



Executive summary

Preventing Selfish Behaviour in Distributed Tactical Airport Planning

Problem area

With the introduction of advanced planning concepts in the CDM framework, the possibility to “cheat the system” will start being exploited. Instead of a co-operative attitude of participants, as often assumed in research on distributed planning, participants will show competitive behaviour. This may lead to suboptimal performance, as participants care more about their own preferences than those of others. Thus, incentives for co-operative behaviour are needed.

Description of work

In this paper, we sketch a future scenario in which arrival, gate, and departure planning is handled distributed by airlines, airports, aircraft, and other parties involved. We present a collaboration framework that does not allow exploitation of strategically advantageous positions. All airlines can participate and are rewarded for a positive attitude. We propose the use of money as a means of providing incentives to collaborate, to ensure equitability, and to find optimal solutions. We introduce a monetary system based on spender-signed money that solves the problem of selfish behaviour.

Airlines that manipulate the planning process to obtain an unfair advantage over others are automatically punished as a result of the spender-signed monetary system.

Results and conclusions

We have performed experiments in which it shows that selfish behaviour can be detected and even countered with the building of coalitions against cheating actors. Simulations prove that cheating will give an initial benefit for one or two times, but afterwards will work in ones disadvantage.

Applicability

In any application area where collaboration is required between parties that serve their own interest the proposed method can be applied to achieve efficient and equitable co-operation. If, for instance, Free Flight would in the future be extended to include communication of intent or preference information, exploitation should surely be prevented. As another application example, the business trajectory as now proposed in SESAR lends itself very well for the described approach.

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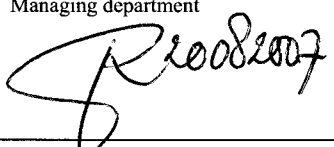
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Summary

In this paper, we sketch a future scenario in which arrival, gate and departure planning is done distributedly by airlines, airports, aircraft and other parties involved. Decision responsibility is shared among multiple parties instead of one. When disruptions occur, plan repair schemes are collaboratively constructed and selected. This results in a plan repair mechanism that takes into account the preferences of all participants. Often in distributed planning research, a cooperative attitude of the participants is assumed. However, it is possible that participants will show a competitive rather than a cooperative attitude. Competitive behaviour can lead to suboptimal performance, as participants care more about their own preferences than those of others. Thus, incentives for cooperative behaviour are needed. We propose the use of money as a means of providing incentives to collaborate, to ensure equitability and to find optimal solutions. We identify a problem that occurs with the use of ordinary money. We introduce a monetary system based on spender-signed money that solves the problem of selfish behaviour.

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PREVENTING SELFISH BEHAVIOUR IN DISTRIBUTED TACTICAL AIRPORT PLANNING

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Abstract: In this paper, we sketch a future scenario in which arrival, gate and departure planning is done distributedly by airlines, airports, aircraft and other parties involved. Decision responsibility is shared among multiple parties instead of one. When disruptions occur, plan repair schemes are collaboratively constructed and selected. This results in a plan repair mechanism that takes into account the preferences of all participants. Often in distributed planning research, a cooperative attitude of the participants is assumed. However, it is possible that participants will show a competitive rather than a cooperative attitude. Competitive behaviour can lead to suboptimal performance, as participants care more about their own preferences than those of others. Thus, incentives for cooperative behaviour are needed. We propose the use of money as a means of providing incentives to collaborate, to ensure equitability and to find optimal solutions. We identify a problem that occurs with the use of ordinary money. We introduce a monetary system based on spender-signed money that solves the problem of selfish behaviour.

1 Introduction

During a standard day of operation at Amsterdam Airport Schiphol, several aircraft arrive and depart later than scheduled, causing disruptions in the gate allocation process. The gate manager is constantly replanning gates in order to optimize the tactical operations, based on the latest information on arrival and departure traffic. ATC and airlines will be informed about the new plan, but do not have an active involvement in the process.

Involving ATC and airlines in this planning process will increase efficiency of the total airport operations. Hub airlines are faced with delays but are the one party to have good insight in the circumstances concerning the transfer of passengers. ATC can be involved through the arrival and departure management process.

In current innovative ATM and airport programs and research, there is a trend to *distribute decision making processes*. This ranges from *information sharing* to *distributed planning and scheduling*, mostly in the context of the U.S. and European Collaborative Decision Making (CDM) programs. In the *Total Airport Management (TAM)* concept [12] current airport optimisation systems evolve from the situation where they act as individual support tools to become components of an integrated airport information architecture that constitutes a holistic decision-support processes for all airport partners.

Examples of the trend to distribute decision processes include the Free Flight paradigm [9], in which aircraft jointly decide on flight paths and conflict resolution, arrival self spacing and merging [4], inbound priority sequencing [8], pre-departure sequencing [14] and the recent *Ground Delay Program Enhancements*, in which airlines have (limited) collaborative planning opportunities.

In general, participants become more actively involved in the decision process than is the case now, either by taking into account submitted information or preferences or by handing over responsibility to them. The shift is from local decision making by independent planners to a distributed environment, where participants act as each others' equals and decisions are taken by subgroups of participants. The benefits are clear: increased information sharing and distributed decision making leads to increased overall quality of the plans.

These new trends also introduce a fundamental problem. The programs mentioned above all assume a *cooperative attitude* of the participants. However, it is not unthinkable that participants will show a *competitive attitude* rather than a cooperative. This is the case in current practice already. Often, it can be commercially attractive for an airline to provide delay information or to cancel a slot as late as possible, to avoid slots from being used by another airline.

If participants have a competitive attitude, a distributed planning system that relies on information sharing and shared responsibility will perform poorly.



As each individual participant will try to maximize its own utility, it might withhold or manipulate information. Also, in joint decisions it will do its best to reach those decisions which are best for itself and ignore the interests of others.

We argue that one should not *assume* a cooperative attitude among the participants, but provide explicit *incentives* for cooperative behaviour. The need for incentives has in fact been mentioned in several CDM and Free Flight studies.

A natural incentive is the monetary incentive. One could financially reward cooperative behaviour or make selfish behaviour costly. This is applying the *market paradigm* to joint decision making. The results have, as we will see, the characteristics of an efficient and equitable decision mechanism. We will show how it also introduces new challenges. As a solution we will introduce a private monetary system which protects users against exploitation of strategic advantages, leading to equitable plan repair.

We will exemplify this in a *distributed tactical airport planning* scenario. In this scenario airlines jointly decide on how to resolve gate planning conflicts. Airlines can cooperate in solving each others conflicts, but can also refuse to help others.

2 Background

In the U.S. and European CDM programs, airlines, pilots and air traffic controllers are asked to make operational information known to others as early as possible, thereby making it possible to plan and replan at an early stage and increase overall planning quality [14, 6]. Current trends include the modelling of preference-based planning techniques that use individual preference functions of airlines, pilots, ground handlers, airports, etc., to determine optimal arrival and departure times [10, 12]. In the CDM programs, a cooperative attitude among the participants is assumed and the provided information is assumed to be true. However, it might very well be beneficial to an individual participant to provide not-so-true information or preferences. It is well known that airlines have a tendency of withholding delay information to avoid negative replanning consequences. Although in one experiment on CDM [2] it was observed that participants were cooperative, in [3] it was argued that participants might start to become competitive once they have familiarized themselves with the new procedures.

Market mechanisms play an increasingly important role in ATM. In the U.S., airlines may trade assigned slots among each other. In Europe, slots may be exchanged among airlines [15]. The use of auctions for initial slot assignment is investigated by both the U.S. and Europe air traffic authorities [21, 15, 5] as well as in several research papers [16, 11]. Other examples of market-based techniques are *congestion pricing* [7] and *peak pricing* [13], which

are techniques that aim to reduce traffic at busy time periods by means of higher prices.

Slot exchange as described above concerns long- and mid-term planning. Slot exchange during the day of operations is to a certain extent made possible in the recent extensions of the *ground delay programs* (GDP's), as part of the U.S. CDM program. GDP's are protocols that specify how arrival slots should be redistributed among airlines when an airport has reached its arrival capacity. The latest extension, Slot Credit Substitution, allows an airline to propose some limited form of rescheduling. It was observed in [1] that this mechanism is only a small step away from a resource market in which airlines trade slots among each other.

2.1 Tactical plan repair

The application domain of this paper is plan repair in arrival, departure and gate planning, which we will call *tactical plan repair*. By plan repair we mean alterations to planning and schedules that are made after the plans have been constructed. Disruptions such as flight delays, cancellations, re-routings, technical failures and weather circumstances can cause plannings to become infeasible. A *repair scheme* solves such planning conflicts by reallocating resources among their users. For instance, if an arriving aircraft is delayed by half an hour, it may cause a conflict on its assigned gate with the aircraft that was assigned on that gate after it. A possible repair scheme could be that the other aircraft waits until the first aircraft leaves or that it is assigned to another gate.

Generally speaking, the goal of plan repair is to solve planning conflicts in such a way that the impact on the overall planning is minimal. There are three criteria ATM planning, and also plan repair, should meet: *punctuality*, *efficiency* and *equity*. By punctuality we mean minimization of the difference between the time an event was planned and the time that it executes. High punctuality means high satisfaction of involved parties. But more important, a high punctuality is an indication of possible excess capacity. If an airport structurally experiences heavy delays, one would not want to schedule more flights. If an airport experiences no delays, there could be room for the scheduling of more flights. Thus, capacity is an underlying goal for the punctuality criterion.

By efficiency we mean the sum of utilities of all involved parties, such as airlines, airport, passengers, ground handlers, governments, etc. Trivially, a higher delay has a lower utility to an airline and its passengers. A gate change has a higher utility for ground handlers if the new gate is not too far from where their equipment is. Governments utilities have to do with noise and emission, which influences planning and repair.

By equity we mean that equal parties should be treated equally. The most important instance is equity between airlines. If an airline feels that it is treated unfairly, be it by discriminating regulations or by receiving an unfairly large share of the plan repair burden, it will protest to the air traffic authorities or even file a lawsuit. The latter, for instance, was the case against the British Airports Authority when they introduced peak pricing rules with the aim of increasing runway throughput [18]. In the case of plan repair, equity means that participants responsible for planning conflicts should bear the burden of solving it, and, when no one is responsible, the burden should be spread out evenly.

Tactical plan repair is currently done manually in an ad-hoc fashion with a limited number of rules of thumb, leading to inefficient repairs. If an aircraft causes a gate conflict, the gate manager manually solves this conflict by scheduling the aircraft at a later moment or at another gate. The major rules concern security, regulations, passenger's level of service, practical solution, and to limit the number of other aircraft/gates involved. Priority rules exist at Schiphol, where airlines from example the Sky Team Alliance (in which Air France/KLM is a member) prefer to be parked close together. Another example is departure plan repair. When an aircraft fails to depart within its time slot, it loses the slot and has to wait until a new slot becomes available. Inter-airline slot exchange mechanisms do not exist, with the exception of the recent GDP extensions.

There are three reasons why tactical plan repair performance is currently suboptimal. First, the fact that plan repair is done by human operators limits the complexity of plan repair schemes considered. Secondly, the equity rule that the causer of a conflict should be the only one affected by the repair limits the number of allowed plan repair schemes. Thirdly, lack of information about status and preferences of the participants involved prevents precise weighing and comparing of different repair schemes. In the next section we will see how the paradigm of *distributed tactical plan repair* alleviates these limitations.

3 Distributed tactical plan repair

We envision a scenario in which the paradigms of *distribution of control* and *market mechanisms* are applied to the tactical plan repair domain, leading to *distributed tactical plan repair*. In this scenario, participants initiate plan repair negotiations and jointly decide on the appropriate plan repair schemes.

We will sketch the scenario. We will use the term *agent* to denote airlines, airports, aircraft, ground handlers, and all other parties involved in tactical plan repair. Initially, a global, feasible planning exists. Due to disruptions, this planning may

become infeasible. An important principle is that the agent responsible for the conflict is responsible for its solution. Note that more than one, even all agents may be responsible, but for now we will assume a single responsible agent each time. The responsible agent initiates a search for repair schemes. This is done by examining several options to solve the conflict, communicating with the agents involved, asking for options and asking for their utilities of the actions required. In fact, it is asking for the *prices* the agents want for their part in the repair. This results in a number of repair schemes, and the corresponding prices that the responsible agent needs to pay to enforce that repair scheme. From these, the agent chooses the scheme with the lowest cost. This scheme is enforced and the corresponding prices are paid. Note that the process described is a *reverse auction*, i.e., an auction with one buyer and more than one possible sellers, where the responsible agent is the buyer.

This mechanism has the following features. It is a *distributed mechanism*, which means that the generation and selection of repair schemes is done by the agents that are involved in or affected by a conflict. In this way multiple conflicts can be resolved simultaneously, without the need for a central problem solver. Secondly, the mechanism achieves *efficient plan repair*, i.e., it minimizes the total effort made by the agents. This is a result of the use of auctions – the repair scheme that requires the least effort of its agents will be least costly and thus be chosen.

Thirdly, if we assume that agents ask fair prices and that agents do not have unlimited wealth, the mechanism achieves *equitable plan repair*. Equitable means that each agent should approximately give as much help to others as it receives. This principle follows from the use of money. An agent that provides help to other agents earns money, which it can spend to receive help when it needs it. An agent can never only receive help without giving help, as it would run out of money at some point.

Thus, the distributed tactical plan repair paradigm provides a basis for efficient and equitable tactical plan repair, where participants have a clear incentive to collaborate and the workload is spread out over all participants. We made one strong assumption however, and that is that the agents ask fair prices, i.e., prices that correspond to the utility of an action. In the next section we will see what happens if this assumption is dropped.

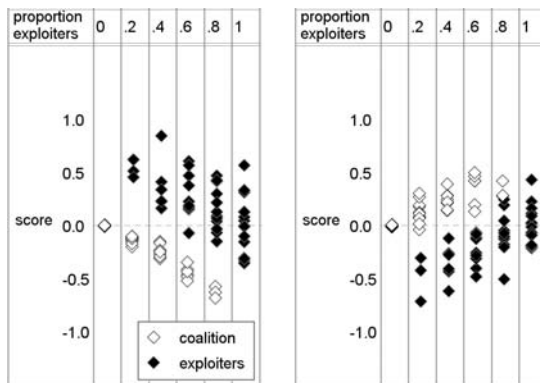


Figure 1. Results of the experiments with coalition agents and exploiters. On the left the experiments of the benchmark scenario. On the right the experiments with collective retaliation. Every column denotes one experiment.

4 Experiments with market mechanisms

4.1 Scenario

At Amsterdam Airport Schiphol 94 gates and 129 other stands are available to allocate aircraft. Schiphol is a hub airport for Air France/KLM. We simulate one week of traffic, in which during normal operation many gate conflicts occur because of late arrival of aircraft from outstations. The length of this period is determined by the need to simulate over a longer period of time in order to be able to measure performance in terms of equity. If on a single day one airline needs a lot of help from another airline, it would be equitable if the other airline is compensated for this in the days following. Usually, one gate conflict has an impact on several other aircraft, which causes the conflict to spread out to up to four (or more) gate re-allocations. In order to keep things controllable in our simulations, we consider situations where four aircraft are involved. One aircraft arrives late and causes a gate conflict with the following aircraft. Then, a number of options for solving the gate conflict are considered, the first being that the following aircraft just waits until the delayed one has departed again. The other options for solving the conflict involve an empty gate being assigned to the late arrival, but in our scenario this will cause a conflict with the aircraft that was originally planned there.

Although simplified above, e.g. buffer positions to disembark passengers are not yet considered, the gate assignment and gate re-allocation process can be modelled in these two types of repair schemes, as the scenario always ends with an aircraft being delayed which now can be the final solution or be the cause of yet another conflict. During a normal arrival peak period at Schiphol, several gate conflicts appear, so

that we can assume in our simplified format 100 gate conflicts to be representative for one week of operations at the airport.

4.2 Exploitation.

In a market with many sellers and many buyers of a given good, if production costs are equal and competition perfect, the selling price will be just above the production cost. In that case, the ask price is an indication of the utility of the seller of producing the good. This is a necessary condition for the market mechanism to be equitable.

However, in the tactical repair market, different sellers sell different goods and as a result, prices need not correspond with utility. Consider the following scenario. Aircraft X is delayed and has a conflict on its gate with aircraft Y, which is scheduled behind it. It considers two repair schemes: 1. aircraft Y waits until X is done and 2. X goes to gate B to disembark its passengers. Aircraft Z, which is scheduled on B, has to wait until X is done. In this example, Y and Z are sellers, selling the service of delaying their flight. Suppose that the utilities of Y and Z in both schemes is equal. Y could then still get away with asking a higher price for its service than Z. This is because Y realizes that for repair scheme 2, X has to change gates, which it doesn't like and will want to avoid even against a certain cost. Y can now raise its price without losing the auction. By doing this, it makes a nice profit, since its production costs are much lower than its selling price. We call this phenomenon *exploitation*: raising ones prices until just below the point where one would lose the auction. Exploitation is possible if a seller is in a *key-position*, which is the case when its services are needed as part of a repair scheme, it can provide the services relatively easy and other repair schemes involve much more or more laborious services.

Exploitation disturbs equitability. When prices no longer correspond with utility, we lose the guarantee that agents provide as much help as they receive. For instance, if a certain agent is in a key-position often, and exploits this fully, it earns much more money than it should. It can spend this money to receive help, which would be more than the help it provided. Thus, the resulting plan repair schemes would be inequitable.

To measure the effect of exploitation, we have set up a benchmark experiment in which aircraft repeatedly find themselves in planning conflicts, and need help from others to solve them. One experiment consists of 1500 rounds, with 15 airline-representing agents. To keep things simple, we assume that for each conflict there is one agent responsible, the *problem owner*. Each agent is problem owner 100 times. For each problem there are 15 repair schemes generated, such that there is a default scheme of doing nothing, with a very low utility for the problem owner, and a number of schemes which involve one,

two or three other agents with randomized utilities. The schemes that involve other agents have, by average, a lower total cost than the default scheme. In every round, the problem owner opens an auction, receives the other agents' price submissions, selects the least costly repair scheme and makes the corresponding payments. After all the rounds the scores are calculated for the agents. The score of an agent is the average balance of effort per round, i.e. received effort minus given effort, plus its monetary balance. Effort is defined as the negation of utility. Thus, if a certain action requires a very high effort of an agent, it has a very low utility to that agent. Monetary balance is added to the score since earned money may still be spent to receive services and thus represents utility.

There are two types of agents: coalition agents and exploiters. Coalition agents are agents that are truthful when submitting prices. We named them 'coalition agents' because throughout this paper they will try to defeat the 'wrongdoers', of which there are two types: exploiters and, as we will later see, forsakers.

Exploiters exhibit the described exploitation behaviour. If there are more than one exploiters involved in the cheapest candidate, they will work in perfect unison; they will each raise their price, but still make sure that the total price doesn't become too high. Their 'profit' is split randomly over the exploiters.

We conducted the experiment six times, with an increasing proportion of the agent population being exploiters. The results can be seen in the left chart in figure 1. In the first column, with only coalition agent, the variance is close to zero, indicating equitable plan repair. When exploiters start to join in, they score much better than coalition agents, which is to be expected. If one assumes that agents will change their strategy to a dominant strategy, the ratio of exploiters can be expected to increase and we move up to the right in the graph, ending up in the column on the very right. In this scenario the variance is high, indicating an inequitable, undesirable situation.

The reason that the variance is high in the last scenario is that we have explicitly modelled the fact that some agents have more exploitation opportunities than others, which we believe is plausible for real life situations. For instance, an airline that has many flights on gates next to each other can easily make changes and thereby accommodate for someone else. It needs to spend less effort to help than others, so it should be a lot cheaper, but it can easily exploit this situation. Because some agents exploit better than others, if all agents would exploit to their fullest, some agents will gain much more from this than others. The result is the inequitable situation we observed in the last experiment.

4.3 Collective retaliation

A straightforward remedy against exploitation, is what we will call *collective retaliation*: agents ask higher prices to the exploiters to nullify the profit they made from exploitation. Agents that are being exploited by an agent should estimate the measure of exploitation and pass this information on to all other agents. Every agent then calculates for every other agent a trust rate, where a low trust rate means that an agent asks too high prices. The trust $t_{a,b}$ that agent a has in agent b is

$$t_{a,b} = \frac{E_b}{P_b}$$

where E_b is the sum of the estimations of the realistic prices agent b should have asked and P_b is the sum of the prices agent b did ask. When problem owner w now asks for price submissions for candidate r , an agent a calculates the price $p_{r,a}$ for its part in r by

$$p_{r,a} = \frac{-u_{r,a}}{t_{a,w}} - S$$

where $u_{r,a}$ is the utility of a for its part in r , $t_{a,w}$ is the trust agent a has in the problem owner w , and S is a punishment factor to make sure that exploiters are not only compensated but also punished a bit, to discourage them from exploiting. S should be greater than zero for exploiters (i.e. when $t_{a,w} < 1$) and zero for non-exploiters.

We have implemented this strategy in a second experiment, of which the results are shown in the right chart in figure 1. It shows that the strategy is successful; coalition agents score better than exploiters. We say that the coalition strategy *dominates* the exploitation strategy. This is our aim, as the dominating strategy will be adopted by all agents, and if all agents adopt the coalition strategy, the resulting plan repair is equitable.

The success of the collective retaliation relies on two factors. First, the exploited agents should correctly estimate and truthfully communicate the amount of exploitation. We will make this assumption in this paper - an airline should be able to make a reasonable estimation of someone else's costs, especially when agents are allowed to give supporting arguments for their prices and discussion is possible. Also, there is no strong direct advantage for an agent to exaggerate another agent's exploitation. Only if an agent consequently lies about all other agents could it cause a relative advantage for itself, but this can hardly go unnoticed and will harm this agent's reputation. The second requirement for collective retaliation to be successful is that all agents correctly enforce the pricing rule. This is something we may not assume, since agents have reasons not to, as we will see in the next section.

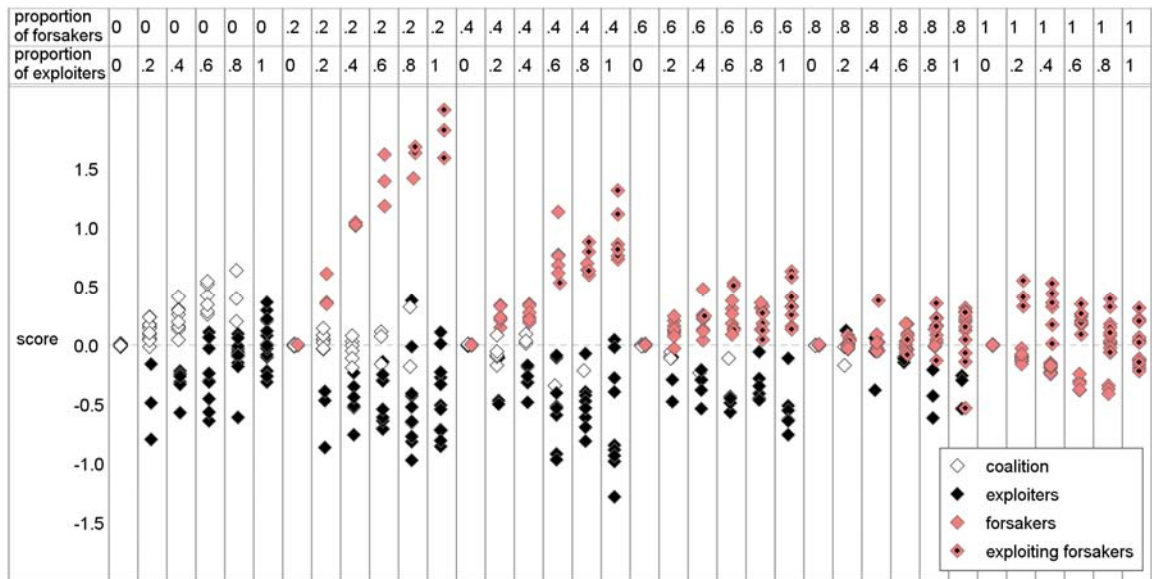


Figure 2. Results of the experiments with collective retaliation and forsaking. In subsequent series of experiments, the number of forsakers is increased, until there are only forsakers in the last six columns.

4.4 Forsaking

The method of collective retaliation works well if all agents enforce the pricing rule. But, a single agent who should at a certain moment raise its price as part of collective retaliation, may have an incentive to raise it less than it should. If there are more suppliers of a desired good or service, an agent might want to lower its price to win the deal. This is especially attractive if others raise their price as a result of collective retaliation; he may raise its price slightly less, win the deal, and make an attractive profit. We will call this kind of behaviour *forsaking*: deliberately asking a price between the realistic price and the one that should be asked as a result of collective retaliation, with the aim of winning the auction and making a profit.

If there are more than one forsakers, they will compete against each other. They will each try to win the deal by setting their price lower than that of the other. This will drive the price down until, possibly, all but one forsaker are at their realistic price. If there are enough forsakers, the effects of the collective retaliation rule may in this way be fully nullified, which is undesirable.

In order to test the effects of forsaking, we introduce a new type of agent in our experiment, the forsaker, and let it compete against coalition and exploiting agents. The coalition agents and exploiters use the collective retaliation pricing rule, the forsakers sell just below that price if the chance occurs. We have explicitly generated conflicts that are prey to exploiters, as well as conflicts that are prey to forsakers. In the first type of conflict there is one candidate with at least one exploiter involved that

is cheaper than all other candidates. In the second type there are several cheap candidates, but in at least one of those there is a forsaker involved. We tested the strategy in 6×6 different distributions of exploiters, forsakers and coalition agents. The results can be seen in figure 2. The chart shows that forsaking is a dominant strategy in every situation. Thus, the ratio of forsakers can be expected to increase. The last six experiments show that, when everyone forsakes, it is also often dominant to exploit. Thus, the ratio of exploiters can be expected to go up, in which case we will end up in the very last column, which shows an unfair, hence undesired situation.

A possible remedy against forsakers could be that the coalition retaliates them too. But this is far-fetched. Forsaking is harder to detect than exploitation, since the drop in price can be quite small. A forsaker could claim that it is not forsaking, but that it is asking a realistic price, which happens to be lower than expected. If the coalition fails to recognize a forsaker, the consequences can be much greater than if it fails to recognize an exploiter. Suppose that the coalition doesn't recognize exploiters and forsakers that stay within 5% of their realistic price. Then, an exploiter that alters its price by 5% will only gain 5%, while the forsaker might gain a lot more, namely the difference between the retaliation price and its realistic price minus 5%. Also, neither the forsaker nor the exploiter who is being retaliated has any incentive to complain about the forsaking – the exploiter likes forsakers. So, coalition agents should then check each bid that is submitted in auctions even in which they have no part. This is a lot of work and it requires that agents reveal pricing information to more agents than only

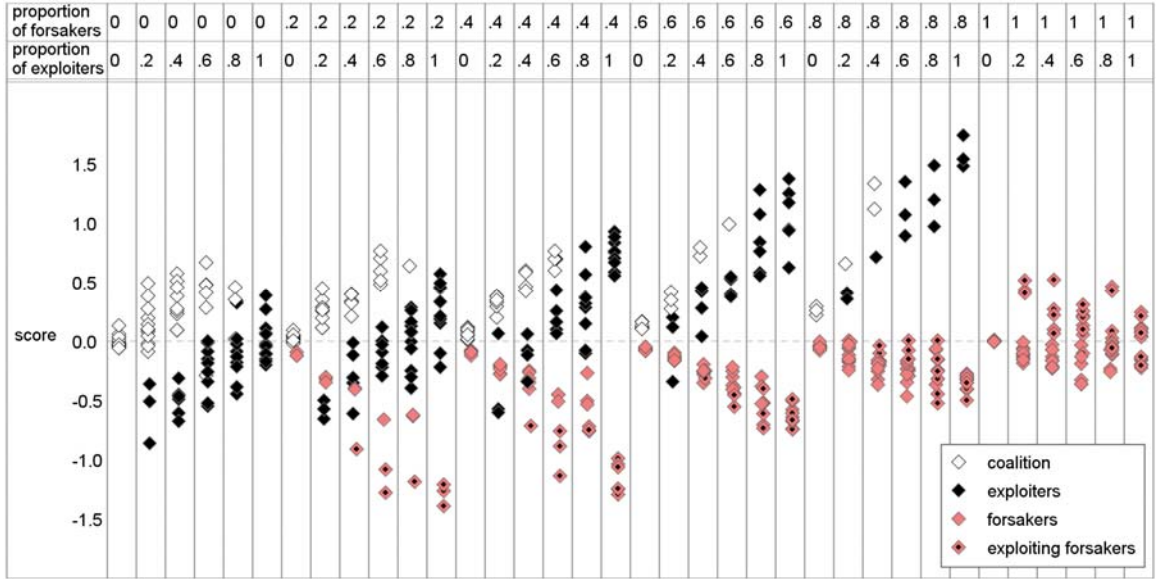


Figure 3. Results of the experiment with spender-signed money.

the problem owner, which is less desirable since agents like their information to remain as private as possible. We therefore do not find this remedy feasible.

The reason that forsaking occurs is the fact that the credits that are unfairly earned can be spent again without any problems. We will solve this problem by introducing a monetary system in which this ‘dirty money’ cannot be spent that easily any more.

5 Spender-signed money

We propose the usage of a new monetary system to solve the exploiter problem. The monetary system is one of a group of systems called *Local Exchange Trading Systems* (LETS). These monetary systems have in common that the currency used is not an existing currency such as the euro or dollar, but a private currency that is accepted within the group of participants of a particular LETS. Our monetary system is based on a LETS called the *WAT system* [19]. In the WAT system, participants may *issue* credits when needed. A credit represents a *promise of goods or services* by the issuer. Credits may be passed on to other participants, which is called *circulation*. When a credit returns to its issuer, it disappears, which is called *redemption*. In the WAT system, it is required that every spender of a credit adds its name to that credit. Thus, every credit contains a list of signatures that show the history of that credit. The last person on the list vouches for the credibility of the credit. If this person would refuse to accept the credit, the second to last person is viable, and so on. The trust one has in a particular credit thus depends on the names written on it. If one sees trustworthy names, the credit’s value is guaranteed. If one sees untrusted or unknown names, one may not want to accept that credit.

In the WAT-system, each credit has value 1. Our system differs in that credits may have any positive fractional value. We define the value of a credit as the product of the trust values of its users. Formally, if agent *a* receives a credit *c* with a list of users $\{b_1, b_2, \dots, b_j\}$, it assesses its value as

$$v_a(c) = t_{a,b_1} * t_{a,b_2} * \dots * t_{a,b_j}$$

where $t_{a,b}$ is the trust agent *a* has in agent *b*. So, every credit *c* has a value $v_a(c)$ for every agent *a*.

The auctioning protocol remains the same. Agents submit their prices to the problem owner, who selects the least costly repair scheme. However, determining which repair scheme is cheapest is not trivial, as credits may have different values to different agents. For instance, if the problem owner has credits that are valued much higher by agent *a* than by agent *b*, and these agents offer the same service for the same price, it would buy the service from agent *a* since he needs to spend fewer credits then. Details on how the cheapest repair scheme is determined can be found in appendix A.

The main innovation of this monetary mechanism is the fact that a credit’s value is determined by the reputations of the agents who have used it. So, if a credit goes through the hands of an exploiter, it loses value. As any other agent can see, the name of the exploiter is on the credit and therefore it is valued lower. As a result of this, the exploiter has trouble spending its money, since every credit he likes to spend turns out to be worth less than when he received it. More importantly, forsaking is no longer an attractive strategy. Forsakers used to make a profit by deviating from the collective retaliation rule. But now there is no such rule anymore. To forsake, they should raise their trust



value of an exploiter. If they do this, they will win the deal but obtain credits that have lost worth. When spending these on non-forsakers, they will incur a loss.

We implemented the proposed monetary system and ran a set of experiments to test its performance. The results are depicted in figure 3. It shows that the coalition strategy dominates exploitation and forsaking in every experiment where coalition agents participate. If all agents adopt this strategy, we get the situation in the first column, with the smallest variance and therefore the most fair allocation.

Note that spender-signed money is a private currency, in use only by the parties participating in plan repair. Also, there is no link between real money and spender-signed money. This is important for the equity criterion. If there would be a link between real money and the private money system, richer airlines for instance would be able to obtain better plan repair quality than poorer airlines. This is in conflict with the equity principle, which states that all airlines have equal rights on quality of plan repair.

6 Requirements for implementation

The negotiations described in this paper, in particular the auctioning, can be performed by *software agents*. These are intelligent computer programs that negotiate on behalf of their owner. A currently fast developing field of research is *multivalent systems*, in which interactions between software agents is studied [20].

In such negotiations, agents promote the interest of their owner. In the case of tactical plan repair, it needs to know the costs it has to ask for several possible repair actions. We assume that such an agent is connected to the computer system of its owner, and thus has access to its information. An owner may program an agent to determine costs in the way the owner likes. For instance, an airline might want an agent to weigh the total delay times the number of passengers heavily in the cost function. An airport might program its agent to assign more weight to environmental consequences.

The emergence of multiagent systems technology enables systems such as described in this paper. Software agents are able to communicate, process information and make calculations much faster than humans. A group of agents could share, evaluate and choose repair schemes and make the necessary payments in a matter of seconds. This allows a higher level of information exchange and repair, leading to more satisfying repairs.

A requirement for the use of spender-signed money is a secure digital cash system. The *i-WAT* system is an implementation of a spender-signed

monetary system similar to ours. It uses the PGP trust model to prevent against fraud [17]. It can therefore act as a starting point for the implementation of the spender-signed money described in this paper.

7 Conclusion and discussion

With the introduction of advanced planning concepts in the CDM framework, the possibility to “cheat the system” will start being exploited. Currently, simple operational procedures are implemented, like “do not send a new expected time more than three times”, to prevent parties from taking an undesired advantage of a profitable situation.

In the context of Total Airport Management, airlines will start to have a say in traffic operations and gate assignment. Inter-airline communications are currently not examined, because of the commercially sensitive information they need to share and hence the possibility to misuse the system.

In this paper, we present a collaboration framework that does not allow exploitation of strategically advantageous positions. All airlines can participate and are rewarded for a positive attitude. Airlines that manipulate the plan repair process to obtain an unfair advantage over others are automatically punished as a result of the spender-signed monetary system.

As an example, we implemented a scenario for gate assignment, but because of the distributed nature of the *agents*, the system is fully scaleable and can be extended towards ATC, the airport, handlers, and passengers. Handlers (or dispatchers in the U.S.) will be able to optimise their processes and negotiate on their resources. They could share information on their activities and buy in services from others.

Different application areas can be examined. In fact, in any application where collaboration is required between parties that serve their own interest the system can be applied to achieve efficient and equitable cooperation. If, for instance, Free Flight would in the future be extended to include communication of intent or preference information, exploitation should surely be prevented. As another application example, the business trajectory as now proposed in SESAR lends itself very well for the described approach.

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Keywords

Distributed Decision Making, Collaborative Decision Making, CDM, Total Airport Management, Turn Around Management, Gate allocation, Market Mechanisms, Auctions, Equity.

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