E.02.14 - D 4.2 - CASSIOPEIA - Study Report: Case Study 2

Document information	
Project Title	CASSIOPIEA
Project Number	E.02.14
Project Manager	The Innaxis Foundation and Research Institute
Deliverable Name	CASSIOPEIA – Study report: Case study 2
Deliverable ID	4.2
Edition	00.00.02
Template Version	03.00.00
Task contributors	
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Abstract

This document shows how agent-based simulations can help to reproduce a collaborative decision-making mechanism and help decision makers to evaluate a concept before actual implementation. In particular it shows how allowing airline operators to exchange slots may reduce total cost by 30% with no total delay increase.

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Document History

Edition	Date	Status	Author	Justification
00.00.01	30/09/2013	In progress	INNAXIS	New Document

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Executive summary

Case Study 2 uses the agent-based modelling capabilities of CASSIOPEIA's platform to analyse to what extent a collaborative decision-making (CDM) mechanism on en-route regulated slots can help to reduce the cost impact for operators. To this end a collaborative exchange mechanism was developed in which operators were given the chance to negotiate between them and swap slots for economic compensation in return. The exchange mechanism has been designed following a Game Theory approach, so that there is no forced participation (i.e. "Individual Rationality" in Game Theory terms), nor source of any external funding (i.e. "Budged Valance"). However, due to the Impossibility Theorem in Game Theory the "Incentive compatibility" was dropped off, leaving the door open for operators to increase their pay-offs by assuming bogus cost (e.g. making erroneous cost estimations on purpose or misrepresenting their cost). Additional properties, specific to the air-traffic domain, are also considered, such as no cost revelation, anonymity and ATM-perspective feasibility of the solution.

In order to determine to what extent the proposed CDM mechanism is suitable for this exchange the CASSIOPEIA platform was adapted to model such a process. An adaptive agent model with a common environment was used. Each of the operators is represented in the model by an agent and is manually attached to a tactic and a cost estimator. A tactic is an overall approach to the negotiation - a set of priorities - and consists of a series of particular strategies to choose from. Depending on the outcomes of previous simulations the agents modify their behaviour according to the tactic, by choosing a new strategy. The cost estimator valuation of other flight slots is based on current literature and accounts both for passenger cost and non-passenger cost.

There are four scenarios analysed in this study: a calibration scenario, a fixed-tactic scenario, a sensitivity-analysis scenario and a realistic scenario. Each of them contributes to the analysis of different aspects of the proposed CDM mechanism. The calibration scenario enables platform validation. The fixed-tactic scenario does not allow agents to change their strategies, enabling an analysis purely based on cost estimation. The sensitivity analysis determines what happens if a significant proportion of the agents suddenly change their behaviour. Finally, the realistic scenario addresses a possible future scenario in which the CDM mechanism is established.

This study shows how, under relatively normal circumstances, allowing a CDM process between operators affected by an en-route regulation may reduce total cost by around 30% with no total delay increase. This is achieved by modifying the shape of delay distribution in such a way that the costs are also reduced. The four scenarios analysed revealed that the proposed CDM mechanism has a low sensitivity to agents suddenly changing behaviour, a high stability after repeated negotiations and that there is no clear dominant or monopolistic strategy for any agent.

1 Introduction

The CASSIOPEIA (Complex Adaptive Systems for Optimisation of Performance in ATM) research project describes and develops a new framework for ATM performance modelling, using Agent Based Modelling and supported by Complex Systems, Complex Networks, Random Graph Theory, Game Theory and affine disciplines. The project establishes a high-level specification and a logical architecture of the proposed model, followed by a demonstrative software system to allow the evaluation of different practical cases; namely case studies. In order to demonstrate the potential of this technique, three case studies have been prepared, addressing, respectively, the impact of regulatory changes, the impact of changes in business and/or operational strategies and the impact of technological changes. This document is the result of the second case study within the project.

1.1 Purpose of the document

This document presents the description of Case Study 2, covering the impact of operational changes and its consequences, describes the procedures for the model application, and discusses the obtained results.

1.2 Intended readership

This report assumes the reader has a good knowledge and understanding of the European air transport system and the ways of working of airlines, airports and ATM within the European Union.

1.3 Structure of the Document

The document is structured into five main sections. After the overall introduction, CASSIOPEIA's second case study is completely defined; the agents and their behaviour, as well as the environment and the concept to be evaluated, completing all the previous work in CASSIOPEIA's D2.3. The material is mostly self-contained and can be followed without knowledge of the previous deliverables or CASSIOPEIA's platform. In the second section the model implementation is revisited; it offers an overview of how the system can be customized to evaluate new scenarios. The third and fourth sections show the results, analysis and conclusions of the different scenarios.

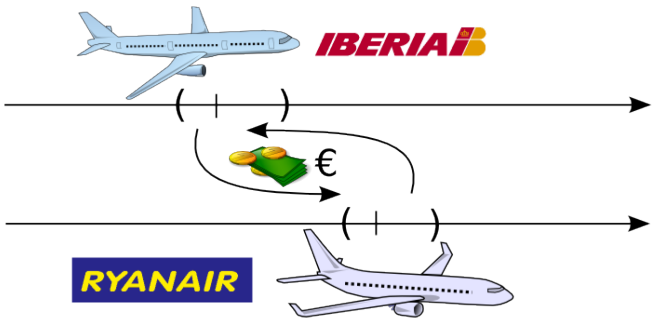
1.4 Acronyms and Terminology

Term	Definition
CDM	Collaborative Decision Making
ATFM	Air Traffic Flow Management
AO	Airline Operator
FPFS	First Planned First Served
€ / min	2010 Euro per minute
NM	Network Manager
CTO	Calculated Time Over

2 Case Study 2 definition

2.1 Definition

Assigning ATFM slots to scheduled flights is a common problem in everyday operations. Regulations may appear for several reasons but, regardless of their nature, slots are usually equally distributed using a first come, first served basis, so that the delay is, roughly, uniformly distributed. This approach has several advantages, including equity (ensuring no flight is given preferential treatment) and minimizing first order delays. However, it is known that second order delays play an important role in airline cost, especially for flights early in the morning with a large number of flight legs ahead. For that reason one of the cornerstones of the SESAR program is to promote Collaborative Decision Making (CDM) processes. Those processes should enable the affected Airline Operators (AOs) to negotiate and ultimately agree on an ATFM slot distribution according to their own preferences and not only to single-flight efficiency, as in some cases agreed distributions may be suboptimal in terms of single-flight delays but reduce cost overall.



In game theory these one-on-one CDM mechanisms (in which a good is traded offering an economic compensation in return) are usually referred to as 'bilateral exchange mechanisms' or 'bilateral trading'.

Despite the particularities of the traded goods, desirable properties of bilateral trading are the following:

1. **Individual rationality**, a participant will only bid or sell when a non-negative payoff occurs (in other words, there is no forced participation. It is up to the participants whether they want to exchange their goods or just remain as they are).
2. **Budged valance**, amounts are transferred among participants, so that prices paid and received add up to zero (or to put it more simply, there is no external funding or profit).
3. **Incentive compatibility**, there is no way for a participant to increase its payoff by misrepresenting its cost, therefore lying shall have no reward.

Unfortunately, according to the Impossibility Theorem (Myerson and Satterthwaite, 1983), a classical result in game theory, there is no bilateral exchange mechanism for which 1, 2 and 3 can possibly hold simultaneously. Since it is not clear how to force AOs to participate in a new slot exchange scheme, it seems reasonable to assume *individual rationality*. It should also be very unlikely to see a slot distribution mechanism funded externally, or making any profit, so it seems a good idea to incorporate *budged valance*. This forces us to relax the *incentive compatibility* condition.

In addition, the ATFM slot exchange mechanism has been designed so that the following additional properties are also met:

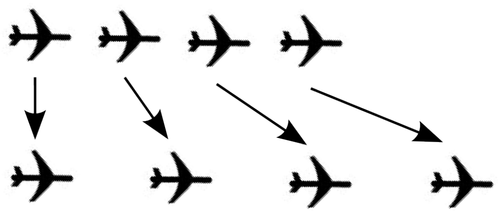
1. **Minimum undisclosed information**, the participants do not share their true cost, nor the maximum amount to bid, but just the amount they are willing to pay in exchange for a given slot.
2. **Anonymous bidding**, the amounts are offered without revealing the identity of the bidder or the rest of the offers/exchanges taking place in the same iteration.

3. **Feasibility of the solution**, the final solution achieved needs to be feasible from the ATM perspective.

Of course in order to fulfil these additional properties, an arbitrator figure should be introduced, namely: the **bid coordinator**. The bid coordinator would collect all bidding information (who is bidding, how much and what for), offer the amounts anonymously, listen to the replies, and communicate the results back to the bidders. The last property would most likely be carried out by the current airspace operator in charge. Very likely the network manager, or a new section inside, will act as bid coordination. For simplicity, throughout the case study we will implicitly assume that the network coordinator takes over the bid coordinator and ensures that these three additional properties are fulfilled.

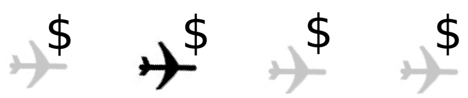
2.1.1 The ATFM Slot exchange mechanism

In order to ensure *Individual Rationality* the first stage of the exchange mechanism reproduces the current solution; immediately after a capacity shortfall or any unexpected event is communicated to the network manager, a list of affected flights (those whose estimated time-over is within the regulation time window) and ATFM slots (equally distributed slots using the restricted capacity) are generated. Afterwards both are matched by a first planned, first served algorithm, always assigning an entry-time-over after the original. This way, the *Individual Rationality* is granted as long as the flights are able to not make any bid and always reject any offer.

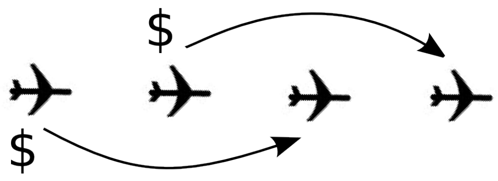


Once each participant knows its assigned slot, they compute the cost of delay for each ATFM slot (including that originally assigned, using the first planned, first served algorithm). This computation varies from one airline to another and for the current case study, costs are estimated using simplified models form (Cook and Graham, 2004), which considers not only aircraft and operational cost but also soft and hard pax cost. For simplicity and clarity, we have provided below a table with the resulting values and we refer the reader to CASSIOPEIA D4.1 for the cost-computation details. We kindly remind the reader that the aim of the case study is not to reproduce the reality but rather to assess the suitability of the proposed exchange-mechanism through extensive use of agent based models.

Once own-costs are computed, each airline selects one slot to bid for and an amount willing to be exchanged in compensation. This selection is made using a set of tactics and strategies which are initially set, but that evolve with each simulation, so that each agent adapts its behaviour to the outcomes of previous rounds. Tactics and strategies, as well as their evolution rules are defined throughout the next sections. When selected, each airline communicates to the network manager the slots to be exchanged as well as the economic compensation.



Once all the bids are placed, or a maximum waiting time is reached to allow no-participation whatsoever, the first round is triggered. If there is any participant bidding for the first ATFM slot, the current owner of the first slot is offered the maximum amount bid for it and is also informed of the slot it will get in return. Then the owner follows a selling strategy (also an adaptive strategy as in the case of bidding) and decides whether to sell his or her slot or turn the offer down. If the exchange takes place, any bid placed on the seller's slot would be automatically cancelled.



The process continues with the second ATFM slot, and continues until all slots and bids have been processed. At this point the first round is over, and the second round starts. Strategies are updated accordingly with the round's results. Using the new slots, costs are recalculated if necessary, and each airline selects a slot to bid for and economic compensation in exchange, following the updated strategy. Bids are communicated to the network manager and the process continues until the maximum number of rounds is reached.

2.1.2 Cost estimation tables

Costs are estimated per minute of delay, taking into account different parameters. First, if the aircraft has already taken off then a tactical cost based on fuel consumption is used. The cost per minute of delay under this circumstance is 100€/min, no matter what the other parameters are. If the aircraft is still on-ground then a strategic cost is used. Each type of airline has an associated strategic cost.

Table 2-1 Strategic cost per airline type

Type AO	Base value	Constant	Schedule modifier	Hub modifier	Already delayed
Hub	**10 €/min**	**1**	yes	yes	yes
Low Cost Carrier	**6 €/min**	**1**	yes	no	no
Regional	**9 €/min**	**1**	yes	no	yes
Charter	**7 €/min**	**1**	no	no	no
Inclusive Tour	**7 €/min**	**1**	no	no	no
Cargo	**4 €/min**	**1**	no	no	no
Integrator	**4 €/min**	**1**	yes	no	yes

The cost per minute of delay is then computed as *cost of minute delay = base value * base factor*, and the base factor is in turn*: base factor = constant + schedule modifier + hub modifier + already delayed*. Modifiers are only considered when they appear as "yes" in the previous table and the values are obtained from the next table, depending on the hour of the day (all times are UTC).

Table 2-2 Modifier values

From	To	schedule modifier	hub modifier*	already delayed**
0:00	0:59	0	0	0.3
1:00	1:59	0	0	0.3
2:00	2:59	0	0	0.3
3:00	3:59	0	0	0.3
4:00	4:59	0	0	0.3
5:00	5:59	0	0	0.3
6:00	6:59	0.1	0	0.5
7:00	7:59	1	-0.8	1
8:00	8:59	1	-0.7	1
9:00	9:59	1	-0.6	1
10:00	10:59	0.9	-0.6	1
11:00	11:59	0.9	-0.7	1
12:00	12:59	0.8	-0.65	0.8
13:00	13:59	0.7	-0.6	0.8
14:00	14:59	0.55	-0.4	0.7
15:00	15:59	0.5	-0.5	0.6
16:00	16:59	0.45	-0.4	0.6
17:00	17:59	0.6	-0.3	0.8
18:00	18:59	0.7	-0.3	0.9
19:00	19:59	0.6	-0.2	1
20:00	20:59	0.6	-0.3	1
21:00	21:59	0.4	-0.2	0.9
22:00	22:59	0.1	0	0.4
23:00	23:59	0	0	0.3

*Hub modifier only applies when the destination airport is a hub for the AO.

**Already delayed only applies when the flight has already been already by any other cause.

Note that this cost already includes aircraft and pax cost (both soft and hard cost) and are not meant to be considered as absolute but, rather, relative values.

2.1.3 Tactics and strategies

As stated in the previous section, in each round each airline is to make two important decisions. First, it has to decide which slot it wants to bid for and how high should be the bid. Secondly, in case of receiving any offer, it has to determine whether it wants to accept the offer and exchange slots or stay as it is. Throughout this section we explain the concepts of tactics and strategies, and their evolution after each simulation or round. But first let's define some concepts:

A **run** of the model consists of several simulations. A **simulation** consists of several consecutive **rounds**. The number of rounds configuring a simulation and the number of simulations forming a run are defined separately for each scenario (defined in the next section).

In each round a **global strategy** drives the behaviour of an agent. A global strategy is composed of two sub-strategies, namely: a **bidding strategy** and a **selling strategy.** Strategies do not change between rounds; on the contrary, a **tactic** is a function within strategies, so that the agents can modify their overall behaviour between simulations. In a similar fashion, tactics do not change within the same run and they are defined separately for each scenario, which in turn will be defined in the next section.

Note that -contrary to common practice- previous definitions may induce to think of tactics as **long-term** behavioural directives, whilst strategies can be viewed as **sort-term** practices.

Each AO knows the available slots for its own flights, labelled as $\mathbf{S_0}$, S_1, ... , S_n sorted by ascending time. S_0 will also be called *best available slot* and the current slot will be denoted by S_c. Each slot has an associated cost: Cost(S_i) which is also known by the AO.

2.1.3.1 Bidding strategies:

Overall rules on bidding strategies, (these override any contradiction with the tables below) are:

- No airline will ever bid for a later than current slot, otherwise the network manager would discard the bid.
- Only positive bids are allowed, otherwise the network manager would discard the bid.
- Initial values of parameters are defined in the tables below, and may be used unless otherwise stated in the scenario definition.
- Even if several flights of the same AOs are affected, each flight will keep its own set of parameters independently of the others.

To help gain a better understanding of scenarios and agent behaviour, assignment-bidding strategies have been classified into three categories according to their motivation.

- Greedy strategies
- Steeper strategies
- Mixed strategies

2.1.3.1.1 Greedy strategies

The strategies defined in the following table share a common factor: they are greedy in the sense that the agent bids the maximum amount each round only changing the slot to bid for.

Table 2-3 Greedy bidding strategy

Name	Parameter(s)	Initial value(s)	Slot to bid	Amount	Next strategy on bid acceptance or when own slot's been sold	Next strategy on bid rejection	Example/comments
G_0	N/A		S_0	$Cost(S_c)$ - $Cost(S_0)$	G_0	G_0	
$G_1(n)$	n - slot to bid for	0	S_n	$Cost(S_c)$ - $Cost(S_n)$	$G_1(0)$	$G_1(n+1)$	
$G_2(n,c)$	n - slot to bid for c - cycle length	0 2	S_n	$Cost(S_c)$ - $Cost(S_n)$	$G_2(0,2)$	$G_2(n+1 \bmod c, c')$ where: c' = c + 1 if ((n+1) mod c) = 0 or c'=c otherwise	Bidding strategy sequence assuming all bids are rejected: $G_2(0,2)$ -> $G_2(1,2)$ -> $G_2(0,3)$ -> $G_2(1,3)$ -> $G_2(2,3)$ -> $G_2(0,4)$ -> ...

2.1.3.1.2 Steeper strategies

Contrary to the greedy strategies the steeper strategies always bid for the best slot and change the amount bid between rounds.

Table 2-4 Steeper bidding strategy

Name	Parameter(s)	Initial value(s)	Slot to bid	Amount	Next strategy on bid acceptance or when own slot's been sold	Next strategy on bid rejection	Example/comments
T_0	N/A		S_0	$Cost(S_c)$ - $Cost(S_0)$	T_0	T_0	
$T_1(p,s)$	p - percentage to bid s - step increase on bid	p_i (=0.1) s_i (=0.1)	S_0	$p^*(Cost(S_c) - Cost(S_0))$	$T_1(p_i,s_i)$	$T_1(\min(s_i+p_i, 1), s_i)$	Linear steps of size s_i Example with p_i=0 and s_i=0.1: $T_1(0,0.1)$ -> $T_1(0.1,0.1)$ -> $T_1(0.2,0.1)$ -> $T_1(0.3,0.1)$ -> ...

Name	Parameter(s)	Initial value(s)	Slot to bid	Amount	Next strategy on bid acceptance or when own slot's been sold	Next strategy on bid rejection	Example/comments
$T_2(p,s)$	p - percentage to bid s - step increase on bid	p_i (=0.1) s_i (=0.1)	S0	$p*(Cost(S_c) - Cost(S_0))$	$T_2(p_i,s_i)$	$T_2(min(s_i+p_i, 1),s_i+s_i)$	Increasing steps, Example with p_i=0 and s_i=0.1: $T_2(0,0.1)$ -> $T_2(0.1,0.2)$ -> $T_2(0.3,0.4)$ -> $T_2(0.7,0.8)$ -> $T_2(1,1.6)$ -> ...

2.1.3.1.3 Mixed strategies

The mixed strategies combine both of the above. The trader may stick to a slot, increasing the amount to bid until some threshold is reached, moving then to the next suitable slot, or try first to get any slot at a cheaper price and then move forward.

Table 2-5 Mixed bidding strategy

Name	Parameter(s)	Initial value(s)	Slot to bid	Amount	Next strategy on bid acceptance or when own slot's been sold	Next strategy on bid rejection	Example/comments
$M_0(n,p,s)$	n - slot to bid for p - percentage to bid s - step increase on bid	n_i (=0) p_i (=0.1) s_i (=0.1)	Sn	$p*(Cost(S_c) - Cost(S_n))$	$M_0(n_i,p_i,s_i)$	$M_0(n',p',s')$ where if p>=1 then n' = n + 1, $p'=p_i$ and$s'=s_i$ otherwise n'=n, p'=p+s, s'=s	Lineally increases the bid for the initial slot, if unsuccessful and reaches maximum possible bid, tries with the next best slot and so on ... on successful exchange, resets the process (if not actually in the best available slot)

M_1(n,c,p,s)	n - slot to bid for c - cycle length p - percentage to bid s - step increase on bid	n_i (=0) c_i (=2) p_i (=0.1) s_i (=0.1)	S_n	p*(Cost(S_c) - Cost(S_n))	M_1(n_i, c_i, p_i, s_i)	M_1(n', c', p', s') where if ((n+1) mod c) = 0 then n'=0, c'=c+1, p'=min(p+s, 1), s'=s otherwise n'=n+1, c'=c, p'=p, s'=s SC: The cycle length only changes when one full cycle is reached or there is a slot exchange (and then it's reset to c_i)	Example sequence all bids rejected: M_1(0, 2, 0, 0.1) -> M_1(1, 2, 0, 0.1) -> M_1(0, 3, 0.1, 0.1) -> M_1(1, 3, 0.1, 0.1) -> M_1(2, 3, 0.1, 0.1) -> M_1(0, 4, 0.2, 0.1) -> M_1(1, 4, 0.2, 0.1) -> ...

2.1.3.2 Selling strategies

Current slot is S_c, offered slot is S_x and exchange compensation is C_x

Table 2-6 Selling strategies

Name	Parameters	Initial value(s)	Accept if	Next selling strategy on offer acceptance	Next selling strategy on offer rejection	Next BIDDING strategy on offer acceptance
R_0	N/A	N/A	if C_x > Cost(S_x) - Cost(S_c) then accept otherwise reject	R_0	R_0	Same as in bid acceptance
R_1	N/A	N/A	Never	R_1	R1	Same as in bid acceptance

Name	Parameters	Initial value(s)	Accept if	Next selling strategy on offer acceptance	Next selling strategy on offer rejection	Next BIDDING strategy on offer acceptance
$R_2(c)$	c - skipped offers	c_i (=1)	if c = 0 and $C_x > Cost(S_x) - Cost(S_c)$ then accept otherwise reject	$R_3(c_i)$	$R_3(c')$ where c' = c - 1 if c >= 1 $c'=c_i$ otherwise	Same as in bid acceptance
$R_3(t)$	t - waiting threshold	t_i (=0.8)	if $t^*C_x > Cost(S_x) - Cost(S_c)$ then accept otherwise reject	$R_4(t_i)$	$R_4(t_i)$	Same as in bid acceptance

Note that selling strategies are independent from bidding strategies, so any combination is possible and would lead to a global strategy. To avoid repetition we do not give global strategies a name, but instead represent them by the pair (bidding strategy, selling strategy) e.g. (M_1(n,c,p,s), R_3(t))

2.1.3.3 Tactics

As stated before, tactics are functions between strategies. Tactics are defined once for each scenario and remain constant throughout the whole run, driving any strategy change between simulations.

For the n-th simulation, the final cost is denoted by C_n and the strategy used is denoted by TC_n

Table 2-7 Tactics

Name	Parameter	Initial strategies (TC_0, TC_1, TC_2, ...)	Next strategy (TC_n)	Comments
Fix	TC - Strategy	TC_i (=G_0)	TC_i	Constant strategy no matter what
TA_0	n_i (=0)	$TC_0 = G_0$ $TC_1 = G_1(n_i)$ $TC_2 = G_2(n_i,2)$	for n > 2 take $TC_n = TC_m$ where m < n is such that $C_m = \min \{C_j : j<n\}$	Starting with G_0 then $G_1(0)$ then $G_2(0,2)$; after that compare cost of previous simulations and select the strategy which gave better results.
TA_1	p_i (=0.1) s_i (=0.1)	$TC_0 = T_0$ $TC_1 = T_1(p_i,s_i)$ $TC_2 = T_2(p_i,s_i)$	for n > 2 take $TC_n = TC_m$ where m < n is such that $C_m = \min \{C_j : j<n\}$	Same as above but now starting with T_0 then $T_1(p_i,s_i)$ and then $T_2(p_i,s_i)$ ...

Name	Parameter	Initial strategies (TC_0, TC_1, TC_2, ...)	Next strategy (TC_n)	Comments
TA_2	n_i (=0) c (=2) p_i (=0.1) s_i (=0.1)	$TC_0 = M_0(n_i,p_i,s_i)$ $TC_1 = M_1(n_i,c,p_i,s_i)$	for n > 1 take $TC_n = TC_m$ where m < n is such that $C_m = \min \{C_j : j<n\}$	"

2.2 Scenarios design

The scenarios have been designed so that the CDM concept presented in the previous section could be evaluated, not to try to foresee the possible outcomes of an actual implementation of the concept. Scenarios are defined to test the proposed CDM concept and ultimately to show how an agent-based platform may help decision makers to develop new concepts and test them before real implementation. Two elements define a scenario: the environment and the set of tactics used by the agents.

2.2.1 Environment definition

In order to be able to compare different results across scenarios, the same environment is shared. Consequently, only one configuration is required. In this configuration one of the busiest sectors in Europe is simulated to have a capacity shortfall. The nature of the shortfall doesn't really matter. The sector selected is the **Nicky Sector, both High and Low, of the Maastricht Upper Area Control Centre Airspace**.

This sector is known for its complexity, since it has main departure and arrival flows of 4 main airports in Europe: **Amsterdam Schiphol, London airports, Frankfurt, and Paris Charles de Gaulle**. This sector capacity is estimated by the scheduled traffic and it is then diminished during a time window to check the agents' reactions and to test the CDM concept.

Table 2-8 Environment definition

Attribute	Value
name	Capacity restriction due to ...
regulation_type	“airspace_capacity_constraint”
initial_time	“2012.07.10 14:00:00”
final_time	“2012.07.10 16:59:00”
intensity	"20%"
Observable_by	{Nicky High Sector, Nicky Low Sector}

2.2.2 Scenario parameters

The calibration scenario was first defined to test the platform as part of verification and validation. Scenarios in which all agents use the same tactics are unlikely to occur, however they can be of interest themselves as the behaviours would be driven mainly by the cost estimation.

Table 2-9 Scenario parameters

Name	Code	Number of rounds	Number of simulations	Agents	Bidding Tactics	Selling strategies
Calibration	CS_0	5	1	All	Fix(G_0)	R_0
	$CS_{0.1}$	5	30	All	TA_0	R_0
	$CS_{0.2}$	5	30	All	TA_1	R_0
	$CS_{0.3}$	5	30	All	TA_2	R_0

The fixed scenario explores the fixed tactics; that is, tactics in which airlines stick to the same strategy between simulations. It may serve to compare the improvement on the results when agents adapt and evolve their behaviours according to previous outcomes.

Table 2-10 Fixed scenario

Name	Code	Number of rounds	Number of simulations	Agents	Bidding Tactics	Selling strategies
Fixed	CS_1	5	30	Network	Fix(T_2)	R_2
				Low cost	Fix(G_1)	R_0
				Regional	Fix(T_1)	R_3
				Cargo, integrators and charter	Fix(G_2)	R_1

The sensitivity scenario measures how the system changes when a significant proportion of the agent's (low cost) airlines suddenly change their behaviour (tactics). This is of fundamental importance as the real CDM concept should be resilient enough to avoid the users changing the overall system behaviour, even if they have a considerable share.

Table 2-11 Sensitivity scenario

Name	Code	Number of rounds	Number of simulations	Agents	Bidding Tactics	Selling strategies

Name	Code	Number of rounds	Number of simulations	Agents	Bidding Tactics	Selling strategies
Sensitivity	$CS_{2.1}$	5	30	Network	TA_1	R_1
				Low cost	TA_0	R_0
				Regional	TA_2	R_3
				Cargo, integrators and charter	Fix(G_2)	R_2
	$CS_{2.2}$	5	30	Network	TA_1	R_1
				Low cost	TA_2	R_2
				Regional	TA_2	R_3
				Cargo, integrators and charter	Fix(G_2)	R_2

Finally, an expert-assessed scenario is run to obtain some more realistic results, and make it possible to compare them with all previous scenarios and reference results.

Table 2-12 Expert assessed scenario

Name	Code	Number of rounds	Number of simulations	Agents	Bidding Tactics	Selling strategies
Realistic	CS_3	5	30	Network	TA_2	R_1
				Low cost	TA0	R_0
				Regional	TA_1	R_3
				Cargo, integrators and charter	Fix(G_1)	R_2

3 Implementation details

Case Study 2 has been implemented using the agent-based software platform developed in the CASSIOPEIA project (see deliverable D3.4). This section describes the specific implementation details of Case Study 2.

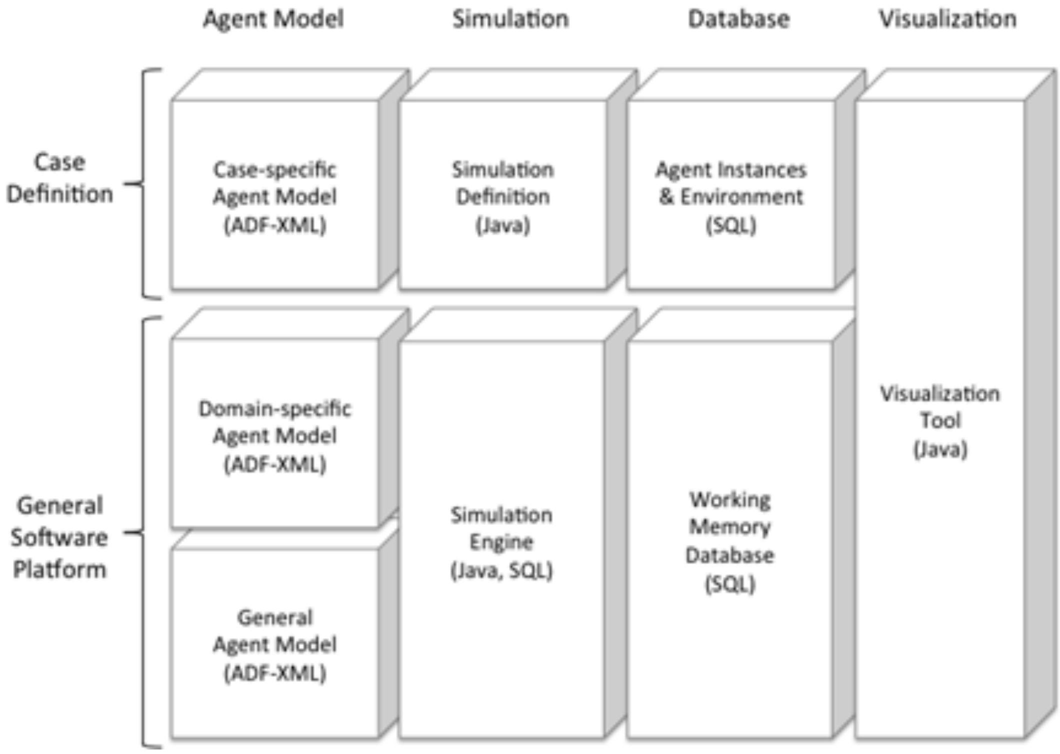


Figure 3-1 Main components of the software architecture

3.1 Case-specific agent model

According to the agent-based model supported by the software platform (Figure 3.1), the implementation of Case Study 2 includes the following components:

- **Agents**: 271 agent instances corresponding to a unique class (airlines) with a total of 20.529 flight plans, and another agent for regulating slot trading ATM (*Network Manager*).
- **ADF-XML:** 1 airline capability that includes new beliefs and behaviours, and another ADF file for the implementation of the Network Manager.
- **XML Plans:** 12 plans (6 for airline agents and 6 for the Network Manager) to implement the steps of this case study.
- **Java Plans:** For each XML plan a Java plan has been created to implement the behavior algorithms.

Figure 3-2 Java implementation of GlobalStrategy class

3.2 Tactics and Strategies logical hierarchy

The bidding tactics and selling strategies for Case Study 2 (described previously in this document) have been implemented as hierarchies of Java classes, with common parameters for similar actions (see figures below). The update of parameters and the processing of strategies and tactics are made within the Java Plans *UpdateStrategiesPlan* and *UpdateTacticPlan* respectively, as described in the previous section.

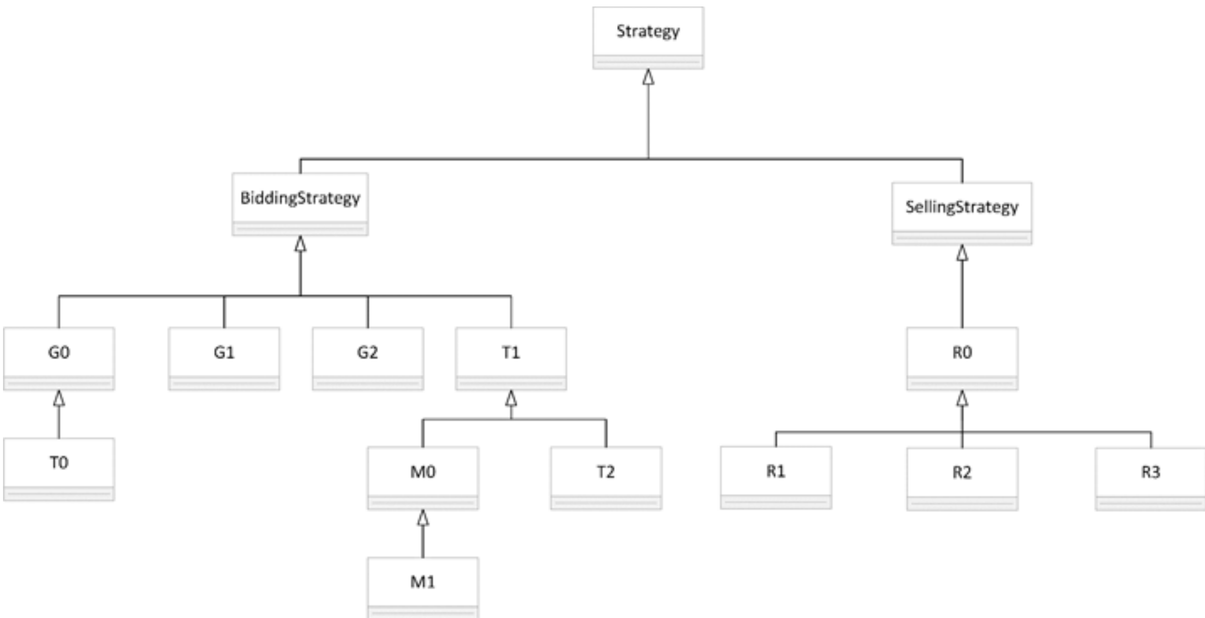


Figure 3-3 Hierarchy of class for implementation of algorithms of strategies

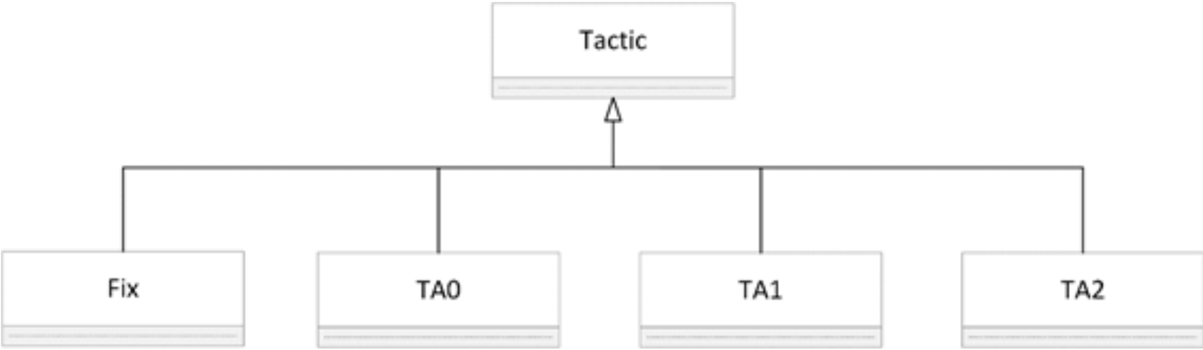


Figure 3-4 Hierarchy of class for implementation of algorithms of tactics.

3.3 XML-schemas and installation instructions

To ease the reading of the document, precise XML-schema definitions and software installation instructions can be found only in the corresponding appendix.

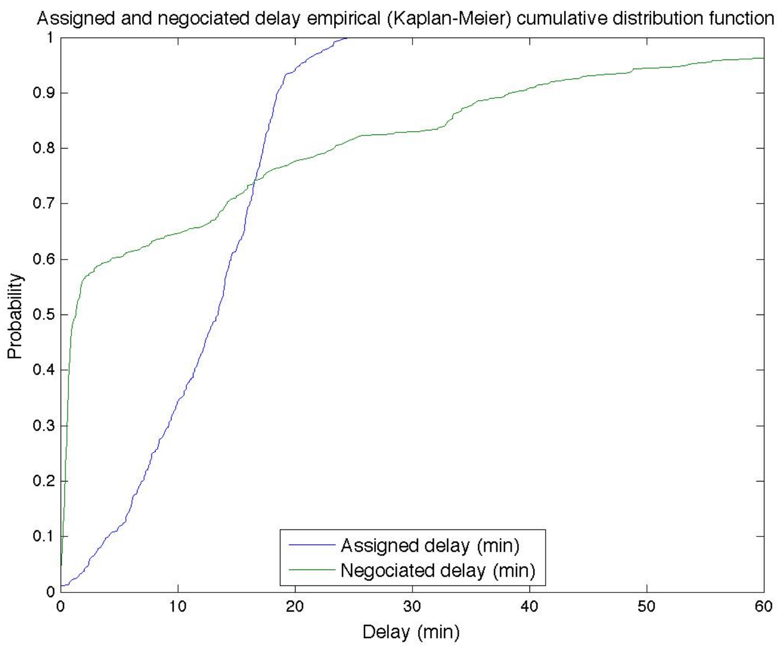
4 Simulation findings

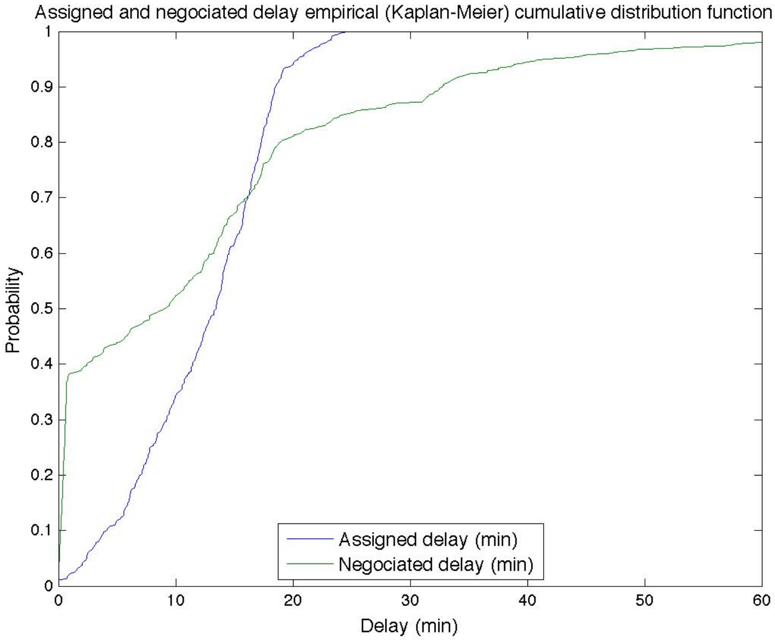
In this section results from the simulation of each scenario previously defined are presented. Supported by a selected series of graphs and tables only key findings are further discussed. The complete set of results is available in appendix B of this document.

4.1 Calibration scenario

As described in the previous section, under the calibration scenario all agents use the same tactics, although they are allowed to vary strategies between simulations and parameters within rounds. This is an artificial situation, since real agents would very unlikely follow the same strategies unless they are strongly encouraged to do so or otherwise strongly monitored by an external entity, which is not expected to be the case for any CDM mechanism. Nevertheless, this scenario provides the first insights on the slot-exchange mechanism under study. Without the complexity of agents adapting their strategies to other agent behaviours it becomes simple to detect overall trends and figures. Later on, we would analyse more involved scenarios in which agents respond to each other creating much richer interactions.

The first thing to notice is that there are no slots wasted. After simulation, flights are still distributed in the available slots without gaps, therefore the capacity of the sector (or the total delay imposed) is not reduced by the CDM process. In fact the average imposed delay remains constant; it is only the shape of the delay distribution that changes. For instance the number of flights delayed more than 3min by the initial FPFS assignment is roughly 400, while after several simulations this figure drops to between 200 and 350. On the other hand there are no flights delayed more than 60min in the initial FPFS solution, but in the worst scenario, after the negotiation process, there are up to 20 flights delayed more than 60min. Those flights are likely not concerned about punctuality and decided to make some profit by shelling their initially assigned slots. In fact there is a critical delay point around 15mins; in other words, most exchanges happen between flights with delays smaller than 15 minutes and those with assigned delay larger than 15 minutes.





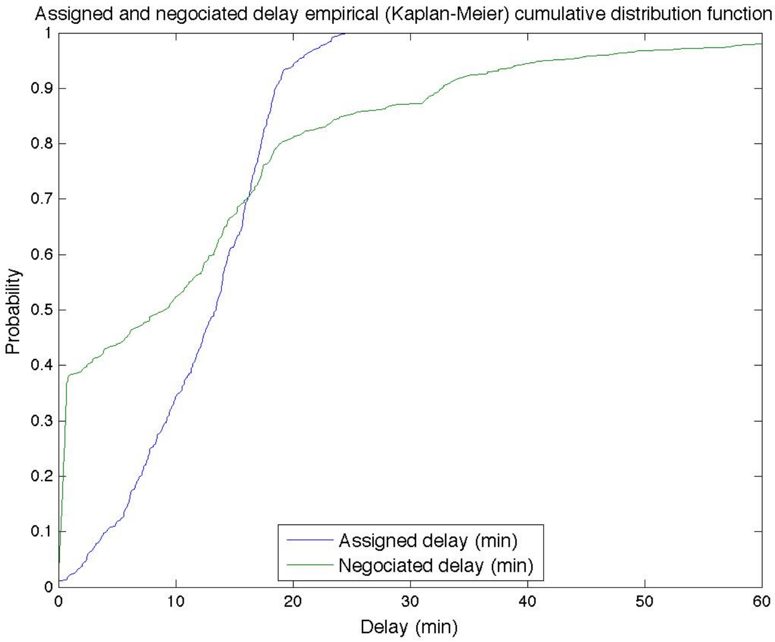


Figure 4-1 Delay distribution in scenarios $CS_{0.1}$ (top), $CS_{0.2}$ (middle) and $CS_{0.3}$ (bottom)

The amount of delay exchanged depends on the common tactic used (roughly 3.5k minutes for TA0, 2.3k minutes for TA1 and 1.6k minutes for TA2) this indicates that the success of the CDM process depends on how the interested parts interact. In fact, since TA2 is a more sophisticated tactic than TA1 and TA0 and arguably TA1 is slightly more elaborate than TA0, it seems that the more sophisticated the agent's strategies, the smaller the interaction and exchange of slots. Of course this also depends on the selling strategies, but those are fixed across all sub-scenarios. In any case more than 40% of the affected flights decide to swap slots; this evidences how the current FPFS criteria does not match airlines' preferences. This is even more striking when all agents use TA0, in this sub-scenario 85% of the flights decided to swap slots.

The average delay reduction ranges from 10 to 12 minutes which contrasts with the average delay increase of 18 to 20 minutes, hence there is a slightly larger proportion of flights improving their initial time in contrast to a few which focus on worsening their slots and getting an economic compensation for it.

Since ATFM slots' timing is fixed and there are not wasted slots, the CDM solution is not suboptimal in terms of primary total delay (delay produced in this sector). However, second order delays may be affected as well. With the current FPFS assignment there is no way to control how ATFM slot distribution will incur secondary delays. In this case study we do not model second order delays explicitly, they are reflected through airline cost. By using CDM on slot swapping the airlines' costs are reduced by between 46% and 60% with respect to the FPFS ATFM initial slot distribution. This is a substantial amount, which in terms of absolute values rounds out to 50k€ in this particular scenario. Surprisingly enough the cost reduction only varies by 10k€ among sub-scenarios, even if, as we already commented, the number of swapped slots changes drastically from one sub-scenario to another. That means that more elaborate agent tactics reduce the number of slot exchanges, but optimize each exchange so that the overall cost reduction is basically the same (within 10% range).

The average cost reduction per flight is from 300 to 400€, while for flights not reducing cost theirs are increased roughly between 100€ and 150€ on average. The latter's will of course compensate this increase in cost by receiving a monetary compensation in return. The total economic exchange varies drastically from one sub-scenario to another. The fewer the exchanges the smaller the total exchange, from 103k€ when all agents use TA0 to only 14k€ when all agents use TA1. A general trend is to be observed; under more sophisticated tactics, agents would stop swapping slots around and become more reluctant to exchange slots and offer large amounts in return. However, swaps still occur and cost would be reduced almost by the same amount. Exchanges still exist but only when they represent a considerable improvement.

Finally, it is important to observe how agents choose particular strategies inside the same tactic to see if some of them are clearly dominant over others (here dominant strategy reflects the agents preferences for a particular strategy to the detriment of other strategies). In the first sub-scenario, when all agents use TA0 and can choose from G0, G1 and G2 there is not a significant preference. G2 is slightly more favourite while G1 is the less popular. In TA1, however, there are major discrepancies. Here T0 seems to dominate over T1 with a large margin and completely dominates over T2. In TA2 the strategy M0 dominates completely M1.

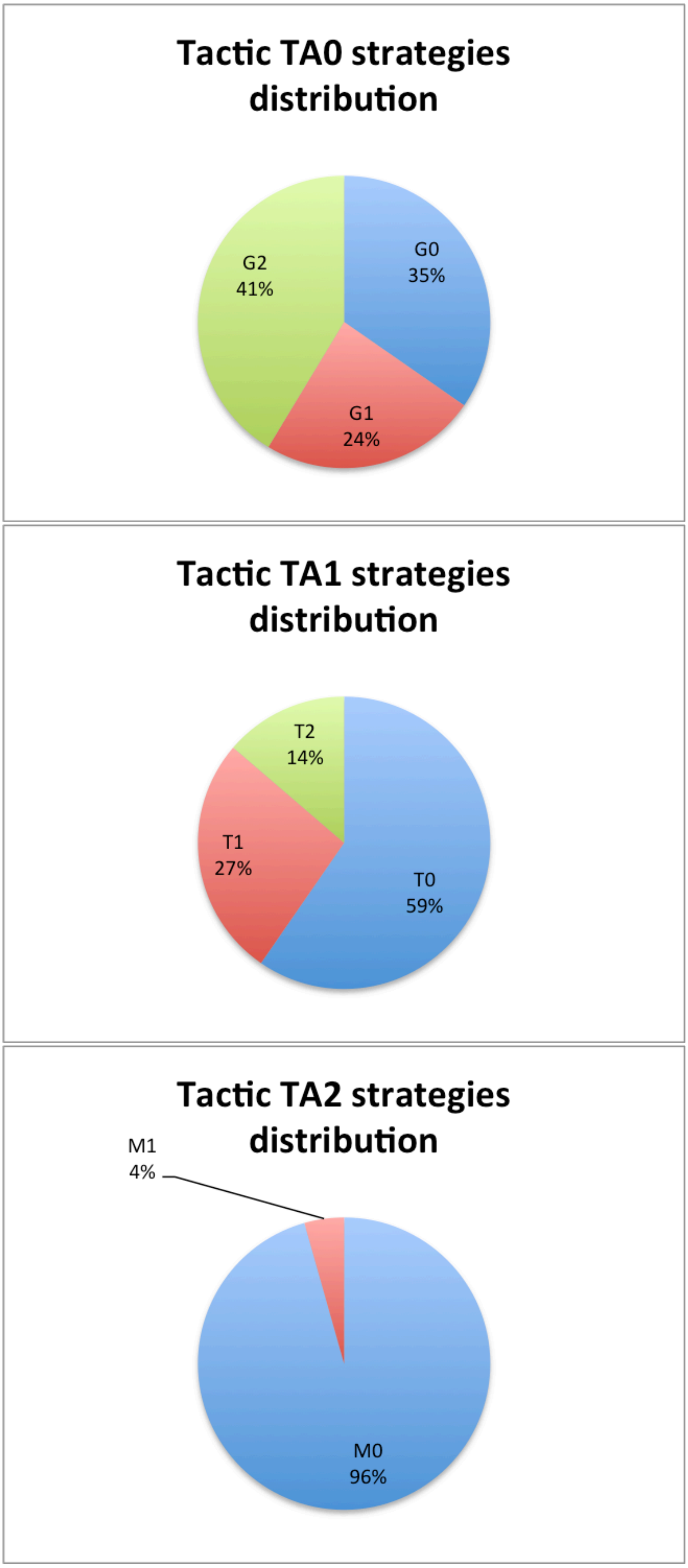


Figure 4-2 Tactic strategies distribution

4.2 Fixed tactics scenario

The fixed tactics scenario forces the agents to use the same strategy throughout all rounds and simulations. These strategies have been selected beforehand in such a way that they are different for each type of airline. Notwithstanding that this is again a simplified example in which agents do not adapt their behaviour, the fixed tactics scenario provides a hint of useful information and when compared to the calibration scenario (especially sub-scenarios CS0.1 and CS0.2) determines how a limited amount of leeway may or may not change the solutions agreed by the slot exchange CDM. We observed that results stay in the same range after each of the simulations. This may be rather obvious since the agents use the same strategies over and over again. There is a small change due to the use of parameters but the effect is negligible.

In scenario SC1, around half of the slots were redistributed with respect to the initial assignment, again showing that the FPFS solution may not be of interest cost-wise for the airlines. There are a slightly large number of flights that reduce their delay rather than increase it (approx. 40% more), which translates into a relatively small average delay-reduction (12 minutes) and a slightly larger average delay-increase (16 minutes). This is reflected in an average cost reduction of 333€ per flight and an average cost increase of 174€ which is in turn compensated by an average slot cost of 213€. Overall there is a cost reduction of over 30%; a total of 30k€ in savings in absolute value for this scenario. Around 2k minutes of delay and 30k€ were exchanged between the agents.

The shape of delay distribution also changes drastically from that initially assigned. The number of flights delayed more than 3 minutes dropped from 92% to 66% while the number of flights delayed more than 30 minutes went from zero, initially, to roughly 10% after slot exchanges. The critical point is around 15 minutes of delay; delay exchange occurs mainly between flights below and over this threshold and flights around 15 minutes of assigned delay do not usually exchange a slot. This trend was already observed in the previous scenario and it is suspected to be present in subsequent scenarios as well. In absolute values it is estimated that 10k passengers will reduce their delay by 5 minutes or more, but less than 500 will be late for more than one hour. This happens when an airline prefers the immediate effect of monetary slot exchange despite passenger cost.

Table 4-1 Fixed tactics scenario flights delay distribution

Flights delayed	FSFP	run 1	run 2	run 3	run 4	run 5	run 10	run 15	run 20	run 30
>3min	488	349	351	350	349	350	350	351	350	350
>5min	463	326	329	327	327	327	328	329	328	327
>10min	344	270	271	271	269	271	270	271	270	271
>15min	201	192	191	192	191	191	192	192	191	191
>30min	0	58	57	58	57	57	59	58	58	57
>60min	0	3	4	3	5	4	3	3	4	4

Interestingly enough, there is a group of flights both reducing their delay and also getting paid for a slot exchange. Due to the design of the slot exchange mechanism this is only possible after making two or more exchanges. This happened for less than 4% of the flights and the share of the total exchanged amount is marginal. However, this is something to consider in further scenarios.

4.3 Sensitivity analysis

The sensitivity analysis explores how the CDM slot distribution changes when a significant proportion of the agents modify their strategies. This is of utmost importance; if the outcomes of the whole system can be driven by the actions of a few agents, then the proposed exchange mechanism is dominated by the market, dismissing the power of regulatory authorities. Instead of studying a progressive transition we just explore two sub-scenarios, initial and final. The only difference between the former and the latter is that the low cost airlines (which comprise around 28% of the affected flights) switch from a simple aggressive tactic TA0 to a more conservative and elaborated tactic TA2. The simulation results between these two scenarios were explored and the key findings are further discussed in this section.

In both sub-scenarios the number of slots swapped varies between 40% and 50% with no significant differences. The cost reduction in both cases stays in a tight range over 30%, with no significant differences either. The economic exchange however, decreases by roughly 30% when the LCC's switch tactics from TA0 to TA2. Implicitly that leads to a drop in the average slot price of 6%. There is a significant detriment to the number of flights improving their slots, dropping from 30% to 26%, and the average delay-reduction stays around 12 minutes. On the other hand, between both scenarios, there is only a difference of 1% in the number of flights increasing their delay . There is a difference in average cost reduction per flight of 13%, almost matching the difference in average cost increase.

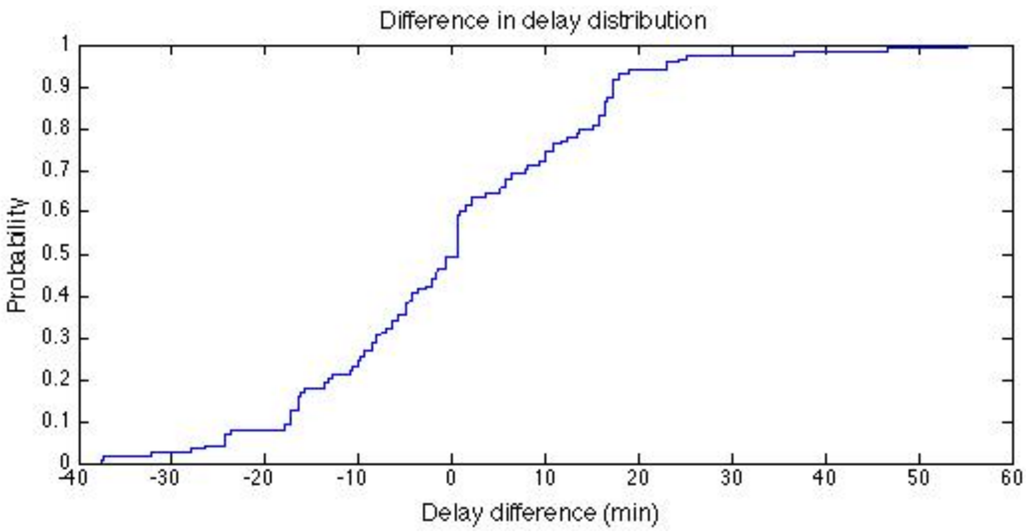


Figure 4-3 Slot distribution changes – sensitivity analysis

It is also of interest to analyse how other agents respond to LCC's change of tactic. In particular full network carriers (which operate 52% of the total number of flights) use TA1 tactic in both sub-scenarios, so in each simulation they can choose between T0, T1 and T2 as different strategies. When the LCC's use TA, 11%, 52% and 36% of the network carriers stick to T0, T1 and T2 respectively in the last simulation, but when the LCC's switch to TA2 then 4% of the network operators which were previously following TA2 switch to TA0 and TA1 in almost exact proportion (2% each). This is due to the fact that the delay, cost and economic compensation trade-offs for agents following T2 are drastically reduced (even reaching negative values in some cases) in the second sub-scenario. There is a small side effect in regional airlines; 11% of them (which is a proportion of <1% of the total flights) will switch from M1 to M0. In fact M1 is completely dominated by M0, as nobody chose the former over the latter.

Table 4-2 Agent response to LCC change of tactic

LCC's using TA0			LCC's using TA2		
strategy	**popularity**	**delay trade-off**	**strategy**	**popularity**	**delay trade-off**
G0	25.90%	127.80 min	G0	0%	0 min

LCC's using TA0			LCC's using TA2		
strategy	**popularity**	**delay trade-off**	**strategy**	**popularity**	**delay trade-off**
G2	18.48%	210.60 min	G2	16.19%	88.20 min
M0	3.24%	1.80 min	M0	31.81%	40.50 min
M1	0.38%	0.00 min	M1	0.00%	0 min
T0	6.10%	39.60 min	T0	6.29%	63.00 min
T1	27.05%	177.30 min	T1	28.95%	96.30 min
T2	18.86%	86.40 min	T2	16.76%	13.50 min

Considering that the LCC's comprise 30% of total flights, the overall figures change by very small margins. That basically means that the influence of this 30% on the whole system is relatively low, although not insignificant when it comes to particular agents (since they have to modify their behaviours accordingly), in all aspects of the trade, minutes of delay, cost and economic compensations. A slot exchange mechanism resilient to participant behaviour, without regulating the mechanism too much, is a highly desirable property. We can at least conclude that under this specific scenario the sensitivity test was successfully passed by our proposed mechanism.

4.4 Realistic scenario

Using expert-based criteria, the realistic scenario matches stereotypical behaviours to each of the airline types, so that a possible real-world situation can be further explored. To that end, network operators use a more sophisticated and less aggressive tactic (TA2) whilst low-cost carriers use a more aggressive tactic (TA0), while regional airlines somehow lie in an intermediate position (using a TA1 tactic). The rest of airline types (cargo, integrators and charter) stick to a fixed G0 tactic focusing basically on selling slots according to their cost estimations. In this scenario we will look at absolute values to give some insight into the order of magnitude and give some hints on how the proposed ATFM slot exchange mechanism would perform if it were ever going to be applied in the real world.

First, after agreeing in a solution, the cost would be reduced by over 30% (or 36k€) with respect to the original ATFM slot distribution (using FPFS criteria). This is a substantial reduction, achieved after almost half of the slots (from 45% to 60%) were swapped. These slots accounted for roughly 2k minutes of redistributed delay and over 26k€ were circulated in terms of slot exchange compensations. In the last simulation 30% of the flights improved their slots, most of them between 4 minutes (25%) and 20 minutes (75%) by an average of 12 minutes. The best improvement was 24min. These flights also reduced their cost by an average of 300€ per flight, up to a high of 2.2k€, but 75% of the slot cost-reductions remained below 500€. This reduction in cost had to be compensated by an average slot buying price of 225€, although the maximum price was 1.3k€. On the other hand, only 20% actually increased their delay. The average increased delay was slightly less than 20 minutes, with most of the values between 5 and 35 minutes, and a maximum delay increase of over 60 minutes. These delays increased cost by an average of 124€ per flight, up to a maximum of 500€. The costs were compensated by an average slot-selling value of 155€, although most (75%) of the slot prices were below 300€.

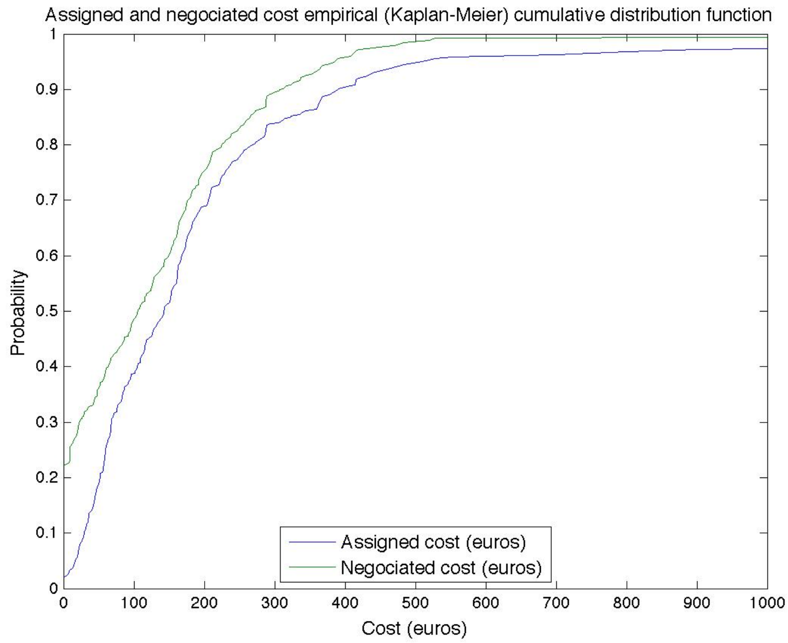


Figure 4-4 Realistic cost distribution

Regarding the distribution of delays, as in previous scenarios, most of the slot exchanges occur between flights with delay below 15 minutes and flights with delay over 15 minutes. This threshold has appeared constantly in every single scenario and it is one of the major findings of this case study. In this way after distributing the ATFM slots using FPFS, around 90% of the flights were delayed by more than 3 minutes. After the CDM takes place this percentage is reduced to 64%. The closer to 15 minutes of delay we move the smaller the relative difference in those percentages. Thus for more than 10 minutes delay we have 65% using FPFS and 51% using CDM. For more than 15 minutes of delay the relative difference reaches its minimum: 38% vs. 34%, or 20 flights (in absolute values). There were no flights delayed more than 30 minutes by the FPFS distribution whilst there were 60 flights delayed more than 30 minutes after the CDM process took place. However only 4 flights were delayed more than 60 minutes.

In terms of passengers it is estimated that 12k pax otherwise delayed by more than 10 minutes by FPFS will reach their destination with less than 5 minutes delay after CDM negotiations. On the other hand, a small proportion of passengers, roughly 400, will suffer severe delays of up to one hour.

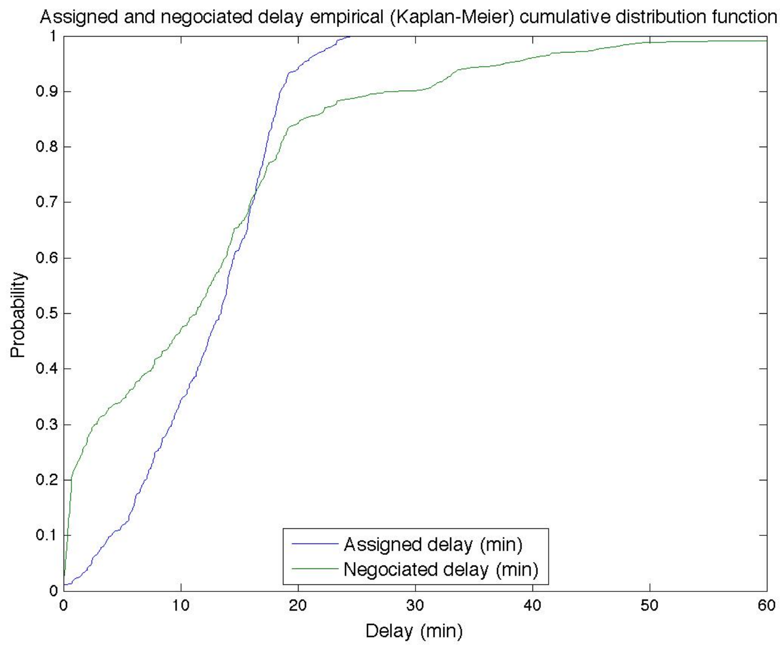


Figure 4-5 Realistic delay distribution

Regarding the strategies, the most popular strategy was by far M0, chosen by 47% of the agents. This strategy produced an economic trade-off (cost modification plus economic exchanges) of over 4k€. Also M0 completely dominates M1 in TA2, which was selected by only 5% of the agents. The second most popular strategy was G1 with 18% of agents selecting it. However, 16% of those were forced to follow G1 because they were using a fixed G2 tactic. G1 is closely followed by G2, with 17% of agents choosing it, and then G0, with just 9%. The strategy G2 performed much better in economic terms (2.8k€ versus 1.6k€ combining G1 and G0) and also doubles the other two strategies in exchanged delay. Lastly, strategies from tactic TA1, namely: T0, T1 and T2 represent only a marginal share of the affected agents (3%) so they do not represent a big share of the overall trade-offs.

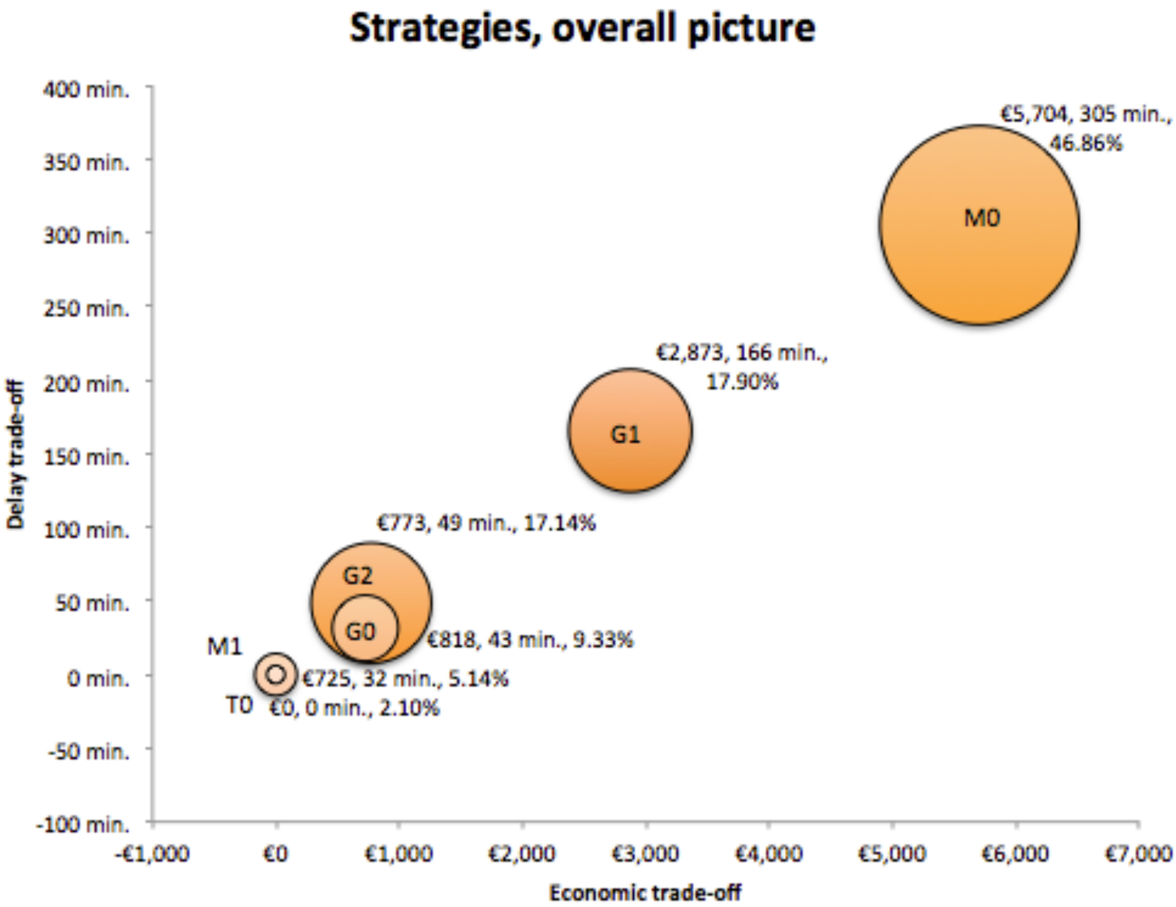


Figure 4-6 Summary of strategies outcomes

5 Conclusions

The previous set of scenarios was designed to test the proposed ATFM slot exchange mechanism by following a very specific CDM process. Recall that, due to the Impossibility Theorem, we dropped the incentive incompatibility condition in this CDM process. Therefore by allowing the agents some freedom regarding their strategies and cost, it is not clear how agent's behaviour may affect the whole system outcome. Aspects such as dominant strategies, monopoly, profits, sensibility and stability need to be analysed before the proposed CDM ATFM slot exchange mechanism is ever to be established. While trying to observe all possible combinations of scenarios seems to be an overwhelming task, agent-based modelling allows us to reduce the number of cases to explore by assuming that the real world operators would be rational in their decisions. In this way we can reduce the number of cases by considering overall tactics instead of individual strategies. This study’s conclusions correspond only to the previously defined scenarios, therefore special care should be taken when extrapolating results to general assertions, even if the scenarios were selected by their representativeness and importance.

The first important fact to consider is that after the CDM process the use of available resources is still optimal in terms of total capacity. Since all the ATFM slots are used in both FPFS and CDM solutions, **the average (or total) delay does not change with the CDM slot distribution**. It is only the shape, or distribution of the delay that changes. This is of utmost importance as many stakeholders are mainly concerned about capacity and overall delay. After the CDM process the delay distribution is flattened; usually the FPFS solution would not assign any flight large delays, but after the CDM process some flights might decide to incur higher delays in exchange for economic compensation. This is of course only possible because the actual total (or average) cost to airlines changes when the slot distribution changes. **Simulations show cost reductions of around 30% after using CDM distribution of ATFM slots without increasing total delay.** Note that this cost reduction is achieved without any operator revealing their cost models or strategies.

There seems to be a **critical delay point around 15 minutes**. At this point both FPFS and CDM delay distributions coincide. Exchanges take place mainly between flights below this threshold of delay and flights with delay over the threshold. It may be worth exploring further mechanisms limiting the maximum/minimum amount of delay to be traded around this critical point. Allowing trades only over this threshold may reduce the number of exchanges while probably keeping a fair cost reduction.

The sensibility analysis performed was very positive. Even if a relatively large proportion of the agents suddenly decided to change their behaviour, the impact over the overall system was still bounded. **As the CDM mechanism self-regulated, no indicator rocketed**; the amount of delay exchanged, cost reductions and economic compensations stayed within a reasonable order of magnitude. As we observed, this was in part due to other agents adapting their behaviour and minimizing the impact of the change. This self-regulation ability is highly desirable in any CDM process, as it reduces the need for external monitoring.

All achieved CDM solutions observed so far are stable; each agent finds a working strategy and sticks to it. Although we conducted 30 simulations of each scenario, usually **in less than three or five simulations the results stabilize and results remain in the same range.** This increases the predictability of the system, again reducing the necessity for continuous external monitoring.

Regarding dominating strategies and monopolies, no strategy has been shown to be dominant except for, possibly, M0. It is not clear from the realistic scenario that given the chance airlines will use M0. Further exploration will be needed to determine if a specific strategy against M0 exists. If this were the case, it would be tempting for any agent to switch to a relatively weaker strategy that works better against M0, leading to a suboptimal equilibrium. In some cases, agents might switch continuously between M0 and its counterpart, eternally oscillating and not reaching equilibrium at all.

Finally, some words of advice regarding some flights improving both their slot time AND making profit from exchange; this has been observed in various scenarios and, due to the way the exchange mechanism was designed, it is possible after making only two or more exchanges. It is not completely clear whether this is legitimate behaviour. Probably it is just a matter of market preferences. The decision to ultimately ban this behaviour would have to be in the hands of the regulatory mechanism. The CASSIOPEIA model can only quantify the impact and magnitude of this behaviour.

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7 Appendices

7.1 Appendix 1 – Simulation Results

7.1.1 Calibration scenarios

7.1.1.1 Results overview for scenario calibration-CS0.1

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.28	6496.23	6496.26	6496.23	6496.25	6496.23	6496.24	6496.25	6496.27
Total cost (euros)	108241.90	58067.00	48924.70	48886.30	52330.70	51156.40	52596.80	51824.60	51365.20	50344.80

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	2835.27	3665.48	3579.97	3454.91	3512.98	3478.39	3471.94	3502.98	3507.77
Economic exchange (euros)	0	84383.50	107505.00	106319.30	100260.30	100623.70	99634.90	100143.30	100833.20	103027.80
Slots swapped	0	391.00	483.00	465.00	453.00	457.00	454.00	450.00	451.00	457.00
Cost reduction (%)	0	46.35	54.80	54.84	51.65	52.74	51.41	52.12	52.55	53.49
Maximum profit (euros)	0	3300.00	2562.00	3400.00	3300.00	3300.00	3300.00	3300.00	3300.00	3300.00

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	247	337	320	308	312	309	309	313	312
Average delay reduction (min)	-11.48	-10.88	-11.19	-11.22	-11.26	-11.26	-11.24	-11.19	-11.24
Flights improving cost	245	338	318	308	312	309	309	313	312
Average cost reduction	-292.31	-246.71	-261.82	-257.20	-258.78	-257.36	-259.85	-257.45	-262.75

(euros)									
Flights profiting from exchange	187	293	258	237	239	236	235	236	238
Average profit per slot (euros)	451.25	366.91	412.09	423.04	421.02	422.18	426.14	427.26	432.89
Flights increasing delay	144	146	145	145	145	145	141	138	145
Average delay increase (min)	19.69	25.11	24.69	23.83	24.23	23.99	24.62	25.38	24.19
Flights worseing cost	141	145	145	143	143	143	139	137	144
Average cost increase (euros)	152.06	166.00	164.84	162.98	165.41	167.00	171.77	173.03	167.22
Flights paying for exchanges	276	359	347	337	340	337	334	337	339
Average cost per slot (euros)	305.74	299.46	306.40	297.51	295.95	295.65	299.83	299.21	303.92

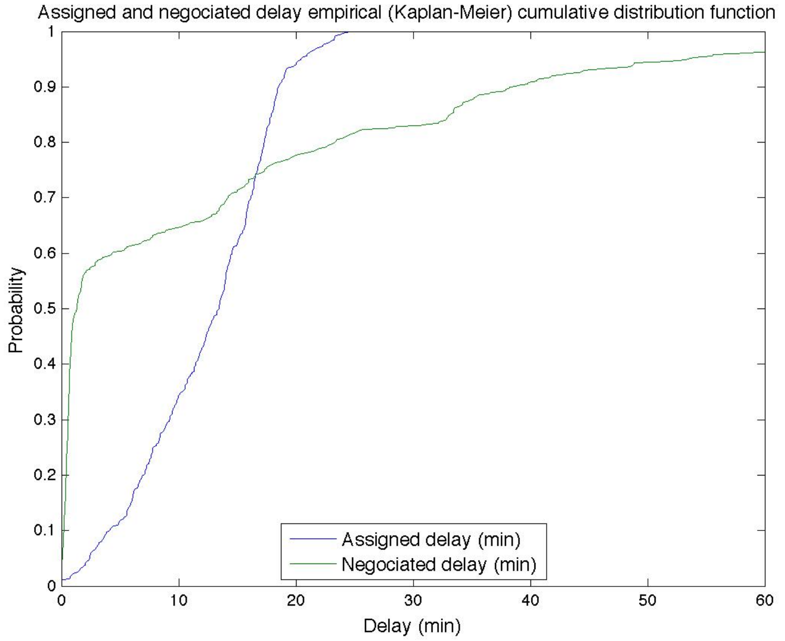
Severe delays

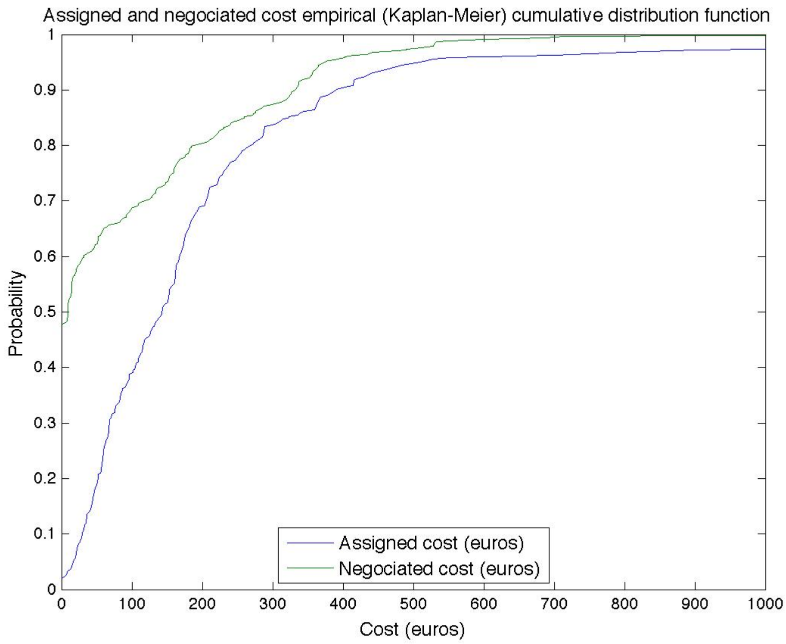
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	272	214	209	222	217	218	220	217	218
>5min	463	264	185	200	211	208	209	210	207	208
>10min	344	233	170	182	189	184	187	186	185	186
>15min	201	172	143	149	149	147	150	151	148	150
>30min	0	80	93	89	87	87	88	85	85	90
>60min	0	12	23	21	21	20	19	20	21	20
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	28560	22470	21945	23310	22785	22890	23100	22785	22890
>5min	48615	27720	19425	21000	22155	21840	21945	22050	21735	21840
>10min	36120	24465	17850	19110	19845	19320	19635	19530	19425	19530
>15min	21105	18060	15015	15645	15645	15435	15750	15855	15540	15750
>30min	0	8400	9765	9345	9135	9135	9240	8925	8925	9450
>60min	0	1260	2415	2205	2205	2100	1995	2100	2205	2100

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	145	24.19	17.20	17.91	20.26	1.40	5.05	15.52	21.72	108.93
Reduced delay (min)	312	-11.24	-17.20	-11.47	5.71	-0.19	2.07	4.85	9.32	-23.65
Improved cost (euros)	144	167.22	28.00	144.25	149.23	2.22	11.34	105.52	167.45	1036.80
Deteriorated cost (euros)	312	-262.75	-176.00	-170.40	348.57	3.37	201.48	15.59	211.20	-2200.00

Slot payers (euros)	339	-303.92	-30.00	-210.00	338.92	3.13	14.57	205.92	246.85	-2200.00
Slot payees (euros)	238	432.89	144.00	289.00	485.08	2.56	11.32	322.06	382.60	3300.00





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
TA0	100.00 %	1002.45 min	5147.50 euros	13177.70 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
G0	34.67 %	341.10 min	1970.70 euros	4284.00 euros
G1	24.00 %	249.30 min	1005.70 euros	2889.60 euros
G2	41.33 %	412.05 min	2171.10 euros	6004.10 euros

7.1.1.2Results overview for scenario calibration-CS0.2

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.27	6496.21	6496.27	6496.20	6496.24	6496.20	6496.21	6496.23	6496.21
Total cost (euros)	108357.90	57862.30	66396.40	59218.50	62281.20	62255.30	61289.60	61559.60	61723.00	61789.20

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	2814.26	1583.18	2617.87	2336.18	2394.75	2479.86	2407.13	2431.49	2381.30
Economic exchange (euros)	0	83396.60	14426.88	36666.84	41200.90	42782.00	44906.70	43828.30	42527.30	43066.20
Slots swapped	0	382.00	204.00	346.00	327.00	333.00	338.00	332.00	330.00	333.00
Cost reduction (%)	0	46.60	38.72	45.35	42.52	42.55	43.44	43.19	43.04	42.98
Maximum profit (euros)	0	3300.00	686.00	1023.60	1800.00	1800.00	1800.00	1800.00	1800.00	1800.00

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	242	127	214	196	203	209	203	203	204
Average delay reduction (min)	-11.63	-12.47	-12.23	-11.92	-11.80	-11.87	-11.86	-11.98	-11.67
Flights improving cost	241	127	215	196	202	208	202	203	202

Average cost reduction (euros)	-296.81	-405.46	-320.83	-324.64	-316.49	-314.10	-319.21	-318.55	-317.71
Flights profiting from exchange	181	83	149	159	162	165	162	158	162
Average profit per slot (euros)	460.75	173.82	246.09	259.13	264.09	272.16	270.55	269.16	265.84
Flights increasing delay	140	77	132	131	130	129	129	127	129
Average delay increase (min)	20.10	20.56	19.83	17.83	18.42	19.22	18.66	19.15	18.46
Flights worseing cost	136	77	131	128	127	126	126	124	126
Average cost increase (euros)	154.68	123.79	151.44	137.14	140.38	144.96	140.34	145.41	139.75
Flights paying for exchanges	268	127	220	216	224	232	224	223	225
Average cost per slot (euros)	311.18	113.60	166.67	190.74	190.99	193.56	195.66	190.71	191.41

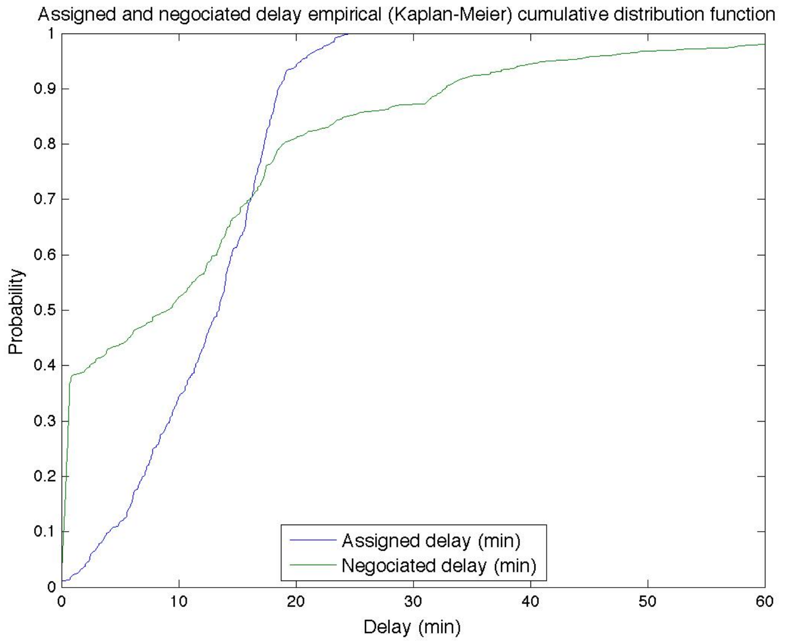
Severe delays

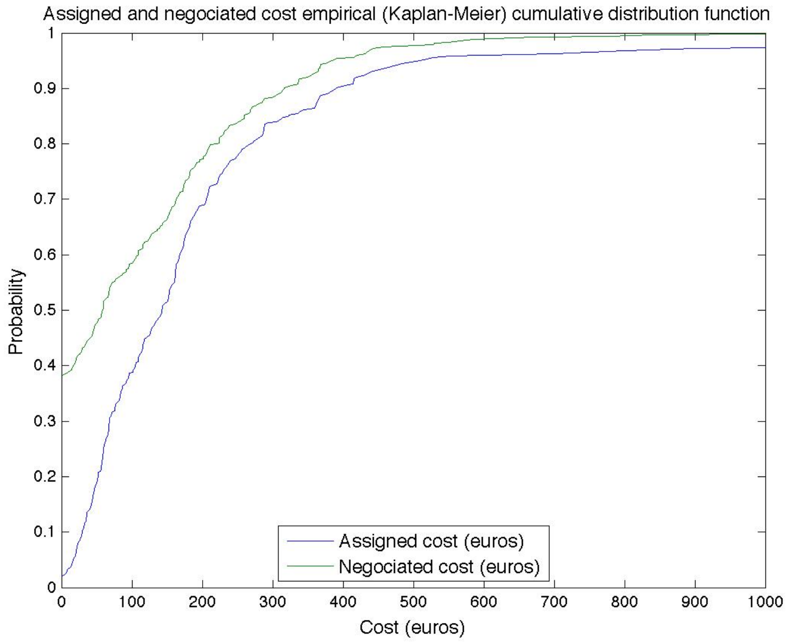
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	278	374	295	312	307	302	307	305	308
>5min	463	268	358	286	299	294	289	294	292	295
>10min	344	227	277	239	252	248	243	247	245	250
>15min	201	167	181	171	174	171	167	170	168	172
>30min	0	77	51	78	71	70	70	69	70	68
>60min	0	13	4	8	10	12	11	13	12	11
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	29190	39270	30975	32760	32235	31710	32235	32025	32340
>5min	48615	28140	37590	30030	31395	30870	30345	30870	30660	30975
>10min	36120	23835	29085	25095	26460	26040	25515	25935	25725	26250
>15min	21105	17535	19005	17955	18270	17955	17535	17850	17640	18060
>30min	0	8085	5355	8190	7455	7350	7350	7245	7350	7140
>60min	0	1365	420	840	1050	1260	1155	1365	1260	1155

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	129	18.46	15.77	15.76	15.28	1.28	4.25	11.19	14.88	70.23
Reduced delay (min)	204	-11.67	-15.05	-12.90	5.84	-0.31	2.14	4.97	8.75	-23.65
Improved cost (euros)	126	139.75	20.00	133.80	114.79	1.54	6.17	83.21	136.00	624.60
Deteriora	202	-	-	-	400.62	2.86	244.2	11.49	252.00	-

ted cost (euros)		317.71	163.20	203.50			7			2200.00
Slot payers (euros)	225	-191.41	-163.20	-156.00	183.16	4.08	31.20	115.50	173.85	-1800.00
Slot payees (euros)	162	265.84	156.00	210.00	240.41	2.65	14.01	161.50	208.00	1800.00





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
TA1	100.00 %	1216.80 min	2838.50 euros	10306.00 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
T0	59.62 %	695.94 min	1612.70 euros	5626.25 euros
T1	26.67 %	458.76 min	1270.00 euros	3900.66 euros
T2	13.71 %	62.10 min	-44.20 euros	779.09 euros

7.1.1.3 Results overview for scenario calibration-CS0.3

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.21	6496.19	6496.20	6496.19	6496.18	6496.19	6496.21	6496.20	6496.20
Total cost (euros)	108357.90	66147.50	76433.90	64303.60	64300.60	64448.60	64756.80	64203.20	64395.80	64303.60

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	1592.11	595.06	1613.70	1614.41	1600.08	1589.52	1620.87	1614.60	1613.70
Economic exchange (euros)	0	14513.68	5637.20	14021.43	14039.23	13911.23	13839.33	14121.71	14035.53	14021.43
Slots swapped	0	204.00	89.00	209.00	210.00	208.00	207.00	209.00	209.00	209.00
Cost reduction (%)	0	38.95	29.46	40.66	40.66	40.52	40.24	40.75	40.57	40.66
Maximum profit (euros)	0	560.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	127	47	128	129	127	126	128	128	128

Average delay reduction (min)	-12.54	-12.66	-12.61	-12.52	-12.60	-12.62	-12.66	-12.61	-12.61
Flights improving cost	127	47	128	129	127	126	128	128	128
Average cost reduction (euros)	-406.94	-763.20	-419.57	-416.34	-421.29	-421.87	-419.96	-418.91	-419.57
Flights profiting from exchange	83	43	85	86	85	85	85	85	85
Average profit per slot (euros)	174.86	131.10	164.96	163.25	163.66	162.82	166.14	165.12	164.96
Flights increasing delay	77	42	81	81	81	81	81	81	81
Average delay increase (min)	20.68	14.17	19.92	19.93	19.75	19.62	20.01	19.93	19.92
Flights worseing cost	77	36	81	81	81	81	81	81	81
Average cost increase (euros)	122.99	109.63	119.14	119.14	118.45	117.96	118.52	119.25	119.14
Flights paying for exchanges	127	47	128	129	127	126	129	128	128
Average cost per slot (euros)	114.28	119.94	109.54	108.83	109.54	109.84	109.47	109.65	109.54

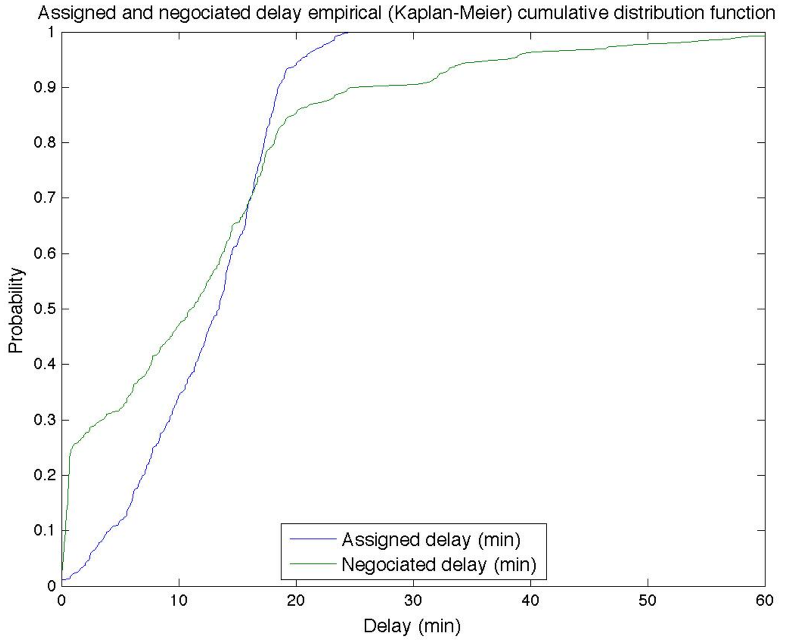
Severe delays

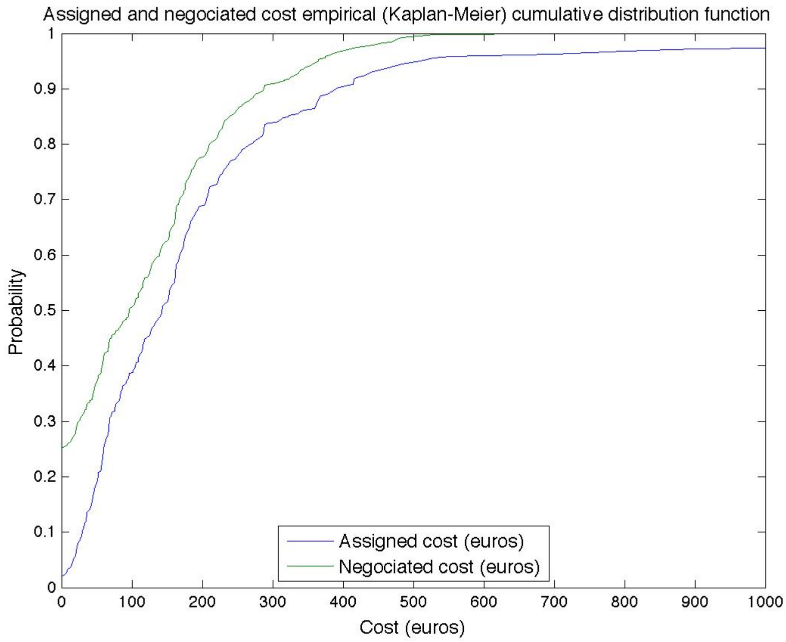
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	374	445	371	371	372	373	371	371	371
>5min	463	358	422	357	357	358	359	357	357	357
>10min	344	277	321	277	277	278	279	275	277	277
>15min	201	180	193	181	181	181	181	180	181	181
>30min	0	51	21	51	51	51	51	52	51	51
>60min	0	5	0	4	4	4	4	5	4	4
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	39270	46725	38955	38955	39060	39165	38955	38955	38955
>5min	48615	37590	44310	37485	37485	37590	37695	37485	37485	37485
>10min	36120	29085	33705	29085	29085	29190	29295	28875	29085	29085
>15min	21105	18900	20265	19005	19005	19005	19005	18900	19005	19005
>30min	0	5355	2205	5355	5355	5355	5355	5460	5355	5355
>60min	0	525	0	420	420	420	420	525	420	420

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	81	19.92	17.20	16.48	12.80	1.00	3.21	9.95	13.34	54.54
Reduced delay (min)	128	-12.61	-15.05	-13.62	5.60	-0.32	2.35	4.63	7.98	-24.37

Improved cost (euros)	81	119.14	24.00	115.60	71.15	0.33	2.13	60.42	116.95	273.00
Deteriorated cost (euros)	128	-419.57	-30.00	-274.00	483.46	2.17	318.99	7.00	271.00	-2200.00
Slot payers (euros)	128	-109.54	-86.40	-86.40	84.16	1.61	5.88	61.45	84.55	-440.00
Slot payees (euros)	85	164.96	13.20	144.50	117.29	0.82	2.98	94.01	172.45	500.00





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
TA2	100.00 %	797.40 min	1725.30 euros	4821.55 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
M0	95.62 %	735.30 min	1443.80 euros	4432.05 euros
M1	4.38 %	62.10 min	281.50 euros	389.50 euros

7.1.2 Fixed tactics scenario

7.1.2.1 Results overview for scenario fixed-CS1

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.35	6496.36	6496.38	6496.37	6496.36	6496.36	6496.37	6496.35	6496.36
Total cost (euros)	108286.10	74934.40	75067.50	74908.70	74950.70	74970.70	74936.70	75092.70	74910.70	74970.70

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	1893.57	1873.68	1880.87	1901.64	1880.85	1888.02	1872.26	1888.72	1880.85
Economic exchange (euros)	0	35764.70	34975.60	35750.00	35649.80	35400.40	35279.20	35273.20	35241.60	35400.40
Slots swapped	0	273.00	269.00	272.00	271.00	271.00	271.00	270.00	271.00	271.00
Cost reduction (%)	0	30.80	30.68	30.82	30.78	30.77	30.80	30.65	30.82	30.77
Maximum profit (euros)	0	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00	2000.00

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	157	155	157	155	158	155	154	156	158
Average delay reduction (min)	-12.06	-12.09	-11.98	-12.27	-11.90	-12.18	-12.16	-12.11	-11.90
Flights improving cost	158	155	158	156	158	156	155	156	158
Average cost reduction (euros)	-334.93	-338.94	-334.44	-339.58	-333.54	-338.83	-339.22	-338.58	-333.54
Flights profiting from exchange	132	132	134	130	134	131	132	132	134
Average profit per slot (euros)	270.94	264.97	266.79	274.23	264.18	269.31	267.22	266.98	264.18
Flights increasing delay	116	114	115	116	113	116	116	115	113
Average delay increase (min)	16.32	16.44	16.36	16.39	16.64	16.28	16.14	16.42	16.64
Flights worseing cost	114	112	113	114	111	114	114	113	111
Average cost increase (euros)	171.65	172.48	172.25	172.27	174.62	171.13	170.05	172.06	174.62
Flights paying for exchanges	167	164	166	166	166	165	164	166	166
Average cost per slot (euros)	214.16	213.27	215.36	214.76	213.26	213.81	215.08	212.30	213.26

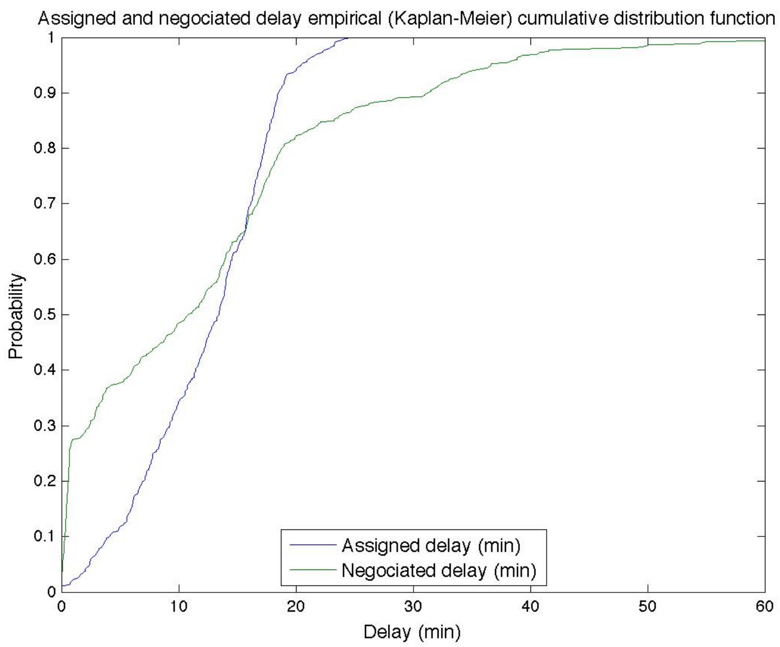
Severe delays

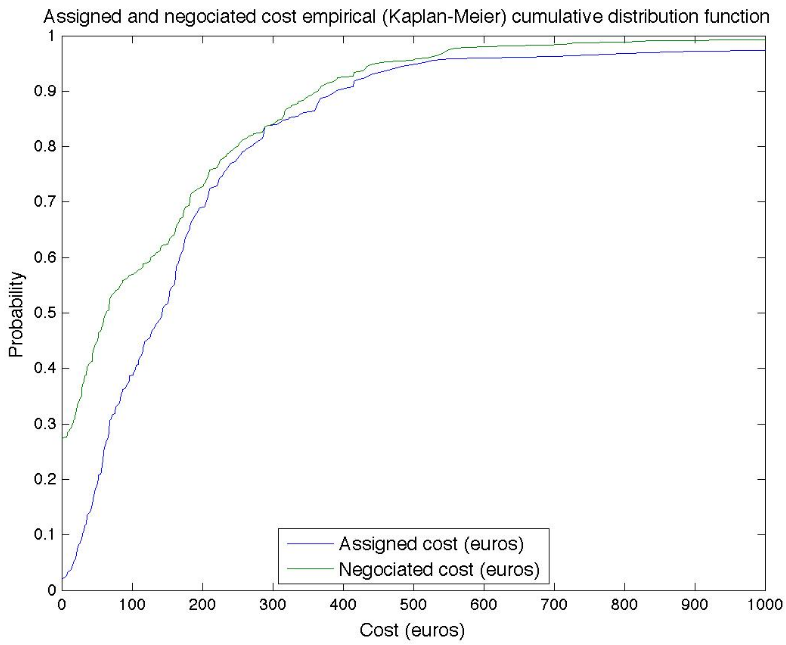
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	349	351	350	349	350	350	351	350	350
>5min	463	326	329	327	327	327	328	329	328	327
>10min	344	270	271	271	269	271	270	271	270	271
>15min	201	192	191	192	191	191	192	192	191	191
>30min	0	58	57	58	57	57	59	58	58	57
>60min	0	3	4	3	5	4	3	3	4	4
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	36645	36855	36750	36645	36750	36750	36855	36750	36750
>5min	48615	34230	34545	34335	34335	34335	34440	34545	34440	34335
>10min	36120	28350	28455	28455	28245	28455	28350	28455	28350	28455
>15min	21105	20160	20055	20160	20055	20055	20160	20160	20055	20055
>30min	0	6090	5985	6090	5985	5985	6195	6090	6090	5985
>60min	0	315	420	315	525	420	315	315	420	420

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	113	16.64	15.77	15.05	11.92	1.48	5.86	8.38	11.65	60.35

Reduced delay (min)	158	-11.90	-17.20	-12.39	5.68	-0.22	2.12	4.83	8.60	-22.93
Improved cost (euros)	111	174.62	10.20	153.60	118.26	0.99	4.01	90.64	139.45	581.40
Deteriorated cost (euros)	158	-333.54	-364.00	-226.00	405.75	2.85	245.63	11.59	275.00	-2200.00
Slot payers (euros)	166	-213.26	-163.20	-169.00	191.83	5.27	47.29	114.71	165.60	-2000.00
Slot payees (euros)	134	264.18	163.20	201.00	242.75	3.36	21.68	157.78	206.40	2000.00





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
FIX:G1	28.19 %	24.30 min	-218.10 euros	281.10 euros
FIX:G2	16.19 %	10.80 min	-201.90 euros	12.00 euros
FIX:T1	3.62 %	-3.60 min	-34.80 euros	-34.80 euros
FIX:T2	52.00 %	49.50 min	-113.30 euros	524.70 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
G1	28.19 %	24.30 min	-218.10 euros	281.10 euros
G2	16.19 %	10.80 min	-201.90 euros	12.00 euros
T1	3.62 %	-3.60 min	-34.80 euros	-34.80 euros
T2	52.00 %	49.50 min	-113.30 euros	524.70 euros

7.1.3 Sensitivity analysis scenario

7.1.3.1 Results overview for scenario sensitivity-CS2.1

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.23	6496.17	6496.24	6496.25	6496.24	6496.27	6496.22	6496.26	6496.23
Total	108217	74148.	74451.	69041.	72371.	72321.	71630.	72298.	71947.	72625.

cost (euros)	.50	80	20	50	50	50	40	70	20	30

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	2443.24	1595.11	2237.44	1943.85	1937.42	1925.60	1942.38	1877.68	1924.47
Economic exchange (euros)	0	54722.70	20192.25	35246.60	27132.25	26391.45	25956.25	27019.95	25252.25	26719.35
Slots swapped	0	314.00	238.00	314.00	268.00	269.00	268.00	266.00	264.00	265.00
Cost reduction (%)	0	31.48	31.20	36.20	33.12	33.17	33.81	33.19	33.52	32.89
Maximum profit (euros)	0	3300.00	2082.40	2430.40	1396.40	1330.40	1330.40	1330.40	1330.40	1330.40

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	205	138	187	163	163	162	163	158	162
Average delay reduction (min)	-11.92	-11.56	-11.97	-11.93	-11.89	-11.89	-11.92	-11.88	-11.88
Flights improving cost	205	138	186	163	163	162	163	158	162
Average cost reduction (euros)	-247.04	-310.27	-290.12	-297.75	-297.23	-303.62	-297.91	-307.56	-297.45
Flights profiting from exchange	129	111	141	119	119	117	119	117	118
Average profit per slot (euros)	424.21	181.91	249.98	228.00	221.78	221.85	227.06	215.83	226.44
Flights increasing	109	100	127	105	106	106	103	106	103

delay									
Average delay increase (min)	22.42	15.95	17.62	18.51	18.28	18.17	18.86	17.71	18.68
Flights worseing cost	108	100	126	102	104	104	101	104	101
Average cost increase (euros)	153.47	90.51	117.35	124.38	120.69	121.14	125.16	118.51	124.70
Flights paying for exchanges	213	148	211	176	174	173	175	169	173
Average cost per slot (euros)	256.91	136.43	167.05	154.16	151.67	150.04	154.40	149.42	154.45

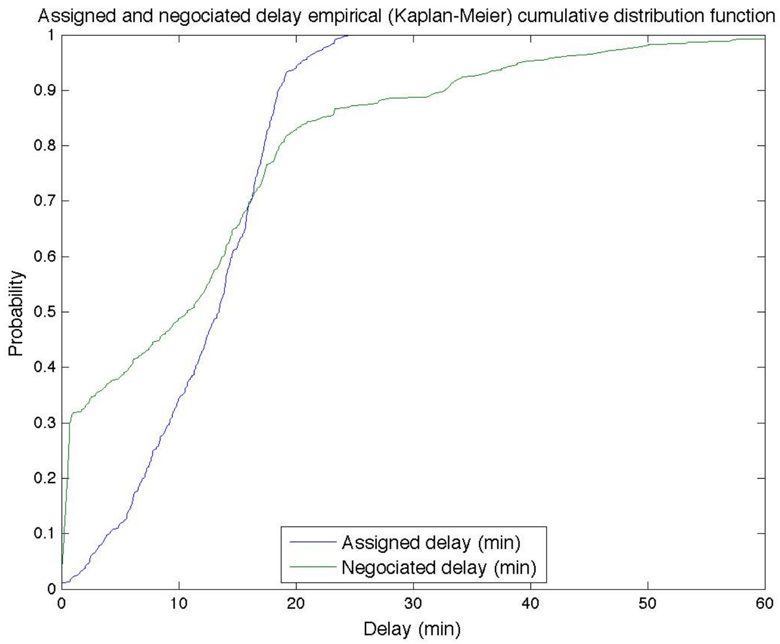
Severe delays

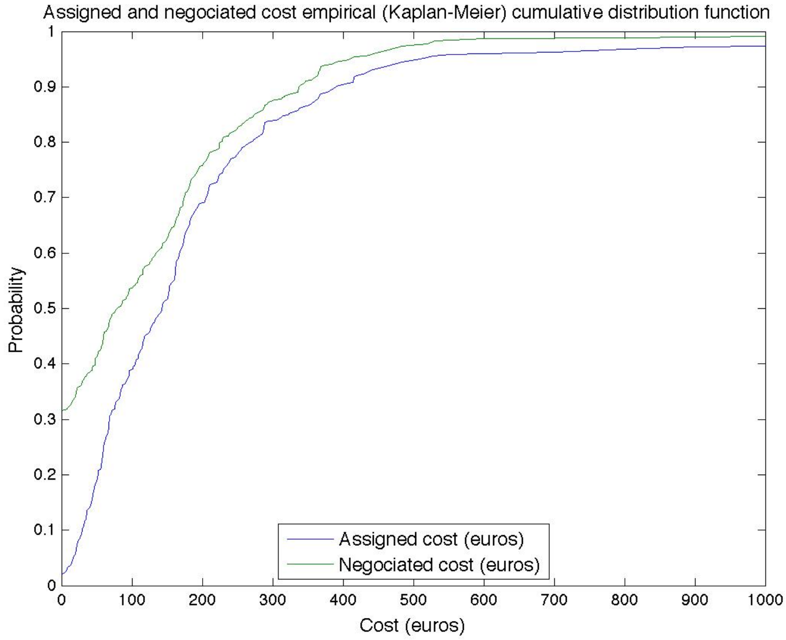
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	302	369	319	337	338	338	338	343	339
>5min	463	291	347	308	323	324	325	324	329	325
>10min	344	245	275	254	269	268	269	265	272	269
>15min	201	167	180	168	179	180	182	178	183	181
>30min	0	70	51	71	61	61	62	61	61	60
>60min	0	8	4	6	4	4	2	4	2	4
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	31710	38745	33495	35385	35490	35490	35490	36015	35595
>5min	48615	30555	36435	32340	33915	34020	34125	34020	34545	34125
>10min	36120	25725	28875	26670	28245	28140	28245	27825	28560	28245
>15min	21105	17535	18900	17640	18795	18900	19110	18690	19215	19005
>30min	0	7350	5355	7455	6405	6405	6510	6405	6405	6300
>60min	0	840	420	630	420	420	210	420	210	420

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum

Increased delay (min)	103	18.68	15.05	16.48	13.46	1.09	4.42	10.09	15.59	66.72
Reduced delay (min)	162	-11.88	-15.05	-12.90	5.45	-0.18	2.11	4.69	8.60	-23.65
Improved cost (euros)	101	124.70	72.00	112.00	96.83	1.47	5.97	71.98	116.80	506.40
Deteriorated cost (euros)	162	-297.45	-182.00	-187.00	377.16	3.22	219.09	14.15	224.00	-2200.00
Slot payers (euros)	173	-154.45	-163.20	-130.00	137.29	3.31	19.70	86.22	112.35	-1100.00
Slot payees (euros)	118	226.44	163.20	173.20	205.27	2.27	10.15	139.84	175.20	1330.40





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
FIX:G2	16.19 %	189.90 min	324.20 euros	1678.80 euros
TA0	28.19 %	148.50 min	-143.10 euros	989.40 euros
TA1	52.00 %	303.30 min	383.40 euros	3194.45 euros
TA2	3.62 %	1.80 min	-5.00 euros	12.30 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
G0	25.90 %	127.80 min	-246.60 euros	798.45 euros
G2	18.48 %	210.60 min	427.70 euros	1869.75 euros
M0	3.24 %	1.80 min	-5.00 euros	12.30 euros
M1	0.38 %	0.00 min	0.00 euros	0.00 euros
T0	6.10 %	39.60 min	43.30 euros	311.45 euros
T1	27.05 %	177.30 min	112.00 euros	2261.75 euros
T2	18.86 %	86.40 min	228.10 euros	621.25 euros

7.1.3.2Results overview for scenario sensitivity-CS2.2

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.2 6	6496.2 7	6496.2 0	6496.2 2	6496.2 7	6496.2 6	6496.2 9	6496.2 7	6496.2 7	6496.2 4
Total	108217	73061.	77472.	69924.	72015.	71759.	71215.	72483.	71514.	72705.

cost (euros)	.50	70	40	60	00	40	40	40	40	50

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	2222.12	1166.57	1840.55	1674.43	1726.63	1677.30	1661.52	1742.40	1718.21
Economic exchange (euros)	0	49560.90	11746.95	26899.63	21166.16	21013.96	21112.56	20069.56	21099.08	20186.91
Slots swapped	0	287.00	171.00	257.00	231.00	237.00	231.00	230.00	238.00	236.00
Cost reduction (%)	0	32.49	28.41	35.39	33.45	33.69	34.19	33.02	33.92	32.82
Maximum profit (euros)	0	3300.00	900.00	2430.40	1966.40	1330.40	1966.40	1330.40	1330.40	1330.40

FPFS relative indicators

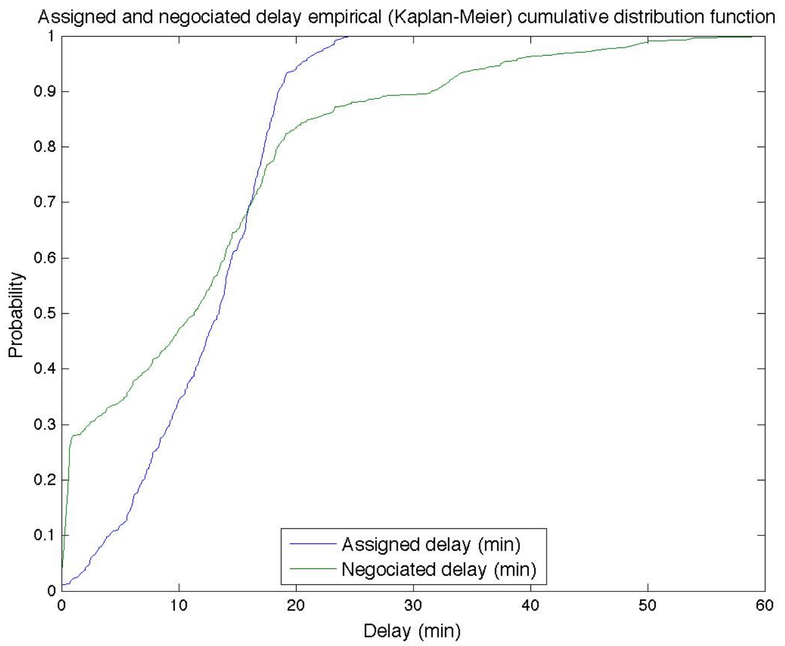
	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	182	98	151	134	138	134	133	140	137
Average delay reduction (min)	-12.21	-11.90	-12.19	-12.50	-12.51	-12.52	-12.49	-12.45	-12.54
Flights improving cost	182	98	151	134	138	134	133	140	137
Average cost reduction (euros)	-275.17	-387.53	-333.85	-351.49	-346.71	-357.61	-349.69	-344.18	-341.66
Flights profiting from exchange	113	73	113	102	103	102	102	103	104
Average profit per slot (euros)	438.59	160.92	238.05	207.51	204.02	206.99	196.76	204.85	194.10
Flights increasing delay	105	73	106	97	99	97	97	98	99
Average delay increase (min)	21.16	15.98	17.36	17.26	17.44	17.29	17.13	17.78	17.36
Flights worseing cost	105	73	106	97	99	97	97	98	98
Average cost increase (euros)	142.14	99.07	114.32	112.35	115.03	112.56	111.07	117.17	115.26
Flights paying for exchanges	182	98	151	135	139	135	134	140	139
Average cost per slot (euros)	272.31	119.87	178.14	156.79	151.18	156.39	149.77	150.71	145.23

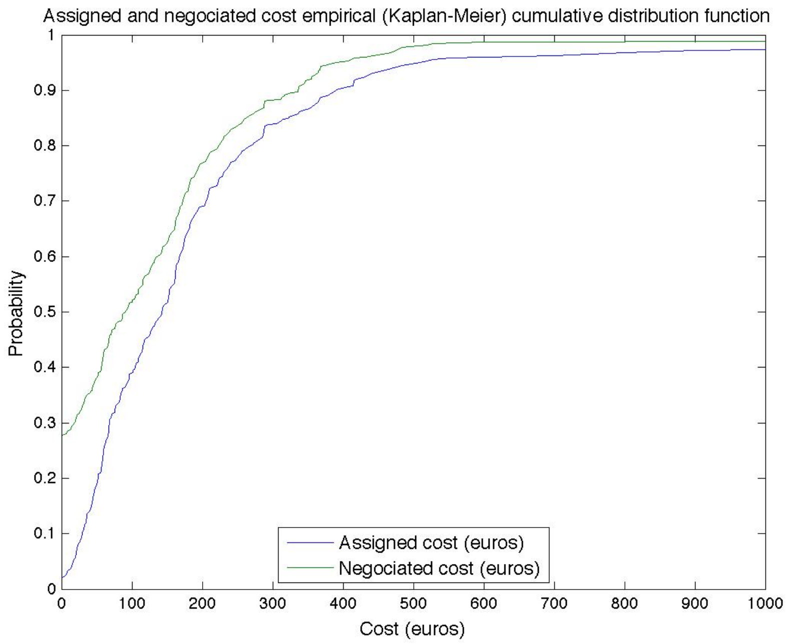
Severe delays

Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	321	400	352	364	360	364	365	358	361
>5min	463	309	385	337	349	345	349	350	343	346
>10min	344	256	301	274	278	276	278	279	277	277
>15min	201	174	193	184	184	184	183	183	184	183
>30min	0	65	39	59	55	56	55	55	56	56
>60min	0	6	1	1	1	1	1	1	1	1
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	33705	42000	36960	38220	37800	38220	38325	37590	37905
>5min	48615	32445	40425	35385	36645	36225	36645	36750	36015	36330
>10min	36120	26880	31605	28770	29190	28980	29190	29295	29085	29085
>15min	21105	18270	20265	19320	19320	19320	19215	19215	19320	19215
>30min	0	6825	4095	6195	5775	5880	5775	5775	5880	5880
>60min	0	630	105	105	105	105	105	105	105	105

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	99	17.36	15.77	15.77	10.64	0.69	2.81	8.28	13.98	47.30
Reduced delay (min)	137	-12.54	-15.05	-13.62	5.31	-0.32	2.30	4.45	8.39	-23.65
Improved cost (euros)	98	115.26	56.00	108.80	75.74	1.08	5.06	59.22	107.20	419.10
Deteriorated cost (euros)	137	-341.66	-182.00	-224.00	408.64	2.94	238.38	11.72	225.00	-2200.00
Slot payers (euros)	139	-145.23	-156.00	-115.20	146.02	3.68	20.95	85.43	105.05	-1100.00
Slot payees (euros)	104	194.10	156.00	162.70	203.01	3.07	14.57	119.50	129.50	1330.40





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
FIX:G2	16.19 %	88.20 min	-59.10 euros	2572.25 euros
TA1	52.00 %	172.80 min	-142.30 euros	3075.10 euros
TA2	31.81 %	40.50 min	-535.90 euros	1099.35 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
G2	16.19 %	88.20 min	-59.10 euros	2572.25 euros
M0	31.81 %	40.50 min	-535.90 euros	1099.35 euros
T0	6.29 %	63.00 min	139.30 euros	759.75 euros
T1	28.95 %	96.30 min	-227.40 euros	2190.85 euros
T2	16.76 %	13.50 min	-54.20 euros	124.50 euros

7.1.4 Realistic scenario

7.1.4.1 Results overview for scenario realistic-CS3

Overall figures

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Total delay (min)	6496.26	6496.17	6496.14	6496.21	6496.21	6496.21	6496.21	6496.21	6496.22	6496.22
Total cost (euros)	108357.90	78098.10	79450.10	73668.20	73220.10	73327.50	73843.50	73442.70	73375.50	73375.50

Agent interactions

	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
Delay exchanged (min)	0	1453.00	1305.84	1681.83	1672.37	1627.93	1603.56	1612.88	1635.10	1635.10
Economic exchange (euros)	0	18057.65	16340.00	21279.92	21564.05	21228.85	20452.75	21069.85	21461.55	21461.55
Slots swapped	0	202.00	197.00	237.00	231.00	225.00	231.00	225.00	233.00	233.00
Cost reduction (%)	0	27.93	26.68	32.01	32.43	32.33	31.85	32.22	32.28	32.28
Maximum profit (euros)	0	956.00	1700.00	1700.00	1700.00	1700.00	1700.00	1700.00	1700.00	1700.00

FPFS relative indicators

	r1	r2	r3	r4	r5	r10	r15	r20	r30
Flights reducing delay	122	118	143	139	137	136	136	138	138
Average delay reduction (min)	-11.91	-11.07	-11.76	-12.03	-11.88	-11.79	-11.86	-11.85	-11.85
Flights improving cost	122	118	143	139	137	136	136	138	138

Average cost reduction (euros)	- 317.22	- 303.49	- 307.72	- 318.38	- 321.25	- 318.99	- 321.86	- 318.08	- 318.08
Flights profiting from exchange	92	96	108	105	103	107	103	108	108
Average profit per slot (euros)	196.28	170.21	197.04	205.37	206.11	191.15	204.56	198.72	198.72
Flights increasing delay	80	79	94	92	88	95	89	95	95
Average delay increase (min)	18.16	16.53	17.89	18.18	18.50	16.88	18.12	17.21	17.21
Flights worseing cost	78	79	92	90	86	93	87	93	93
Average cost increase (euros)	108.22	87.39	101.24	101.31	104.43	95.36	101.82	95.83	95.83
Flights paying for exchanges	131	118	151	149	146	146	146	149	149
Average cost per slot (euros)	137.84	138.47	140.93	144.73	145.40	140.09	144.31	144.04	144.04

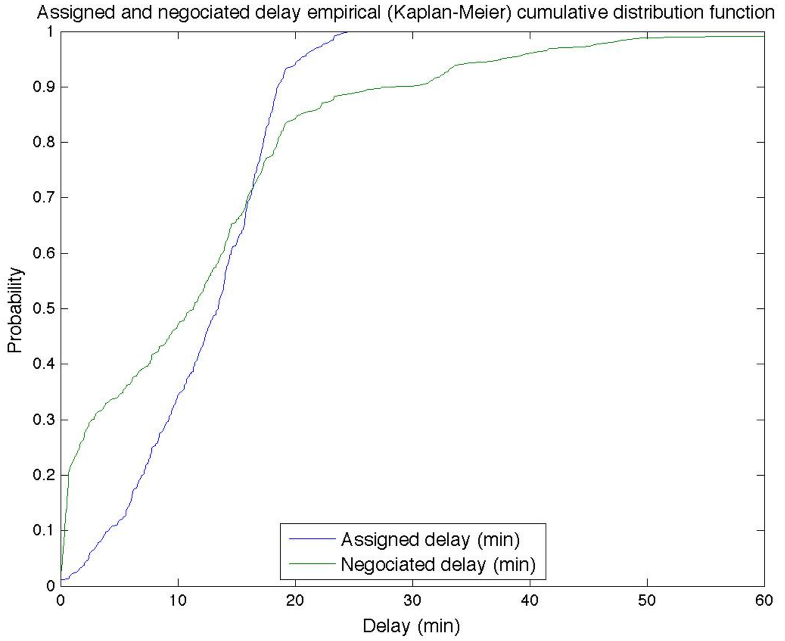
Severe delays

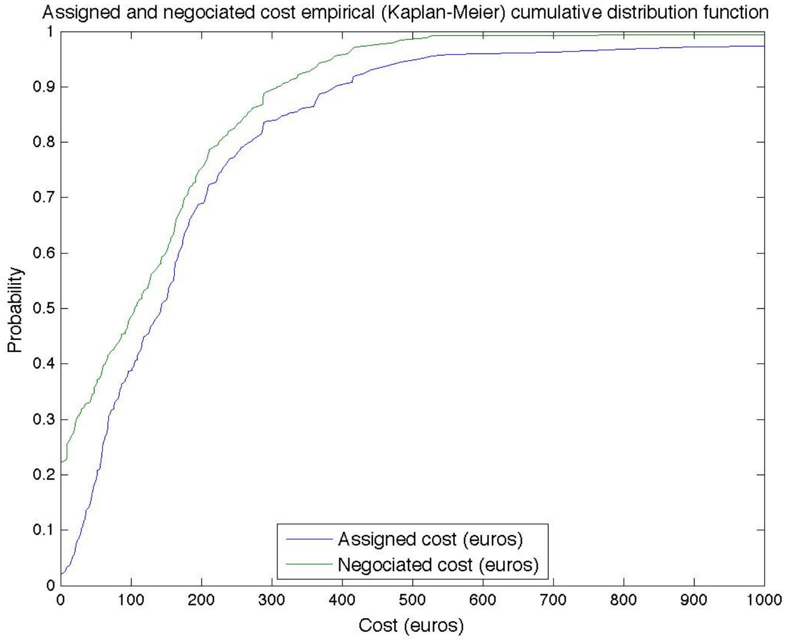
Flights delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	488	376	389	358	360	363	364	364	362	362
>5min	463	363	360	344	343	347	347	348	345	345
>10min	344	286	286	271	274	275	279	276	277	277
>15min	201	183	182	177	175	178	180	179	178	178
>30min	0	46	44	54	50	52	53	53	52	52
>60min	0	3	1	5	6	6	3	5	5	5
Pax delayed	FSFP	r1	r2	r3	r4	r5	r10	r15	r20	r30
>3min	51240	39480	40845	37590	37800	38115	38220	38220	38010	38010
>5min	48615	38115	37800	36120	36015	36435	36435	36540	36225	36225
>10min	36120	30030	30030	28455	28770	28875	29295	28980	29085	29085
>15min	21105	19215	19110	18585	18375	18690	18900	18795	18690	18690
>30min	0	4830	4620	5670	5250	5460	5565	5565	5460	5460
>60min	0	315	105	525	630	630	315	525	525	525

Final round detailed results

	Number of flights	Average	Mode	Median	Std. deviation	Skewness	Kurtosis	Mean abs. deviation	Interquartile range	Maximum
Increased delay (min)	95	17.21	17.20	15.77	13.15	1.35	5.27	9.29	14.51	66.72
Reduced delay (min)	138	-11.85	- 15.77	- 12.90	5.71	-0.20	2.10	4.91	9.31	-23.65
Improved cost (euros)	93	95.83	32.00	76.00	71.42	1.21	5.71	57.33	96.85	412.80
Deteriora	138	-	-	-	405.77	2.58	260.9	9.69	271.60	-

ted cost (euros)		318.08	144.00	175.00			4			2200.00
Slot payers (euros)	149	-144.04	-163.20	-115.20	177.12	5.67	45.19	88.91	114.07	-1700.00
Slot payees (euros)	108	198.72	163.20	163.20	222.64	3.83	22.89	127.23	148.00	1700.00





Particular tactics

Tactics

tactic	popularity	delay trade-off	cost trade-off	economic trade-off
FIX:G1	16.19 %	148.50 min	626.20 euros	1853.25 euros
TA0	28.19 %	108.90 min	246.00 euros	1738.45 euros
TA1	3.62 %	0.90 min	4.00 euros	8.70 euros
TA2	52.00 %	336.60 min	1794.00 euros	4635.25 euros

Strategies

strategy	popularity	delay trade-off	cost trade-off	economic trade-off
G0	9.33 %	43.20 min	106.20 euros	711.60 euros
G1	17.90 %	165.60 min	755.30 euros	2117.80 euros
G2	17.14 %	48.60 min	10.70 euros	762.30 euros
M0	46.86 %	305.10 min	1587.20 euros	4116.95 euros
M1	5.14 %	31.50 min	206.80 euros	518.30 euros
T0	2.10 %	0.00 min	0.00 euros	0.00 euros
T1	0.38 %	0.00 min	0.00 euros	0.00 euros
T2	1.14 %	0.90 min	4.00 euros	8.70 euros

7.3 Appendix 2 - Case Study configuration

7.3.1 Airline capability

The capability for airlines calculates the cost of affected ATM slots, generates bids for the best slots of an airline and evaluates the received bids of other airlines. Below are the header and the footer of the file *reschedule.capability.xml*, located in the *simulator.airline* package.

```
<?xml version="1.0" encoding="UTF-8"?>
<!--
    <H3>Airline: Case Study 2</H3>
    Define Beliefs
-->
<capability xmlns="
    xmlns:xsi="
    xsi:schemaLocation="http://jadex.sourceforge.net/jadex

    name="Reschedule"
    package="simulator.airline">
  <!-- Behavior elements -->
</capability>
```

The description includes several beliefs (see below XML description). Some of them are inherited from the airline definition, such as the ICAO, type, homebase, simulation and round. The specific beliefs have the following meaning:

- *flights:* list of flights associated with an airline.
- *affected_flights:* list of affected flights that have been reassigned.
- *global_strategy:* bidding and selling strategies used by the airline. Figure 3.2 illustrates the Java implementation of this class.
- *StrategiesAFPs:* current value of the parameters of each affected flight for the strategies of the airline.
- *sent_bids:* list of bids proposed by the airline (maximum one per flight).

```
<beliefs>
  <beliefref name="simulation" >
    <abstract/>
  </beliefref>
  <beliefref name="round" >
    <abstract />
  </beliefref>
```

```
  <beliefref name="icao" >
    <abstract />
  </beliefref>
  <beliefref name="type">
    <abstract />
  </beliefref>
  <beliefref name="homebase" >
    <abstract />
  </beliefref>
  <belief name="flights" class="ArrayList" />
  <belief name="affected_flights" class="ArrayList" />
  <beliefref name="global_strategy">
    <abstract />
  </beliefref>
  <belief name="strategiesAFPs" class="HashMap" />
  <belief name="sent_bids" class="List" />
</beliefs>
```

There is a unique goal (see below XML description), *cms_search_components*. It is inherited from the airline agent. No more goals are required as the *Network Manager* manages the execution and the actions taken by the airlines are dispatched with events.

```
<goals>
  <achievegoalref name="cms_search_components">
    <abstract />
  </achievegoalref>
</goals>
```

This definition includes a plan for each reasoning step (see below XML description):

- *initialize*. Creates an airline agent initializing its beliefs.
- *costDelayComputation*. Calculates the cost delay of every affected flight plan when a *notify_affected_flights* message is received.
- *generateBidsPlan*. If there is some slot better than the slot assigned for each affected flight plan the agent bids for the slot (according to the current bidding strategy). It is performed when airline receives a *request_bids* message.
- *evaluateBid*. Evaluates a proposed exchange of slot. The agent will accept/reject the exchange according to the selling strategy that it's using. This plan is dispatched when a message *proposed_bid* is received.
- *updateStrategies*. Updates the parameters of strategies (for each flight plan) when a round has ended and a *notify_end_round* message is received.

- *updateTactic*. Updates the parameters of tactic for the next simulation when a message of type *update_tactic* is received.

```
<plans>
  <plan name="initialize">
    <body class="AirlineInitializationPlan"/>
  </plan>
  <plan name="costDelayComputation" >
    <body class="CostDelayComputationPlan"/>
    <trigger>
      <messageevent ref="notify_affected_flights"/>
    </trigger>
  </plan>
  <plan name="generateBidsPlan" >
    <body class="GenerateBidsPlan"/>
    <trigger>
      <messageevent ref="request_bids" />
    </trigger>
  </plan>
  <plan name="evaluateBid">
    <body class="EvaluateBidProposalPlan"/>
    <trigger>
      <messageevent ref="proposed_bid"/>
    </trigger>
  </plan>
  <plan name="updateStrategies">
    <body class="UpdateStrategiesPlan"/>
    <trigger>
      <messageevent ref="notify_end_round"/>
    </trigger>
  </plan>
  <plan name="updateTactic">
    <body class="UpdateTacticPlan"/>
    <trigger>
      <messageevent ref="update_tactic"/>
    </trigger>
  </plan>
</plans>
```

There are several message events to perform the desired behaviour:

- *inform_initialized*: outgoing message that notifies the Network Manager that the airline has been initialized and it is ready to start the execution (internal control).
- *notify_affected_flights*: incoming message which contains the list of affected flights of the airline.
- *delay_computation_ready:* outgoing message which informs to the Network Manager that the airline has finished the cost delay computation.
- *new_bids_set:* outgoing message which notifies to Network Manager the list of proposals of slots exchanges.
- *proposed_bid:* incoming message which informs of an offer for a slot property of the airline.
- *accept_proposed_bid*: outgoing message which accepts a proposed offer of exchange by another airline.
- *reject_proposed_bid*: outgoing message which rejects a proposed offer of exchange by another airline.
- *request_bids*: incoming message which request the shipment of new slot exchanges.
- *notify_end_round*: incoming message that notifies the end of a round of exchanges of slots.
- *ready_for_next_round*: outgoing message that notifies to the Network Manager that the airline has updated its strategies (ready for the next round).
- *update_tactic*: incoming message which notifies the end of the current simulation.
- *update_tactic_response*: outgoing message which informs to the Network Manager that the airline has updated its tactic and it is ready to go for the next simulation.

```
<events>
  <messageevent name="inform_initialized" direction="send" type="fipa">
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.CONFIRM</value>
    </parameter>
  </messageevent>
  <messageevent name="notify_affected_flights" type="fipa" direction="receive" >
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.INFORM</value>
    </parameter>
    <match>$content instanceof AffectedAirline</match>
  </messageevent>
  <messageevent name="delay_computation_ready" type="fipa" direction="send" >
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.INFORM</value>
    </parameter>
  </messageevent>
  <messageevent name="new_bids_set" type="fipa" direction="send" >
    <parameter name="performative" class="String" direction="fixed">
```

```
      <value>SFipa.INFORM</value>
    </parameter>
  </messageevent>
  <messageevent name="proposed_bid" type="fipa" direction="receive" >
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.PROPOSE</value>
    </parameter>
    <match>($content instanceof Bid)</match>
  </messageevent>
  <messageevent name="accept_proposed_bid" type="fipa" direction="send" >
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.ACCEPT_PROPOSAL</value>
    </parameter>
  </messageevent>
  <messageevent name="reject_proposed_bid" type="fipa" direction="send" >
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.REJECT_PROPOSAL</value>
    </parameter>
  </messageevent>
    <messageevent name="request_bids" type="fipa" direction="receive" >
      <parameter name="performative" class="String" direction="fixed">
        <value>SFipa.REQUEST</value>
      </parameter>
      <match>($content instanceof int)</match>
    </messageevent>
    <messageevent name="notify_end_round" type="fipa" direction="receive" >
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.INFORM</value>
       </parameter>
       <match>($content instanceof MessageNotifyEndRound)</match>
    </messageevent>
    <messageevent name="ready_for_next_round" type="fipa" direction="send" >
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.CONFIRM</value>
       </parameter>
    </messageevent>
    <messageevent name="update_tactic" type="fipa" direction="receive" >
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.INFORM</value>
```

```
        </parameter>
        <match>($content instanceof MessageUpdateTactic)</match>
    </messageevent>

<messageevent name="update_tactic_response" type="fipa" direction="send" >
        <parameter name="performative" class="String" direction="fixed">
              <value>SFipa.CONFIRM</value>
        </parameter>
    </messageevent>
</events>
```

These are the required libraries for the capability:

```
<imports>
<import>jadex.bridge.fipa.*</import>
<import>simulator.environment.*</import>
<import>simulator.*</import>
<import>simulator.cs2.*</import>
<import>java.util.ArrayList</import>
<import>java.util.LinkedHashMap</import>
<import>simulator.cs2.messages.*</import>
</imports>
```

7.3.2 Network Manager

The *Network Manager* agent controls the execution and creates the airline agent instances. This case study extends the general definition of the manager agent (see the general definition in the deliverable D.3.4 System Implementation). Below are the header and the footer of the file *NetworkManager.agent.xml*, located in the *simulator.cs2.netManager* package.

```
<?xml version="1.0" encoding="UTF-8"?>
<!--
    <H3>Network Manager</H3>
    <h5>Case Study 2</h5>
    Version 2.6<br>
    Author: Sergio Carrasco Herranz
-->
<agent xmlns="
```

```
    xmlns:xsi="
    xsi:schemaLocation="http://jadex.sourceforge.net/jadex

    name="NetworkManager"
    package="simulator.cs2.netManager">
<!-- Behavior elements -->
</agent>
```

This agent uses one capability (see the below XML description), *cmscap*, for starting airline agents.

```
<capabilities>
  <!-- Predefined capability to start other agents. -->
  <capability name="cmscap" file="jadex.bdi.planlib.cms.CMS"/>
</capabilities>
```

The agent has several beliefs (see below). Some of these have a constant initial value as it is common to all simulations. Other beliefs are initialized by the Java plan because their initial values are dynamic.

- *simulation*: simulation data for the current simulation (identifier, regulation…).
- *round*: number of the current round. Updated at the beginning of each round.
- *flights:* list of all loaded flights (from the database) in the current simulation.
- *airlines:* list of all airlines loaded.
- *bids*: list of all bids proposed by all agents in the current round. Updated within each round.
- *replied_bids:* number of bids notified to the owner of requested slot in a bid (internal counter).
- *slots*: list of all affected slots by the regulation.
- *affected_airlines*: list of affected airlines by the regulation.
- *affected_flights*: list of affected flights by the regulation.
- *total_exchanges*: number of accepted exchanges of slots in the current round. Updated at the end of each round.
- *start_time*: time when the simulator was started (for execution time control).
- *sim_start_time*: time when the current simulation was started (for execution time control). Updated at the start of every simulation.
- *previous_simulations*: list of simulations run before the current simulation.
- *strategies_AFPs:* list of strategies parameters used by each AFP of every airline in each round.

```
<beliefs>
  <belief name="simulation" class="Simulation" />
```

```
  <belief name="round" class="int">
    <fact>0</fact>
  </belief>
  <belief name="flights" class="List" />
  <belief name="airlines" class="LinkedHashMap" />
  <belief name="bids" class="List" />
  <belief name="replied_bids" class="long">
    <fact>0</fact>
  </belief>
  <belief name="slots" class="List" />
  <belief name="affected_airlines" class="List" />
  <belief name="affected_flights" class="List" />
  <belief name="total_exchanges" class="int" />
  <belief name="start_time" class="long">
   <fact>System.currentTimeMillis()</fact>
  </belief>
  <belief name="sim_start_time"  class="long">
    <fact>System.currentTimeMillis()</fact>
  </belief>
  <belief name="previous_simulations" class="ArrayList">
   <fact>new ArrayList()</fact>
  </belief>
  <belief name="strategies_AFPs" class="HashMap" />
</beliefs>
```

The agent has six goals:

- *cms_create_component*. Create components through the CMS component in the simulator (part of the predefined capability).
- *regulate_flights.* Distribute the delay causes by the regulation among all affected flights, and notify the new assignments to the airline agents.
- *new_slot_exchange_round*: Start a new round and direct the exchange of slots between airlines.
- *update_slot_distribution*: Update the slot distribution of slots (exchanges slots of accepted bids).
- *create_cs2_indicators*: Calculate the indicators when all rounds have been completed.
- *new_strategy_simulation*: Create a new simulation with the same flights (each airline agent will update its tactic before start the new simulation).

```
<goals>
```

```
    <achievegoalref name="cms_create_component">
      <concrete ref="cmscap.cms_create_component"/>
    </achievegoalref>

    <!-- Performs goals -->
    <performgoal name="regulate_flights" />
    <performgoal name="new_slot_exchange_round" />
    <performgoal name="update_slot_distribution" />
    <performgoal name="create_cs2_indicators" />
    <performgoal name="new_strategy_simulation" />
</goals>
```

There are six plans to achieve these goals, one plan for each goal, and another one to initialize the environment:

- *initialize*. Load the simulated flights, the strategies of agents and create the agents.
- regulateFlights. Achieve the objectives of goal *regulate_flights.*
- *newSlotsExchange*. Achieve the objectives of goal *new_slot_exchange_round.*
- *updateSlotDistribution*. Achieve the objectives of goal *update_slot_distribution.*
- *createCS2Indicators*. Achieve the objectives of goal *create_cs2_indicators.*
- *newStrategySimulationPlan*. Achieve the objectives of goal *new_strategy_simulation.*

```
<plans>
  <plan name="initialize" >
   <body class="NetworkManagerInitializationPlan" />
   <waitqueue>
     <messageevent ref="inform_initialized" />
   </waitqueue>
  </plan>
  <!-- Find affected flights by the regulation -->
   <plan name="regulateFlights" >
    <body class="RegulateFlightsPlan" />
    <trigger>
      <goal ref="regulate_flights" />
    </trigger>
    <waitqueue>
      <messageevent ref="delay_computation_ready" />
```

```
    </waitqueue>
  </plan>
  <!-- Update the slot and cost distribution -->
  <plan name="updateSlotDistribution" >
    <body class="UpdateSlotDistributionPlan" />
      <trigger>
        <goal ref="update_slot_distribution" />
      </trigger>
      <waitqueue>
        <messageevent ref="ready_for_next_round" />
      </waitqueue>
  </plan>
  <plan name="newSlotsExchange" >
    <body class="NewRoundSlotsExchangePlan" />
    <trigger>
      <goal ref="new_slot_exchange_round" />
    </trigger>
    <waitqueue>
      <messageevent ref="new_bids_set" />
    </waitqueue>
  </plan>
  <!-- Create the indicators -->
  <plan name="createCS2Indicators" >
    <body class="CreateIndicatorsPlan" />
    <trigger>
      <goal ref="create_cs2_indicators"/>
    </trigger>
  </plan>
  <!-- Create a new simulation with the next strategy -->
  <plan name="newStrategySimulationPlan" >
    <body class="NewStrategySimulationPlan" />
    <trigger>
      <goal ref="new_strategy_simulation"/>
    </trigger>
    <waitqueue>
      <messageevent ref="update_tactic_response" />
    </waitqueue>
  </plan>
</plans>
```

There are several events for interact with the airline agents (exchange of messages):

- *inform_initialized*: incoming message sent by an airline informing that it has been initialized and it is ready to start the execution.
- *notify_affected_flights*: outgoing message which contains the list of affected flights of the airline that receives this message.
- *delay_computation_ready:* incoming message which informs that an airline has finished its cost delay computation.
- *new_bids_set:* incoming message which notifies the list of proposals of slots exchanges of an airline.
- *proposed_bid:* outgoing message which informs of an offer for a slot of message receiver.
- *accept_proposed_bid*: incoming message which informs about the acceptance of a proposed offer of exchange.
- *reject_proposed_bid*: incoming message which informs about the rejection of a proposed offer of exchange.
- *request_bids*: outgoing message which request the shipment of new slot exchanges.
- *notify_end_round*: outgoing message that notifies the end of a round of exchanges of slots to an airline agent.
- *ready_for_next_round*: incoming message that notifies that an airline has updated its strategies (ready for the next round).
- *update_tactic*: outgoing message which notifies the end of the current simulation to an airline.
- *update_tactic_response*: incoming message which informs that an airline has updated its tactic and it's ready to go for the next simulation.

```
<events>
  <messageevent name="inform_initialized" direction="receive" type="fipa">
    <parameter name="performative" class="String" direction="fixed" >
      <value>SFipa.CONFIRM</value>
    </parameter>
    <match>($content instanceof String) &amp;&amp;
           ($content.equals("inform_initialized"))
    </match>
  </messageevent>
  <messageevent name="notify_affected_flights" direction="send" type="fipa">
    <parameter name="performative" class="String" direction="fixed">
         <value>SFipa.INFORM</value>
      </parameter>
  </messageevent>
  <messageevent          name="delay_computation_ready"          type="fipa"
direction="receive" >
```

```
    <parameter name="performative" class="String" direction="fixed">
      <value>SFipa.INFORM</value>
    </parameter>
    <match>($content instanceof MessageDelayComputationReady)</match>
  </messageevent>
    <messageevent name="new_bids_set" type="fipa" direction="receive" >
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.INFORM</value>
       </parameter>
       <match>($content instanceof ArrayList)</match>
    </messageevent>
    <messageevent name="proposed_bid" type="fipa" direction="send" >
       <parameter name="conversation_id" class="String">
          <value>SFipa.createUniqueId($scope.getAgentName())</value>
       </parameter>
       <parameter name="performative" class="String" direction="fixed">
          <value>SFipa.PROPOSE</value>
       </parameter>
    </messageevent>
    <messageevent name="accept_proposed_bid" type="fipa" direction="receive"
>
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.ACCEPT_PROPOSAL</value>
       </parameter>
       <match>($content instanceof Bid)</match>
    </messageevent>
    <messageevent name="reject_proposed_bid" type="fipa" direction="receive"
>
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.REJECT_PROPOSAL</value>
       </parameter>
       <match>($content instanceof Bid)</match>
    </messageevent>
    <messageevent name="request_bids" type="fipa" direction="send" >
       <parameter name="performative" class="String" direction="fixed">
             <value>SFipa.REQUEST</value>
       </parameter>
    </messageevent>
    <messageevent name="notify_end_round" type="fipa" direction="send" >
       <parameter name="performative" class="String" direction="fixed">
```

```
                <value>SFipa.INFORM</value>
        </parameter>
    </messageevent>
    <messageevent name="ready_for_next_round" type="fipa"
direction="receive" >
        <parameter name="performative" class="String" direction="fixed">
                <value>SFipa.CONFIRM</value>
        </parameter>
        <match>($content instanceof MessageReadyForNextRound)</match>
    </messageevent>
    <messageevent name="update_tactic" type="fipa" direction="send" >
        <parameter name="performative" class="String" direction="fixed">
                <value>SFipa.INFORM</value>
        </parameter>
    </messageevent>
    <messageevent name="update_tactic_response" type="fipa"
direction="receive" >
        <parameter name="performative" class="String" direction="fixed">
                <value>SFipa.CONFIRM</value>
        </parameter>
        <match>($content instanceof MessageUpdateTacticResponse)</match>
    </messageevent>
</events>
```

It is configured to start the *initialize* plan at the initial time.

```
<configurations>
  <configuration name="standard">
    <plans>
      <initialplan ref="initialize" />
    </plans>
  </configuration>
</configurations>
```

Below are the required libraries for this agent.

```
<imports>
  <import>jadex.bridge.fipa.*</import>
  <import>simulator.cs2.*</import>
  <import>simulator.environment.*</import>
  <import>java.util.ArrayList</import>
```

```
  <import>java.util.LinkedHashMap</import>
  <import>simulator.airline.*</import>
  <import>simulator.cs2.messages.*</import>
</imports>
```

7.3.3 Application

The application file (contained in the package *simulator*) has two component types: airline and Network Manager. The application file starts the Network Manager and controls the execution creating the airline agents.

```
<?xml version="1.0" encoding="UTF-8"?>
<!--
  <h2>Case Study 2 : Airspace capacity constraint</h2>
-->
<applicationtype xmlns="
    xmlns:xsi="
    xsi:schemaLocation="http://jadex.sourceforge.net/jadex

    name="CS2" package="simulator">
    <!-- Version 2.0 -->
    <imports>
      <import>java.lang.String</import>
      <import>java.util.Date</import>
      <import>simulator.cs2.netManager.*</import>
    </imports>

    <arguments>
      <!-- Regulation attributes -->
      <argument name="Regulation name" class="String" />
      <argument name="Initial time" class="String" />
      <argument name="Final time" class="String" />
      <argument name="Current time" class="String" />
      <argument name="Intensity" class="String" />
      <argument name="Number of rounds" class="int" />
      <argument name="Number of simulations" class="int" />
        <argument name="Strategies definition file" class="String" />
      <argument name="Timeout of bidding (secs)" class="int" />
      <argument name="Already delayed time (secs)" class="int" />
```

```
    </arguments>

    <componenttypes>
      <componenttype name="NetworkManager"
              filename="simulator/cs2/netManager/NetworkManager.agent.xml"/
>
    </componenttypes>

    <configurations>
         <!-- Predefined scenarios -->
       </configurations>

    <properties>
        <!-- Output log -->
        <property name="logging.level">
                java.util.logging.Level.ALL
             </property>
        <property name="logging.level.exceptions">
                java.util.logging.Level.ALL
             </property>
        <property name="debugging">true</property>
        <!-- Print log messages to console -->
        <property name="logging.useParentHandlers">true</property>
    </properties>
</applicationtype>
```

Between the tags *<configuration></configuration>* (see below) a set of predefined scenarios for Case Study 2 have been defined to facilitate the execution of each scenario without the necessity of changing the arguments of this application file. For example, the following code shows the definition of a configuration for the scenario *CS0-Calibration*:

```
 <configurations>
  <!-- Calibration-CS0-->
  <configuration name="Calibration-CS0">
    <!-- Default value for the arguments -->
    <arguments>
      <argument            name="Regulation            name">&quot;Capacity
restriction&quot;</argument>
      <argument            name="Initial            time">&quot;2011-07-10
14:00:00&quot;</argument>
        <argument            name="Final            time">&quot;2011-07-10
```

```
17:00:00&quot;</argument>
        <argument name="Intensity">&quot;20%&quot;</argument>
        <argument name="Current time">&quot;2011-07-10 13:30:00&quot;</argument>
        <argument name="Number of rounds">5</argument>
        <argument name="Number of simulations">1</argument>
        <argument name="Timeout of bidding (secs)">300</argument>
        <argument name="Already delayed time (secs)">900</argument>
        <argument name="Strategies definition file">"strategies.CS0_0.xml"</argument>
    </arguments>
    <!-- Started component -->
    <components>
      <component type="NetworkManager" name="NETMA" configuration="standard"
        master="true"/>
    </components>
  </configuration>
</configurations>
```

7.4 Appendix 3 - Software installation and execution

This page contains the files and the procedure to install and execute the simulator. Both procedures are further explained in D3.5.

The simulator has been tested in the following platforms:

- Intel i5@2Ghz with 8GB RAM and Windows 7 Professional
- Intel i7@1.6Ghz with 4GB RAM and Ubuntu 12.04 LTS
- Intel i7@1.6Ghz with 4GB RAM and Windows 7 Professional
- **There exists however compatibility problems using Jadex and Windows Server.**

The duration of a simulation is about 1min. The duration of a complete execution depends on the number of simulations/executions specified as a parameter of the execution.

Following are the steps followed in the installation procedure:

1. Install Java JRE 7 from Oracle.com
2. Install MySQL installer 5.6 from mysql.com (Requires Net Framework 4).
3. Install the server and MySQL Workbench (Import data and export simulation results)
4. Download the dump file.
5. Import the previous dump file to the database
6. Create a user in the database server using
7. User: cass
8. Pass: cassiopeia
9. This user uses the following statements: INSERT, SELECT, UPDATE, DELETE, EXECUTE
10. Download the simulator CS2 package (see table below, contains all required libraries)
11. Extract the downloaded package. It's ready to simulate.

The default scenario to execute is CS0. All defined scenarios have a configuration predefined (see table below). To choose them, show the help in the main frame of the simulator.

1. Execute *'**run_cs2Simulator.bat' (windows)*** or *'**run_cs2Simulator.sh' (Linux)*** located in the root folder of the package downloaded.
2. *Add the downloaded file (and moved into the \lib folder) 'cs2Simulatorv2_x.jar' (**only if it isn't)**.*
3. *Uncollapse the binary 'cs2Simulatorv2_x.jar' and clic on CS2.application.xml (**only if not in it)**.*
4. Now all predefined configuration will appear in the list-menu '*configuration*'. Select one.
5. Press start, you can see a start message in the terminal and a timestamp and several log messages will appear.
6. Wait for the end of the simulation. The terminal window will show an end message and the simulator will be closed. If no exceptions have been thrown, all worked fine.

To run a new simulation, close current console and repeat the step 1-5 (skip steps 2-3 if not necessary)