

CREW AND AIRCRAFT RECOVERY THROUGH A MULTI-AGENT AIRLINE ELECTRONIC MARKET

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ABSTRACT

Airline companies do not collaborate when dealing with problems that arise during their own operational control plan. These problems are related with aircrafts, crew members and passengers and the actions towards the solution of these problems are usually known as operations recovery. In this paper we present a possible solution to the problem of lack of collaboration between different airlines, based on an electronic market. This electronic market is based on a Distributed Multi-Agent System we are developing to help airline companies in solving unexpected operations recovery problems and matching them with potential solutions. The proposed electronic market uses ontology services that we have developed for other domains, allowing an airline company to access resources of other airline companies, such as aircrafts and crew members. The potential solutions obtained through the electronic market interactions will compete with the solutions found by the airline company own system. We present a real case study taken from TAP Air Portugal operational control including the description of how the ontologies services work. We believe that using our system architecture and services for this application domain is a possible and interesting solution but we are also aware of challenges and problems that might arise from using this approach.

KEYWORDS

Electronic Market, Ontology, Business oriented e-commerce, Disruption Management, Operations Recovery.

1. INTRODUCTION

Nowadays, each airline company tries to solve the operations recovery problems (Castro and Oliveira, 2005) with their own resources. If they have an OPEN position for a specific type of crew in a flight, they try to find a suitable one from their own staff. The same happens with aircrafts. The companies always try to find a solution using their own aircrafts. Sometimes, airline companies have to rent aircrafts and their crews from other companies to solve the problem. Airline companies rent aircrafts and crew members when needed, but through a direct contact with charter airline companies. It is not a usual practice to use only crew members (without being part of the aircraft) from other companies. An electronic market (EM) could reduce costs and time for the airline company that has a specific problem, while increasing flexibility and access to new possibilities.

According to (Kohl *et al.*, 2004), “research on the recovery operation to this date only deals with a single airline. Cooperation between airlines is not supported”. Additionally, most of the systems proposed or commercial available approach the recovery operation by trying to solve each problem (crew, aircraft or passenger) individually instead of having an integrated approach (Clansen *et al.*, 2005). We believe our proposal is a step forward in achieving the cooperation between airlines. We are proposing an EM based on a

MAS paradigm, where each airline company will be represented by an agent. It works as a market of solutions to specific local problems of the airline companies. These solutions would compete with the solutions obtained from the own airline company system. However, in a decentralized and distributed approach, agents may negotiate with other geographically distributed agents and interoperability problems may arise. The interoperability problems make the negotiation process more difficult and consequently a final agreement is difficult to be reached. For helping to solve these interoperability problems the Ontology-based Services (Malucelli and Oliveira, 2005) are integrated into the EM.

In order to test our solution we are observing the Airline Operations Department of TAP Portugal¹ - the major Portuguese airline.

The rest of this paper is structured in the following way. Section 2 introduces the airline electronic market, the proposed MAS architecture, and explains the ontology-based services, which are integrated in the EM. Section 3 presents a real case study and Section 4 gives some conclusions and future work.

2. ELECTRONIC MARKET SOLUTIONS

Many electronic markets have been proposed, but they are mainly related with auctions and business-to-consumer (B2C) domains, as for example TAPAuctions² and eBay³. Regarding the specific domain of aircraft and crew recovery in airline operations control and to the best of our knowledge, this is the first proposal for an EM applied to this specific domain. Figure 1 shows the architecture of the Distributed Multi-Agent System for helping solving airline operations recovery problems and where the EM is integrated.

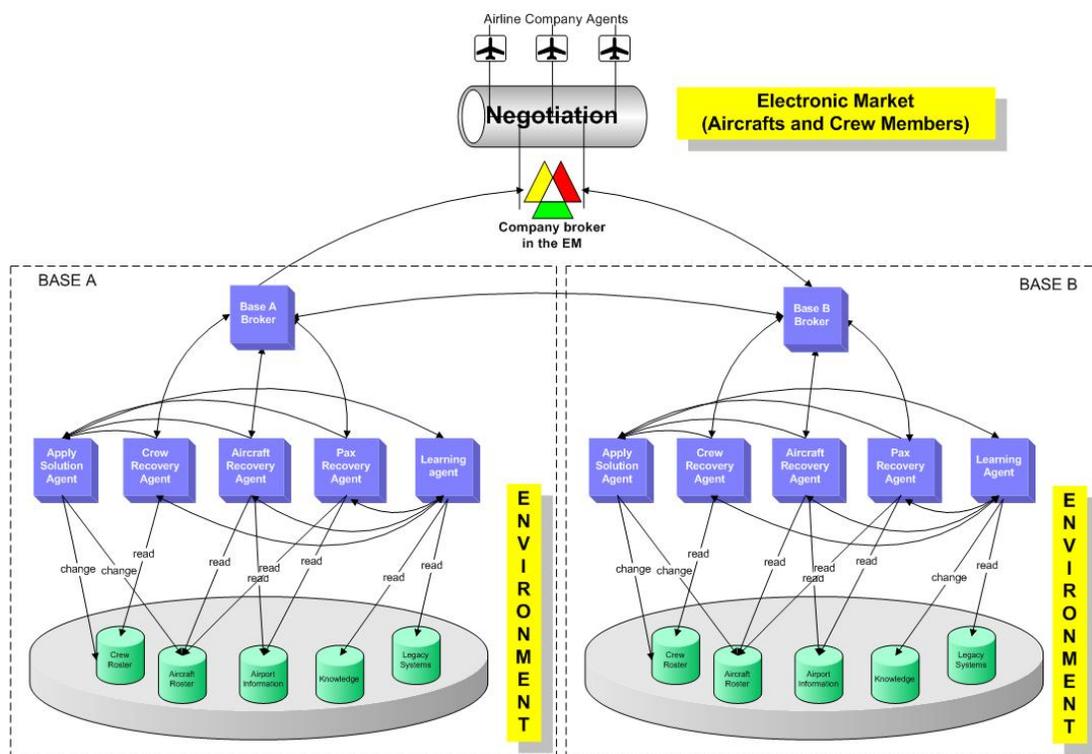


Figure 1- Architecture of the MAS where the EM is integrated

¹ TAP Portugal, <http://www.tap.pt>, October 2005

² TAP Auctions, <http://www.tap.pt/portal/v10/PT/jsp/leilao/salaLeilao.jsp>, October 2005

³ eBay, <http://www.ebay.com/>, October 2005

The EM proposed here is a permanently open virtual marketplace where registered airline companies (represented by agents) can meet each other through the web to purchase services according to established norms and rules. There are three main advantages for the proposed market:

- (i) The companies that participate in this EM will have more resources available to solve their problems;
- (ii) The companies may take advantage of exceeding resources in specific dates and times and sell the services performed by these resources (crew members and aircrafts) to other companies;
- (iii) The airline companies might use this market to supply themselves in high seasons of passenger demand. The companies might have a fixed number of crew members and aircrafts for the majority of their regular operation and, for the high seasons, they can use this market. In such a competing market the prices might even drop;

Furthermore, each airline company has its own ontology about the structure of the organization, which means that during communication interoperability problems may arise. For helping with interoperability problems the ontology-based services are included in the market. The architecture of the market as well as the ontology-based services is explained in the next subsections.

2.1 Airline electronic market architecture

In the proposed architecture, agents representing airline companies will interact in the market with other agents. This framework includes five types of agents: facilitator agent, airline company agents (services' customer and supplier), external entity agents and an ontology-based services agent.

Figure 2 shows an instance of the MAS architecture for the EM. Each Airline Company, represented here by an agent (Supplier or Customer) has its own architecture and functionalities.

The **Facilitator Agent (FA)** is the entity that matches the right agents and supports the negotiation process.

The **Customer Airline Company Agent (CAA)** represents airline companies interested in the crew members or aircrafts renting services. There are several airline companies in the world that could provide these services, with different prices and conditions. Each Customer Airline Company Agent sends a message with the identification of needs to the facilitator agent announcing which service is needed.

The **Supplier Airline Company Agent (SAA)** represents airline companies interested in providing crew members or aircrafts renting services. Whenever there is a needed service, the facilitator agent conveys this announcement to all registered interested supplier airline company agents. The airline company agents (customer and suppliers) have to register themselves in the EM to be able to participate. Each agent has its own private ontology, built in a private and unknown (to the overall system) process.

The **External Entity Agent (EEA)** represents entities that are responsible for the validation of the providers' proposals, such as operational constraints established by airports and other international organizations such as FAA⁴, IATA⁵, and JAA⁶.

The **Ontology-based Services Agent (OSA)** helps when some of the ontology-based services (currency conversion or matching terms, for example) are required.

⁴ Federal Aviation Administration, <http://www.faa.gov/>, October 2005

⁵ International Air Transport Association, <http://www.iata.org/index.htm>, October 2005

⁶ Joint Aviation Authorities, <http://www.jaa.nl/>, October 2005

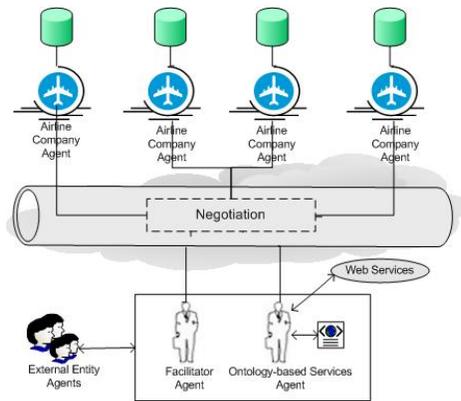


Figure 2 - MAS Architecture of the EM

The airline company agents are cooperating together through a website with the objective of providing or getting resources, in collaboration, but keeping their own preferences and objectives. When a request for a resource is made, the facilitator agent will look for the registered airline companies that may provide that resource. The ontology-based services agent enables appropriate conversations and makes possible to reach agreements between agents representing different airline companies. In order to avoid that the EM indicates a crew member/aircraft that will satisfy the customer needs but that will have later (after contracting phase) some special airport constraints, the facilitator agent requests to the external entity agent the validation of the crew member and/or aircraft.

2.2 Ontology-based services

As pointed out in the previous section, several agents are necessary to manage the ongoing operations. According to that, several problems are involved in a MAS architecture and one of the most important is the lack of understanding that may arise during agents' interaction, due to the structural as well as semantic representation heterogeneity (Malucelli and Oliveira, 2004). Besides having different knowledge, each airline company wishing to negotiate and succeed with other companies that are distributed all over the world, must recognize and adapt to existing differences, like for example, different currencies.

The easiest way of solving this problem is to use either a common ontology or a shared one which may be understood by all the companies (agents) participating in the process. However, each agent may have one of the existing different ontologies and, in that case a shared ontology will not be universal. Thus, the companies will not waste time converting all the content of their ontology if the new one is not considered a universal one.

We have created an Ontology-based Services Agent (Malucelli *et al.*, 2006), which is responsible for providing services to other agents in order to ensure an effective, meaningful negotiation. The ontology-based service agent provides the Matching Terms Service (MTS), the Currency Conversion Service (CCS) and the Measurement Conversion Service (MCS). The MTS is required when some of the agents do not understand the content of a message; i.e. the item under negotiation. The MCS may be useful in the calculation of prices when agents are dealing with different currencies and when dealing with different measurement units. The MCS is implemented as Web Services. A case study is presented in the next section taking into account the MTS.

3. CASE STUDY

The typical type of interaction taking place between airline companies (and which are always tried to be solved) can be briefly described as follow. Suppose that TAP Portugal has the hypothetical following flight:

Flight Number: TP5555,
From: LIS (Lisbon) to REC (Recife),
Number of Passengers: 200,
Date/Hour of Departure: 2005-10-18 10:00 (UTC),
Date/Hour of Arrival: 2005-10-18 18:00 (UTC),
Aircraft Type: A340 (airbus A340) with **License Number:** CS-TIH.

This aircraft and crew would do the return flight with the following characteristics:

Flight Number: TP6666,
From: REC to LIS,
Number of Passengers: 240,
Date/Hour of Departure: 2005-10-19 11:00 (UTC),
Date/Hour of Arrival: 2005-10-19 19:00 (UTC),
Aircraft Type: A340 (airbus A340) with **License Number:** CS-TIH.

Suppose that the Commander of this flight did not report for duty. Now TAP has to find a suitable replacement for this crew member. TAP will try to do it first locally (solve the problem with their own resources) and then making use of the EM. In the latter case the request might be similar to this one:

Number of crew required: 1,
Crew Rank: Commander,
Aircraft Model: A340 Series,
Aircraft Type Rating: A340,
Instrument Rating: IFR,
Operation Category: CAT III,
Crew Fleet Qualification: NA,
Route: LIS-REC-LIS,
Route Aerodrome Competence: NA,
Flight Numbers: TP5555/TP6666,
Date Time Check-in: 2005-10-18 09:00 (UTC),
Date Time Check-out: 2005-10-19 20:00 (UTC),
Long Range Qualification: ETOPS,
RNAV Qualification: yes.

The other airline companies, participating in the EM, would have to understand this message and its meaning, without having to disclosure their ontology. Besides that, there are a lot of other guarantees to take into account when responding to such a message. For example, World, European, Country and Company regulations would have to be guaranteed as well as privacy and security problems. The resolution of these problems is not considered in this paper.

3.1 Airline ontologies

Figure 3 presents a part of the Airline Ontology (concept, characteristics and description for “Commander”) built with Protégé ontology tool (Gennari *et al.*, 2002). All the ontologies are composed of a set of concepts, each concept having a description, relations with other concepts and a set of characteristics, called attributes. Each attribute has a type and a value assigned to it.

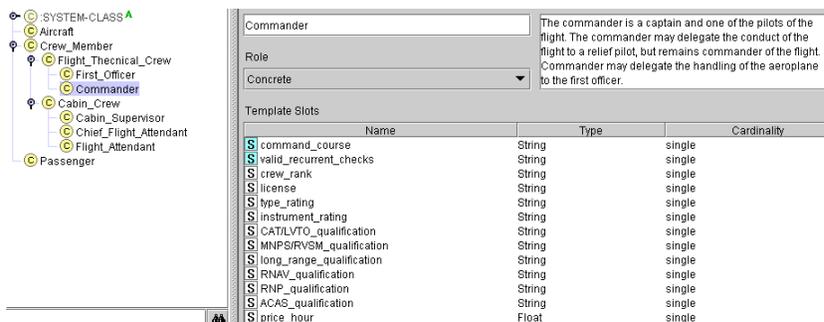


Figure 3 - Part of Airline Ontology

Through this example we may observe some differences, which may cause the interoperability problem during the negotiation process. For example, in figure 4 we may observe that the concept “Commander” (a crew member that may be requested), in Airline Ontology - Company 3, has correspondent terms/concepts in other ontologies (Company 1 and Company 2) which are written in a different way. However, they are in the same domain and have the same meaning. The Company 1 refers to the concept “Commander” as “Captain” and Company 2 refers to “Commander” as “Senior_Pilot”.

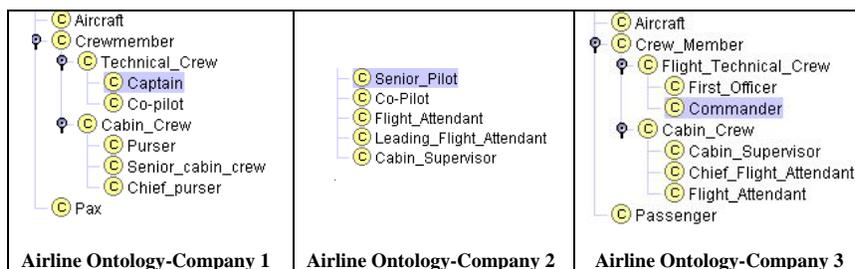


Figure 4 - Part of the three different airline ontologies

The interoperability problem may happen even if the same concept is used for all airline companies. In this case differences may occur in the names of the attributes, relations, and in the concepts’ description. Furthermore, the same concept may also be used with different meaning for different airline companies.

Assisting the establishment of agreements is the first step in managing a business relationship. According to that the airline companies have to be able to understand the terms under negotiation and for it we have integrated the ontology-based services agent in the electronic market. The ontology-based services agent may be requested when some concept is not fully understood by some of the registered agents or when some conversion service is necessary. The currency conversion service is also useful in this case when the airline company agent interested in renting a “commander” is negotiating in a different currency from the airline company agents interested in providing the “commander”.

3.2 Applying the ontology-based services

Figure 5 shows an example of a message that is sent from a customer airline company agent interested in renting a crew member to all known supplier airline company agents that may provide the requested crew member. This is a performative CFP (Call-For-Proposal) with the content parameter containing the Predicate “IsPurchasable” which is defined in the ontology “eCommerce” (Malucelli *et al.*, 2006). This performative denotes that the customer airline company agent seeks proposals for a crew member named “Commander”. This term originates from its own, private, ontology.

```
(CFP
:sender
(agent-identifier
:name customer@sutton:1099/JADE
:addresses (sequence http://sutton:7778/acc))
:receiver
(set
(agent-identifier
:name cust1@sutton:1099/JADE
:addresses (sequence http://sutton:7778/acc)))
:content (IsPurchasable (
item: Commander
quantity: 1
currency: EUR))
:reply-with R20364762_0
:language fipa-sl
:ontology eCommerce
:reply-by 20041112T102012611Z
:protocol fipa-contract-net
:conversation-id 1100254802611
)
```

Figure 5 - ACL message CFP

The ontology-based services are required by the supplier airline companies which do not understand the CFP. The protocol for exchanging information is the following:

After having received a CFP and not being able to interpret the requested item, the supplier airline company agent sends a message with the performative NOT_UNDERSTOOD to the ontology-based service agent, acquainting who sent the CFP and the name of the unknown item.

The ontology-based service agent sends the name of the item it has just received to the customer airline company agent in order to get further information about it. The customer airline company agent will analyze that request and send back attributes and types of the item (concept), price and the description, i.e. all the information about this item.

Following that, a pre-selection process is executed. As the name suggests, the pre-selection process aims at getting candidate concepts, which could be the correspondent for the requested item and therefore reducing the target quantity. After having received the requested item information, the ontology-based services agent knows the price of the item under negotiation and sends it to the supplier airline company agent.

The process selects among all items the ones whose price value is in the range between 75% and 125% of the received value. This process results in a list of product candidates that is returned to the ontology-based services agent, including their names, the characteristics and description in natural language.

In applying the pre-selection process, we reduce the set of potential matching concepts, which is absolutely essential in huge ontologies defining many entities. Otherwise the number of pairs, meaning concepts that have to be compared, would be too high. The currency conversion service provided by the ontology-based service agent might be needed and can be requested if the supplier airline company agent pricing of items uses a different currency from the customer airline company agent pricing. After the selection, the supplier airline company agent answers with a list containing names, documentation and attributes of potential correspondent concepts.

After receiving all the information about the item under negotiation and a list of possible corresponding items, the ontology-based services agent is able to apply methods in order to match the terms. These ontology mapping methods aim at detecting syntactic and semantic similarity of terms. Every term of the proposed, potential correspondent item is compared to the requested term.

After that, the ontology-based service agent informs the supplier airline company agent about the result of the comparisons delivered from the ontology mapping methods, i.e. informs the name of the correspondent item or an appropriated message if this could not be discovered. The supplier airline company agent is then able to respond to the customer airline company agent, either with a PROPOSE or with a REJECT_PROPOSAL.

4. CONCLUSION

There has been some research in the field of operations recovery and other related areas like aircraft and crew scheduling, planning and operations of aviation infrastructure, among others. Most of the research comes from the operations research field and a good overview of the applications that exist in the air transport industry can be found in (Barnhart et al., 2003).

As stated before and regarding the operations recovery (or disruption management) problem, most of the proposed systems approach this problem by trying to solve each recovery problem individually instead of having an integrated approach (Clansen et al., 2005) and using the specific resources (crew and aircrafts) that each airline company has.

An electronic market enabling simple negotiation processes and including ontologies services, to solve aircraft and crew recovery problems during airline operational control has been proposed. Our proposal aims to achieve the cooperation between airlines in solving aircraft and crew recovery problems. According to (Kohl et al., 2004) this is still an open issue.

We have implemented a prototype with several agents representing different airline companies cooperating through a website. Each agent has its private ontology which were built using Protégé ontology

editor and stored in Web Ontology Language⁷ (OWL) format. A facilitator agent and an ontology-based services agent were integrated in order to monitor and support the negotiation process. The agents representing the external entities were not integrated in this phase. The ontology-based services were tested and the efficiency of the applied methods depends on the quantity of available information and the quality of the concepts' description. The ontology-based service agent is enhanced with learning characteristics, for learning terms and concepts already compared, avoiding to perform all the similarity matching process in the next negotiation process when the same item is requested.

As stated in (Castro and Oliveira, 2005) "things are not so linear, regarding the use of crew members from other airlines companies. Airline internal rules, labor and country specific rules, European rules and crew qualifications, just to mention a few, are to be taken into account when approach this subject." Our proposed EM already deals with these subjects, in an elementary way, but there is still space to make a lot of improvements. Other issues like communication between different information systems, security, privacy and authorization, are also problems that we will have to address in our proposed EM as well as specific EM subjects like contracts and negotiations.

We know that it is a hard job but we believe that, after solving all the issues related with the previous mentioned subjects, our proposed EM might be a profitable one for airline companies or to companies that might be created just specialized in supplying cooperative solutions to these operations problems.

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⁷ OWL, <http://www.w3.org/TR/owl-ref/>, October 2005