Computational Assessment of Different Air-Ground Function Allocations

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Designing Transformative NextGen Concepts of Operation

Big question in design: Who does what?

✧ New functions can be assigned to the aircraft (e.g., Flightdeck Interval Management)

✧ New functions can be assigned to the ground (e.g., Communicating autopilot targets via CPDLC)

We need to evaluate radically new function allocations early in design
Terminology

- **Autonomy**: Functions that an agent can perform independently

- **Authority**: Functions an agent is asked to perform

- **Responsibility**: Which outcomes will an agent be accountable for

- **Function allocation**: Assigning agents with the authority and/or responsibility for functions
Coherence of a Function Allocation

Coherence is a qualitative measure of a function allocation:

- **Coherent function allocation**
  - Groups together related actions
  - Groups together actions using the same information
  - Assigns these groups (functions) to agents

- **Incoherent function allocation**
  - Requires different agents to perform interleaved actions
    - Need to wait on each other
    - Need to coordinate and transfer information
Emergence

In concepts of operation with multiple, interacting agents:

- High level performance can emerge
  - Eg: Traffic stream emerges out of individual aircraft

- Demands on individual agents can emerge
  - Eg: When speed change is required to maintain position in stream
Computational Simulation of Concepts of Operation

Early in design, can simulate different function allocations to:

✧ Predict overall system performance
✧ Predict which functions each agent will need to complete, and when
✧ Predict what information each agent will need, and when
✧ Predict what information needs to be transferred, and when
✧ Identify monitoring required by authority-responsibility mismatches
Simulation Framework: Work Models that Compute (WMC)

- Concepts of operation described by the work they require
  - Functions
  - Detailed actions comprising the functions
- Work modeled outside the agents
  - During simulation, actions allocated to agents

Different function allocations can be created between – or dynamically within – simulation runs
Case Study

Source: Jeppesen EHAM
WMC Setup

- (Perfect) agents:
  - 3x flight crew
  - 1x air traffic controller

- Work modeled through actions

- Actions are linked to agents in two modes:
  - Authority
  - Responsibility
WMC Setup

- Lateral profile management
- Set a target waypoint
- Control heading to direct aircraft to target waypoint
- Command a response maneuver
- Execute either fanning or trombone maneuver
WMC Setup

- Vertical profile management
- Determine TOD
- Initiate 2 degree glide slope
- Perform OPD
- Intercept ILS
- Land the aircraft
WMC Setup

- Speed management
- Calculate distances to merge and determine arrival sequence
- Assign a lead aircraft
- Maintain separation
# Function Allocation Matrix

<table>
<thead>
<tr>
<th>Functions</th>
<th>Authority allocations (AA)</th>
<th>Responsibility allocations (RA)</th>
<th>Incoherent Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Vertical profile</td>
<td>G</td>
<td>A</td>
<td>A</td>
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<tr>
<td>A/C config mgmt</td>
<td>G</td>
<td>A</td>
<td>A</td>
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<tr>
<td>Lateral control</td>
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<td>Speed control</td>
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<td>Vertical profile</td>
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<tr>
<td>Speed mgmt</td>
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<tr>
<td>Non-nominal situation mgmt</td>
<td>G</td>
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<td>G</td>
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</tbody>
</table>
Action Time Traces FA4
Action Time Traces FA6

Nominal scenario

Off-nominal scenario
Aggregate Number of Actions

- **AIR**
  - Average Number of Actions Required of Agent
  -的责任

- **GROUND**
  - Average Number of Actions Required of Agent
  - 的责任

- **Taskwork**
- **Monitoring Due to Authority-Responsibility Mismatch**
Aggregate Information Requirement

- **AIR**
  - Information transfer requirements
  - Responsibility
  - Authority
  - Taskwork
  - Monitoring Due to Authority-Responsibility Mismatch

- **GROUND**
  - Information transfer requirements
  - Responsibility
  - Authority
  - Taskwork
  - Monitoring Due to Authority-Responsibility Mismatch
Summary

- We can simulate concepts of operation early in design
  - Simple case study here scales to larger analyses
- Can identify problems in the inherent function allocation
  - Static function allocation
  - Can also examine dynamic function allocation and delegation

Helps identify and design-out human factors concerns with taskload and information
Further Extensions

- Here focused on ‘early-on design’
  ✦ Because agents executed actions perfectly, results reflect concept of operation and function allocation
  ✦ Ought to design-out such problems before detailed design of technology, training, procedures and interfaces

- Can then progressively incorporate more detail
  ✦ Different methods of performing same function
    ▪ Depending on which agent executes the work
    ▪ Depending on immediate taskload of agent
  ✦ Verifiable aspects of human performance
    ▪ Taskload limits
    ▪ Response Time
Further Extensions

- Models of communication between agents
  - Latency/duration/delay
  - Drop-out or communication error rates
  - Cost per bit of communication
Thank You!

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