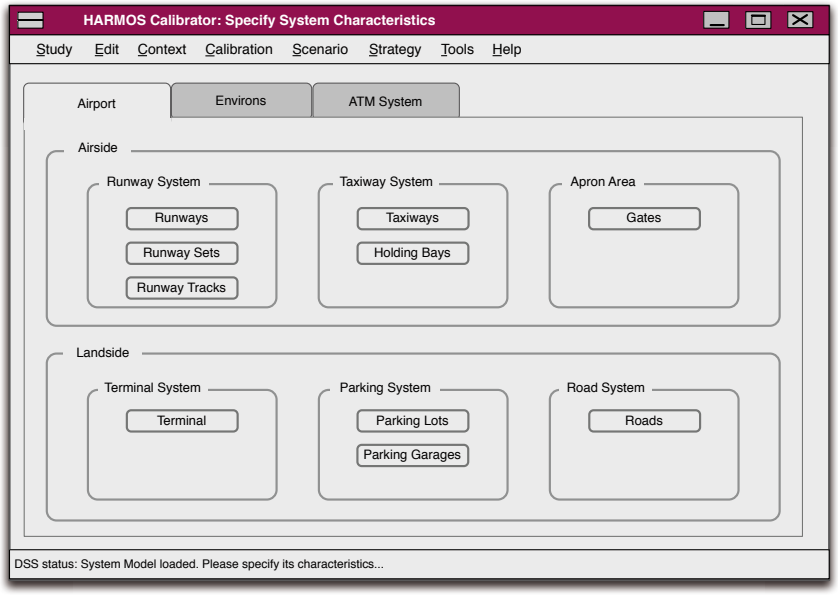



Figure A.2: The Specify System Characteristics Panel of the Calibrator

The use of the Calibrator by the domain experts and decisions advisors to calibrate a newly created study will be described in Section 8.5.1.

## A.4 Scenario Builder

The Scenario Builder exposes the Domain Model functionality related to developing scenarios (implemented as the Scenario Service described in Section 7.5.1). As such, the Scenario Builder implements that part of the GUI that exposes the functionality described in Section 6.3.4—Develop Scenarios.

The Scenario Builder provides a tree with the planning period on the left side of the panel, as shown in Figure A.3. The planning period is presented in terms of distinct years (e.g. 2011, 2016, and 2021), and specific days within those years (e.g. 31-08-2011, 12-06-2016, etc.). On the right-hand side, there is a notebook that contains five pages:

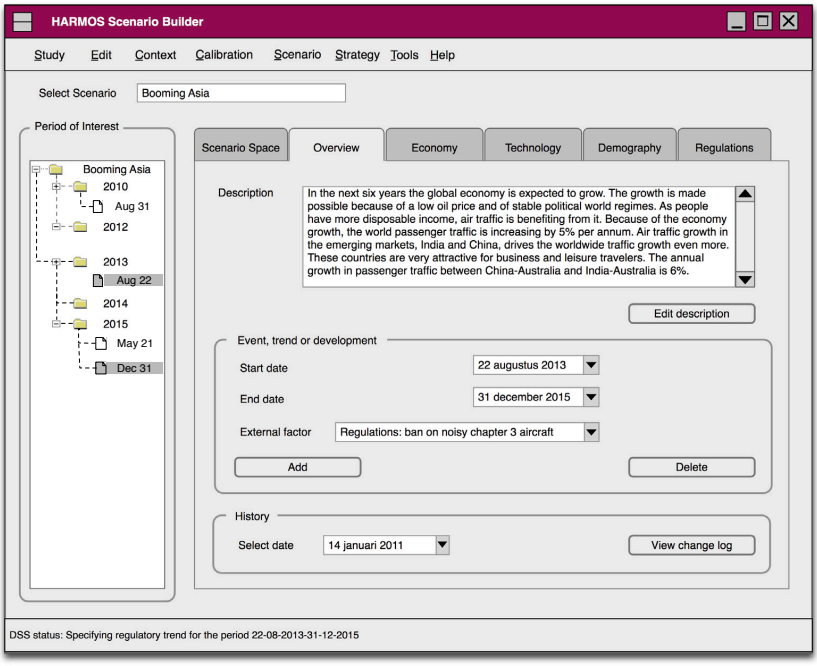



Figure A.3: The Scenario Builder

**Overview Page.** The overview page shows the name of the scenario, a short description of the scenario, and a **History** button for showing the editing history. The four other pages are related to the external factors. The information that is shown through these panels depends on the period of interest that is selected by a user.

**Economy Page.** This page is for specifying economic developments, for example, the rate of change in traffic demand throughout the years.

**Technology Page.** This page is used to specify technological developments, for example, developments in aircraft size, aircraft noise and emissions, and ATM.

**Regulations Page.** This page is for specifying regulatory developments, for example, related to noise impact or local air quality.

**Demography Page.** This page is for specifying demographic developments, for example, the density and distribution of people living in the vicinity of the airport.

This functionality has already been further developed by Cuijpers (2008). The focus of that development effort was on using the scenario building method by van der Heijden *et al.* (2002). By doing so, we were able to identify which information—generated during the steps of the scenario method—to document and store in the DSS. Kwakkel (2010) has designed and implemented so-called generator objects. These objects are used to define the future development of specific external factors, like the development of traffic demand, population, and technology. The detailed design and code from both Cuijpers (2008) and Kwakkel (2010) needs to be integrated with the existing code base of the HARMOS architecture.

The use of the Scenario Builder by the decision advisors and domain experts to develop scenarios is described in Section 8.4.1.

## A.5 Strategy Builder

The Strategy Builder exposes the Domain Model functionality related to defining strategies (implemented as the Strategy Service described in Section 7.6.1). As such, the Strategy Builder implements that part of the GUI that exposes the functionality described in Section 6.3.5—Define Strategy.

The Strategy Builder, shown in Figure A.4, is very similar in layout to the Scenario Builder (as described in the previous section). Again, on the left-hand side there is a tree for visualizing the planning period. On the right-hand side there is a notebook with five pages:

**Overview** Provides an overview of the general characteristics of the strategy. The next three pages are related to defining change to the system and the fourth and final page is related to the operational plan. The information that is shown on these panels depends on the period of interest that is selected by a user.

**Structural.** Used to define infrastructural changes to the system as a result of the strategy, e.g. the characteristics of a new runway.

**Operational.** Used to define operational changes to the system as a result of the strategy, e.g. the new runway configurations.

**Managerial.** Used to define managerial changes to the system as a result of the strategy, e.g. an increase in landing fees to recover higher operational costs.

**Operational Plan.** Used to specify the operational plan.

How the Strategy Builder is used by the decision advisors to define strategies is described in Section 8.4.2.

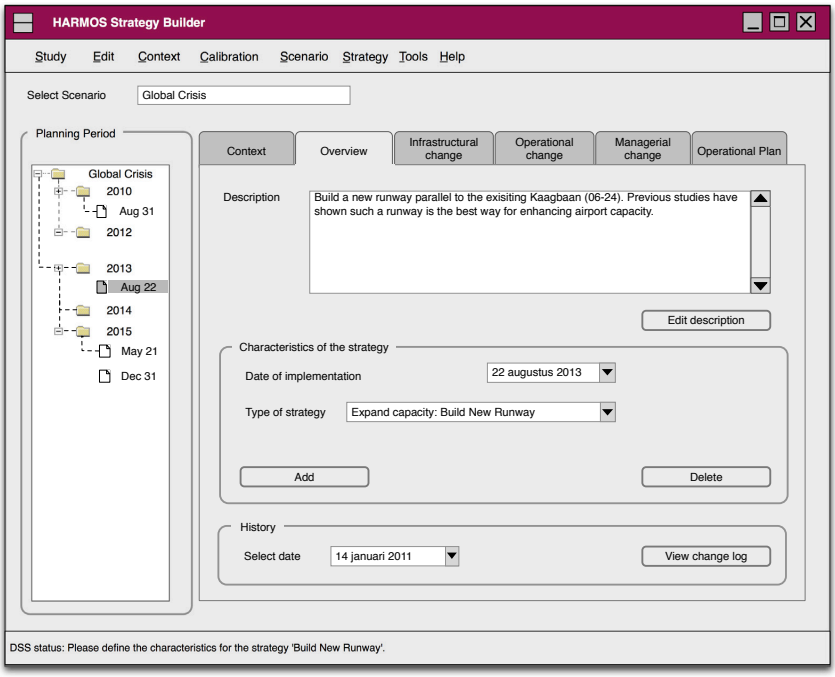



Figure A.4: The Strategy Builder

## A.6 Strategy Evaluator

The Strategy Evaluator exposes the Domain Model functionality related to evaluating strategies in terms of the outcomes of interest against each of the scenarios (as implemented through the Case class (Section 7.3.4), the performance analysis module (Section 7.8), and the outcome of interest module (Section 7.7). As such, the Strategy Evaluator implements that part of the GUI that exposes the functionality described in Section 6.3.6—Evaluate Strategy.

The Strategy Evaluator is implemented as a *separate* window, instead of a panel of the main window; this makes it possible to work with more than one strategy at the same time. A drop-down box is provided for selecting the scenario against which the strategy is to be evaluated. Just as in the Scenario Builder and the Strategy Builder, the Strategy Evaluator has a tree for visualizing the planning period. For each year, a user is able to specify days to conduct a performance analysis on a daily basis (if required). A notebook is used to present general information, the traffic demand, and the outcomes of interest. The notebook features seven pages:

**Overview Page.** Provides general information related to the evaluation of the strategy as shown in Figure A.5(a). Particular outcomes of interest can be (de)selected from this page (i.e. capacity, delay, noise, emissions, third-party risk, and financial).

**Demand Page.** Provides an overview of the traffic demand that is to be allocated. The traffic demand itself is derived from the scenario that is selected.

The other five pages are dedicated to each of the outcomes of interest. The information that is shown through these panels depends on the period of interest that is selected by a user.

**Capacity Page.** Used to select outcome indicators (e.g. daily and/or annual runway capacity), check inputs (i.e. runway sets, configurations, aircraft separation standards, runway scheme), run a capacity analysis on a daily or annual basis, and view the results (e.g. capacity envelopes, a capacity coverage chart). The detailed design and implementation of this part of the GUI has been done by Tse (2006).

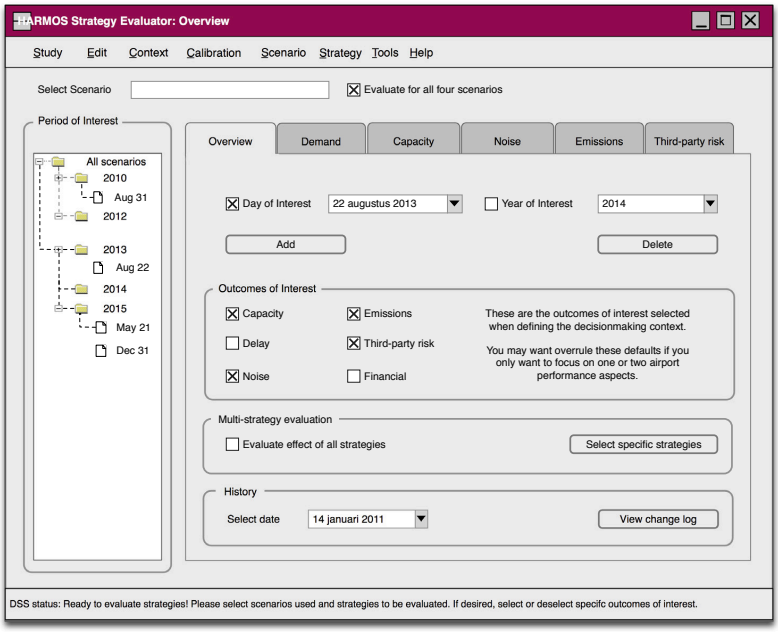
**Delay Page.** Used to select outcome indicators (e.g. daily delay), check inputs (i.e. terminals, gate allocation scheme), run the delay analysis on a daily or annual basis, and view the results (e.g. delay statistics and passenger load for each landside element, gate occupancy).

**Noise Page.** Used to select outcome indicators (e.g. contours, population affected, annoyance), check inputs (i.e. runway tracks, population data), run the noise analysis on an annual basis, and view the results (e.g. contours on a map, number of people annoyed). This panel is shown in Figure A.5(b).

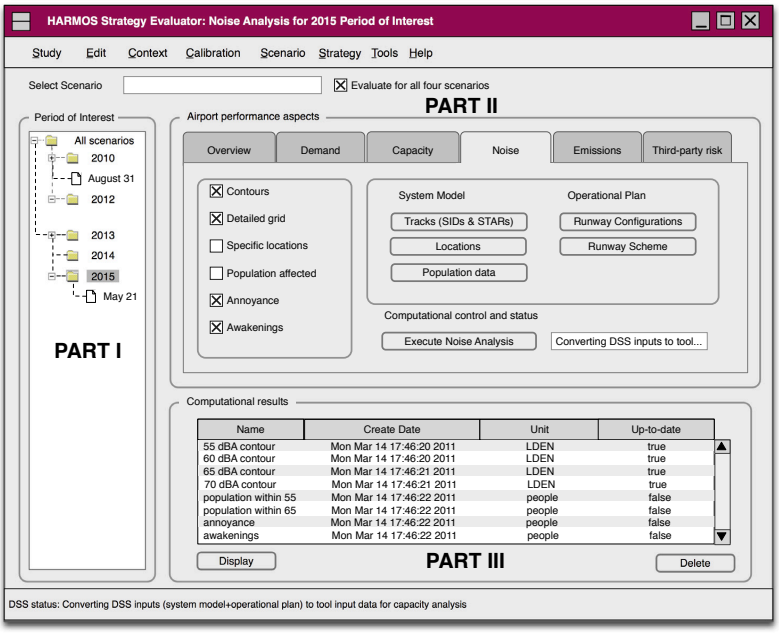
**Emissions Page.** Used to select outcome indicators (e.g. CO2, particle matter, NOx), check inputs (i.e. parking lots, ground support equipment used, vehicle distributions), run the emissions inventory on an annual basis, and view the results (e.g. inventory of emissions by source). The detailed design and implementation of this part of the GUI has been done by Vreeswijk (2007).

**Third-party Risk Page.** Used to select outcome indicators (e.g. societal risk, individual risk), check inputs (i.e. crash rates, distribution of aircraft types over the runways), run the third-party risk analysis on an annual basis, and view the results (e.g. individual risk contours, expected casualties).

Whenever an outcome indicator is selected from Part I of the panel, as indicated in Figure A.5(b), HARMOS checks whether the appropriate inputs in terms of system model, scenario, and strategy have been specified. For example: the decision advisor might want to obtain information about population inside noise contours, but no information about the population density has been specified. If that is the case, HARMOS notifies the user about the missing data. The decision advisor or domain expert can then directly use the appropriate input button to specify the missing data from Part II of the panel, as indicated in Figure A.5(b).




(a) Overview Panel




(b) Noise Analysis Panel

Figure A.5: Two panels of the Strategy Evaluator

The computations with the specific tools are started from Part III of the panel, as indicated in Figure A.5(b). The button **Run** is for executing the performance analysis. When pressed, the specific tool, which had been selected and configured when the DSS was deployed, is executed.

The results from the computations are presented in the lower half of the panel, i.e. Part IV of the panel, as indicated in Figure A.5(b). The **Display** button is used to generate a graphical or other form of presentation of the selected outcome indicator.

The use of the Strategy Evaluator by the decision advisors and domain experts is described in Section 8.5.2.

## A.7 Strategy Comparator

The Strategy Comparator exposes the Domain Model functionality related to the comparison of strategies (implemented as the Scorecard Service described in Section 7.6.4). As such, the Strategy Comparator implements that part of the GUI that exposes the functionality described in Section 6.3.6—Compare Strategies.

The Strategy Comparator has two listboxes—one for selecting a scenario and one for selecting strategies—and a notebook with three pages:

**Outcome Indicator Selection Panel.** Used for selecting the outcome indicators to be included in the scorecard (not shown).

Advanced Processing. Used for specifying rules for processing information to be shown in the scorecard.

**Scorecard Panel.** Presents a scorecard with the selected strategies (the rows) and outcomes indicators (the columns), as shown in Figure A.6. Each of the strategies can be assessed in terms of its performance and compared among each other and the Business As Usual strategy. The scorecard provides the starting point for discussing the strategies among decisionmakers of the airport operator and its stakeholders.

Section 8.3.2 describes how the Strategy Comparator is used by the decisionmakers and decision advisors to compare strategies.

## A.8 Summary and Conclusion

The HARMOS GUI follows from the functionality described in the use cases in Section 6.3. The GUI has been designed as a fairly thin layer responsible for exposing the functionality of the Domain Model. The design of the HARMOS DSS has been driven by the need to be able to deal with the three problem areas discussed in Section 1.2, as captures by the problem statement presented in Section 5.1.2. The GUI design reflects this as well.

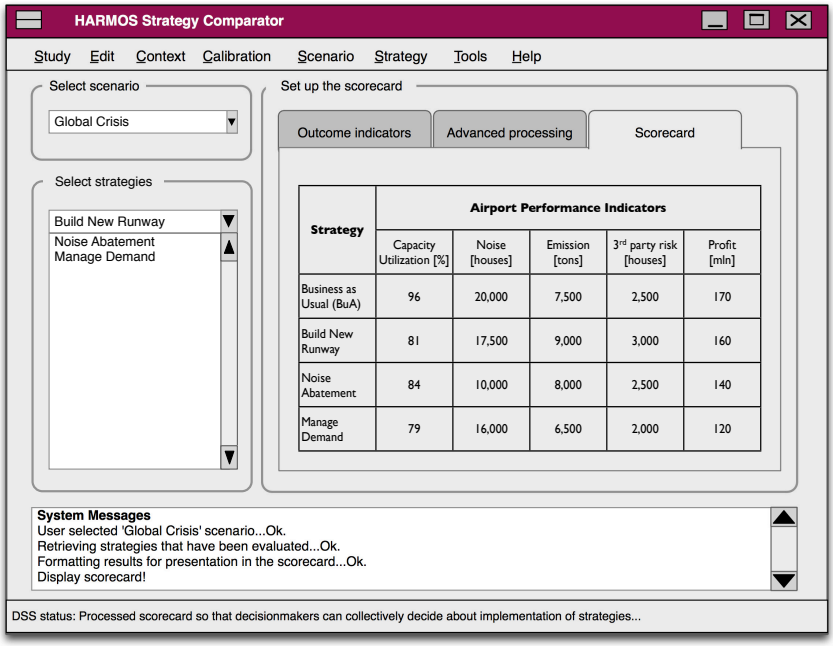



Figure A.6: The Strategy Comparator

In Chapter 4, we concluded that previous and current decision support projects mainly focus on computer-based systems for airport performance analysis. Functionality for problem formulation or interpretation is not explicitly provided. HARMOS provides functionality for each phase of the problem solving process, and this is reflected through the components of the GUI. Within each of the phases, the GUI components are used as follows:

**Formulation.** The Study Manager is used to start a new strategic planning effort. The Study Manager is used to capture information about the planning problem, the airport operator and its stakeholders, and their objectives.

**Analysis.** The Scenario Builder is used for quantitatively developing scenarios. The Strategy Builder is used for defining strategies. The Strategy Evaluator is used to evaluate the strategies against the scenarios in terms of the outcomes of interest.

**Interpretation.** The Strategy Comparator is used to compare strategies within a collaborative setting involving the airport operator and its stakeholders.

So, the HARMOS DSS supports the entire problem solving process, from formulation, through analysis, to interpretation.

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# Summary

R.A.A. Wijnen

This dissertation is about airport strategic planning and how to support it. We researched this broad subject because airport strategic planning is currently understood mostly within a narrow technical context, and hence is only supported from that point of view. This is unfortunate, since the construction of airport infrastructure is expensive, land-use intensive, and remains in place for many years. In addition, the effects of an airport's operation are felt by a large group of stakeholders. So, an airport should be looked at as a socio-technical system. Therefore, the airport operator and its stakeholders should be working together on how the airport is developed in the future.

This dissertation describes the development of a Decision Support System (DSS) called HARMOS that can facilitate such collaborative strategic planning. It presents the architecture for such a DSS, and how the DSS can potentially be used.

AIRPORT STRATEGIC PLANNING

Airport strategic planning involves finding an appropriate match between capacity and demand, given a number of constraints (e.g. environmental and financial). An airport has to be managed such that demand for services matches the capacity of the infrastructure. At the same time, the airport operator has to manage the environmental impacts of the airport operation. Part of the business process of airport operators is, therefore, to formulate and implement plans that make sure that airport capacity matches demand and societal needs as the future unfolds. This problem situation is illustrated in Figure 1, conceptualizing the airport as a *socio-technical* system.
The traditional planning approach of merely trying to keep pace with the growing demand is not enough anymore. Airport operators have to think strategically

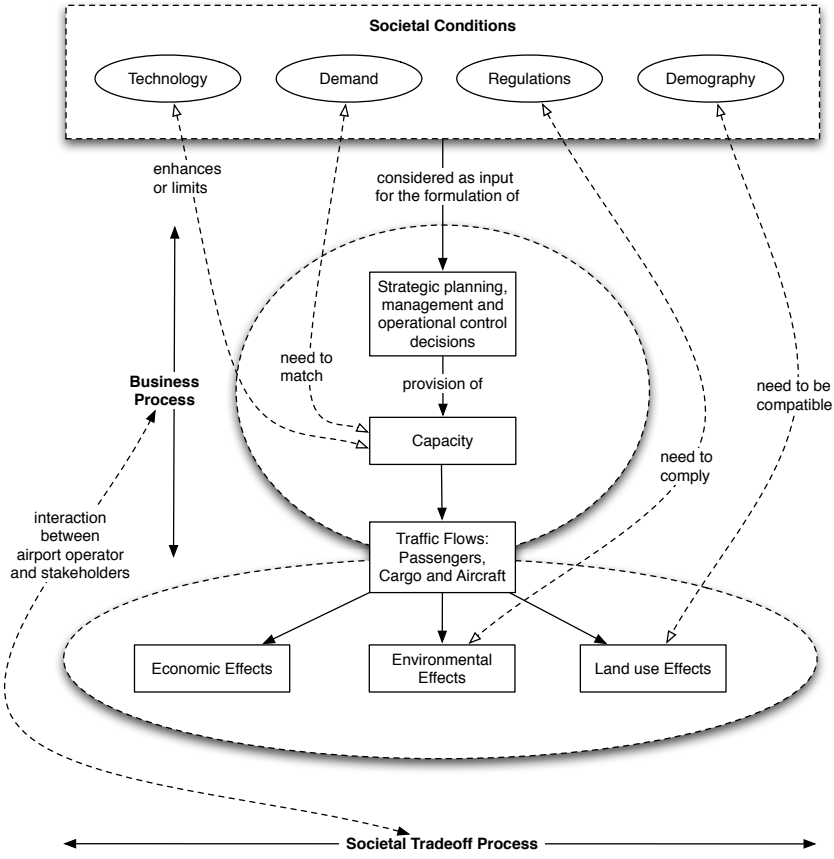



Figure 1: The airport conceptualized as a socio-technical system

about shaping the demand, while at the same time considering ways to mitigate the adverse effects of the airport's operation. Ideally, this should result in strategies that not only satisfy the airport operator's business objectives, but also satisfy the objectives of its stakeholders. Additionally, these strategies have to be developed within a limited time and budget. In modern day airport planning, current and future societal conditions, the potential impact of a strategy on the airport's capacity, and its economic, environmental, and land use effects need to be considered concurrently. Strategic thinking and planning, therefore, is essential for the long-term success of an airport operator.

### Problems with airport strategic planning

Current airport strategic planning has three major problem areas, which are described below.

**I: A lack of involvement of the stakeholders.** Stakeholders are usually not directly involved in the airport strategic planning process; their inclusion often comes late in the process, with room to comment and suggest changes, but having no real input into the original planning direction. If some stakeholders feel that the plan for an airport's development does not satisfy their objectives, the implementation of the plan can be delayed or hampered significantly. This is seen as a fundamental problem that affects not only the development of a robust plan, but also the likelihood of a plan being accepted.

**II: An inadequate approach for dealing with the future.** Planners consider only a limited number of plausible futures (usually only one). As is often acknowledged: 'the forecast is always wrong'. Therefore the traditional 'predict-and-act' approach to airport planning is likely to produce a plan that performs poorly. The future context in which the airport has to operate is usually based on a single trend extrapolation of demand. Besides demand, other external factors, such as technology, regulations, and demographics should be seriously considered when dealing with the future, because they also have impacts on demand, the entire airport system, and its performance.

**III: An inefficient problem solving process.** Strategic planning for airports requires evaluating each of many different strategies that could potentially be implemented. Often, different people (from different organizations or departments) work on different questions related to the evaluation of strategies, each using different models/tools, assumptions, and data. So, it is difficult to produce a consistent, integrated set of results that can be used to analyze the effects of a specific strategy. And, even if the separate analyses used consistent assumptions and data, an integral view of the airport's performance can be produced only by manually collecting, combining, and post-processing the individual results, which is very time consuming.

The need to address all three problem areas concurrently motivated our design of HARMOS.

### The research questions

The goal of this research is to find out how to better support airport strategic planning through a DSS.

In order to meet this goal, we formulated five Research Questions:

**Research Question 1.** How should the concept of strategic planning be understood within the airport decisionmaking and planning context?

**Research Question 2.** What lessons can be learned from past and current efforts to build computer-based systems for airport strategic planning?

**Research Question 3.** How can airport strategic planning be supported through a DSS and how should the decision support system be designed?

**Research Question 4.** How is the architecture to be implemented such that the DSS vision is realized and a solid foundation for growing HARMOS into a business application is created?

**Research Question 5.** How can a Proof of Concept and a Proof of Usefulness be provided?

The sections that follow present the answers to each of these five questions, based on our research.

### RESEARCH QUESTION 1: HOW SHOULD THE CONCEPT OF STRATEGIC PLANNING BE UNDERSTOOD WITHIN THE AIRPORT AND DECISIONMAKING CONTEXT?

The term 'airport strategic planning' is used in different ways, yet hardly ever defined. The definition we adopted is a rather broad definition and does not imply a specific approach. We therefore studied management science, current approaches to airport strategic planning, and the resources involved in airport strategic planning.

#### Strategic planning

In order to better understand the concept of strategic planning, we surveyed literature from the management field. Strategic planning was initially conceived as an analytical approach to formulate strategies for aligning company resources with its business environment. Many strategic planning models exist. Each of them can be characterized by a formal and elaborate sequence of steps. Following all the steps would produce the strategy as a result.

The type of strategic planning just described is not the way we see strategic planning. We used a definition that defines strategic planning as a broad concept, which stresses that strategic planning should be viewed as a set of concepts, procedures, and tools that must be carefully *tailored to a specific context* if desirable outcomes are to be achieved. This perspective on strategic planning is therefore much more comprehensive than how it was originally conceived in the 1960s.

In our opinion, airport strategic planning should not be understood as or confined to a *purely analytical activity*. Instead, airport strategic planning should

be an activity that initiates *strategic thinking* about the many plausible futures and potential strategies for facing those futures. A comprehensive approach to airport strategic planning should focus not only on the economic performance of an organization, but its social performance as well.

**Approaches to airport strategic planning versus problem areas**

A number of specific approaches to airport strategic planning are available. Master Planning is the most prominent one, since it is used by many airport operators to create plans for the future development of the airport. Often, Master Plans become obsolete because they are based on single-demand forecasts (Problem Area II) and there is often opposition from one or more stakeholders because the Master Plan does not satisfy their objectives (Problem Area I).

Dynamic Strategic Planning (DSP) is an approach that is more flexible, since it urges airport operators to dynamically adjust their plans over time to accommodate the variety of futures. As such it deals directly with Problem Area II. Other approaches have recently been proposed as well. These approaches are mostly conceptual in nature and focus on Problem Area II as well.

Table 1 shows to what extent these approaches deal with each of the problem areas. As can be seen from the table, we found that none of the current approaches to airport strategic planning deals with all three problem areas.

Table 1: Approaches versus problem areas

| **Problem area** | **Approach** | | |
|---|---|---|---|
| | Master Planning | Dynamic Strategic Planning | Other approaches |
| I: Lack of stakeholder involvement | Advice for early involvement | Fair negotiation process after design of a plan | Not addressed |
| II: Inadequate approach for dealing with the future | Single demand forecast | Scenarios | Scenarios, among others |
| III: Inefficient problem solving process | Sequence of analytical steps | Advice to appropriately use computer-based tools | Not addressed |

**Fragmentation of resources**

From our decision support perspective, we looked at the resources—people, data and information, and tools—involved in a strategic planning effort as shown in Figure 2.

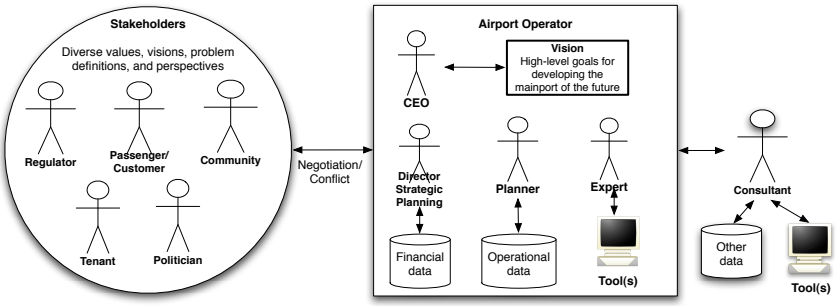



Figure 2: Current planning: potential conflicts between the airport operator and its stakeholders (Problem Area I) and a huge coordination effort (Problem Area III)

Three types of resources are involved in a strategic planning effort: people, data and information, and tools. As can be seen in Figure 2, there are two types of *people* involved in planning—those outside and inside the airport operator's organization. People inside the airport operator's organization are the ones that are directly and continuously involved in the strategic planning process; they carry out different types of activities in order to come up with a strategic plan that has the potential for realizing the airport's management vision. People outside the airport operator's organization are typically associated with organizations or groups that have a stake in the airport's development. These stakeholders (e.g. airlines, national and local authorities, community groups, and the Air Traffic Control authority) have conflicting goals and objectives with respect to the airport's development.

Creating an effective strategic plan requires consistent *data and information* about a wide range of aspects, such as business objectives, the airport system and its environment and an airport's performance for the given future context and strategies. With respect to an airport's performance, information at different levels of detail is required concerning capacity and delay, and environmental impacts—noise, emissions, and third party risk. Often, external consultants are contracted to provide information about some or all of these airport performance aspects.

Much of the data and information are generated using analytical *tools*, typically related to capacity and delay, environmental impacts (noise, emissions,

and third party risk), and finance. In most cases, the data are not used and information is not generated in a consistent, integrated way. Typically, only a single aspect of the airport's operation (e.g. its capacity and delay, noise, or emissions) is evaluated at a single time.

Integration and consolidation of these resources for a specific planning study cannot be easily done. Hence, the problem-solving process is inefficient and not able to support the formulation, analysis, and interpretation of strategies for an airport's development within the multi-stakeholder context. We believe that *fragmentation* of the above resources is a fundamental cause of the problem areas that exist with respect to airport strategic planning. This fragmentation leads to an inefficient problem-solving process that is not able to support the creation of strategies for an airport's development acceptable to all stakeholders.

### RESEARCH QUESTION 2: WHAT CAN BE LEARNED FROM PAST AND CURRENT PROJECTS TO BUILD COMPUTER-BASED SYSTEMS FOR AIRPORT STRATEGIC PLANNING?

To answer this research question, we investigated why previous attempts at building computer-based systems have not succeeded. The systems have hardly any functionality to project into the future, besides extrapolating a flight schedule. They do not directly provide functionality for comparing alternatives among each other and with the objectives of the decisionmaker, so decisionmakers cannot directly use the results for making trade-offs. Finally, the planning problems that can be analyzed with the systems are limited.

Some of the specific problems that we discovered are the following. There is a lack of insight into the decision environment in which the systems are to be used and no identification of the users of the system. Early projects that were carried out focused exclusively on capacity and delay. Almost all projects have a strong focus on tools and models: the projects are *tool-oriented* as opposed to *problem-oriented* or *people/user*-oriented. The systems constrain the problem space that can be explored: some systems were more concerned with integrating tools into a single system than with designing and building functionality that could readily support airport planning problems. Finally, the airport models have been developed by Air Traffic Management (ATM) and airport specialists for whom software development has been a secondary consideration. As a result, the usability, robustness, and user interfaces of many existing models are severely deficient. We have used these insights as important lessons for our DSS design effort.

RESEARCH QUESTION 3: HOW CAN AIRPORT STRATEGIC PLANNING BE SUPPORTED THROUGH A DSS AND HOW SHOULD THE DECISION SUPPORT SYSTEM BE DESIGNED?

We conducted an extensive analysis of airport strategic planning from a business and decision support point of view. We also described an airport from a technical and social perspective. And, we studied past and current projects to build computer-based systems for airport performance analysis to extract lessons learned. Based on that information, Part II of this dissertation presents our decision support design.

**What is needed?**

We identified what is needed in terms of a decision support design and development process. At the start of the DSS design and development process, a vision on how to provide decision support was developed. During the development process, we stayed true to that vision. Our vision is based on the idea that the DSS should address all three problem areas of current airport strategic planning simultaneously.

Our proposed solution, the Holistic Airport Resource Management and Optimization System (HARMOS) DSS, enables an airport operator to deploy its resources—people (knowledge), data and information, and tools—more efficiently, resulting in an improved understanding of the airport system, its problems and potential strategies for airport development. The HARMOS DSS explicitly facilitates the involvement of stakeholders in the planning process, as shown in Figure 3.

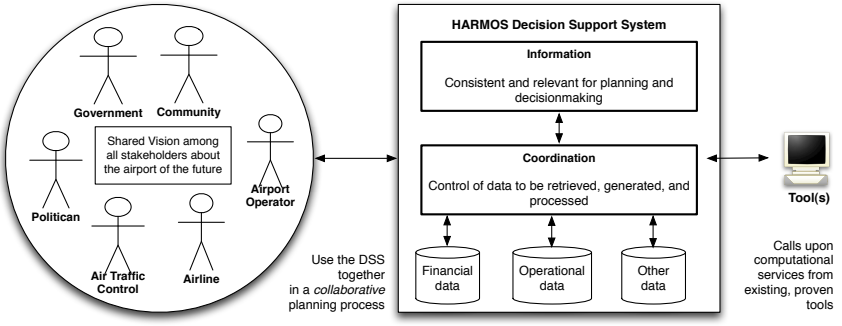



Figure 3: HARMOS—bringing people together.

The HARMOS DSS becomes the centerpiece of the planning effort. The DSS provides *coordination* of the data and information, and tools, so that consistent

and relevant *information* for planning and decisionmaking is obtained. As such, HARMOS significantly reduces the huge coordination effort that currently needs to be taken by airport staff and consultants. Instead of spending their time on this coordination effort, planners, consultants, and experts can use their valuable time to more extensively explore planning problems given the uncertain future, and the potential strategies that address those problems.

HARMOS enables airport staff *and* stakeholders to effectively share information and work together on their problems so that they gain an understanding of each other's perspectives, perceptions, values, and objectives. Only when there is a mutual understanding is it possible to look for strategies that are satisfactory to all parties involved (see the left side of Figure 3). As a result, an airport operator and its stakeholders can create a *shared vision* for the future airport.
The key design principles used to turn this concept into an executable architecture for the HARMOS DSS are *policy analysis* and the *integration of resources*. Through the HARMOS DSS, the resources have been embedded in a unified structure. As can be seen in Figure 3, the DSS coordinates data and tools to provide the users relevant information. The DSS is used in a collaborative planning process by the airport operator and its stakeholders.

We realized that a comprehensive and structured approach is needed that brings the technical and the social perspective together to adequately address airport strategic planning problems. Therefore, we adopted the policy analysis approach as shown in Figure 4 for designing the problem solving functionality of the DSS.

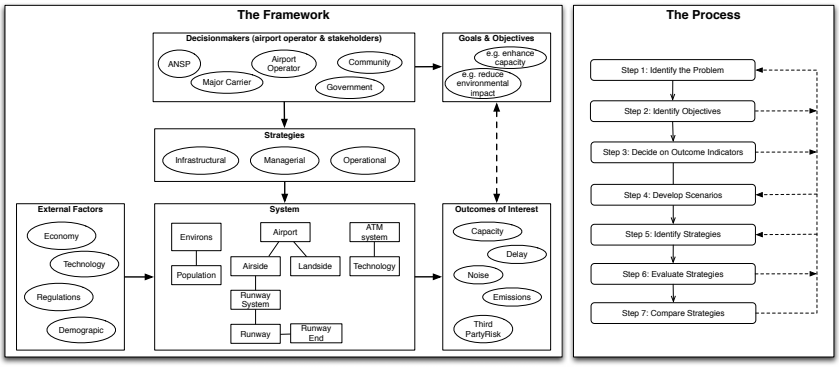



Figure 4: The policy analysis approach used as design principle for the DSS

This approach provides a well-defined *framework* for structuring airport strategic problems. The framework explicitly identifies the decisionmakers, stakeholders,

and their objectives, the *system*, the *outcomes* from the system, and the forces acting upon the system (external factors and strategies).

The approach also provides a *process* for systematically organizing the problem-solving process. The process defines seven steps: (1) identify the problem; (2) identify objectives; (3) decide on outcome indicators; (4) develop scenarios; (5) identify strategies; (6) analyze strategies; (7) compare strategies. Steps 1–3 are related to problem *formulation*, Steps 4–6 are related to *analysis*, and Step 7 is about *interpretation*.

We used policy analysis as a way to formalize airport strategic planning in order to turn the concept shown in Figure 3 into a software system. In order to do that we used an iterative development process combined with Domain Driven Design (DDD).

### The HARMOS architecture

Airport strategic planning involves many people with different roles conducting many activities. It is essential to understand these roles and activities, because the roles need to be mapped to the users of the DSS, and a part of these activities drive the functionality of the DSS. The first step of our DSS development process was therefore to analyze the problem domain and business activity, in order to identify the scope and users for the DSS. We identified three major roles in the airport strategic planning effort, which are performed by one or more persons. The three primary actors are decisionmakers, decision advisers, and domain experts. Tools for airport performance analysis have been identified as supporting actors: they support the DSS in providing the required functionality to the users. The users and the functionalities needed to fulfill the user goals are captured through the Functional View shown in Figure 5. These functionalities are described below.

**Define Decisionmaking Context.** Decisionmakers from the airport operator and its stakeholders define the problem at hand or opportunity to be seized, their objectives, and the outcome indicators to be used for quantifying the effects of the strategies. This functionality supports the formulation phase of problem solving and is directly related to Steps 1–3 of the policy analysis process—identify the problem, identify objectives, and decide on indicators.

**Calibrate Study.** Right after a new study is created, domain experts calibrate the study. Decision advisors and domain experts collect existing information about the airport's performance for the calibration year, using HARMOS to store that information. Domain experts execute performance analysis with respect to capacity, noise, emissions, and third-party risk for the calibration year. Decision advisors compare the *computed* performance with the *known* performance

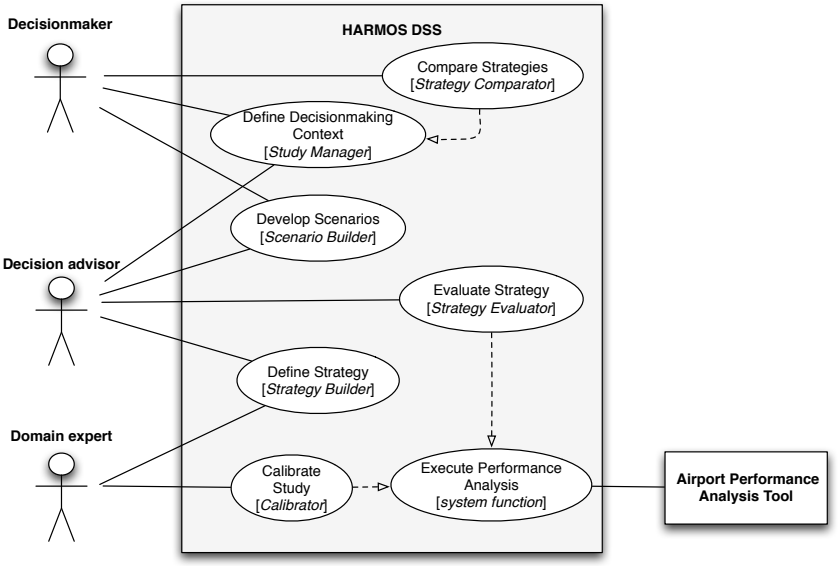



Figure 5: DSS users and functionalities provided by the HARMOS DSS.

**Develop Scenarios.** The HARMOS DSS supports a proven method for scenario building. The scenarios, i.e. stories describing different plausible futures built by the decisionmakers of the airport operator and its stakeholders, are stored in the DSS by the decision advisor. Decision advisors quantify various elements of each of these scenarios so that they can be used to test the strength and robustness of strategies. This functionality is directly related to Step 4 of the policy analysis process—developing scenarios.

**Define Strategy.** Based on discussions among decisionmakers from the airport operator and its stakeholders, decision advisors define strategies related to managing airport capacity, demand, and operations. Decision advisors specify all the necessary details of the strategy. This functionality is directly related to Step 5 of the policy analysis process—define strategies.

**Evaluate Strategy.** Each strategy defined within a study needs to be evaluated for all the scenarios. Decision advisors evaluate each strategy in terms of the outcomes defined within the study against all of the scenarios that have been developed. This functionality is directly related to Step 6 of the policy analysis process—evaluate strategies.

**Compare Strategies.** Once all of the strategies have been evaluated for all of the scenarios, the results are presented to the decisionmakers of the airport operator and to its stakeholders. Decision advisors use HARMOS to

generate a 'scorecard' for each scenario, presenting the effects on the airport's performance for each of the strategies. This functionality is directly related to Step 7 of the policy analysis process—compare strategies.

The goals that have been mentioned above have been used to drive the design of the functionality of HARMOS.

Each part of the functionality discussed has been realized by designing and implementing the overall structure for the DSS shown in Figure 6. As can be seen from the figure, the architecture is based on the Layered pattern, separating concerns with respect to the Graphical User Interface (GUI), the *Domain Model*, and lower-level Technical Services. Within the layers, separation of concerns has been further established by designing Modules, each with clear and distinct responsibilities.

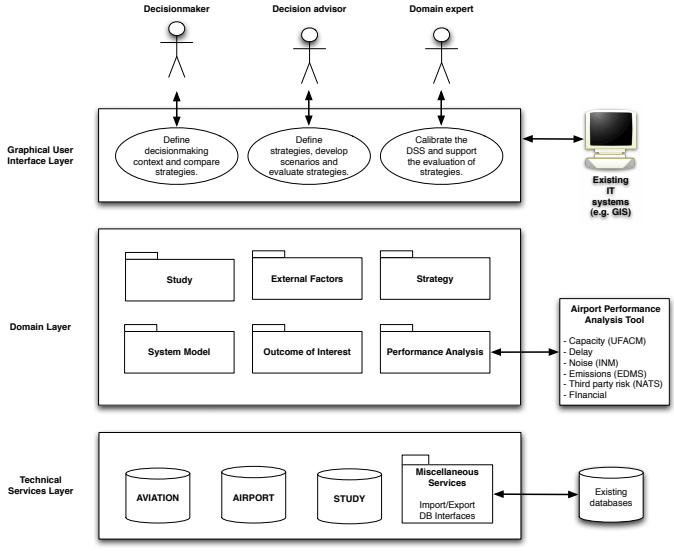



Figure 6: Logical view of the HARMOS architecture.

RESEARCH QUESTION 4: HOW IS THE ARCHITECTURE TO BE IMPLEMENTED SUCH THAT THE DSS VISION IS REALIZED AND A SOLID FOUNDATION FOR GROWING HARMOS INTO A BUSINESS APPLICATION IS CREATED?

The complexity of the airport domain and the business activity of strategic planning motivated the use of a Domain Model as the heart of the HARMOS DSS. We argue that without it, it is not possible to realize the functional requirements.

### The use of a Domain Model to deal with complexity

The Domain Model, featuring both *data* and *behavior*, turned out to be very beneficial in realizing a direct mapping of the policy analysis framework to software.

The Domain Model structures the Domain Layer of the DSS such that the software's structure can be easily understood by the potential users and developers (see Figure 7). The modules and underlying classes that form the structure of the DSS are based on domain aspects (i.e. airports and aviation) and business aspects (i.e. strategic planning).

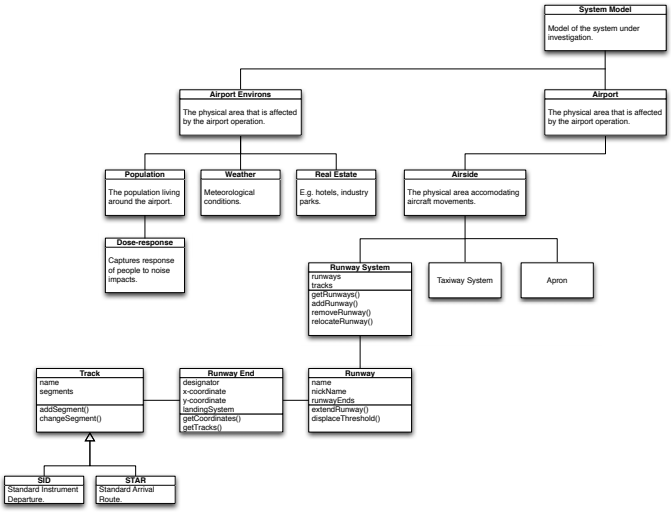



Figure 7: Part of the structure of the HARMOS Domain Model

The Domain Model includes all the functionality for supporting airport strategic planning. The added value of the Domain Model can be summarized as follows:

**Problem-oriented.** The framework according to Walker defined a large part of the Domain Model. The policy analysis framework provided a way to structure data and information. Categorization according to the policy analysis framework provided the means to effectively deal with all the information and reason about problems caused by the airport. The most important advantage of structuring data and information according to the policy analysis framework is that there are clear distinctions among data that are related to the system, the external factors, the strategies, and the outcomes of interest for the problem at hand.

**Natural representation of the system.** The System Model is a natural way of specifying and presenting the real world system, featuring classes such as (1a) airside, runway system, runway end, track; (1b) landside, terminal, road; (2) environs, population, dose-response; (3) ATM system, and separation standards.

**Independent of tools.** The introduction of the Performance Analysis module realizes an important separation of concern. The DSS becomes independent of the third-party tools used to quantify airport performance.

**Flexible presentation.** The Outcome of Interest module implements a generalized Outcome Indicator class (superclass), which incorporates behavior commonly needed to deal with the presentation of specific outcome indicators (e.g. noise, emission, and risk contours). Combined with the Presentation Service, a common and consistent way for presenting the various indicators has been established.

**Extendability.** The modules in the Domain Model can easily be extended to accommodate changing or new user-requirements.

**Scalability.** The functionality included in this module also scales very well. If the System Model is extended to include more elements (e.g. roads outside the airport property), the analysis services can be extended to provide quantification of outcome indicators related to those elements as well.

These qualities of the Domain Model brings business value and paves the way for commercialization.

### RESEARCH QUESTION 5: HOW CAN A PROOF OF CONCEPT AND A PROOF OF USEFULNESS BE PROVIDED?

The scope of the DSS development effort had to be limited because of the academic character of the effort. This means that only a stable architecture (and not a fully functional business application) has been delivered as a result.

We provided a Proof of Concept (PoC) for our research by demonstrating how the HARMOS DSS is able to address specific problems in each of the problem areas, based on the strategic planning of Amsterdam Airport Schiphol (AAS). The Proof of Concept is summarized in Table 2. The table shows how specific problems in each of the three problem areas are addressed by the functionality of the HARMOS DSS.

Identifying specific problems within each of the three problem areas allowed us to show that each of them can be addressed by the HARMOS DSS. As such, a proof of concept was provided. Potential users were also invited to provide feedback on the DSS and its functionality. We found that the HARMOS DSS was perceived as useful for supporting an airport operator and its stakeholders to collaborate and collectively decide about an airport's future development.

Table 2: How HARMOS addresses the problems in each of the problem areas

| Problem Area | Specific Problem | How Addressed |
|---|---|---|
| I | Lack of collaboration in pre-planning phase | Study Manager for defining different perspectives on the planning problem |
| | Lack of trust among stakeholders | Strategy Comparator for integrated assessment of strategies against multiple futures |
| | No collective sensemaking or decisionmaking | Every part of HARMOS, but the Study Manager, Scenario Builder and Strategy Comparator in particular |
| II | Single view of the future | Scenario Builder for co-creating four scenarios |
| | Narrow set of alternative strategies | Strategy Builder for defining a wide range of strategies |
| III | Computational errors | Calibrator providing a single and consistent system model for extracting data to execute airport performance analysis |
| | Huge time investment for translating computational results to understandable format | Strategy Evaluator for integrated assessment of the outcomes for a single strategy |

## SCIENTIFIC CONTRIBUTIONS

This dissertation addresses the three identified problem areas with airport strategic planning through the development of a DSS. We used knowledge from different fields and disciplines to arrive at the design of the DSS and to implement its architecture.

Knowledge from *management science*, in particular the strategic planning and strategic management literature, was explored to better understand the concept and different aspects of strategic planning. *Policy analysis* was used to investigate airport strategic problems in a holistic way, dealing with the complexity of the system, the uncertain future, and the multi-stakeholder context. Knowledge from *aeronautical engineering*, in particular experience with a range of tools for

airport performance analysis, was used to find out how to generate the appropriate information for decisionmaking. *Software engineering* principles and best practices were applied to specify the requirements, design the DSS' architecture, and implement that architecture. The scientific contributions of this research are:

1. The research provides a deeper understanding of the concept of airport strategic planning and how it can be improved. We thoroughly surveyed the general management literature and investigated the problems with airport strategic planning, current approaches for airport strategic planning, and the resources used within a strategic planning effort. Because we looked at airport strategic planning from different angles, we have been able to show why so many past projects to support airport strategic planning fail to meet the needs of airport decisionmakers.
2. The research contributes to the field of decision support systems in a number of different ways. We showed how modern software engineering is able to deal with many of the issues in the field. The application of use case writing ensures that the users and their needs are explicitly defined (something that is missing in 70% of DSS development projects). We showed that architectural design of a DSS needs to encompass domain, business, and technology aspects. Our use of Domain Driven Design ensures that the focus of the design effort is on understanding the domain and the business, and formalizing that knowledge in order to come up with an executable version of the DSS' architecture.
3. The research demonstrates the advantages of using a solid framework for decisionmaking as a basis for the DSS design. According to our knowledge, we are the first to use a policy analysis approach as the foundation for defining part of the structure and functionality of a DSS. Using this policy analysis framework makes the problem solving capabilities of the DSS quite flexible and comprehensive. This choice enables the DSS users to explore the problem space any way they want. That is quite a new approach, as many DSSs are tied to some sort of mathematical algorithm.

# Samenvatting

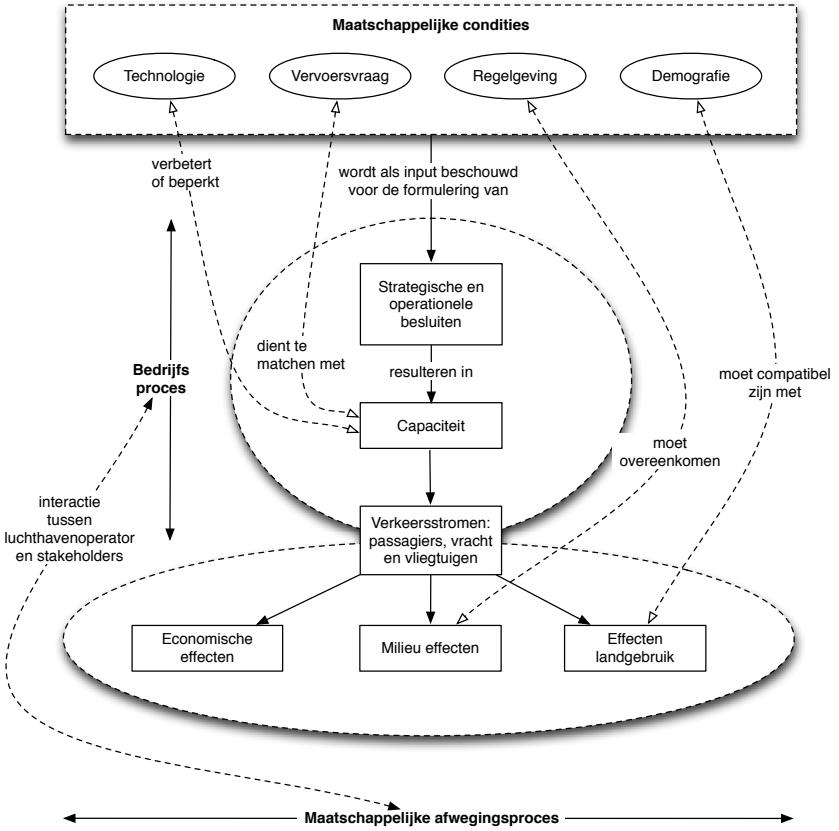
R.A.A. Wijnen

Dit proefschrift gaat over de strategische planning van luchthavens en de ondersteuning daarvan. Wij hebben voor dit onderwerp van studie gekozen omdat momenteel de langetermijnplanning van luchthavens meestal wordt uitgevoerd in een nauw gedefinieerde technische context en dus alleen ondersteund wordt vanuit dat oogpunt. Dat is om meerdere redenen problematisch. Ten eerste omdat de bouw van luchthaveninfrastructuur duur is en het beslag op de ruimte groot. Daarnaast creëert een luchthaven effecten die diverse groepen stakeholders raken. Een luchthaven moet dus worden gezien als een sociaal-technisch systeem waarbij de luchthavenoperator en haar stakeholders moeten samenwerken aan de toekomstige ontwikkeling van de luchthaven.

Dit proefschrift presenteert een Decision Support System (DSS) dat de gezamenlijke strategische planning door een luchthavenoperator en haar stakeholders ondersteunt. We laten zien hoe de architectuur van dit DSS eruit ziet en beschrijven hoe dit systeem kan worden gebruikt.

## STRATEGISCHE LUCHTHAVENPLANNING

Strategische planning voor luchthavens is het bepalen van een passende match tussen vraag en capaciteit, rekening houdend met beperkingen door bijvoorbeeld milieu- en financiële eisen. Een luchthaven moet zodanig worden beheerd dat de vraag naar vliegbewegingen overeenkomt met de capaciteit van de infrastructuur. Tegelijkertijd moet de luchthavenoperator maatregelen nemen om de milieueffecten die de luchthaven veroorzaakt te beperken. Een van de onderdelen van het bedrijfsproces van een luchthavenoperator is dus het formuleren van plannen die ervoor zorgen dat de capaciteit van luchthavens nu en in de toekomst




Figuur 1: De luchthaven geconceptualiseerd als een sociaal-technisch systeem

aansluit op de behoeften van de samenleving. Bovenbeschreven strategische planningsprobleem wordt geïllustreerd in Figuur 1, dat een luchthaven als een *sociaal-technisch* systeem weergeeft.

De traditionele manier van plannen waarbij wordt getracht gelijke tred te houden met de groeiende vraag werkt niet meer. Luchthavenoperators moeten strategisch denken over het creëren van de vraag en tegelijkertijd de negatieve effecten veroorzaakt door de luchthaven beperken. Idealiter resulteert dit in strategieën die niet alleen de zakelijke doelstellingen van de luchthavenoperator behaalt, maar er ook voor zorgen dat de doelstellingen van haar stakeholders worden behaald. Daarnaast moeten deze strategieën ontwikkeld worden binnen beperkte tijd en budget. Een moderne manier van luchthavenplanning houdt rekening met

huidige en toekomstige maatschappelijke omstandigheden (dat wil zeggen ontwikkelingen in technologie, demografie, regelgeving, en de vervoersvraag) en beschouwt gelijktijdig de potentiële impact van een strategie op de capaciteit van de luchthaven en het effect op economie, milieu en landgebruik. Strategisch denken en plannen is dus van essentieel belang voor lange-termijn succes.

**Problemen met strategische luchthavenplanning**

De huidige manier van strategische luchthavenplanning kent drie probleemgebieden die hieronder staan beschreven.

**I: Onvoldoende betrokkenheid stakeholders.** Stakeholders worden vaak te laat betrokken in het proces zonder een echte inbreng te kunnen leveren. Stakeholders kunnen de uitvoering van het plan wel vertragen of ernstig bemoeilijken.

**II: Ontoereikende aanpak in het omgaan met de toekomst.** Planners overwegen vaak maar één of slechts een beperkt aantal mogelijke toekomsten. De traditionele ”voorspellen-en-handelen’ aanpak resulteert daarom in een plan dat niet voldoet. De toekomstige context waarin de luchthaven moet opereren wordt meestal gebaseerd op een enkele trendextrapolatie van de vervoersvraag. Naast de vervoersvraag, moeten andere externe factoren, zoals technologie, regelgeving en demografie serieus worden overwogen bij de beschouwing van de toekomst. Al deze factoren hebben namelijk gevolgen voor de vervoersvraag, het hele luchthavensysteem, en haar prestaties.

**III: Een inefficiënt proces voor probleemanalyse.** Strategische luchthavenplanning vereist beoordeling van vele verschillende strategien die mogelijk kunnen worden geïmplementeerd. Vaak werken verschillende mensen (uit verschillende organisaties of afdelingen) aan verschillende vragen met betrekking tot de evaluatie van strategieën, elk met behulp van verschillende modellen/tools, aannames en gegevens. Het is daarom moeilijk om een consistente en geïntegreerde analyse uit te voeren naar de effecten van een specifieke strategie. Het verkrijgen van een integraal beeld van de luchthavenprestaties is zeer tijdrovend omdat kan alleen worden verkregen door handmatig de resultaten van individuele analyses te verzamelen, combineren en te verwerken.

De noodzaak om alle drie de probleemgebieden tegelijkertijd te adresseren motiveerde het ontwerp van een DSS.

**De onderzoeksvragen**

Het doel van dit onderzoek is het bedenken van betere ondersteuning van strategische luchthavenplanning door middel van een DSS. Om dit doel te bereiken, hebben wij vijf onderzoeksvragen geformuleerd:

1. Hoe moet het concept van strategische planning worden begrepen binnen de context van besluitvorming en planning van een luchthaven?
2. Welke lessen kunnen worden getrokken uit eerdere en huidige inspanningen om computer-gebaseerde systemen te bouwen voor strategische luchthavenplanning?
3. Hoe kan strategische luchthavenplanning worden ondersteund door middel van een DSS en hoe moet het DSS worden ontworpen?
4. Hoe kan de architectuur worden geïmplementeerd zodat de visie op beleidsondersteuning wordt gerealiseerd en een solide basis wordt gelegd voor het uitbouwen van het DSS tot een bedrijfsapplicatie?
5. Hoe kan een 'proof of concept' en een 'proof of usefulness' worden verkregen?

De volgende secties beschrijven de antwoorden op elk van deze vragen.

### ONDERZOEKSVRAAG 1: HOE MOET HET CONCEPT VAN STRATEGISCHE PLANNING WORDEN BEGREPEN BINNEN DE CONTEXT VAN BESLUITVORMING EN PLANNING VAN EEN LUCHTHAVEN?

De term strategische luchthavenplanning wordt op verschillende manieren gebruikt, maar nauwelijks gedefinieerd. De definitie die wij hanteren is een nogal brede definitie en impliceert geen specifieke aanpak voor strategische luchthavenplanning. We bestudeerden daarom de managementwetenschappen, de huidige manier van strategische luchthavenplanning, en de middelen die daarbij betrokken.

#### Strategische planning

Om het concept van strategische planning beter te begrijpen hebben we de managementliteratuur bestudeerd. Strategische planning werd aanvankelijk opgevat als een analytische benadering om strategieën te formuleren. Veel modellen voor strategische planning zijn zo ontstaan. Elk van die modellen kan worden gekenmerkt door een formele en uitgebreide volgorde van stappen. Door alle stappen te doorlopen zou een strategie geformuleerd kunnen worden.

Deze manier van strategisch plannen is niet de manier waarop wij strategische planning zien. We hebben een definitie gebruikt die strategische planning definieert als een breed begrip. In deze definitie wordt benadrukt dat strategische planning moet worden gezien als een verzameling van concepten, procedures en tools die zorgvuldig moet worden *afgestemd op een specifieke context* om de gewenste resultaten te bereiken.

Naar onze mening moet strategische luchthavenplanning niet worden beperkt tot een *zuiver analytische activiteit*. In plaats daarvan moet strategische luchthavenplanning een activiteit zijn die *strategisch denken* initieert over de vele

mogelijke toekomsten en bijbehorende strategien. Een brede aanpak voor strategische luchthavenplanning moet rekening houden met zowel de economische als sociale prestaties van een organisatie.

**Manieren van strategische luchthavenplanning versus probleemgebieden**

Er bestaan meerdere manieren om strategische luchthavenplanning aan te pakken. Masterplanning is de meest prominente en wordt gebruikt door veel operators om plannen voor de toekomstige ontwikkeling van de luchthaven te maken. Masterplannen zijn vaak snel achterhaald omdat ze gebaseerd zijn op eenzijdige prognoses van de vraag (Probleemgebied II). Een masterplan genereert vaak weerstand van een of meer stakeholders omdat het Masterplan niet voorziet in hun doelstellingen (Probleemgebied I).

Dynamic Strategic Planning is een aanpak die flexibeler is: het zorgt ervoor dat operators op dynamisch wijze hun plannen en ontwerpen aanpassen aan de veranderende wereld (Probleemgebied II). Recent zijn ook andere manieren voorgesteld. Deze benaderingen zijn vooral conceptueel van aard en richten zich op Probleemgebied II.

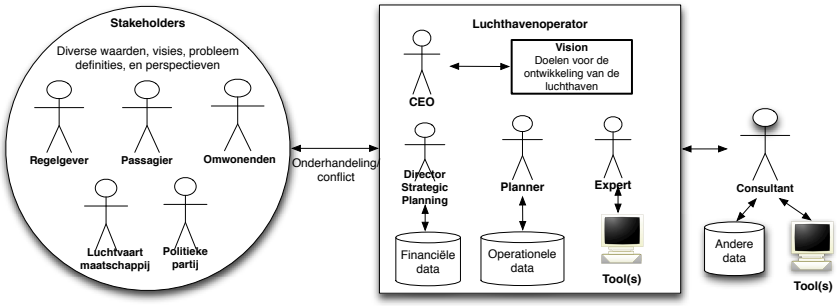
Tabel 1 laat zien in hoeverre een benadering elk van de probleemgebieden adresseert. Zoals blijkt uit de tabel, adresseert geen van de huidige benaderingen gelijktijdig alle drie de probleemgebieden.

Tabel 1: Manieren versus probleemgebieden

| **Probleemgebied** | **Manier** | | |
|---|---|---|---|
| | Masterplanning | Dynamic Strategic Planning | Andere manieren |
| I: Gebrek betrokkenheid stakeholders) | Advies om eerder te betrekken | Eerlijk onderhandelingsproces na vaststelling plan | Niet geadresseerd |
| II: Ontoereikende aanpak toekomst | Eenzijdige voorspelling vervoersvraag | Scenarios | Scenarios (onder andere) |
| III: Inefficiënte probleemanalyse | Volgorde van de analyse stappen | Advies om computertools juist te gebruiken | Niet geadresseerd |

### Versnippering van middelen

Vanuit ons perspectief op het ondersteunen van besluitvorming, hebben we gekeken naar de middelen—mensen, data en informatie en tools—betrokken bij strategische planning. Wij zijn van mening dat de versnippering van deze middelen een fundamentele oorzaak is van de problemen met strategische luchthavenplanning. Deze middelen kunnen niet gemakkelijk worden geïntegreerd of samengebracht voor een specifieke planstudie. Het probleemanalyse proces is daardoor inefficiënt. Dit proces ondersteunt hierdoor niet de formulering, analyse en interpretatie van strategieën voor de ontwikkeling van een luchthaven binnen de multi-stakeholder context.




Figuur 2: Huidige planning: een enorme coördinatie inspanning (Probleemgebied III) en potentiële conflicten (Probleemgebied I).

Drie soorten middelen worden ingezet: mensen, data en informatie en tools. Zoals weergegeven in Figuur 2, zijn er twee soorten *mensen* betrokken bij de planning—mensen van buiten en binnen de luchthavenorganisatie. Mensen binnen de organisatie zijn degenen die direct en voortdurend betrokken zijn bij het strategische planningsproces. Deze mensen voeren verschillende activiteiten uit om te komen tot een strategisch plan dat de visie van het luchthavenmanagement realiseert. Mensen buiten de organisatie zijn doorgaans geassocieerd met organisaties of groepen die een belang hebben bij de ontwikkeling van de luchthaven. Deze stakeholders (zoals luchtvaartmaatschappijen, nationale en lokale overheden, maatschappelijke groeperingen, en de luchtverkeersleidingsorganisatie) hebben conflicterende doelstellingen met betrekking tot de ontwikkeling van de luchthaven.

Het creëren van een effectief strategisch plan vereist consistente *gegevens en informatie* over allerlei aspecten, zoals doelstellingen, het vliegveldsysteem en haar omgeving en de luchthavenprestaties voor de gegeven toekomstige context en strategieën. Met betrekking tot de prestaties van een luchthaven is informatie

op verschillende niveaus van detail vereist ten aanzien van capaciteit en vertraging, en milieueffecten—geluid, emissies, en third party risk. Vaak worden externe adviseurs gecontracteerd om informatie over sommige of alle van deze luchthavenprestaties te verstrekken.
Veel van de gegevens en informatie worden gegenereerd met behulp van analytische *tools*. In de meeste gevallen worden de gegevens niet gegenereerd op een consistente en geïntegreerde manier. Gewoonlijk wordt slechts één enkel aspect (bijvoorbeeld de capaciteit en vertraging, geluid of emissies) geëvalueerd. Alleen als er een afhankelijkheid te verwachten is met andere aspecten worden aanvullende analyses uitgevoerd. Dit komt doordat verschillende aspecten meestal worden beoordeeld door verschillende deskundigen.

Wij zijn van mening dat de *versnippering* van bovenstaande middelen een fundamentele oorzaak is van de eerder geïdentificeerde probleemgebieden. Deze versnippering leidt tot een inefficiënte probleemanalyse waardoor het niet mogelijk is strategieën te formuleren die voor alle stakeholders aanvaardbaar zijn.

**Conclusie**

Het concept van strategische luchthavenplanning moet worden opgevat als een breed begrip in plaats van een louter analytische activiteit. Strategisch denken en maatschappelijk verantwoord ondernemen moeten worden gekoppeld aan het strategische planningsproces. Strategische luchthavenplanning moet een inclusief en niet een exclusief proces zijn. Tenslotte moet de versnippering van middelen—mensen, data en informatie, en tools worden aangepakt.

De volgende paragraaf geeft een overzicht van eerdere en huidige onderzoekinspanningen met betrekking tot het bouwen van computer-gebaseerde systemen voor strategische luchthavenplanning.

### ONDERZOEKSVRAAG 2: WELKE LESSEN KUNNEN WORDEN GETROKKEN UIT EERDERE EN HUIDIGE INSPANNINGEN OM COMPUTER-GEBASEERDE SYSTEMEN TE BOUWEN VOOR STRATEGISCHE LUCHTHAVENPLANNING?

Om deze onderzoeksvraag te kunnen beantwoorden, hebben we onderzocht waarom eerdere pogingen om computer-gebaseerde systemen te bouwen niet zijn gelukt. Het blijkt dat deze systemen hebben naast het extrapoleren van een vluchtschema om de vervoersvraag te bepalen geen functionaliteit om de toekomst te verkennen. Ze bieden geen functionaliteit voor het vergelijken van strategieën onderling of met de doelstellingen van de beslisser. Het is daardoor voor beslissers moeilijk om de resultaten van analyses te gebruiken voor het maken van afwegingen. Tenslotte kunnen maar een beperkt aantal planningsproblemen met de systemen worden geanalyseerd.

Enkele van de specifieke problemen die we ontdekten, zijn de volgende. Er is een gebrek aan inzicht in de besluitvorminscontext waarbinnen de systemen worden gebruikt en potentiële gebruikers van het systeem zijn niet geïdentificeerd. Eerdere projecten waren uitsluitend gericht op de analyse van luchthavencapaciteit en vertragingen. Bijna alle projecten hebben een sterke focus op rekentools en modellen: de projecten zijn *tool georiënteerd* in plaats van *probleemgericht* of *gebruikers*-georiënteerd. De planningsproblemen die met de systemen kunnen worden onderzocht zijn beperkt: sommige systemen zijn meer gericht op de integratie van tools in een enkel systeem dan met het ontwerpen en bouwen van de functionaliteit voor beleidsondersteuning. Ten slotte zijn de systemen ontwikkeld door Air Traffic Management (ATM) en luchthavenspecialisten voor wie softwareontwikkeling bijzaak is. Dit betekent dat de de bruikbaarheid, robuustheid, en gebruikersinterfaces van de systemen ernstig tekort schiet. Bovenstaande inzichten hebben we gebruikt als belangrijke input voor ons ontwerpproces.

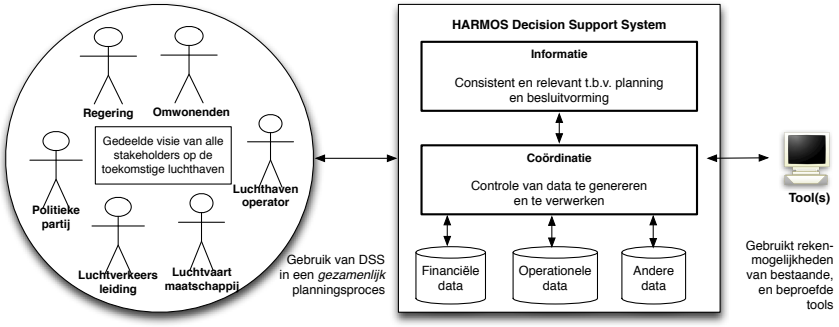
ONDERZOEKSVRAAG 3: HOE KAN STRATEGISCHE LUCHTHAVENPLANNING WORDEN ONDERSTEUND DOOR MIDDEL VAN EEN DSS EN HOE MOET HET DSS WORDEN ONTWORPEN?

Wij hebben een uitgebreide analyse van strategische luchthavenplanning uitgevoerd vanuit het perspectief van beleidsondersteuning en strategievorming. We hebben ook een luchthaven beschreven vanuit een technisch en sociaal perspectief. We bestudeerden ook eerdere en lopende projecten die gericht zijn op het ontwikkelen van computer-gebaseerde systemen. Op basis van die informatie, presenteert deel II van dit proefschrift ons ontwerp van een DSS.

**Wat is benodigd?**

We identificeerden wat er nodig is in termen van een decision support ontwerp en ontwikkelingsproces. We hebben eerst een visie ontwikkeld op decision support. Gedurende het ontwerpproces hebben we vastgehouden aan deze visie. Onze visie is gebaseerd op het idee dat een DSS alle drie probleemgebieden tegelijk moet adresseren.

Onze voorgestelde oplossing, het Holistic Airport Resource Management and Optimization System (HARMOS) DSS, maakt het een luchthavenoperator mogelijk haar middelen—mensen (kennis), gegevens en informatie en tools—efficiënter in te zetten, hetgeen resulteert in een beter begrip van het luchthavensysteem, de problemen en mogelijke strategieën voor de ontwikkeling van de luchthaven. Het HARMOS DSS betrekt de stakeholders expliciet in het planningsproces, zoals weergegeven in Figuur 3.
Het HARMOS DSS staat centraal in het planningsproces. Het DSS biedt *coördinatie* van gegevens en informatie, en tools, resulterend in consistente en relevante

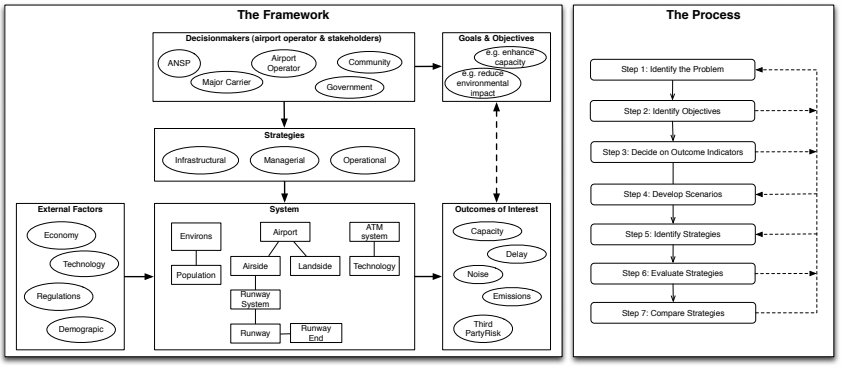



Figuur 3: HARMOS—brengt mensen bij elkaar.

*informatie* voor planning en besluitvorming. Als zodanig vermindert HARMOS de enorme coördinatie-inspanningen die op dit moment nodig zijn. In plaats van hun tijd te besteden aan coördinatie, kunnen planners, consultants en experts hun kostbare tijd gebruiken om planningsproblemen uitgebreider te verkennen.
HARMOS stelt luchthavenplanners *en* stakeholders in staat effectief informatie te delen en samen te werken aan planningsproblemen, zodat ze een goed begrip van elkaars perspectieven, percepties, waarden en doelstellingen te krijgen. Alleen met wederzijds begrip is het mogelijk om te zoeken naar strategieën die bevredigend zijn voor alle betrokken partijen (zie de linkerkant van Figuur 3). Hierdoor kunnen een luchthavenoperator en haar stakeholders een *gedeelde visie* voor de luchthaven ontwikkelen.
De belangrijkste ontwerpprincipes die we hebben gebruikt om dit concept te vertalen naar een architectuur voor het HARMOS DSS zijn *beleidsanalyse* en de *integratie van middelen*. Het HARMOS DSS brengt de middelen bij elkaar in een uniforme structuur. Zoals weergegeven in Figuur 3, coördineert het DSS informatie en tools om voor de gebruikers relevante informatie te genereren. Het DSS wordt gebruikt in een gezamenlijk planningsproces door de luchthavenoperator en haar stakeholders.

We realiseerden ons dat een gestructureerde aanpak nodig is die het technische en het sociale perspectief op een luchthaven bij elkaar brengt om de probleemgebieden adequaat aan te pakken. Daarom hebben we gekozen voor de beleidsanalyse benadering zoals weergegeven in Figuur 4 voor het ontwerpen van de functionaliteit van het DSS.

Deze aanpak biedt een goed gedefinieerd *framework* voor het structureren van strategische planningsproblemen. Het framework maakt de doelstellingen van planners en stakeholders, het *luchthavensysteem*, de *prestaties* van het systeem, en de krachten die op het systeem werken (externe factoren en strategien) expliciet.



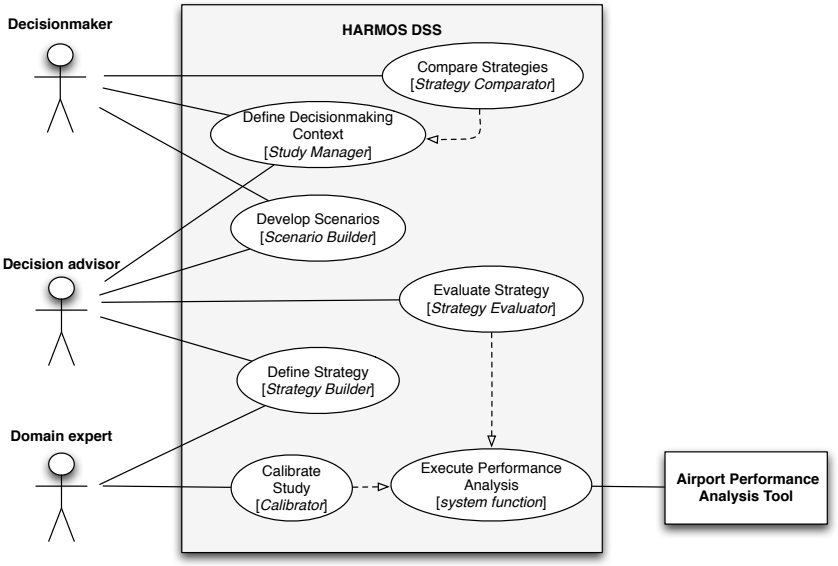

Figuur 4: De beleidsanalyse aanpak gebruikt als ontwerpprincipe voor het DSS

De aanpak biedt ook een *proces* voor het systematisch inrichten van het proces van probleemanalyse. Het proces definieert zeven stappen: (1) identificeer probleem, (2) definieer doelstellingen, (3) vaststelling prestatieindicatoren; (4) ontwikkeling van scenario's; (5) identificeren van strategieën; (6) analyse van strategieën; (7) vergelijking van strategieën. Stap 1-3 hebben betrekking op probleem *formulering*, Stap 4-6 hebben betrekking op *analyse* en Stap 7 heeft betrekking op *interpretatie*.

We hebben beleidsanalyse gebruikt als manier om strategische luchthavenplanning te formaliseren om het concept weergegeven in Figuur 3 te vertalen naar een softwaresysteem. We hebben daartoe gebruik gemaakt van een iteratief ontwikkelproces in combinatie met Domain Driven Design (DDD).

### De HARMOS architectuur

Strategische luchthavenplanning vergt een groot aantal mensen met verschillende rollen die vele activiteiten uitvoeren. Het is essentieel om deze rollen en activiteiten te begrijpen, omdat de rollen moeten worden toegewezen aan de gebruikers van het DSS, en een deel van deze activiteiten de functionaliteit bepaalt van het acDSS. De eerste stap van ons DSS ontwikkelproces was het analyseren van het domein en bedrijfsproces, gericht het identificeren van de gebruikers. Dit resulteerde in de definitie van drie belangrijke rollen, die worden uitgevoerd door een of meer personen. De drie primaire actoren zijn beslissers, beleidsadviseurs en domeinexperts. De tools voor analyse van de luhthavenprestaties zijn geïdentificeerd als ondersteunende actoren: zij ondersteunen het DSS in het leveren van de gewenste functionaliteit voor de gebruikers.
De gebruikers en de functionaliteiten die de gebruiker in staat stellen zijn doelen te bereiken staan weergegeven in Figuur 5. Deze functionaliteiten worden hieronder beschreven.




Figuur 5: DSS gebruikers en functionaliteit van het HARMOS DSS.

**Define Decisionmaking Context.** Beleidsmakers van de luchthaven en haar stakeholders definiëren het probleem, hun doelstellingen, en de prestatieindicatoren die moeten worden gebruikt voor het kwantificeren van de effecten van de strategieën. Deze functionaliteit ondersteunt de formuleringsfase en is direct gerelateerd aan de stappen 1-3 van het beleidsanalyse proces—identificatie van het probleem, definitie van doelstellingen, en vastelling van prestatieindicatoren.

**Calibrate Study.** Direct nadat een nieuwe studie is gemaakt, calibreren domeinexperts de planstudie. Beleidsadviseurs en experts verzamelen bestaande informatie over de prestaties van de luchthaven voor het te calibreren jaar en leggen die gegevens met behulp van HARMOS vast. Domeinexperts voeren een analyse uit met betrekking tot capaciteit, geluid, emissies en externe veiligheid voor het calibratie jaar. Beleidsadviseurs vergelijken de *berekende* prestaties met de *bekende* prestaties.

**Develop Scenarios.** Het HARMOS DSS ondersteunt een beproefde methode voor het uitwerken van scenario's. De scenario's, dat wil zeggen verhalen die verschillende plausibele toekomsten beschrijven worden gemaakt door de beslissers en opgeslagen in het DSS. Beleidsadviseurs kwantificeren verschillende elementen van elk van de scenario's, zodat ze kunnen worden

gebruikt om de strategieën te testen. Deze functionaliteit is direct gerelateerd aan Stap 4 van het beleidsanalyse proces—ontwikkeling van scenario's.

**Define Strategy.** Op basis van discussies tussen beslissers van de luchthavenoperator en haar stakeholders, definiëren beleidsadviseurs strategieën ten aanzien van het capaciteitsmanagement van de luchthaven, de afhandeling van de vervoersvraag, en operaties. Beleidsadviseurs specificeren alle noodzakelijke details van een strategie. Deze functionaliteit is direct gerelateerd aan Stap 5 van het beleidsanalyse proces—definitie van strategieën.

**Evaluate strategy.** Elke strategie gedefinieerd binnen een studie moet worden geëvalueerd voor alle scenario's. Beleidsadviseurs evalueren elke strategie op het gebied van de prestatieindicatoren gedefinieerd binnen de studie voor alle scenario's die zijn ontwikkeld. Deze functionaliteit is direct gerelateerd aan Stap 6 van het beleidsanalyse proces—evaluatie van strategieën.

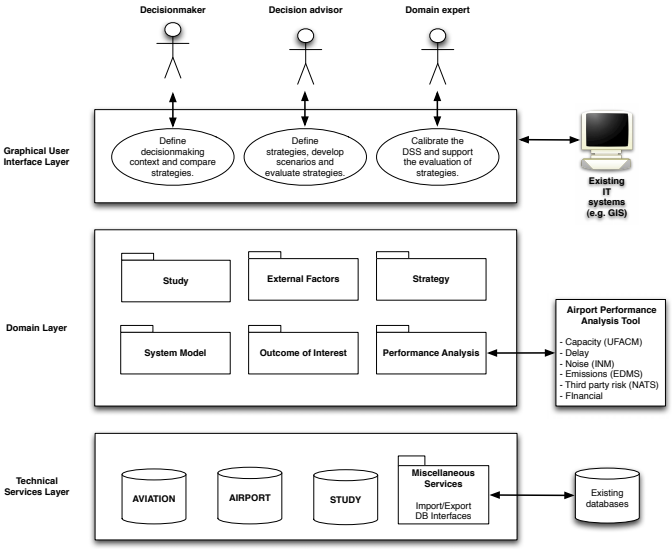
**Compare Strategies.** Zodra alle strategieën zijn geëvalueerd voor alle scenario's, worden de resultaten gepresenteerd aan de beslissers van de luchthavenoperator en haar stakeholders. Beleidsadviseurs genereren met HARMOS een 'scorekaart per scenario om de effecten op de prestaties van de luchthaven voor elk van de strategieën te presenteren. Deze functionaliteit is direct gerelateerd aan Stap 7 van het beleidsanalyse proces—vergelijking van strategieën.

De doelen van de gebruikers hierboven genoemd zijn gebruikt om de functionaliteit van HARMOS te ontwerpen.

Elk van de besproken functionaliteiten is gerealiseerd door het gebruik van de algemene structuur voor de DSS weergegeven in Figuur 6. Zoals te zien is in deze figuur is de architectuur gebaseerd op het Layered patroon. Dit patroon waarborgt de scheiding tussen Graphical User Interface (GUI) laag, de *Domain Model* laag en de Technical Services laag.

### ONDERZOEKSVRAAG 4: HOE KAN DE ARCHITECTUUR WORDEN GEÏMPLEMENTEERD, ZODAT DE VISIE OP HET DSS WORDT GEREALISEERD EN EEN SOLIDE BASIS WORDT GELEGD VOOR HET VERDER ONTWIKKELEN VAN HARMOS TOT EEN BEDRIJFSAPPLICATIE?

De complexiteit van het domein van een luchthaven en strategische planning motiveert het gebruik van een domeinmodel als het hart van het HARMOS DSS. We zijn van mening dat alleen door implementatie van een domeinmodel de functionele eisen gerealiseerd kunnen worden.



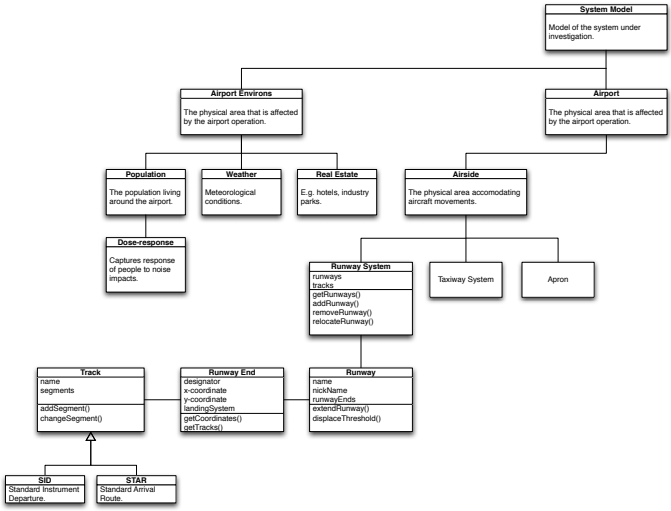

Figuur 6: Logical view van de HARMOS architectuur.

### Het gebruik van een domeinmodel

Het domeinmodel, met zowel *data* als *gedrag* bleek zeer nuttig voor het realiseren van een directe vertaling van het beleidanalyse framework naar software.
Het domeinmodel structureert de Domain Layer van het DSS zodanig dat de structuur van de software makkelijk kan worden begrepen door potentiële gebruikers en ontwikkelaars (zie Figuur 7). De modules en de onderliggende klassen die de structuur van het ac DSS vormen zijn gedefinieerd op basis van het domein (luchthavens en luchtvaart) en het bedrijfsproces (dat wil zeggen strategische planning).

Het Domein Model bevat alle functionaliteit voor het ondersteunen van strategische luchthavenplanning De toegevoegde waarde van het domein model kan als volgt worden samengevat:

**Probleem-georiënteerd.** Het framework volgens Walker definieert een groot deel van het domeinmodel. Het beleidsanalyse framework structureert gegevens en informatie. Deze structurering is een voorwaarde om effectief om te kunnen gaan met alle informatie gerelateerd aan een planningsprobleem. Het belangrijkste voordeel hiervan is het duidelijke onderscheid tussen gegevens die betrekking hebben op het systeem, externe factoren, strategieën, en rekenresultaten.




Figuur 7: Een deel van de structuur van het HARMOS Domeinmodel

**Natuurlijke weergave van het systeem.** Het systeemmodel is een natuurlijke manier om het luchthavensysteem te modelleren en te presenteren.

**Tool onafhankelijk.** Het ontwerp van de Performance Analysis module zorgt voor een belangrijke scheiding van verantwoordelijkheden. Het DSS wordt hiermee onafhankelijk van externe tools die gebruikt worden om de luchthavenprestaties te kwantificeren.

**Flexibele presentatie.** De Outcome of Interest module implementeert een gegeneraliseerde Outcome Indicator klasse (superklasse), die operaties implementeert om specifieke indicatoren (bv. geluid-, emissie- en risicocontouren) te presenteren. In combinatie met de Presentation Service, is de manier om verschillende indicatoren te presenteren gemeenschappelijk en consistent.

**Uitbreidbaarheid.** De modules van het domeinmodel kunnen eenvoudig worden uitgebreid om tegemoet te komen aan veranderende of nieuwe gebruikerseisen.

**Schaalbaarheid.** De functionaliteit van het domeinmodel is goed schaalbaar Als het systeemmodel wordt uitgebreid met aanvullende elementen (bijv. wegen buiten de luchthaven), kunnen de analysis services worden uitgebreid voor kwantificering van nieuwe prestatieindicatoren.

De eigenschappen van het domeinmodel biedt waarde voor bedrijfsmatige toepassing en effent de weg naar commercialisering.

ONDERZOEKSVRAAG 5: HOE KAN EEN PROOF OF CONCEPT EN EEN PROOF OF USEFULNESS WORDEN GELEVERD?

De scope van de DSS ontwikkeling is beperkt door het academisch karakter van dit werk. Dit betekent dat alleen een stabiele architectuur (en niet een volledig functionele bedrijfsapplicatie) is geïmplementeerd.

Wij hebben een Proof of Concept (PoC) geleverd door aan te tonen hoe het HARMOS DSS specifieke problemen in elk van de probleemgebieden, met Amsterdam Airport Schiphol (AAS) als voorbeeld, adresseert. Het Proof of Concept is samengevat in tabel 2. De tabel laat zien hoe specifieke problemen in elk van de drie probleemgebieden worden geadresseerd door de functionaliteit van het HARMOS DSS.

Tabel 2: Hoe HARMOS problemen in elk van de probleemgebieden adresseert

| Probleem gebied | Specifiek probleem | Hoe geadresseerd |
|---|---|---|
| I | Gebrek aan samenwerking in initiële fase | Study Manager om verschillende perspectieven op het planningsprobleem te definiëren |
| | Gebrek san vertrouwen tussen stakeholders | Strategy Comparator voor integrale assessment van strategieën |
| | Geen collective begrip en besluitvorming | Alle onderdelen van HARMOS, met de Study Manager, Scenario Builder en Strategy Comparator in het bijzonder |
| II | Eenzijdige bilk op toekomst | Scenario Builder om samen vier scenario's te ontwikkelen |
| | Beperkte set san strategyën | Strategy Builder om een brede set aan strategieën te definiëren |
| III | Rekenfouten | Calibrator die zorgt door een enkel en consistent systeemmodel om data te genereren om te rekenen |
| | Enorme tijdsinvestering om rekenresultaten begrijpelijk te maken | Strategy Evaluator voor integrale assessment van strategieën |

Door specifieke problemen binnen elk van de drie probleemgebieden te identificeren konden we laten zien dat elk probleem kan worden aangepakt door het HARMOS DSS. Dit leverde een proof of concept. Potentiële gebruikers werden ook uitgenodigd om feedback te geven op het DSS en de functionaliteit ervan. Hieruit hebben we geconcludeerd dat het HARMOS DSS als nuttig werd gezien voor het ondersteunen van een luchthavenoperator en haar stakeholders om samen te werken aan en te beslissen over de ontwikkeling van de luchthaven.

### BIJDRAGEN AAN DE WETENSCHAP

Dit proefschrift richt zich op de ontwikkeling van een DSS voor de drie geïdentificeerde probleemgebieden van strategische luchthavenplanning. We gebruikten kennis uit verschillende vakgebieden en disciplines om te komen tot het ontwerp van het DSS en implementatie van de architectuur.

Kennis uit de *managementwetenschappen*, in het bijzonder de strategische planning en strategische management literatuur werd bestudeerd om het concept en de verschillende aspecten van de strategische planning beter te begrijpen. *Beleidsanalyse* is aangewend om de strategische luchthavenproblemen te onderzoeken op een holistische manier, om te kunnen gaan met de complexiteit van het luchthavensysteem, de onzekere toekomst, en de multi-stakeholder context. Kennis uit de *luchtvaarttechniek*, in het bijzonder onze ervaring met een scala aan analytische tools is gebruikt om te bepalen hoe de juiste informatie voor besluitvorming kan worden gegenereerd. *Software engineering* principes en best practices zijn toegepast om aan de ontwerpeisen te specificeren, de DSS architectuur te ontwerpen, en de architectuur te implementeren. De wetenschappelijke bijdragen van dit onderzoek zijn:

1. Het onderzoek geeft een dieper inzicht in het concept van de strategische luchthavenplanning en de verbetering daarvan. We hebben de managementliteratuur bestudeerd en onderzoek gedaan naar de problemen met strategische luchthavenplanning, de huidige benaderingen voor strategische luchthavenplanning, en de middelen die gebruikt worden bij strategische luchthavenplanning. Door vanuit verschillende invalshoeken naar strategische luchthavenplanning te kijken, waren we in staat om aan te tonen waarom zo veel eerdere projecten niet aan de behoeften van luchthavenplanners konden voldoen.
2. Het onderzoek draagt op verschillende manieren bij aan DSS onderzoek. We hebben laten zien hoe moderne software engineering veel van de problemen van het onderzoeksveld adresseert. Het gebruik van use cases zorgt ervoor dat de gebruikers en hun behoeften expliciet worden gedefinieerd (iets dat ontbreekt in 70 % van de DSS ontwikkelingsprojecten). We toonden aan dat architectonisch ontwerp van een DSS betrekking moet

hebben op domein, business en technologie aspecten. Ons gebruik van Domain Driven Design zorgt ervoor dat de focus van de ontwerpinspanning ligt op het begrijpen van het domein en het bedrijfsproces, en het formaliseren van die kennis om te komen tot een werkende versie van de DSS architectuur.

3. Het onderzoek toont de voordelen van het gebruik van een framework voor besluitvorming als basis voor het DSS ontwerp. Voor zover ons bekend, zijn wij de eersten die een beleidsanalyse benadering gebruiken als basis voor het definiëren van een deel van de structuur en de functionaliteit van een DSS. Dit beleidanalyse framework maakt het DSS flexibel en volledig. Deze keuze maakt het mogelijk de DSS gebruikers het probleem te verkennen op hun manier. Dit is een nieuwe aanpak, omdat een DSS vaak is gebaseerd zijn op een of ander wiskundig algoritme.

# About the author

Roland Wijnen was born in Valkenswaard on May 21, 1974. He studied Aeronautical Engineering at Delft University of Technology. He graduated in 1998 on a thesis about the optimization of aircraft departure trajectories. He worked at the Faculty of Aerospace Engineering from 1998 till 2007. The first years he worked in a small team doing contract research for Amsterdam Airport Schiphol, the Ministry of Transport, Public Works, and Water Management, and other organizations. During later years, he combined PhD. research with working on research projects for the European Commission. From 2007 till 2009 he worked at the Faculty of Technology, Policy and Management.

During his PhD. research, he co-authored various papers related to airport planning and environmental impact assessment. He also worked on a European fifth and sixth framework project called SPADE, which aimed at developing a decision support system for airport strategic and operational planning. He has mentored students in their Master thesis projects and other assignments. He was also one of the team members that developed the Airport Business Suite and the corresponding course on airport strategic planning.

In 2009, Roland became an independent professional working with others in a networked organization to support organizations in becoming more collaborative. In 2011 he started offering a scenario based approach to business model innovation to his clients. Currently he is a business consultant at Business Models Inc., supporting international organizations to adapt in a world of change through the development of new business models and accompanying strategies.

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