

DISTRIBUTED DECISION SUPPORT SYSTEM APPLIED TO TACTICAL AIR TRAFFIC FLOW MANAGEMENT IN THE CASE OF CINDACTA I

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Abstract

This paper describes a research proposal to develop a Distributed Decision Support System for Air Traffic Flow Management (SISCONFLUX) targeted at the First Integrated Center of Air Defense and Air Traffic Control (CINDACTA I) in Brasilia. The decision making process in a distributed system such as ATFM is very complex since there is a considerable number of techniques and operation procedures that must work together. The use of a distributed approach is strongly suited for this kind of problem since the entities of the system (pilots, air traffic managers and controllers) are geographically distributed and communicate with each other by message exchange. This paper specifies the role of CINDACTA I, presents the problem diagnosis and the proposed solution including the system architecture, implementation procedures, methodology and a brief theoretical discussion about the Ground Holding Problem – GHP.

Keywords: Distributed Decision Support System, Air Traffic Flow Management, Air transport

1. INTRODUCTION

In the context of the crisis that arose in the Brazilian air transportation, there is a variety of influence factors generated from the whole system. At this moment, it is difficult to identify and resolve all of them. However, one of these factors can be associated to the empirical form techniques for tactical management of the traffic flow applied, evidenced by the intuitive application of restrictive actions to the air traffic flow, aiming at preventing the saturation of air traffic control sectors within the Brasilia Flight Information Region - FIR-BS.

The application of restrictive actions to air traffic flow is used with the purpose of complying with the established rules in force, as a way of preventing flight controllers from working with a higher overload than that established by law. Restrictive actions have severe impact on all operational activities and logistic of airports.

The selection of techniques and the correct evaluation of the level to be applied, regarding restrictive actions in air traffic flow, results from an empirical rationale, strongly conditioned by the experience of the controllers exerting a supervisor's role. However, the number of factors and variables involved in this process turns the decision making practice, empirically based, only

partially efficient. In other words, there is a lot to be optimized in the traffic flow by means of improving the applied restrictive measures efficiency, which will be made possible through the systemized choice of the most adequate measure, considering the great number of factors and variables involved (capacity of control sectors, dimension of these sectors, demand for airports, aircraft performance, airports prioritization needs, routes, staff availability, meteorological restrictions amongst others).

As clearly shown from what has been presented, it is unnecessary to mention the strategic, economic and political importance attributed to the development of a system that processes these factors and variables, returning as a result the restrictive measure of the adjusted flow control for the current scenario.

This work, therefore, aims at presenting the proposal of a distributed system to support decisions that assist controllers in the management of air traffic flow control actions. Furthermore, the concept of related system is the first result of a strategic cooperation between the First Integrated Center of Air Defense and Air Traffic Control (CINDACTA I) and the University of Brasilia (UnB).

2. DIAGNOSIS AND SPECIFICATION IN CINDACTA I

2.1 General Scenario

In 1990, the System of Brazilian Airspace Control was instituted (SISCEAB), with the purpose of integrating the following Systems: Flight Protection (SPV), the Telecommunication of the Ministry of Aeronautics (STMA), Search and Rescue (SISSAR) and the Air Defense and Air Traffic Control (SISDACTA). The System of Brazilian Airspace Control is conducted by the Command of Aeronautics, through the central agency of the System, the DECEA (Department of Airspace Control). This agency manages the Brazilian airspace through its multiple Regional agencies, among which CINDACTA (Integrated Centers of Air Defense and Airspace Control) is detached, permanent links within the SISDACTA which are responsible for secure and constant air traffic flow in areas under its jurisdiction.

The Brazilian airspace is divided into four Flight Information Regions (FIR), each one under the responsibility of a CINDACTA. Hosted in Brasilia-DF, CINDACTA I was the first SISDACTA Center to be installed. With jurisdiction over the quadrilateral formed by the airports of Rio de Janeiro, São Paulo, Belo Horizonte and Brasilia, CINDACTA I

controls about 50% of the air traffic flow related to regular flights in Brazil (CGNA, 2005).

2.2 Operational procedures Applied to Air Traffic Flow Control

As established in the Command of Aeronautics Instruction 100-22 (ICA 100-22), dated 22 June 2007, control agencies are responsible for the identification of risks of congestion and/or saturation of control sectors and, hence, for adopting restrictive measures to air traffic flow, in order to prevent violation of safety limits. This Instruction defines the applicable measures, which are: holding on the ground, holding en route, reduction of speed, alternative routes, measures for delays en route, and landing and hold at intermediate aerodromes.

2.3 Emergent Technical problems

CINDACTA I, through the Area Control Center of Brasilia (ACC-BS) and of Approach Control Centers (APP), makes use of a set of systems capable of carrying out adequate air movements' control in its area of responsibility. However, it does not have a specific system directed toward the tactical management and the synchronization of air traffic flow, especially in places where control tools degradation or other factors which may cause significant modifications in the

expected traffic flow are verified, such as meteorological conditions, aeronautical incidents and/or accidents, amongst others.

The degradation of traffic control tools, as well as the many other factors capable of modifying the expected traffic flow, can result in saturation of control sectors, characterized by the simultaneous permanence of 14 or more aircraft in a sector. The saturation of a sector can be conditioned by various factors, such as: the dimensions of the sector, the geographic position and the schedule of the day.

The FIR-BS is subdivided into fourteen control sectors, under operational jurisdiction of the ACC-BS, and grouped into three regions: Brasilia Region, Rio de Janeiro Region and São Paulo Region. The FIR-BS still accumulates seven control terminals areas (TMA) under jurisdiction of their respective APPs: Anápolis, Belo Horizonte, Brasilia, Cuiabá, Rio de Janeiro, São Paulo and Vitória. Each sector is monitored by an operational position, to which a controller and an assistant are provided. There is still a supervisor role, assigned to perform decisions on occasions at which a region is being controlled by two or more operational positions.

In the event of sector saturation, it is the supervisor's responsibility to evaluate the

amount of traffic with the forecast of entrance in the sectors under its supervision and to approve the restrictive measures for air traffic flow suggested by the operator. A hierarchic structure is therefore observed, once this process is conducted, for the decision making.

The decisions made by the supervisor are based on his/her experience. The restrictive measures applied are taken after an empirical analysis, not supported, therefore, by any type of computational decision tool. Another important matter related to this issue is the impossibility to perform a thorough quantitative evaluation of the impact of the measures adopted in one specific sector on the traffic flow of adjacent sectors. As a consequence, it does not have an adequate forecasting level concerning the effect of the adopted restrictive measures on the air traffic flow demand within FIR-BS as a whole. Thus, considering that FIR-BS accommodates about 50% of the air traffic volume (regular flights) in Brazil, the inadequate sizing of measures applied by the ACC-BS will certainly imply traffic flow problems all over Brazil.

3 STATE OF THE ART FOR ATFM PROBLEMS

The management of air traffic flow (Air Traffic Flow Management - ATFM) is a task that involves the problem of synchronization in real time (Stoltz and Ky, 2001; Stoltz and

Guerreau, 2002). Although many researches have already been conducted with the intention of finding a solution to this problem, the computational solutions face difficulties, as all critical problems seem to do, in the efficiency of computational systems, in the need for stability, high security and synchronization. Most of the systems already considered (Gosling, 1987; Karppinen et al., 1991; Schlatter, 1994; Bonzano et al., 1996; Weigang et al., 1997; Targa, 2001; Gonzaga Da Silva, 2001; Prevôt, 2002; Nguyen-Duc et al., 2003; Ball et al, 2003; Dell'Olmo et al, 2003; Rizzi, 2003; Mukherjee, 2004; Zhang, 2005 and Liu et al, 2006) present a centered architecture, while Heymann et al (2003) and Dib (2004) present solutions with a distributed character. All of these solutions present excellent characteristics towards efficiently resolving the problem. However, they also present problems related to the performance, that is, the necessary time for attaining the solution and for forming a "communication link".

The aeronautical information exchange, as well as examples of meteorological measures, airspace situations, congestion forecasts, all on a global scale, is of crucial importance to improve performance and to assure safety in all the different segments of airport services (IATA, 2003a). Aircraft and airports are

equipped with sophisticated instruments which allow monitoring and fast transfer of information, with the aircraft being either on land or in flight (IATA, 2003b).

Thus, it is through intuition, associated with experience, that the controllers, based on these pieces of information, decide on the adjustments of trajectories, delay on takeoffs and landings, adjustment of new schedules, adequate use of tracks, etc. It is also necessary for the foreseen trajectories to be followed in order to determine when a pair of aircraft will infringe the minimum distance necessary for separation and, in the occurrence of this problem, which action will have to be taken for its solution (Bonzano et al., 1996).

It is verified, therefore, that the pressure over air traffic controllers tends to increase with the increment of information acknowledged, generating a rising load of stress and, closely related, more difficulty at reasoning. As a consequence, decisions made roughly, under such conditions, can lead to a pressured action from a set of solutions where some may have been more reasonable; the urgency or stress, though, does not allow the controller to accomplish a more careful analysis of the problem (Bonzano et al., 1996).

In this context, the problem of holding on the ground emerges (Ground Holding Problem - GHP), the resolution methodology of which is

based on the search for synchronization between adjacent sectors, under the analysis of a set of landings and take-offs expected within one same area of supervision, so that the best flow between these sectors is guaranteed. For this search, literature concerning GHP suggests the use of the integer linear programming (Rizzi, 2003, Mukherjee, 2004, Ball et al. 2003).

More recently, authors started suggesting methodologies based on dynamic programming in order to attain better results (Dell'Olmo et al. 2003) and (Zhang et al. 2005). There are also distributed models established based on multi-agents techniques (Heymann et. 2003) and (Dib, 2004) using communication by messages exchange in order to negotiate a global balance amongst the participants of the system.

Latest proposals suggest multi-agent architecture, implementation approach and software prototype of a multi-agent system for air traffic control within airport airspace capable of automatic detection of potential violations of safety policies by individual aircraft and corresponding incident management (Gorodetsky et al. 2008); or Multi-agent Simulation of Collaborative Air Traffic Flow Management, in which the authors evaluated several simple strategies for the Airline Operations Center (AOC) agents

to select routes, using two different approaches, the Airline Planning approach and the Mixed approach (Wolfe et al. 2009).

4 DISTRIBUTED DECISION SUPPORT SYSTEM APPLIED TO TACTICAL AIR TRAFFIC FLOW MANAGEMENT (SISCONFLUX).

The proposed solution contemplates the development of a modular system capable of suggesting, to the supervisor of a traffic control region, the most effective restrictive traffic flow control measures under certain constraints. These measures will represent the most adequate solution for the maintenance of air traffic flow best condition in the entire FIR-BS.

The SISCONFLUX will also have to be capable of suggesting restrictive flow measures considering conditions of forced traffic flow, according to which certain flights, routes or airports could be prioritized over others. Such actions will be established according to the directions emanated from the agencies responsible for the management of traffic flow in the Brazilian airspace.

The architecture of the system foresees a modular conformation, as in figure 1, by means of the development of specific modules and interfaces for the preexisting modules aggregation. Therefore, the amount of processing required for generating the

suggestions to the Supervisors will be distributed by system modules, as specified next.

4.1 Module of Monitoring and Scenario Forecast (MAPC)

The Module of Monitoring and Scenario Forecast aims at providing the system, in real time, with the expectation of air traffic flow in different control sectors by means of air traffic movement information processing in the FIR-BS (current scene) together with the available information in CINDACTA I Flight Plan Center.

The scenario will be defined considering information of repetitive flight plans (RPL), provided by the Air Navigation Management Center (CGNA), together with the information of eventual flight plans (FPL).

The RPLs are inherent to air movements of regular commercial flights. The FPLs correspond to flight plan files which must be presented when there is a forecast of an eventual flight (military or non regular civil). The FPLs are presented with a minimum of forty-five minutes prior to take-off schedule, and are processed by the flight treatment system twenty minutes before that schedule. From this moment, the FPL information, together with the information of RPL and the current information of air movements in the

FIR-BS, composes the database for the scenario management.

This module, therefore, will need an interface in order to get the information of current air movements in the FIR-BS, as well as the information of flight plans (RPL and FPL). This information could be extracted from the System of Data Treatment and Visualization - STVD, in operation at CINDACTA I.

4.2 Interface with the STVD System.

The STVD is an air traffic control system that processes information from radars that are part of the System of Air Defense and Air Traffic Control (SISDACTA) presenting traffic controllers with the real time scenario of the air traffic in the FIR-BS.

The related system also processes all the information about air movements with real time forecast in the FIR-BS, which is given by the compilation of the flight plans (RPL and FPL) available.

The interface with the STVD will allow the extraction of the necessary information for the scenario composition, which is then processed by the Module Monitoring and Scenario Forecast.

4.3 Module of Flow Balancing (MBF)

The Module of Flow Balancing should operate in constant interaction with the MAPC, besides receiving information from

the Evaluation Module and Decision Support (MAAD) concerning the modifications in the current scenario not determined in the air movements and that could imply alterations in air traffic flow.

Once the scenario related to the air traffic flow in the FIR-BS is projected, the module of flow balancing will proceed to the analysis of air movements distribution in evolution, as well as the evolution intentions (RPL and FPL), in the different control sectors.

When the projected values show to be next to congestion limits (80% of the capacity of the sector) or saturation (100% of the capacity of the sector), associated or not with the restrictive factors informed by the MAAD, this module will initiate the process of the traffic flow balancing, by means of a new scenario projection.

This new scenario will be projected by means of the application processes for conflict resolution, considering the possibilities of applying restrictive measures to traffic flow.

In this new scenario, the aircraft in flight will

be able to receive restrictions in speed or instructions to hold at points established beforehand; furthermore, the aircraft with schedules to initiate their flights can be instructed to delay the take-off.

This module should search, in a constant and uninterrupted form, the possibilities which imply the ideal condition for air traffic flow. This condition is characterized by the maintenance of the largest traffic flow possible, considering that the control sectors do not reach levels of congestion and/or saturation. The choice of the parameter, congestion or saturation, will be determined by supervisors, taking into consideration operational and technical factors at the moment at which the application of traffic flow restrictive measures shows to be necessary. Once the deliberations are defined, the module will direct its suggestions to the MAAD.

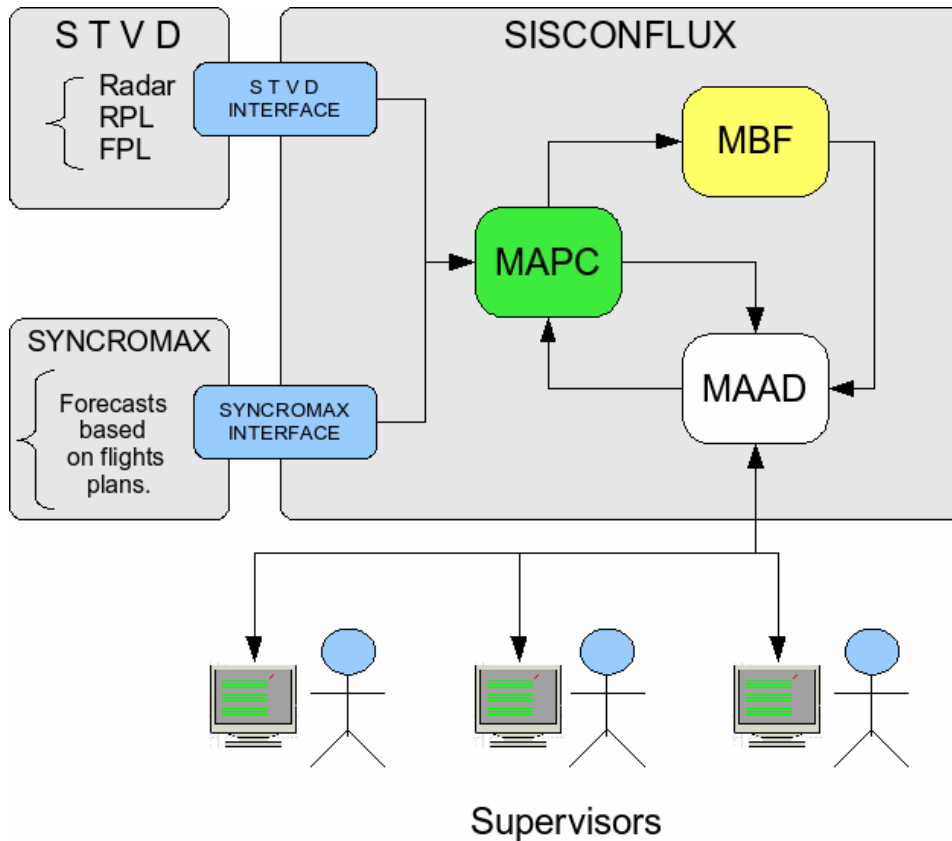


Figure 1: the System Architecture

4.4 Module of Evaluation and Decision Support (MAAD)

The present module has as its main function to suggest to the Supervisor the most adequate restrictive traffic flow measure to the projected scenario, so that traffic control sectors do not reach the congestion or saturation condition. The suggested measure, therefore, will be defined amongst the possibilities raised by the Module of Flow Balancing.

The definition of the best restrictive measure can be conditioned by the specific parameters

application that will be defined by the Supervisor, such as the need for prioritization of some or all the flights at a certain airport. For this, the MAAD has to be provided by the Supervisor, with the above-mentioned parameters, which will be sent to the MAPC for the new scenario projection and restart of the cycle.

5 METHODOLOGIES

The system modules will be developed according to specific methodologies, by means of creating the module or adapting preexisting applications.

5.1 Module of Monitoring and Scenario

Forecast

The Module of Monitoring and Scenario Forecast will result from the adaptation of the System of Accelerated Simulation for the Air traffic Flow Analysis, developed so as to provide information about the future demand in airspace traffic and the national aerodromes to the agencies responsible for the Air Traffic Flow Management (ATFM), in order to allow them to identify, with anticipation, the occurrence of extrapolation of their respective air traffic control sectors capacity, in a certain period, on a certain day (Gonzaga da Silva, 2001).

5.2 Interface with the STVD

The System of Treatment and Visualization of Data is composed of many different subsystems, all developed on a CPU platform 333MHz UltraSPARC-II, with operational system Solaris 2.6.

The information processed by the SISCONFLUX will be made available by two subsystems: the subsystem of flight plans processing and the subsystem of radar information processing.

As for the interface, it will be developed according to the parameters specified for the communication and support subsystem, in which lies the communication layer.

5.3 Module of Flow Balancing

The Module of Traffic Flow Balancing, as in figure 2, will be developed by the application of a model in order to obtain the dynamic balance between independent sectors by the use of GHP resolution techniques. The main purpose is the resolution of the GHP applied to a set of airports located in the Flight information region of Brasilia (FIR-BS) and the use of regulating procedures correcting the need of allocating resources for flights originated out of FIR. The following can be listed as excellent criteria to the implementation of the system:

a) The existence of a balancing model for obtaining an objective function based on programming entirely associated with dynamic programming resources;

b) A set of excellent and sub-excellent analyses with the use of heuristics based on standard actions commonly used by the flight controllers;

c) Prioritizing of intervals adjustment between takeoffs by the use of solutions for the wait in ground problem so as to avoid the congestion or the saturation of air traffic sectors;

d) All the flight delay actions will be converted into takeoff frequencies associated with the origin points. This comes from the fact that flight controllers work by limiting the

interval between takeoffs in a determined airport and not specifically with the flight times. Specific actions of schedule adjustments are of the aerodromes responsibility.

and decision support for analysis and submitted to the supervisors who will appreciate the suggestions, being able to accept them and effectively apply them or to request a new processing.

e) The actions will not be directly applied, but sent to the module of evaluation

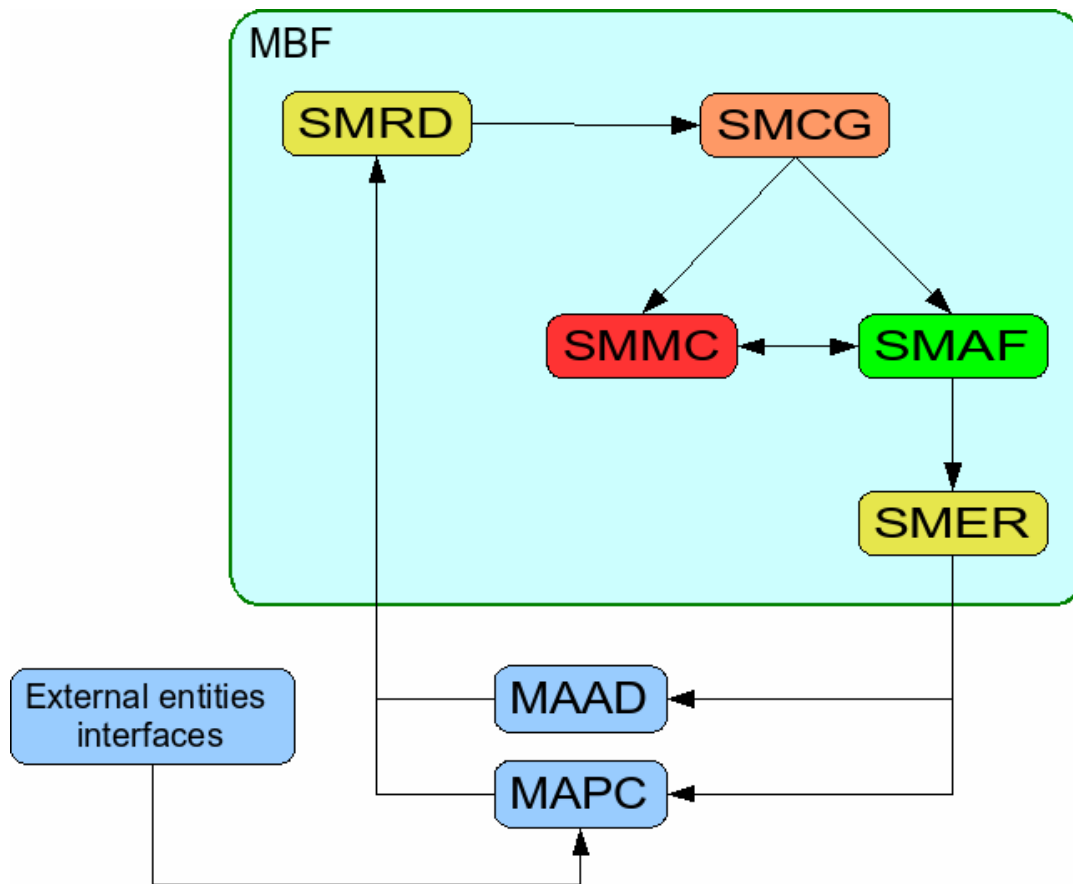


Figure 2: Architecture of the Module of Flow Balancing (MBF)

In the resolution of GHP, the Linear Programming and the Dynamic Programming are applied. The Linear Programming is useful for the optimization problems in which the objective function and the restrictions are all linear (Strang, 1988; Cormen et al. 1998).

The Dynamic Programming, however, is a method for algorithms construction aiming at deciding computational problems, especially those of combinatory optimization (Cormen et al. 1998), in which a problem can be decomposed into sub problems, being then an

excellent solution for sub problems that are extended incrementally for the solution of the problem as a whole (Denardo, 2003). In (Dell'Olmo et al. 2003) and (Zhang et al. 2005) generic models can be found as the solution of the wait in ground problem (GHP). These models will have to be adapted to the specific situation of CINDACTA I, under the optics of the needs of controllers and supervisors.

5.4 Module of Evaluation and Decision Support

The Module of Evaluation and Decision Support will make the interface between human agents and other system modules. Basically, it has the function of capturing the experience of the supervisors and air traffic controllers, including these variants to the set of results analyzed by the previous modules, but it also functions as the data origin for the system as a whole.

Once the decisions are accepted by the supervisors, they will be stored and will start to be part of the system as an accepted decision for the current scenario. Amongst the tasks of this module responsibility, the following can be mentioned:

- a) Presentation of the results to the supervisors;
- b) Data collection for learning purposes;

- c) Storage of the set of pairs (state; action);

- d) Log of events such as operators' action, etc.

In order to support the decision, the technique of Meta-Level Control will be modified and applied to the system to improve the performance of the communication (exchange of messages) between modules. During the control process, the decision is taken based on the experience and knowledge acquired through reinforced learning.

The model of Meta-Level Control proposed by Lesser and Raja (2005) includes the construction of a multi-agents system in which the Control layer is monitored by goal level. Through a series of parameters, the actions that are related to the communication between the agents/modules are executed to the relative actions to the set of tasks organized for the system. The model uses meta-parameters that are added to the messages exchanged between the agents/modules and the Meta-Level Control, based on the meta-parameters, through an analysis of the Markov decision process, reinforced learning and a set of heuristics applied on these meta-parameters.

In this context, the Meta-Level Control decides what actions must be carried through, concerning the messages exchanged between

the agents, for the performance of the supervised system and for the other actions involved in the negotiation that must be carried through with other agents/modules of the system (Alves, 2006).

6. FINAL CONSIDERATIONS

The proposal of the SISCONFLUX constitutes the scope of a strategic project of cooperation between the Command of Aeronautics and the University of Brasilia, with the purpose of developing a system of extreme importance to the operational context of the traffic control agencies, which will bridge an important gap existing in the national concept of air traffic management.

The SISCONFLUX, with applicability directed to the tactical ATFM, will be used along with the Visualization System and Data Processing of the Aerial Navigation Management Center (SYNCROMAX). In this sense, the SISCEAB will be able to make use of a set of tools capable to fully support the traffic flow management in its three levels: strategic, pre-tactical and tactical.

The project group presents a multidisciplinary characteristic and is integrated by researchers of the UnB, CINDACTA I and the Commission for the Implementation of the Airspace Control System (CISCEA). The Project, expected to be concluded in three years, has already received important

financial investments and equipment supports, besides having an intense interchange with the of Air Navigation Management Center, agency of the DECEA responsible for the conception and execution of the air traffic management in Brazil.

Finally, the application of this model in the air traffic flow control is seen by the authors as viable considering the existing security norms and also as an assisting tool for air traffic controllers. As the System potential is explored and eventual limitations are observed, new functionalities can then be added and some can even be automated.

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