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# Function Allocation between Automation and Human Pilot for Airborne Separation Assurance

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**Abstract:** Maintaining safe separation between aircraft is a key determinant of the airspace capacity to handle air transportation. With the advent of satellite-based surveillance, aircraft equipped with the needed technologies are now capable of maintaining awareness of their location in the airspace and sharing it with their surrounding traffic. As a result, concepts and cockpit automation are emerging to enable delegating the responsibility of maintaining safe separation from traffic to the pilot; thus increasing the airspace capacity by alleviating the limitation of the current, non-scalable, centralized, ground-based system. In this paper, an analysis of allocating separation assurance functions to the human pilot and cockpit automation is presented to support the design of these concepts and technologies. A task analysis was conducted using Petri nets as a representation tool to identify the main separation assurance functions and their interactions. Each function was characterized by three behavior levels that may be needed to perform the task: skill, rule and knowledge based behavior levels. Then recommendations are made for allocating each function to an automation scale based on their behavior level characterization and with the help of subject matter experts.



*Keywords:* Function Allocation, Automation, Air Traffic Management, Separation Assurance, Petri Nets.

## 1. INTRODUCTION

A principal function of air traffic management is separation assurance, which is responsible for maintaining minimum separation distances between aircraft and from hazardous or restricted airspace. This function is performed predominantly by air traffic controllers based in air traffic control facilities using radar surveillance of aircraft location and voice communication with pilots. Each controller is assigned a volume of airspace with a maximum number of aircraft to control simultaneously thus imposing capacity limits that are based on their workload. Therefore, currently this function is centralized with ground-based controllers.

With the advent of technologies such as the satellite-based automatic dependent surveillance and broadcast (ADS-B), aircraft can maintain awareness of their position and share it with their surrounding traffic. Hence, concepts of distributed, airborne-based separation assurance have emerged, where aircraft equipped with ADS-B are delegated the responsibility of maintaining separation with their surrounding traffic, partially or completely. Distributed separation assurance promises to increase airspace capacity by mitigating the workload limitation of the centralized air traffic controller. However, due to pilot workload limitation, it is believed that automation in the aircraft cockpit is needed to enable the new separation responsibilities. NASA has developed a prototype of such automation, called the autonomous operations planner (AOP) and a concept for autonomous flight rules (AFR) (Wing 2011). NASA has also conducted several human-in-the-loop (HITL) experiments to assess the concept feasibility using the AOP prototype (Wing 2010). AOP detects potential violations of the separation requirements between aircraft, called conflicts, based on shared ADS-B surveillance and intent information and advises the pilot of trajectory change maneuvers that resolve these conflicts.

A key design question for airborne-based separation assurance is the allocation of functions between the human pilot and the cockpit automation. This question has been addressed implicitly relying primarily on elicitation of subject matter experts, engineering judgment, and human in the loop experiments, which are typically conducted in limited contexts in order to enable high fidelity prototype design and development. In this paper, a more thorough function allocation analysis for airborne-based separation assurance is presented, using AOP as a guiding example, but addressing functions that may not have been considered in the AOP design. A similar analysis was conducted for ground-based separation assurance (Landry 2011), which recommended additional functions such as traffic intensity avoidance. Landry developed a top-down task analysis approach to


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identify key separation assurance tasks and then recommended function allocations using the automation levels developed by Sheridan (Sheridan 1992).

The approach of this function allocation assessment consisted of: (1) A task analysis to identify the main functions of separation assurance. (2) Formal modeling using Petri nets in order to highlight complex interactions between the tasks. (3) Characterizing key tasks by the behavior level needed to perform them according to Rasmussen's skill-based, rule-based and knowledge-based levels (Rasmussen 1983) and correspondingly allocating them to an automation scale based on Sheridan's automation levels (Sheridan 1992).

The analysis approach is detailed in the next section followed by the analyses of two main separation assurance functions, conflict detection and conflict resolution, as examples. Finally, an overall function allocation analysis of a larger set of key separation assurance functions is presented based on elicitation of a small group of subject matter experts.

## 2. Analysis Approach

The function allocation approach consisted of the following:

### *2.1 Task analysis*

The separation assurance tasks were identified in an abstract framework independently from who may perform them to enable identifying possible function allocation schemes. They were initially divided into four high level tasks:

(1) Conflict Identification (CI): Identify potential loss of separation (LOS).

(2) Conflict Assessment (CA): Determine the need to resolve a conflict based on its severity.

(3) Resolution Selection (RS): Select a resolution maneuver for the conflict.

(4) Resolution Implementation (RI): Implement the resolution through communication and maneuvering.

Then, these tasks were divided into subtasks gradually whenever a function was too complex to be allocated to the human or to the automation. Scenarios were used to provide context where AOP and the AFR concept were used as an example automation instantiation. However, additional tasks that AOP did not consider were identified. Two scenarios, one for conflict detection and one for conflict resolution, are presented as examples in the next two sections.

### *2.2 Petri Net Modeling*

Petri nets (Jensen 1990) were used to provide a formal representation of the functions, and the information flows and interactions between them. Petri nets (Fig. 1) consist of places (circles) that represent conditions, transitions (rectangles) representing tasks, and arrows that lead from input places to transitions and from transitions to output places. Tokens (small circles that may have multiple colors as identities) are placed inside places when the corresponding conditions are true. Transitions fire (i.e., tasks are performed) once tokens are present in all their input places, which results in removing tokens from the input places and adding tokens to the output places according to additional rules attached to them. When a transition fires the net moves to a new state (i.e., configuration of tokens in places). Using Petri nets one may identify, represent and analyze issues associated with allocating the separation assurance tasks among agents. In this analysis, the human and automation agents were represented as tokens: if a task is allocated to the human, the automation, or both, then a human token, an automation token, or both, respectively, are needed in input places for it to fire. This representation enables modeling collaborative and dynamic allocations, where a task is allocated to one and/or the other resource based on which is available at the time. While Petri nets enable quantitative simulation and assessment, in this preliminary analysis they were used qualitatively to represent and identify complex tasks that were then allocated to human and/or automation roles based on the behavior level needed to perform them, as described next. Quantitative assessment using the Petri nets developed may be performed in future extensions to this analysis.

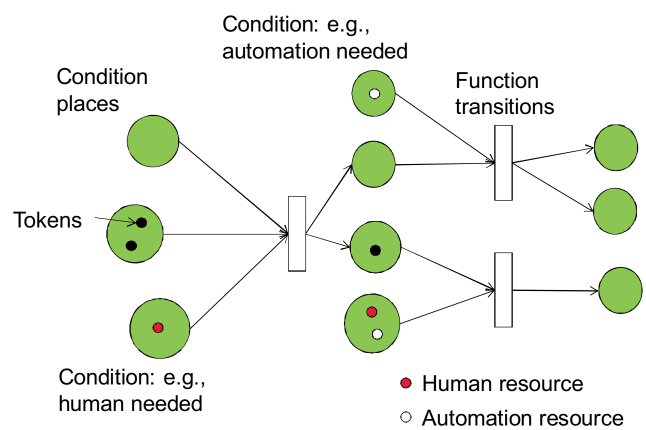


Fig. 1. Petri nets basic components.

### *2.3 Behavior and Automation Level Analysis*

The criteria used to guide function allocation between the human and the automation started from Fitts' 1951 list of men are better at – machines are better at (MABA-MABA). More recently, Sheridan proposed in his supervisory control theory a systematic approach where each function is characterized along two dimensions: physiological locus (consisting of sensory, cognitive or response activities) and behavior level, based on Rasmussen's knowledge-based, rule-based and skill-based model (Sheridan 1992). Sheridan suggested that skill-based functions be allocated to task-interactive automation, rule-based functions be allocated to a human-interactive computer, while Knowledge-based functions requiring experience are allocated to the human supervisor. Recently (Cummings 2014) suggested the addition of an expert level of behavior and related these levels to the uncertainty involved in a task (Fig. 2). She also suggested allocating functions to the human and the automation according to these behavior levels: A skill-based