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A New Approach for Disruption Management in Airline Operations Control

 Springer

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*Subtly,
you brought something new to my life.
I hardly realized what it was
and its importance.
After all, it was just a distant star
that you decided to bring closer.
It seemed one among many,
but it had a special feature:
when I'm near it,
my heart glows with happiness.
I will keep it close, hoping
that you will never take it back from me.*

António J. M. Castro

Preface

This book is a major outcome of the research performed during the Ph.D. studies of one of the authors under the supervision of a co-author and from the collective work that took place at the LIACC-DAIAS group at the Faculty of Engineering, University of Porto, Portugal.

For our study we followed the problem-oriented research methodology, i.e., we started from the problem description and sought the most appropriate techniques to solve it, trying to pursue, at the same time, an *out-of-the-box* thinking. By *out-of-the-box* thinking we mean to try to think beyond the requirements of the specific problem we were solving as of this moment in time, exploring alternative directions and involving a variety of aspects that, at this moment in time, might not be that relevant but, in the future, might become an asset.

Starting from an hypothesis that could have social impact, and that we can rephrase as follows: "Can we automatically derive improved solutions for disruptive events at an airline control center, in such a way that other than the company, also the crew and the passenger interests are taken into account?", our research lead us to a proposal general enough for being considered for the all plan-disruption class of problems.

By using a well understood paradigm as it is the case of Multi-Agent Systems, enhanced with generic protocols for agents' interaction, learning algorithms enabling continuous system improvement and parameterized utility functions, the proposed model is intended to be used by all those who are willing to solve unexpected problems that arise in dynamic environments and put previous established plans at risk. Application domains include, besides airlines control centers, all other kinds of transport systems, shop floor production plans, crisis management, robotics, etc.

We here advocate that the most flexible reasoning methodology for multi-faceted and dynamic situations includes decentralized cooperation among distributed, kind of autonomous computing entities, here acting as experts in different domains. Although contributing for a final joint commitment and better solutions to the problem at stake, these entities, or software agents, embed strategies for mutual convergence through negotiation mechanisms that enable them to learn with the experience.

The very kernel of what is described and shown in this book is that, for solving relevant and practical problems, we may elegantly intermingle sophisticated AI-based methodologies together with more classical programming to reach useful objectives. Multi-agent systems, negotiation protocols, reinforcement learning, are here put at work in the framework of a demanding practical every-day kind of application and present a solution that can be generalized for many kind of problems of the decentralized, distributed and dynamic type.

The work done was possible not only, but mainly, due to the dedicated work of Antonio Castro who, besides being an expert on the domain was willing to get a PhD thesis. It also capitalizes on the research work towards the development of adaptive negotiation protocols due to Ana Paula Rocha. More than ten years ago, Eugenio Oliveira had a vision on the importance of these technologies for relevant application domains if they could be appropriately integrated.

The result is not only this book but also the robust software system that we are now trying to put in place for social benefit.

Porto, Portugal,
March 2014

Antonio J. M. Castro
Ana Paula Rocha
Eugenio Oliveira

Contents

Preface	VII
Acronyms	XIII
Nomenclature	XVII
List of Figures	XXI
List of Tables	XXIII
1 Introduction	1
1.1 Overview	1
1.2 Motivation	2
1.3 Research Methodology	4
1.3.1 Observations	5
1.3.2 Hypotheses	7
1.3.3 Expected Results	8
1.4 Main Contributions	9
1.5 Structure	11
Part I Background Information	
2 Background	15
2.1 Introduction	15
2.2 Multi-Agent Systems	16
2.3 Automated Negotiation	18
2.4 Reinforcement Learning	24
2.5 Problem Solving Algorithms	25
2.6 Chapter Summary	27
3 Literature Review	29
3.1 Introduction	29

- 3.2 Definitions 31
 - 3.2.1 Related to Disruption Concepts 31
 - 3.2.2 Related to Recovery Processes 32
 - 3.2.3 Related to Aircraft, Crew Roster and Passenger Itinerary 33
- 3.3 A System Classification 33
- 3.4 Disruption Management in Airline Operations 35
 - 3.4.1 Literature on Aircraft Recovery 38
 - 3.4.2 Literature on Crew Recovery 43
 - 3.4.3 Literature on Partial-Integrated Recovery 48
 - 3.4.4 Literature on Integrated Recovery 51
 - 3.4.5 Literature on Simultaneously-Integrated Recovery 62
- 3.5 Chapter Summary 62
- 4 The Airline Operations Control Problem 63**
 - 4.1 Introduction 63
 - 4.2 Airline Scheduling Problem 64
 - 4.3 AOCC Organization 65
 - 4.4 Typical Problems 70
 - 4.5 Current Disruption Management Process 74
 - 4.6 Main Costs Involved 80
 - 4.7 Brief Problem Statement 81
 - 4.8 Chapter Summary 81
- Part II A New Approach for Disruption Management**
- 5 The System Design 85**
 - 5.1 Introduction 85
 - 5.2 Why Agents and a Multi-Agent System Paradigm? 87
 - 5.3 Towards an Advanced and Autonomous Integrated AOCC 88
 - 5.4 Generic Q-Negotiation 90
 - 5.4.1 Definitions 91
 - 5.4.2 Protocol Description 97
 - 5.4.3 Organizer Agent Architecture 102
 - 5.4.4 Respondent Agent Architecture 105
 - 5.5 MASDIMA Architecture 110
 - 5.5.1 Single-Instance Agents Architecture 110
 - 5.5.2 Multiple-Instance Agents Architecture 114
 - 5.6 Advanced Features 118
 - 5.7 Chapter Summary 121
- 6 Implementation 123**
 - 6.1 Introduction 123
 - 6.2 Operational Costs 123
 - 6.2.1 Direct Operational Costs 124
 - 6.2.2 Quality Operational Costs 128

- 6.3 Decision Mechanisms and Learning 133
 - 6.3.1 Manager Agents Level 135
 - 6.3.2 Team Agents Level 139
 - 6.3.3 Learning 140
- 6.4 Specialist Agents: The Problem Solving Experts 150
 - 6.4.1 Aircraft Specialist Agent 150
 - 6.4.2 Crew Specialist Agent 153
 - 6.4.3 Passenger Specialist Agent 157
- 6.5 Chapter Summary 159
- 7 Experiments 161**
 - 7.1 Introduction 161
 - 7.1.1 Scenarios 162
 - 7.1.2 Metrics 165
 - 7.1.3 Approaches 178
 - 7.2 Results and Discussion 184
 - 7.3 Chapter Summary 193

Part III Conclusions

- 8 Conclusions 197**
 - 8.1 Overview 197
 - 8.2 What About the Hypotheses? 198
 - 8.3 Main Contributions 201
 - 8.4 Limitations and Future Work 201
 - 8.5 Final Remark 203

Part IV Appendixes

- MASDIMA - Multi-Agent System for Disruption Management 207**
 - A.1 MASDIMA User Interface 207
 - A.2 Decision Process Information 209
 - A.3 Protocol Sequence Chart 211
- MASDIMA - Costs Information 215**
- References 231**
- Bibliography 241**
- Glossary 243**

Acronyms

ACARS	Aircraft Communications Addressing and Reporting System: A digital datalink system for transmission of short, relatively simple messages between aircraft and ground stations via radio or satellite.
ACMI	Aircraft Crew Maintenance Insurance: Also known as Wet Lease. The leasing of an aircraft including the crew members, maintenance and insurance.
AEA	Association of European Airlines: An association that includes 32 major airlines and that has been the voice of the European airline industry for over 50 years.
AMS	Agent Management Services: The core agent which keeps track of all JADE programs and agents in the system.
AOCC	Airline Operations Control Center: An airline entity responsible for monitoring and problem solving during the execution of the airline plan.
AOCP	Airline Operations Control Problem: The daily process of solving unexpected events that might disrupt the airline schedule (or plan) with the minimum cost and according to specific rules. See also Disruption Management below.
AOSE	Agent Oriented Software Engineering: A methodological approach for the development of software oriented or based on software agents.
ASAS	Automatic or Semi-Automatic Systems: A software system that replaces the functional part of an entity by computerized programs that work autonomously. In an automatic system, decision making is also undertaken by the system. In a semi-automatic system, the final decision is made by the human operator.
ASP	Airline Scheduling Problem: The process of creating the airline schedule (or plan) that covers all of the airline network, maximizing the revenue and minimizing the costs related to aircraft and crew members, in a specific period.
ATA	Actual Time of Arrival: The actual time of arrival of a flight.
ATC	Air Traffic Control: A service provided by ground-based controllers who direct aircraft on the ground (at airports for take-off and landing) and in the air.
ATD	Actual Time of Departure: The actual time of departure of a flight.
CDM	Collaborative Decision Making: Information about the aircraft/flight movement in several airports. It helps in making decisions.

CDSP	Cooperative Distributed Problem Solving: A process of solving problems in a distributed way (physical, functional or spatial) in an environment where the entities are willing to cooperate, either because they have the same goal or because they are not able to solve the problem entirely by themselves.
CFMU	Central Flow Management Unit: A tool from EUROCONTROL that provides information about ATC slots.
DBQS	Database Query System: A system that allows a human operator to query a database and get information.
DF	Directory Facility: A yellow page service in JADE, where agents can publish their services.
DM	Disruption Management: A dynamic process of solving disruptions that affect an existing plan, in such a way that the impact and costs are minimized and, at the same time, complying with the required rules. See also Airline Operations Control Problem above.
DSS	Decision Support System: A computer-based information system that supports business or organizational decision-making activities.
EFB	Electronic Flight Bag: An electronic information management device that helps flight crews perform flight management tasks more easily and efficiently, in a paperless environment.
ETA	Estimated Time of Arrival: An estimated time of arrival for a flight.
ETD	Estimated Time of Departure: An estimated time of departure for a flight.
FAA	Federal Aviation Administration: An agency of the United States Department of Transportation with authority to regulate and oversee all aspects of civil aviation in the U.S.
GDP	Gross Domestic Product: The market value of all officially recognized final goods and services produced within a country in a given period of time.
GQN	Generic Q-Negotiation: An automated negotiation protocol proposed in this book that is an evolution of the Q-Negotiation protocol proposed by one of the authors.
HCC	Hub Control Center: An entity that some airlines have at their major or central airports (hubs) to help control the incoming and outgoing airline traffic. This entity typically exists when the airline operates a hub-and-spoke network.
HUB	Hub-and-Spoke Network: A system of connections arranged like a chariot wheel, in which all traffic moves along spokes connected to the hub at the center. Medium to large airline companies use this kind of network as a way of making a more efficient use of transportation resources. For example, aircraft are more likely to fly at full capacity, and can often fly routes more than once a day.

IATA	International Air Transport Association: IATA represents some 240 airlines comprising 84% of scheduled international air traffic. It is present in over 150 countries and has 101 offices around the globe.
IR	Integrated Recovery: A process that is able to recover all problem dimensions separately (not simultaneously). Usually sequentially and, as such, having a solving order.
MAS	Multi-Agent System: A software system composed of multiple interacting (intelligent) software agents.
MASDIMA	Multi-Agent System for Disruption Management: The advanced MAS prototype developed during this study that implements the approaches proposed by us.
MCS	Movement Control System: A software system to control the flight and aircraft information related to departures, takeoff, landing and arrival, amongst other information.
MTOW	Maximum Takeoff Weight: The maximum weight at which the pilot of the aircraft is allowed to attempt to take off, due to structural or other limitations.
MVT	Aircraft Movement Message: A message that includes information about the movement of an aircraft/flight. Typically the OOOI information.
NB	Narrow Body: An aircraft with a single aisle. Typically used to perform short to medium-range flights.
NOTAM	Notice to Airmen: Notifications to aircraft pilots of any hazards en route or at a specific location. The NOTAMs are usually provided by the aviation authority.
OOOI	Out, Off, On and In: For every flight/aircraft there are four important times to register: Out of gate time (gate departure), Off ground time (takeoff), On ground time (landing) and In gate time (gate arrival).
OR	Operations Research: Mathematical or scientific analysis of a process or operation, used for making decisions.
PIL	Passenger Information List: A list with the names, seats and other relevant information of the passengers on board of a flight.
PIR	Partial Integrated Recovery: A process that is able to recover at least two, but not all, of the problem dimensions, simultaneously or not.
RMA	Remote Management Agent: The agent in JADE which handles the GUI interface
SEF	Portuguese Immigration Services: The service responsible for give effect to the policy of immigration and asylum in Portugal, according to the provisions of the Constitution and the law and government guidelines.

SIR	Simultaneously Integrated Recovery: A process that is able to recover all problem dimensions simultaneously. Here, all dimensions are of equal importance since there is no solving order.
SITA	Société Internationale de Télécommunications Aéronautiques: Provider of global information and telecommunication solutions for the air transport industry.
STA	Schedule Time of Arrival: The original arrival time of a flight.
STD	Schedule Time of Departure: The original departure time of a flight.
WB	Wide Body: An aircraft with two passenger aisles, also known as a twin-aisle aircraft. Typically used to perform long-range flights.
ULD	Unit Load Device: A pallet or container used to load luggage, freight, and mail on a aircraft.

Nomenclature

Sets

A	Set of attribute names of a dimension.
Ac	Set of aircraft in a specific time.
$Airp$	Set of airports.
As	Set of activities in a specific time.
CA	Set of attributes of a competence.
CD	Set of attribute domains of a competence.
CS	Set of candidate solutions of a respondent agent.
Cw	Set of crew members in a specific period of time.
Edg	Set of flights in graph G .
Fl	Set of flights in a specific period of time.
I	Set of attribute domains of a dimension.
J	Set of negotiation attributes.
L^o	An ordered set of negotiation messages in $NegP^o$ (OA negotiation process).
L^{Ra}	An ordered set of negotiation messages in $NegP^{Ra}$ (RA negotiation process).
O	Set of organizer agents (in a negotiation).
PA	Set of problem domain attributes.
Pxd	Set of disrupted passengers in a flight.
R	Set of respondent agents (in a negotiation).
R_a	Set of respondent agents in a negotiation $NegP^o$ (organizer agent negotiation process).
R_b	Set of respondent agents in a negotiation $NegP^{Ra}$ (respondent agent negotiation process).
RT	Set of restrictions.
Sac	A Solution Set for the aircraft problem as seen by the <i>aircraft specialist</i> agent.
Scw	A Solution Set for the crew problem as seen by the <i>crew specialist</i> agent.
Spx	A Solution Set for the passenger problem as seen by the <i>passenger specialist</i> agent.
V	Set of attribute score functions of a dimension.
Vrt	Set of airports in graph G .
VP	Set of preferred attribute values of a dimension.

Tuples

AT	A q-learning action.
AV	Partial-Solution attribute values.
C	Competence of an agent.
d	Dimension of a problem.

<i>F</i>	Feedback for each attribute of each dimension.
<i>G</i>	A graph used by the <i>passenger specialist</i> agent.
<i>IP</i>	Interaction Protocol in the negotiation model NegMod.
<i>NegMod</i>	Our Negotiation Model.
<i>NegP^o</i>	A negotiation process from the point of view of an organizer agent.
<i>NegP^{Ra}</i>	A negotiation process from the point of view of an organizer agent.
<i>P</i>	Problem to be solved.
<i>ps</i>	Partial-solution.
<i>Q</i>	State, action and Q-Value of the Q-learning algorithm.
<i>S</i>	Solution to a problem.
<i>ST</i>	A q-learning state.

Elements of Sets and Tuples or Indexes

<i>a</i>	An agent (in general).
<i>ac</i>	A specific element of the set <i>Ac</i> .
<i>as</i>	A specific element of the set <i>As</i> .
<i>at</i>	An action, i.e., an element of the n-tuple <i>AT</i> .
<i>b</i>	Another agent (in general).
<i>cw</i>	A specific element of the set <i>Cw</i> .
<i>f</i>	A feedback.
<i>fl</i>	A specific element of the set <i>Fl</i> .
<i>i</i>	Index of a dimension.
<i>j</i>	An index of an element of a set or tuple; An issue or attribute.
<i>o</i>	An organizer agent.
<i>pa</i>	An attribute (in general) from the problem domain.
<i>pxd</i>	A specific element of the set <i>Pxd</i> .
<i>r</i>	A respondent agent.
<i>rt</i>	A restriction.
<i>sac</i>	A specific element of the set <i>Sac</i> .
<i>scw</i>	A specific element of the set <i>Scw</i> .
<i>spx</i>	A specific element of the set <i>Spx</i> .
<i>st</i>	A state, i.e., an element of the n-tuple <i>ST</i> .

Variables

<i>ad</i>	A disrupted aircraft included in the set <i>Ac</i> .
<i>asd</i>	A disrupted activity included in the set <i>As</i> .
<i>c</i>	A comment by the organizer agent to a proposal presented by a respondent agent.
<i>cwd</i>	A disrupted crew member included in the set <i>Cw</i> .
<i>ev</i>	Evaluation assigned by the organizer agent to a proposal.
<i>fd</i>	A disrupted flight included in the set <i>Fl</i> .
<i>id</i>	An identifier of something.
<i>m</i>	Total number of attributes on a partial-solution; Total number of attributes on a dimension; Total number of respondent agents.
<i>n</i>	Total number of dimensions in a problem; Total number of partial-solutions in a solution; Total number of organizer agents.

p	Total number of proposals received; Total number of proposals sent.
rw	A reward (value of) in the q-learning algorithm.
s	Total number of requests and informs received.
t	An instance of time or a round in a negotiation.
uv	Utility value of a proposal/solution for the agent that sent it..
V^P	Value of an offer according to a score function.
V_j^i	The score value of issue j in dimension i .
V_o^t	Evaluation made by agent o does at round t .
w	Total number of attributes (in general).
W_j^i	Weight of issue j in dimension i .
α_i	Weight of dimension i .

Miscellaneous

CL	Communication language of a negotiation model.
CV	A scoring function that evaluates the preferred solutions (partial) according to the competence of an agent.
DL	Domain language of a negotiation model.
E	Environment of a negotiation model.
RF	A List of request and inform tuples received during the inter-respondent agents negotiation.
$O_{r \rightarrow o}^t$	Offer from a respondent agent r to an organizer agent o at round t ; vector of values proposed by agent r to agent o at round t .
$O_{r \rightarrow o}^t [j]$	Value of attribute j presented by agent r to agent o at round t .
$Q(st, at)$	The Q-value (in the q-learning algorithm) that corresponds to the execution of action at when at state st .
RI	Rules of interaction of an IP (Interaction Protocol).
$Rw_r^{t+1}(O_{r \rightarrow o}^t)$	A function that calculates a reward (q-learning) that agent r receives at round $t+1$ after presenting a proposal O to agent o in the previous round t .
SM	Sequence of messages exchanged during a negotiation process.
$U_o(O_{r \rightarrow o}^t)$	Utility of offer o for an organizer agent o .
V^i	Score function for dimension i .

Air Transport Metrics

\overline{CC}	Average of Crew Costs in m.u.
\overline{CCrcv}	Average of Crew Cost Recovery Ratio.
\overline{CCmin}	Average of Crew Cost per Minute of the original problem flight delay.
\overline{CwD}	Average of Crew Delays in minutes.
\overline{FC}	Average of Aircraft and Flight Costs in m.u.
\overline{FCrcv}	Average of Flight Cost Recovery Ratio.
\overline{FCmin}	Average of Flight Cost per Minute of the original problem flight delay.
\overline{FD}	Average of Flight Departure Delays in minutes.
$\overline{FD15min}$	Average Number of Flights with Departure Delays greater than 15 minutes.

$p(\overline{FD15min})$	Percentage of the Number of Flights with Departure Delays greater than 15 minutes.
\overline{FDrcv}	Average of Flight Departure Delay Recovery Ratio.
\overline{PC}	Average of Passenger Costs in m.u.
\overline{PCmin}	Average of Passenger Cost per Minute of the original problem flight delay.
\overline{PD}	Average of Passenger Trip Time Delays in minutes.

Negotiation Outcome Metrics

\overline{GF}	Global Fairness of the negotiation winner solutions.
$\overline{Ua/c}$	Average of the Aircraft partial-solutions Utility of the Negotiation Winner Solutions for the Aircraft Agent.
\overline{Ucrew}	Average of the Crew partial-solutions Utility of the Negotiation Winner Solutions for the Crew Agent.
\overline{Upax}	Average of the Passenger partial-solutions Utility of the Negotiation Winner Solutions for the passenger Agent.
\overline{Usup}	Average of the Negotiation Winner Solutions Utility for the Supervisor Agent.
\overline{Usw}	Average Utilitarian Social Welfare of the Negotiation Winner Solutions for the Supervisor Agent.

Protocol Performance Metrics

\overline{Mprb}	Average Number of Messages per Problem, exchanged by agents during the negotiation.
\overline{Mmsg}	Average Number of Messages Exchanged by agents during the negotiation.
\overline{NR}	Average Number of Negotiation Rounds to Reach an Agreement.
\overline{NT}	Average Negotiation Time.
\overline{ST}	Average Negotiation Search Time.

Solution Quality Metrics

$\overline{A/Cact_{ei}}$	Arithmetic Average of the percentage of times that an action i was used to solve the aircraft part of a problem in the experimental run e .
$\overline{A/Cqual}$	Aircraft Solution Quality.
$\overline{CRWact_{ei}}$	Arithmetic Average of the percentage of times that an action i was used to solve the crew part of a problem in the experimental run e .
$\overline{CRWqual}$	Crew Solution Quality.
$\overline{PAXact_{ei}}$	Arithmetic Average of the percentage of times that an action i was used to solve the passenger part of a problem in the experimental run e .
$\overline{PAXqual}$	Passenger Solution Quality.
$\overline{ITGqual}$	Integrated Solution Quality, i.e., the quality of the solution that includes the three dimensions of the problem: aircraft, crew and passenger.

List of Figures

1.1	Europe departure punctuality 2010 vs 2011	3
2.1	Simulated Annealing algorithm	26
3.1	Related work by Category from 1984-2012	37
3.2	Related Work by Recovery Process from 1984-2012	38
4.1	The airline scheduling process	64
4.2	AOCC Decision Center	66
4.3	Integrated AOCC	67
4.4	AOCC Decision Center with a HUB	68
4.5	Integrated AOCC with a HUB	68
4.6	Typical AOCC Problems and Relations	71
4.7	TAP Delays by Events Category	74
4.8	AOCC Disruption Management Process	75
5.1	New Concept for an Integrated Airline Control Center	89
5.2	GQN Agent Types, Roles and Negotiations	98
5.3	Main Negotiation State Diagram	99
5.4	Inter-RA Negotiation State Diagram	101
5.5	Organizer Agent Architecture	102
5.6	Respondent Agent Architecture	105
5.7	Multi-Agent System Architecture	111
5.8	Multi-Agent System GUI Example	114
5.9	Multi-Instance Architecture and Agents Interaction	116
5.10	Example of User Interface for <i>Human-in-the-loop</i> feature	120
6.1	Case Study Trend Formulas for the Profiles	132
6.2	Typical Sequential Approach	134
6.3	GQN Negotiation Protocol Applied in MASDIMA	135
6.4	Contract Net Protocol (simplified) Applied at Crew Team Level in MASDIMA	140
6.5	Q-Learning in MASDIMA	145

7.1	Possible % of Cost Reduction	188
7.2	Possible Cost Reduction for TAP considering 2010 revenue	189
7.3	Average Flight Departure Delay Recovery Ratio (FDrcv)	190
7.4	Average of Combined Cost (FC, CC, PC) per minute	191
7.5	Average Utilitarian Social Welfare (Usw)	192
7.6	Agent’s Utilities and $\Delta(optimal)$	193
A.1	MASDIMA Full User Interface	208
A.2	Supervisor Proposals Utilities Chart	210
A.3	Manager Proposals Utilities Chart	210
A.4	Example Solution Proposal	211
A.5	Example Solution Plan	211
A.6	MASDIMA GQN Protocol (Partial) Sequence Chart	212

List of Tables

2.1	Comparison of GQN with Related Work	20
3.1	Comparative summary regarding operations recovery	53
4.1	AOCC Information Sources - Part 1	69
4.2	AOCC Information Sources - Part 2	70
4.3	Flight/Aircraft events category	73
4.4	Crew events category	73
4.5	Actions and candidate solutions for Aircraft Problems	76
4.6	Aircraft Team Probabilistic Solution Action	77
4.7	Crew Team Probabilistic Solution Action	78
4.8	Passenger Team Probabilistic Solution Action	79
5.1	JADE Specific Agents	112
5.2	Properties necessary to register services for Monitoring agents	117
5.3	Properties necessary to subscribe notifications of new services	117
6.1	Passenger Profiles	131
6.2	Boarding Information	131
6.3	Possible values for the <i>evc</i> attribute	142
6.4	Possible values for the <i>A/C manager pda</i> attribute	143
6.5	Possible values for the <i>Crew manager pda</i> attribute	144
6.6	Possible values for the <i>Passenger manager pda</i> attribute	144
6.7	Example of evaluation of partial-solution that are <i>near an action</i>	147
6.8	Initial Q-Values used in MASDIMA	148
7.1	Monthly percentage of delays for TAP Portugal from April 2009 to April 2010	163
7.2	Information available in the operational plan	163
7.3	Operational Plan	164

7.4	Problem Data	165
7.5	Weights and parameters for the agents utility functions (Equations 6.18, 6.15, 6.16 and 6.17)	180
7.6	Approaches comparison	183
7.7	Equations and parameters used in the learning mechanism	183
7.8	Results for approaches <i>TAP-AOC</i> , <i>TSA</i> , <i>FB10</i> and <i>Q10-Min</i>	185
7.9	Results for approaches <i>Q10-Best</i> , <i>Q10-Best-Filter</i> , <i>Q20-Best</i> and <i>S10-Best</i>	186
7.10	Results for approaches <i>S10-Best-Filter</i> , <i>S20-Best</i> , <i>Q10-Best-V2</i> and <i>Q20-Best-V2</i>	187
B.1	Average Takeoff, Landing and Parking charges	215
B.2	City Pairs Distance	218
B.3	Average ATC, Maintenance, Fuel and Handling Costs by Aircraft Model	228
B.4	Crew member DHC (Extra-Crew) Costs	228
B.5	Hotel Costs per Night for Crew members and Disrupted Passengers	229
B.6	Monthly and Hourly Salary and Perdiem Values for each Crew Salary Rank	230