# INTELLIGENT OPERATIONAL DECISION SUPPORT VIA AUTOMATION OF AIR SPACE-TIME ALLOCATION AND CONTROL

**BLAGA N. IORDANOVA** (*,**)
blaga@computer.org

(*) BIOR KNOW-HOW Ltd, Warnford Court, 29 Throgmorton Street, LONDON, EC2N 2AT, UK,

(**) The University of the West Indies, St. Augustine (since 1 August 2004)

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## Résumé

This paper introduces intelligent systems and mechanisms for automation of allocation and of control of global air space-time and of airport resources and decision support in monitoring and in controlling four dimensional (4D) trajectories of flights. They operate via distributed and parallel processes in a global network of integrated operational decision support systems for airports, airlines and global air traffic control. They provide a new global control mechanisms for controlling end-to-end trajectories of flights and global traffic flows and for ensuring conflict-free and efficient allocation of air space-time and use of capacity of airports. The intelligent mechanisms embedded in integrated systems provide new generation intelligent, interactive and integrated operational decision support to airports and airline operators, and to air traffic controllers and pilots too.

# 1 Introduction

In this paper we introduce global integration of systems via new processes and intelligent mechanisms automating the allocation and the control of global resources and providing intelligent, interactive and integrated operational decision support (IODS) in response to series of requests. The new processes and control mechanisms benefit airlines and airports, controllers and pilots, and passengers too.

## 1.1 The background of the work.

The background of the work on IODS technology automating Air Space-Time (AST) allocation and control is described in the included refereed publications.

A brief outline of this published work is as follow. The Hierarchies of Air Space-Time (AST) knowledge-and-data control structures [4] are designed to set a new technology of managing traffic, knowledge and resources of great importance to conflict-free planning for global air traffic [2,5,6] and a new air traffic knowledge management [1] policy. It brings Integrated Operational Decision Support (IODS)[2,3,5,6] for pilots and controllers. It also brings the benefits of an automated and synchronised AST allocation and a global planning and controlling of traffic flows, 4D end-to-end trajectories of flights and of their automated revisions and conflict-free updates though direct data communications with on-board equipment of aircraft via satellites. It brings IODS parallel processes of continuous end-to-end monitoring of 4D trajectories of flights and of their automated clearances. Any predicted conflicts between trajectories are resolved off-line [5,6] during a certain air space-time period ahead of current positions of aircraft reported and verified through ground positioning system and satellites. The above principles of future global air traffic management system we invented during our doctoral work completed 1999/2000 as jounior visitor at Cambridge Univeristy Engineering Department. We claim a prior art on those major innovative principles of a global vision and of a global system for future air traffic management since 2000 [5,6].

Our further work includes a design of a global neural network [1] and computational intelligence mechanisms for automation of air space-time allocation and control embedded in IODS processes. Thus the new IODS technology brings the new global control mechanisms for keeping the use of air space-time and airports resources conflict-free via global network of IODS systems for airlines, airports, pilots and controllers and communications through satellites.

## 1.2 Global resources and Intelligent Control Mechanisms.

According to published statistics one in four flights have been delayed 15 minutes or more since 1997 in Europe causing substantial costs to airlines. Delays of flights are described as equally caused by congested airports and airlines inefficiencies, and by the complexity of the rules and procedures of some national and local centres.

Spokesmen of the European Airlines Association and the European Union's commissioner for energy and transport agree that the current air traffic control system and the current occurrences of congestions on the ground make it impossible to put more planes in the air at the present time. The cost and time required is estimated to be too high to render feasible any attempt at reducing the "bottlenecks" caused by low capacity sectors under the current system. The system in current use do not enable the efficient use of the global air space-time and of capacity of airports. Yet air traffic is growing at a rate of 4 percent a year.

With the ever increasing demand for the capacity of airspace and airports the global control of traffic flows is becoming of supreme importance if we are to make the best use of the existing capacity of airports and airspace.

New technology of global processes and control mechanisms and embedded computational intelligence is necessary for provision of an intelligent, interactive and integrated operational decision support (IODS) for pilots and controllers, airports and airlines. It is necessary too for automating the allocation of global air space-time and airport resources and for control of global traffic flows. The computational intelligence imbedded in the IODS processes will improve the management and the control of global traffic flows. The congestions at airports will no longer occur with IODS intelligent control mechanisms in place. The keeping to the departure and arrival times of flights will be significantly improved and thus savings and increased profits for airlines accomplished.

The aircraft fly today in predefined corridors crossing air traffic control sectors and national boundaries. Under the current system and with the need of reducing the workload of controllers the airspace is divided into sectors and the traffic is controlled in smaller sectors today due to the increased traffic. The throughput of a sequence of sectors along a corridor of flights is limited by the sector with the lowest capacity within each corridor of flights. The current system does not make it possible to create efficient mechanisms to allow cost and time efficient reductions of bottlenecks by avoiding sectors with limited capacity.

The computational intelligence embedded in the IODS technology, processes and global control mechanisms will plan, monitor and control 4D end-to-end trajectories of flights and thus will obviate the current practice of the division of airspace by sectors and the controlling airspace and traffic within sectors. The IODS technology obviates also the need for arranging predefined corridors of flights as is in the current practice. Instead the global networking architecture of IODS systems will monitor, control and manage safely 4D end-to-end trajectories and global traffic flows from departure to arrivals at destination airports.

The IODS embedded intelligent decision support mechanisms provide the flexibility needed in planning global traffic flows and in the use of global air space-time and airport resources. The IODS processes and global mechanisms monitor and control the conflict-free use of global resources by 4D end-to-and trajectories of fights. Thus the new technology and proposed IODS systems provide efficient control mechanisms not available under the current systems in use for sector-less management of 4D end-to-end trajectories of flights and thus avoiding congestions or so called "bottlenecks" occurring frequently under the current practice due to sectors with low capacity causing frequently delays of flights and high airlines costs.

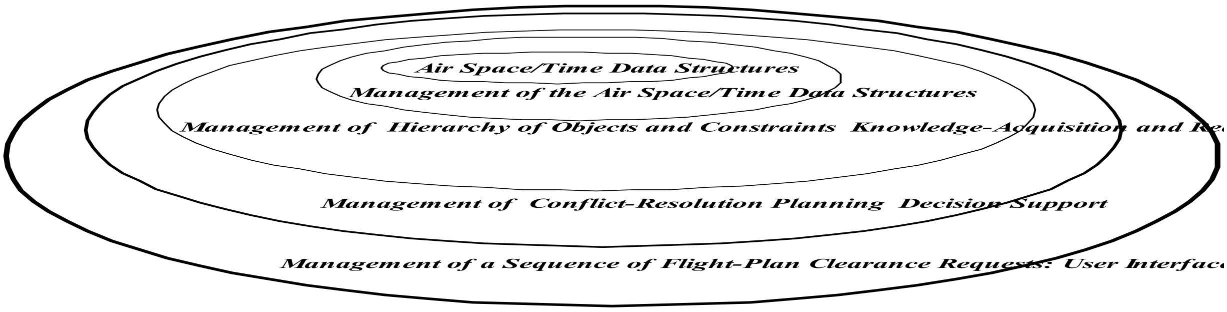
The IODS technology of new processes and new control mechanisms fundamentally change the global system. The embedded computational intelligence provides global mechanisms of control together with the global processes of planning global traffic flows and of controlling the allocation and the conflict-free use of air space-time and of airport resources. It provides automated mechanisms of learning clearance-categories of 4D end-to-end trajectories of flights and global processes of planning, of clearing and of controlling most efficiently 4D end-to-end trajectories according to the global resources available.

# 2 The IODS embedded intelligent processes.

Now I would like to introduce the design of the embedded processes and mechanisms of intelligent and integrated operational decision support (IODS) for airlines, airport operators, controllers and pilots via satellites.

## 2.1 Global architecrure.

The computational intelligence embedded in the IODS technology accomplishes the automation of the Air Space-Time (AST) design, allocation and control and the conflict-free planning of its use and of airport resources too by parallel and distributed processes learning knowledge from series of distributed flight requests. The global networking architecture of ground IODS systems for airlines and airport operators and for air traffic control and management will accomplish a conflict-free planning for global air traffic through communications with on-board equipment of aircraft via satellites.



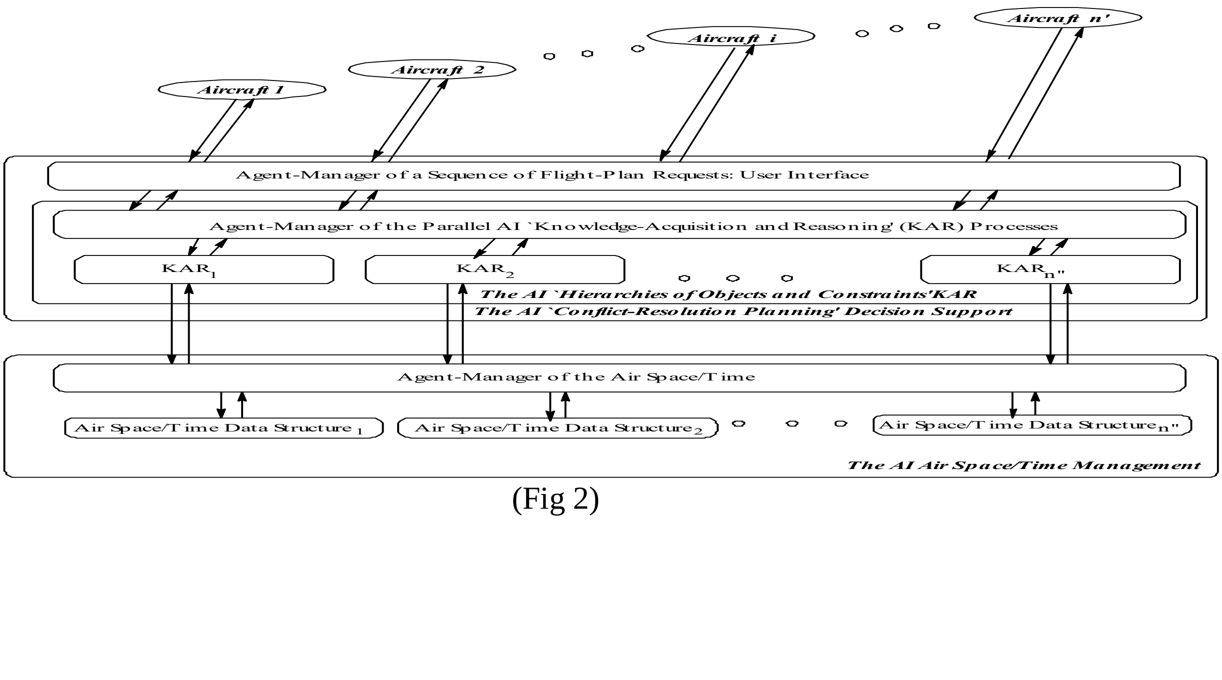

(Fig. 1)

Figure 1 shows five management layers of components of the global networking architecture of IODS systems. Each of these layers forms a concentric circle which associates certain hierarchical components of IODS intelligent systems, their Agent-managers and Agents connected with their internal hierarchy and management models. Each of them communicates with the Agents managing components in the adjacent management layers.

The outermost layer represents the User-Interface components managed by Agent-managers of sequences of flight-plan clearance requests and their interface-agents. These agents communicate with the software agents of on-board equipment of aircraft, and the Agents managing the Conflict-Resolution Planning Decision Support Components. The Agent-managers of the latter components communicate with the Agents managing the Hierarchies of Objects and Constraints of components of AI Knowledge-Acquisition and Reasoning (KAR) processes.

The Agents managing individual KAR processes are associated with the internal hierarchy of the management of the Hierarchy of Objects and Constraints components of the architecture. The latter Agents communicate with the Agents managing the Air Space-Time (AST) components and their internal hierarchy of agents managing AST monitoring processes (Fig. 2). They monitor AST knowledge-and-data control structures of clearance-categories of 4D end-to-end trajectories of flights during a certain air space-time period ahead of the current position of aircraft along the way of aircraft on that trajectory from their departure to their destination. These structures are associated with the innermost hierarchical layer of the agent-based architecture (Fig. 1).

## 2.2 Integrated Intelligent Systems.




(Fig 2)

The IODS model sets up the following two main intelligent management models (Fig 2) of the internal hierarchical components of the future global infrastructure of IODS systems, the intelligent management model of the Air Space-Time components together with their parallel AST monitoring processes, and also the management model of Intelligent Decision Support Components. The latter model contains the following internal hierarchical components managed by agents, the user interface and the management of flight-plan clearance requests queue, and the Hierarchies of Objects and Constraints (HOC) components of parallel Knowledge-Acquisition and Reasoning (KAR) processes.

The IODS systems architecture (Fig 2) integrate these two main intelligent management components. They manage the efficient allocation of the air space-time and airports resources according to the technical capabilities of the various aircraft and to the efficiency requirements of flight trajectories and of global air space-time and airports capacity use. They generate the decision support knowledge for efficient clearances of flight-plans (4D end-to-end trajectories) and for keeping them conflict-free and most efficient within the resources available. They IODS technology communicates this decision support knowledge to pilots via data communications with the on-board computer of aircraft through satellites. The global networking architecture of integrated intelligent systems communicate decision support via synchronized and secure communications between a ground IODS system and the relevant terminals of the airlines, airport operators, and air traffic controllers concerned with the updates and/or clearances of 4D trajectories of flights. The global networking architecture exchange knowledge between integrated intelligent systems via communicating synchronized updates of AST knowledge- and data control structures through satellites.

### 2.2.1 Intelligent User Interface and Communications.

The agent-managers of the user interface components of IODS systems manage the sequences of flight-plan clearance requests. Their interface agents communicate with the on-board computer of aircraft via direct data communications through satellites and the terminal of the controllers, airlines and airport operators via synchronised and secure communications.

The agent-managers prioritise flight-plans requested for clearance, and communicate with the agents managing the AI Hierarchies of Objects and Constraints components and their parallel KAR processes. Each individual KAR process generates the Air Space-Time knowledge-and-data structure of flight-plans (4D end-to-end trajectories) requested during a certain AST period. The result of all parallel KAR processes is a flow of AST structures of conflict-free and optimised flights (4D end-to-end trajectories) given the resources available. The flows of AST control structures are communicated between ground IODS systems via synchronised communications established between intelligent user interfaces of the integrated intelligent systems and though communications via satellites.

### 2.2.2 Knowledge-acquisition and reasoning processes.

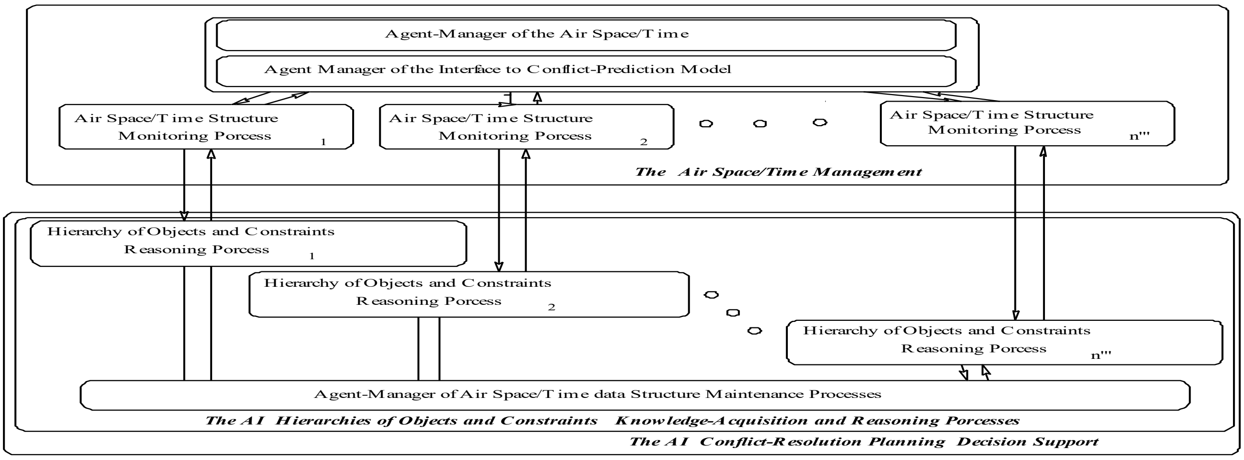
The agent-manager of the Hierarchies of Objects and Constraints (HOC) component attends to the management of the parallel Knowledge-Acquisition and Reasoning (KAR) Processes, and of communications between agents managing the individual KAR processes. He also attends to the management of the communications between the agents managing the individual KAR processes and an agent managing the AST component of the system.

The agent managing the individual KAR processes performs automated reasoning about the most efficient AST design and creates the AST knowledge and data structure of conflict-free and optimised flights from a set of flight-plans clearance requests during a certain AST period. He also attends to the maintenance of the AST knowledge-and-data structure and of flight-plans (4D end-to-end trajectories) in order to keep them conflict-free and efficient within the available resources. The agent managing the HOC component creates and maintains a flow of AST knowledge and data structures of conflict-free and optimised flights, given the available resources, by parallel KAR processes.

### 2.2.3 Intelligent Monitoring Processes.

Each of the AST structures is monitored by monitoring processes of the AST management component (Fig. 3). They test a 4D end-to-end trajectory for conflict prediction during a certain air space-time period ahead.

The agent managing the AST Management component also manages the parallel AST Monitoring processes, and the communications with its agents managing them. The agent also attends to the management of the communications between its agents managing the AST Monitoring processes and the agents managing individual KAR processes of the HOC component.

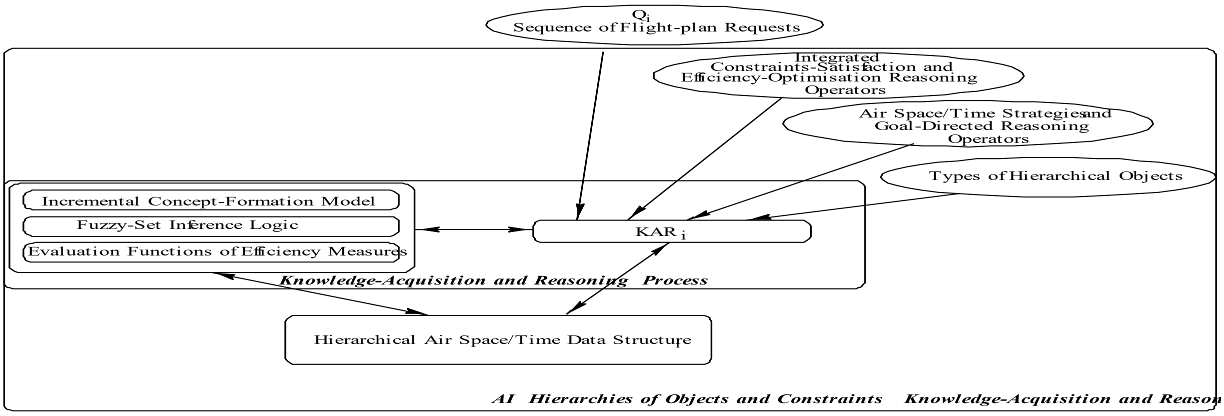



(Fig. 3)

The task of the Agents managing individual monitoring process is to monitor an individual 4D end-to-end trajectory from an AST knowledge-and-data control structure of clearance-categories of conflict-free and optimised 4D end-to-end trajectories of flights, to verify and update the recorded current position of the aircraft on the trajectory with reports of real-time positions of aircraft via GPS communicated through satellites, to revise the 4D trajectory and perform trajectory projection from the reported real position of aircraft and perform tests for conflicts along the updated 4D end-to-end trajectory ahead of the currently updated real position of the aircraft. If required, the agent also attends to communications with a KAR process relating to a service for the maintenance of the AST knowledge-and-data control structure and the knowledge of conflict-free and most efficient alterations of 4D end-to-end trajectories within the current or new clearance-category. These communications include the request for the maintenance service asked for by the agent managing the AST monitoring process. This is provided by the agent managing the KAR process of the HOC component.

When an AST conflict is predicted during an AST period ahead the monitoring process (Fig. 3) communicates with the relevant KAR process. This process plans conflict-resolution alterations of the flight-plans and their AST structures off-line during this AST period in advance. These alterations are communicated through the user interface of the system to the terminal of the controllers, airlines and airport operators and to the on-board computer of the aircraft.

#### 2.2.3.1 Learning clearance-categories of flights.



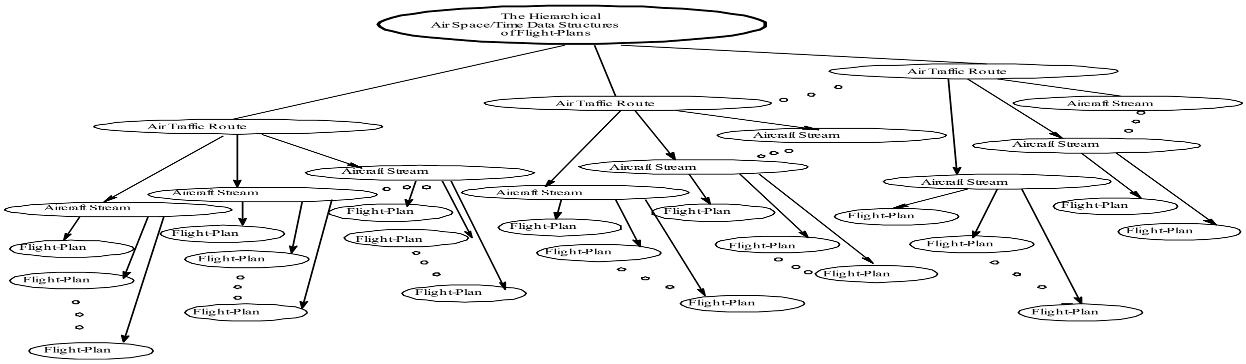

(Fig. 4)

An individual KARi process (Fig. 4) carries out learning of knowledge from distributed series of requested flights. It generates the decision support knowledge about the most efficient clearances-categories of 4D end-to-end trajectories of flights given the resources available. A clearance-category of a flight consists of hierarchical objects of an AST knowledge-and-data structure (Fig 5) such as air traffic route, stream of aircraft that most efficiently accommodate the 4D end-to-end trajectory of the flight in respect of its own efficiency and the efficiency of its air space-time and airport capacity use. The KARi process organises this knowledge of the most efficient clearance-categories of flights in a hierarchical AST knowledge-and-data control structure of conflict-free and optimised flights, and thus it automatically generates these structures and provides an automated air space-time design, allocation and control.

The hierarchical AST strategies and integrated constraints-satisfaction and efficiency-optimisation reasoning operators guide the learning at various hierarchical levels of the automated acquisition of an AST knowledge-and-data structure (Fig. 5) from series of flight requests.

#### 2.2.3.2 Distributed flight requests.

There exists two types of requests: requests for flight-plans (4D end-to-end trajectory of requested flight prior to departure) clearances from agents of on-board computer of aircraft and requests for conflict-resolution alterations of the flight-paths (4D end-to-end trajectory of aircraft in flight) made by agents of the AST management component, monitoring the AST control structures (Fig. 2). The KARi processes deal with the above two types of requests. They maintain and update incrementally the AST knowledge-and-data control structures of conflict-free and optimized 4D end-to-end trajectories of flights. Thus they also generate the decision support knowledge for sustaining the efficiency of the AST use and of the 4D end-to-end trajectories of flights in the long term.




(Fig. 5)

The aircraft agents who have requested clearance have the capacity to influence the decision of an agent managing the relevant KAR process, by providing him with certain efficiency parameters together with their requests. The agent managing the KAR process takes into account efficiency measures and functions for evaluating the possible clearance-categories according to the requested efficiency and meanwhile communicates them in order of priority to the agents requesting them. The latter agents can make their final choice according to their objectives.

### 2.2.4 Interactive, Intelligent and Integrated Systems.

The IODS technology, processes and control mechanisms provide intelligent, interactive and integrated ($I^3$) operational decision support (ODS) to pilots via data communications though satellites with en-board computer of aircraft and to controllers, airlines and airport operators synchronized and secure communications within the global I3ODS infrastructure of the networking dedicated ground IODS systems architecture controlling global traffic and air space-time and airport capacity use.

The global $I^3$ODS infrastructure of networking IODS systems communicate to each other AST knowledge-and-data control structures via satellites and secure conflict-free planning for global traffic and controlling of the conflict-free use of global resources

It accomplishes the latter by the intelligent management and control of allocation of air space-time and of airport resources planning of global traffic flows according to resources available via global computational intelligence mechanisms and AST control structures.

The embedded computational intelligence in parallel AST and KAR processes in a global infrastructure of networking architecture of IODS systems and their collaboration provide the generation of the knowledge and the planning of conflict-free and efficient AST use and the most efficient clearances of 4D end-to-end trajectories of flights. This collaboration also keeps the 4D end-to-end trajectories conflict-free and most efficient in the long term. This is accomplished by the planning of conflict-resolutions off-line during a certain AST period in advance before signs of AST conflict can develop in real-time.

The satellites communications of the global I3ODS infrastructure of networking dedicate ground IODS systems architecture and the on-board computers of aircraft will deliver the synchronised updates of conflict-free 4D end-to-end trajectories of flights to the pilots via the on-board computer and to the other concerned parties via synchronised communications between the ground IODS system and the relevant terminals of airlines, controllers and airport operators.

## 3. Global Infrastructure meeting global challenges.

The IODS automation of air space-time allocation ensures flexibility in the planning of global traffic flows and their use of AST and airport resources. It enables better control of the resources and the traffic and prevents occurrences of congestions on the ground and in the air.

The IODS automation processes and control mechanisms provide intelligent operational decision support to air traffic controllers, pilots, airlines, airports via a global infrastructure of networking architecture of IODS systems. The efficiency of allocating air space-time and airport resources and of controlling of their better use by four dimensional (4D) end-to-end trajectories of flights will be significantly improved. The computational intelligence embedded in the IODS systems will provide automated allocation and control of global air space-time and of airport resources for flights booked by airlines in advance and also at the time of their requested clearances before the take off of the aircraft. It ensures the conflict-free use of allocated resources by end-to-end trajectories of aircraft in flight too.

The computational intelligence automating the air space-time allocation and control together with processes monitoring the 4D end-to-end trajectories of flights control the global traffic flows and ensure their conflict-free use of air space-time resources and thus improve the use of capacity of airports.

The embedded intelligence of learning clearance-categories of flights and of controlling the air space-time allocation will significantly reduce the workload of air traffic controllers. The intelligent and integrated operational decision support for pilots and controllers, and for airports and airlines will secure synchronised operations and will improve further efficiency and safety of global air traffic and operations.

The automated global control of traffic flows benefits airlines, air traffic control and the airport operators too. The capacity of airports will be increased. Airport operations will not be disrupted. Congestions of aircraft in the air or on the ground will be avoided. Airports will no longer as happen now from time to time be closed until such congestions are cleared.

The benefits for all parties involved in the air traffic industry is an intelligent and interactive and integrated infrastructure of IODS systems controlling global resources, securing conflict-free planning for global air traffic and communicating decision support to airports operators and airlines, and to air traffic controllers and to pilots through satellites.

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