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AIR TRAFFIC MANAGEMENT SYSTEM USED INTELLIGENT COMPUTING

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ABSTRACT

This paper presents the new real time approach based on agent architecture for intelligent and real time air traffic management systems. The proposed method consists to modulate the airport by two agents; the first one is the P-Agent or planner agent, it consists to negotiate with other airport and controls the aircrafts departures, also, it allows to schedule the aircraft landing, the second agent is aircraft landing execution agent (ALE-Agent), which allows controlling the aircraft landing operation inside air traffic management advisor (TMA). Also we propose the ATC-agent, it consists to separate and to manage the air traffic in the transit airspace between the departure airport and arrival airport. To separate the aircrafts in the transit space and to schedule the aircrafts landing we proposed a new real time method based on the least laxity first algorithm. Our approach is developed to analyse and optimize the air traffic management process and it's compared by the classic method.

Keywords: air traffic management, intelligent computing, real time scheduling, agent, least laxity first algorithm.

INTRODUCTION

The air traffic continues to increase, so the air transportation becomes a highly competitive area and it forecasted to face strong challenges. Therefore, there is need for new approach of air traffic management ensures a high air traffic capacity, a high level of safety and reduces the environmental impact of this increase.

The air traffic management (ATM) is the all systems that assist the aircraft from the depart airport to arrival airport and in the transit aerospace. In a complex environment such as ATM where the information flow is intensive, to manage the aircraft by the efficient and safety method become a complex task, this particular problem become more important when we considers the air traffic increase.

To manage the air traffic efficiently, new methods based on the intelligent computing using multi-agent systems have been successfully introduced and thus can replace verbal information with digital message communication and coordination.

Multiagent systems have been applied to solve many complexes scientific problems in the different fields such as medicine, energy management, transportation related applications or transportation scheduling systems (Fischer *et al.*…etc. So, it's normally to use this powerful technology to optimize the air traffic management process. Currently, the widely used method for air traffic management is FCFS – First Come First Served -, where the service priority is done in the order of the aircrafts arrival on the Traffic Management Advisor (TMA) of the airport or in the transit airspace. This method presents two advantages; it is easy to implement and it also minimizes the number of aircraft deviations, but the aircraft with low speed can affect the flight time the aircraft with high speed, so it's not optimal method. Alternative solutions based on meta-heuristics approach [2] and linear programming [1] has been proposed to manage the air traffic in a more efficient way. In this context we proposed a new method used intelligent computing.

The proposed system IATMS (Intelligent Air Traffic Management System) consists to modulate the Air Traffic Management process by multiagent systems and implement a distributed architecture, that allows for a natural decomposition and facilitate the Air Traffic Management execution. Also to manage and separate the aircrafts in the transit airspace or in the Traffic Management Advisor, we use the real time scheduling algorithm, such as, Least Laxity First (LLF) algorithm.

The paper is organized as follows; Section 2 presents the air traffic management process and explains the all steps of aircraft flying. In section 3, we present the new air traffic management system based on the multiagent architecture. The inference process and the algorithms of the proposed system are presented in the Section 4. In the section 5 we present the air traffic management system infrastructure. The result analysis is discussed in Section 6. In the final section, we conclude and the direction of future studies.

AIR TRAFFIC MANAGEMENT DEFINITION

Air Traffic Management consists of three distinct activities:

Air Traffic Control (ATC): It's the process by which aircraft are safely separated in the sky as they fly and at the airports where they land and take off again. This activity is provided by the air traffic controller in the airport Tower and in the regional control center. ATC process composed by tree sub process; (i) Regional Air Traffic Control, that allow to separate and manage the aircrafts in the regional airspace or transit airspace, (iii) Approach Air Traffic Control, it consists to manage and separate the aircrafts inside the Terminal Management Advisor (TMA) around the airport and (iii) Aerodrome Air Traffic Control, it allows to manage and control the aircrafts in the airport ground, taxiway and in the aircrafts parking.

Air traffic flow management (ATFM): consists by the all activities that are done before flights take place,

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such as , flight plan treatment, aircrafts take-off planning. For safety reasons, air traffic controllers cannot handle too many flights at once so the number of flights they control at any one time is limited. Sophisticated computers used by air traffic flow management calculate exactly where an aircraft will be at any given moment and check that the controllers in that airspace can safely cope with the flight. If they cannot, the aircraft has to wait on the ground until it is safe to take off.

Aeronautical Information Services (AIS): These services are responsible for the compilation and distribution of all aeronautical information necessary to airspace users, which include safety, technical, navigation information.

This paper is focused on the Air Traffic Control (ATC) and Air Traffic Flow Management (ATFM) process.

INTELLIGENT AIR TRAFFIC MANAGEMENT SYSTEM (IATMS) DESIGN

Air Traffic Management was the subject of several researches work, so the Artificial Intelligence (AI) has been used to solve the Air Traffic Management (ATM) problems and recently, the distributed architectures have been employed to elaborate ATM infrastructure. Our proposed system IATMS is the distributed system based on the multiagent architecture and used the Least Laxity First algorithm, one of the more popular real-time algorithms scheduling, to separate the aircrafts in the transit airspace and to Aircraft Landing Scheduling in the TMA (Traffic Management Advisor) close to arrival airport.

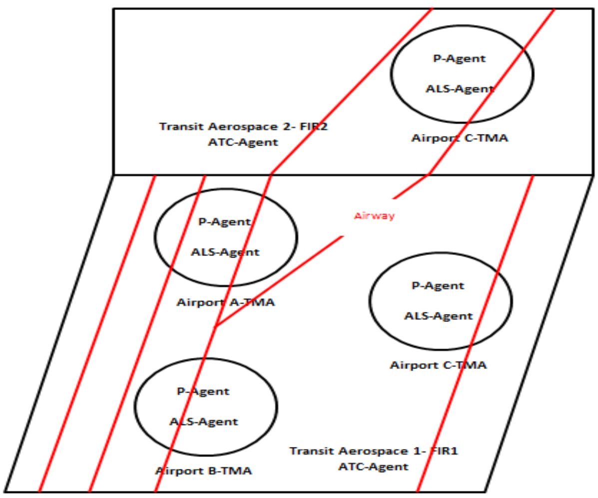

Figure-1. IATMS design.

The proposed system consist to analyse the potential congestion points and solving them before they occur, to separate the aircrafts in the transit airspace with the optimal manner and to schedule the aircraft landing in order to minimise the landing cost.

Each member country of ICAO (International of Civil Aviation Organization) defines its transit airspace that named FIR (Flight Information Region). This transit airspace contains many airways, so these airways used by the aircrafts to fly between the departure airport and arrival airport. Normally, the air traffic controller is the responsible to separate the aircrafts and give them the information flight in order to ensure the safety and control the air traffic. Also the air traffic controller coordinates with the air traffic controller of the adjacent FIR.

In the proposed system (IATMS), we modulate the air traffic controller by ATC-Agent. Then the latter consist to separate the air traffic in the airspace transit or FIR, to coordinate with the adjacent ATC-Agent. Also ATC-Agent transmits, collects and analyses the air traffic information inside the FIR.

The management of air traffic in the space defined by the TMA (Traffic Management Advisor) is provided by the air traffic controllers from the airport control tower. In general the TMA is a space with a cylindrical shape and the runway is placed in the center of its base. Each aircraft entering the TMA through the predefined points, named points of entry, and flying until a holding position that defined by radio-navigation equipment, named VOR (Very high frequency Omni Range). When the aircraft is vertical VOR equipment, it becomes ready to land and expects a landing clearance from the control tower when the runway becomes free.

IATMAS modulate this process by two agents; the first one is the P-Agent or planning agent, it consists to recover the air traffic information from the ATC-Agent, to analyse this information, to negotiate with the P-Agent of the departure airport, to elaborate the timetable departure with a real time meaner and to communicate the results of the negotiation process to ALS-Agent. The second agent is the ALS-Agent; it allows receiving the traffic information from the P-agent and scheduling the aircrafts landing in the TMA. In general the air traffic controllers use the FCFS method; the first arrived on the holding point is the first receiving the landing clearance when the runway becomes free and other constraints required by the national and international norms are satisfied such as the minimum separation distance between two aircrafts imposed by ICAO (International Civil Aviation Organization). The IATMAS through the ALS-Agent use the LLF (Least Laxity First) to schedule the aircrafts landing and management the traffic in the TMA space. LLF is real time algorithm scheduling, pre-emptive and optimal for independent and periodic real time tasks.

INTELLIGENT AIR TRAFFIC MANAGMENT SYSTEM INFERENCE PROCESS

Basic considerations

The proposed system IATMS composed by tree different process; planning process, air traffic control process and aircrafts landing scheduling process. All these process must respect the following constraints:

a. The runway can be used by one aircraft at a time;
b. The aircraft landing have absolute priority over aircraft departure; so the take-off aircraft may not be

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released if we have the landing aircraft is less than a specified distance from the runway threshold.

c. In the transit airspace, the aircraft with low laxity are served and take the airway.
d. In the TMA, the management of the Aircraft Landing Scheduling (ALS) is based on the LLF (Least Laxity First) algorithm.
e. The transit airspace or FIR contains the airways and each airway composed by many flight levels.
f. Successive landing are spaced at a minimum time separation, this time is defined by ICAO.
g. Successive departures are spaced at a minimum time separation equal to the departure service time.
h. The TMA space has a cylindrical shape.
i. The TMA contains one runway.

Air traffic management service quality factor ATMSQF definition

The air traffic management service quality consists to:

- Minimize the global air traffic delay, that the sum of the air traffic departure delay, the air traffic delay in the transit airspace and the air traffic landing delay, in order to offer the high passengers service quality and to use the aircrafts with the optimal manner.
- Reduce the air traffic fuel quantity to preserve the energy resources and the environment.

Flight efficiency id defined by a high air traffic management service quality factor value. So, it consists to give all possibility to air traffic to fly on the short airways, to take-off and landing with optimal manner.

We consider the air traffic flies in the tow or tree adjacent transit airspaces. It applies for the international air traffic.

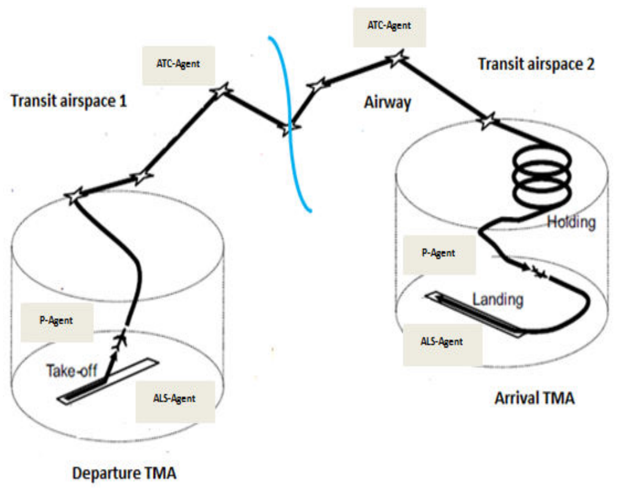

Figure-2. Air traffic control process.

In the taking-off phase, the air traffic is characterized by:

- T^{TR}_i: the take-off request time.
- T^{T}_i: the real take-off time.
- T^{PE}_i**:** the predicted time when the air traffic exit the TMA space.
- T^{RE}_i: the real time when the air traffic exits the TMA space.

In this phase, we use the First Come First Served method, the taking-off authorization gives according with the departures schedule, and so the air traffic departure delay will be defined by:

$$ADD_i = (T^{T}_i - T^{TR}_i) + (T^{RE}_i - T^{PE}_i) \quad (1)$$

Each air traffic landing is characterized by:

- T^{FC}_i: first contact time with Tower of the arrival TMA, it's the time when the air traffic asked authorization to enter in the arrival TMA space and start the landing procedures.
- T^{LS}_i: the real time when the air traffic started the landing procedures.
- T^{L}_i**:** the air traffic real landing time.
- T^{P}_i: the air traffic expected landing time.
- $D_{E\text{-}L}$: The distance between the aircraft position and the runway threshold, it's the distance flaying by aircraft during the landing process.

In this phase, the aircraft landing is considered a real-time task, it can be:

- Ready: when the aircraft flying at the entry point and waiting the authorization from the ALS-agent to enter inside the TMA space.
- Executed: when the aircraft flying inside the TMA space and it's in the landing phase.
- Blocked: when the aircraft landing process is blocked, the aircraft flying in the waiting area.
- Terminated: **t**he aircraft landing process is terminated when the aircraft landed and runway become free.

Also the aircraft landing task is characterized by:

- R_i: The aircraft activation time, the time when the aircrafts arrives at the TMA entry point.
- T_i: The aircraft landing period.
- D_i: The aircraft landing deadline

$$D_i = T^{P}_i$$

- C_i: The aircraft landing execution time.

$$C_i = D_{E\text{-}L}/V_i$$

In this phase, the landing priority is grant to the aircraft with low critical time, according to the Low Laxity First algorithm [3].

- CT (t_i) : The aircraft landing Critical time at a time t_i : CT $(t_i) = D_i - C_i\ (t_i)$
- DLO_i : Aircraft Landing delay outside TMA space:

$$DLO_i = T^{LS}_i - T^{FC}_i \quad (2)$$

- DLI_i: Aircraft Landing delay inside TMA space:

$$DLI_i = (T^{L}_i - T^{P}_i) - DLO_i \quad (3)$$

Each air traffic in the transit airspace is characterized by:

- V_i: The air traffic speed inside the transit airspace, it is considered constant.
- $DP_{i\text{-}o}$: The predicted distance flayed by the air traffic inside the transit airspace.
- $DR_{i\text{-}o}$: The real distance flayed by the air traffic inside the transit airspace.
- T^A_i: the air traffic arrival time at the transit airspace or FIR.
- T^E_i: the air traffic entry time at the transit airspace.
- T^P_{outi}: the predicted exit time (when the air traffic leaves the transit airspace).
- T^R_{outi}: the real exit time.

In the airspace, the air traffic is considered a real time task so:

- R_i: The air traffic activation time, the time when the air traffic arrives at the transit airspace.
- T_i: The air traffic period in the transit airspace.
- D_i: The maximal (deadline) air traffic time between the entry point and the exit point in the transit airspace, it equals:

  $DP_{i\text{-}o}/ V_i$
- C_i: The real air traffic time between the entry point and the exit point in the transit airspace (execution time), it equals:
  $DR_{i\text{-}o}/V_i$
- L_i: The air traffic laxity at given moment t_i:

$L_i(t_i) = D_i\ (t_i) – C_i(t_i)$

Also, in this phase, the optimal airway is grant to the aircraft with low laxity time, according to the Low Laxity First algorithm [3].
So, we define:

- $ATDO_i$: The air traffic delay outside the transit airspace:

$$ATDO_i = T^E_i - T^A_i \quad (4)$$

- $ATDI_i$: The air traffic delay inside the transit airspace:

$$ATDI_I = T^R_{outi} - T^P_{outi} \quad (5)$$

In order to define the Air Traffic Management Service Quality Factor (ATMSQF), we consider tow parameters; (i) the air traffic safety and (ii) the fuel quantity that consumed by air traffic Durant the flight. In the landing process, the air traffic presents the high

So we define:

- W_d: the departure delay weight coefficient, that equals 0.2;
- W_l: the landing delay weight coefficient, that equals 0.5;
- W_t: the delay weight coefficient in the transit space, that equals 0.3;
- n: the air traffic number between t_i and t_{i+1}

The global air traffic departure delay between t_i and $t_{i+1}$is defined by:

$$GATDD\ (t_i, t_{i+1}) = \sum_{i=1}^{n} ADDi * Wd \quad (6)$$

The global air traffic landing delay between t_i and t_{i+1}:

$$GATLD\ (t_i, t_{i+1}) = \sum_{i=1}^{n} (DLOi * Wt) + (DLIi * Wd) \quad (7)$$

The global air traffic delay in the transit space between t_i and t_{i+1}:

$$GATTD\ (t_i, t_{i+1}) = \sum_{i=1}^{n} (\mathrm{ATDOi} * Wl) + (ATDIi * Wt) \quad (8)$$

The Air Traffic Management Service Quality Factor (ATMSQF) between t_i and t_{i+1}:

$$ATMSQF\ (t_i,t_{i+1}) = (GATDD+GATLD+GATTD)/AD*100 \quad (9)$$

AD: Acceptance Delay, fixed by Management and quality system.

This work consists to maximize the ATMSQF under some constraints:

$Di \leq Ci$

$$\sum_{i=1}^{n} \left(\frac{Di}{Ti}\right) \leq 1$$

INTELLIGENT AIR TRAFFIC MANAGEMENT SYSTEM INFRASTRUCTURE

Since the airports are geographically distributed, also the Air Traffic Management operations are operated by the different controllers the same or different country. Some-times, these operations are operated with differing specifications. The main goal of the proposed system is sharing the ATM resources and coordinating the ATC operations in order to ensure an optimal and safety air traffic control system.

We are opted for distributed architecture based on the web services and using the Real-Time Specification for Java (RTSJ) and they run on a Computer of 2.3 GHz CPU.

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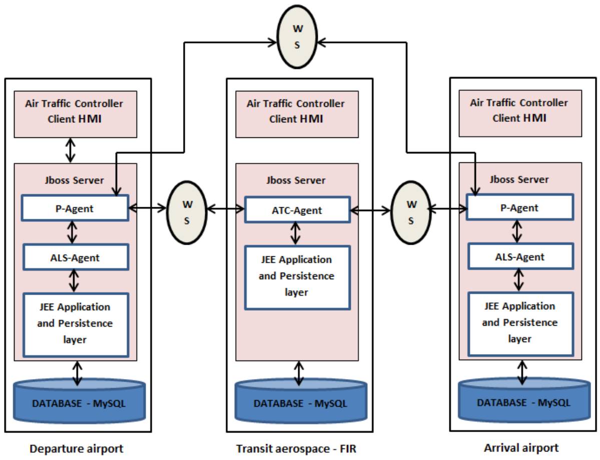

Figure-3. IATMS infrastructure.

The software architecture and the relationship among the IATMS parts are shown in figure 2. Each airport or transit airspace (FIR) is composed by three main components: (i) the interface (HMI), (ii) the software component consists of agent grid, application and data persistence layer, (iii) the database. The communication and data transfer between the airports and FIR is ensured by web services.

AIR TRAFFIC MANAGEMENT CASE STUDY USING IATMS

To evaluate the feasibility and efficiency of the proposed method, we compared it with FCFS method (First Come First Served) and with the method based on the fuzzy linear programming approach. The FCFS is the most used method to solve the Air traffic control in the TMA space and in the transit airspace. Two comparative experiments have been carried out on the benchmark set to illustrate the performance of the proposed method. The Comparative study between our approach and existing algorithms such as FCFS method or the fuzzy programming methods is based on calculation of the Air Traffic Management Service Quality Factor (ATMSQF) between ti and ti+1. The results are presented in the Table-1 and Table-2.

The proposed method performances are tested through two experiments; the first one consists to investigate the effects of the aircraft number and the second experiment allows evaluating the proposed method behaviors with the different airways number.

First experiment: air traffic number effect

This step consists to execute the proposed method with the different air traffic sequences, each time, we change the air traffic number and we consider the transit airspace with the fixed airways number equals 4. The comparative results were obtained by executing the proposed method and the existing methods for 10 independent executions, and averaging over the achieved results.

The Air Traffic Management Service Quality Factor (ATMSQF) is calculates for a period equals 3 hours and we are used the real data of the arrivals and departures aircrafts at the international airport of Casablanca and the air traffic in the Moroccan airspace (Moroccan FIR).

The air traffic number presents the total aircraft operations (landing and tacking-off) inside the TMA space and the inside the airspace.

Table-1. The air traffic number effect.

Air traffic number	Air traffic management service quality factor (%)		
	IATMS	FCFS method	Fuzzy linear programming approach
5	95	98	97
10	95	92	95
50	93	82	91
100	91	74	82
200	90	63	81
500	89	45	72

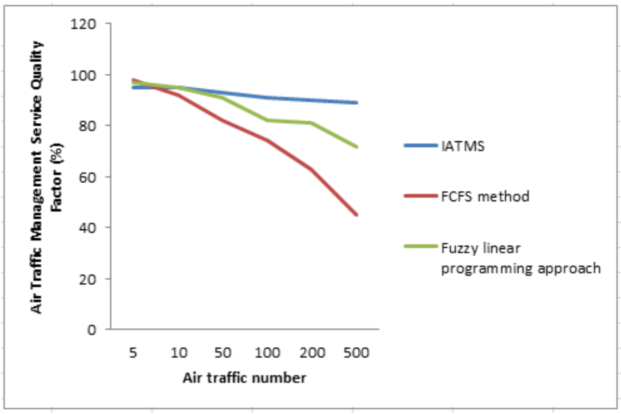

Figure-4. Experiment results, air traffic number effect.

The air traffic number can affect the performance of our approach, we not that the proposed method gives an important ATMSQF value if the air traffic number increase. We proposed a new approach that offers the optimal solution of air traffic management problem.

Air traffic management is considered a complex problem (NP-hard problem). Experiments results show the performance of our approach compared to FCFS method and fuzzy linear programming approach, especially if we have a high air traffic number.

Second experiment: airways number effect

In this part we consider the transit airspace with multiple airways and we evaluate the effects of the airways' number on the proposed method performances. The simulation is operated with 500 air traffic inside the transit airspace and the TMA space.

Also the experiment consists to change the airways' number and evaluate the performances of the

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proposed method. The comparative results were obtained by executing the proposed method and the existing method such as FCFS and the method based on the fuzzy linear programming for 10 independent executions, and averaging over the achieved results. The Air Traffic Management Service Quality Factor (ATMSQF) is calculates for a period equals 3 hours and we are used the real data of Moroccan transit airspace and the TMA of Casablanca airport.

Table-2. The airways number effect.

Airways number	Air traffic management service quality factor (%)		
	Proposed method	**FCFS method**	**Fuzzy linear programming approach**
4	78	36	79
10	82	44	81
20	93	54	89
30	95	67	90
50	97	71	92

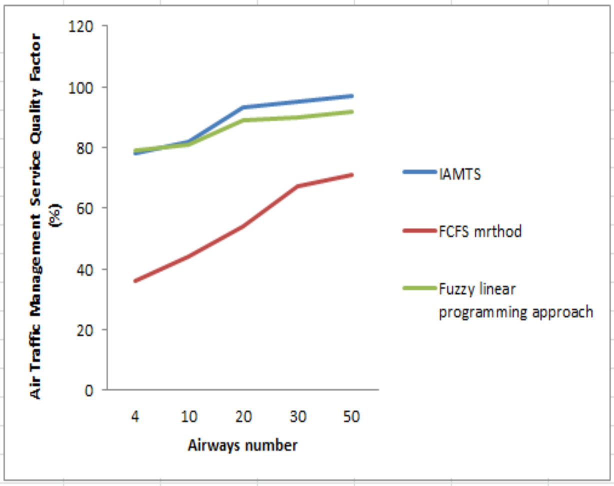

Figure-5. Experiment results, airways number effect.

The comparative result shows the benefits of the proposed method than the existing method if the airways number increases.

The proposed method presents the high performances than the FCFS method and the fuzzy linear programming approach. It gives the Air Traffic Management Service Quality Factor (ATMSQF) equals 97% for 500 air traffic, in 3 hours of flight analysis with 50 airways, is a strong indicator of the benefits of this method.

Other important benefits of our approach; it offers more flexibility to air traffic controller and ensure the air traffic safety.

CONCLUSION AND THE DIRECTION OF FUTURE STUDIES

To manage the air traffic from the departure airport, in the transit space, to the arrival airport, this contribution presents the new intelligent real time method based on the Least Laxity First algorithm and implemented by Multi-agent systems and web services in order to develop a new intelligent and distributed system (IAMTS).

The proposed method presents enough benefits than the exiting method such as FCFS method or fuzzy linear programming approach; it's give a high Air Traffic Management Service Quality Factor, so it preserves the environments, ensures the air traffic safety and offers the high passenger service quality. Also, our approach gives to the air traffic controller more the flexibility to manage the air traffic inside the transit airspace and TMA space with the optimal manner.

The researches in the Air Traffic Management are still in developing stage, so the future work consists to:

- Manage the emergency air traffic.
- Manage the Traffic Management Advisor space with multiple runways.

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