Quantifying Air Traffic Controller Mental Workload

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INTRODUCTION
Basic Concepts

- **Air Traffic Complexity**
  - Difficulty perceived by ATCo

- **ATCo Mental Complexity**
  - Ability to perceive and respond to variables
    - Prior experience
    - Prior developed personal constructs

- **Personal constructs**
  - Mental structures used to interpret & respond
  - How each one relates, overlaps & influences the others determines cognitive complexity
How do we define complexity

Currently:

• “…measure of the difficulty that a particular traffic situation will present to an air traffic controller...”

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• “number of simultaneous or near-simultaneous interactions of trajectories in a given volume of airspace”

Factors impacting complexity:

• Geometrical nature of the air traffic
• Operational procedures and practices used to handle the traffic
• Characteristics and behaviour of individual controller
Two basic hypotheses

Complexity inside a sector is a function of the ATCo mental workload

Assessing the ATCo mental workload inside a sector will provide an estimation of the associated complexity
What is ATCo Mental Workload?
The ATCo Mental Workload Framework
Multiple Resource Workload Model (MWM)
Experimental system

MODELLING ATCO WORKLOAD
Human Behavior can be represented/segmented in **Primitive Operator Tasks**

**Perception (Visual & Auditory)** → **Comprehension** → **Strategic Thinking** → **Decision Making** → **Responding (Manual & Verbal)**

### Visual & Auditory Processing

<table>
<thead>
<tr>
<th>Visual</th>
<th>Auditory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixate Object</td>
<td>Listen</td>
</tr>
<tr>
<td>Track Object</td>
<td>Monitor Audio</td>
</tr>
<tr>
<td>Search with pattern</td>
<td>Scan with pattern</td>
</tr>
</tbody>
</table>

Primitive Operator Tasks

Human Behavior can be represented/segmented in **Primitive Operator Tasks**

**Perception** (Visual & Auditory) | **Comprehension** | **Strategic Thinking** | **Decision Making** | **Responding** (Manual & Verbal)

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**Central Processing**

<table>
<thead>
<tr>
<th>Comprehension</th>
<th>Strategic Thinking</th>
<th>Decision Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recall</td>
<td>Recognise</td>
<td>Select</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decide</td>
</tr>
</tbody>
</table>

Human Behavior can be represented/segmented in **Primitive Operator Tasks**

### Primitive Operator Tasks

- **Perception (Visual & Auditory)**
- **Comprehension**
- **Strategic Thinking**
- **Decision Making**
- **Responding (Manual & Verbal)**

### Responding Processing

<table>
<thead>
<tr>
<th>Manual</th>
<th>Verbal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reach Object</td>
<td>Press with foot</td>
</tr>
<tr>
<td></td>
<td>Move with pattern</td>
</tr>
<tr>
<td>Grasp</td>
<td>Touch</td>
</tr>
<tr>
<td>Push &amp; hold</td>
<td>Write</td>
</tr>
<tr>
<td>Write</td>
<td>Type</td>
</tr>
<tr>
<td>Type</td>
<td>......</td>
</tr>
</tbody>
</table>

What is workload?

Required psychological resources

Available psychological Resources

Task load

Workload
Demand Mental Resources (Task Load):

- Physical and mental activities demanded to carry out perceptual actions, cognitive actions and motor skills
- Empirical research and psychological theories of human cognitive processes

Available Mental Resources:

- Physical and mental abilities (perceptual actions, cognitive actions and motor skills) that an ATCo has available to provide the control service
- Psychological factors (e.g. fatigue, stress) shape the available resources

Threshold:

- Value beyond which Demanded Mental Resources (Task Load) exceeds the Available Mental Resources
Mental Workload Framework

- Underload
  - How a Controller does it
  - Operating Concept
  - Operating modes
  - Control Events
  - Flight Events

- Overload

Available Mental Resources

Demanded Mental Resources (Task Load)

Threshold

- Demanded Mental Resources
- Available Mental Resources
- Overload
- Underload
- Flight Events
- Control Events
- Situation Awareness
- Decision Making
- Response

Mental Workload Framework

CRIDA
This is nice, but how do we use it?

Develop an experimental system that is able to estimate the workload

- Identification of flight events
- Identification of control events

- Required cognitive channels
- Interference matrix
- Resolution of the Matrix

Multiple Resources Workload Model algorithm (MWM)
<table>
<thead>
<tr>
<th>Flight Event Layer:</th>
<th>Controller Event Layer:</th>
<th>Cognitive Process Layer:</th>
</tr>
</thead>
</table>
| • Identification & use of flight events | • Actions expected from an ATCo  
  • e.g. solve conflict | • Manner in which an ATCo performs a specific action  
  • Operating concept  
  • Mental processes required to perform said actions |
| • Traffic demand / Traffic data or sector configuration data | | |
| • Aircraft behaviour within a specific airspace | | |
What is WAC?

Use of WAC

WORKLOAD ANALYSIS COMPONENT (WAC)
Workload Analysis component

Stand alone workload estimation and measurement
Calculates workload per sector / volume
A sample application of WAC
Use of mental workload to estimate sector capacity

Assessment of the coherency of mental workload results through the comparison of Predicted and Perceived Workload

Further work
Validating the model

Not easy

Difficult to measure the actual workload

Using indirect methods to perform the validation
- Use of Mental Workload to Estimate Sector Capacity
- Assessment of the coherency of mental workload results through the comparison of Predicted and Perceived Workload
Use of mental workload to estimate sector capacity

- Representative sample of actual traffic
- Use WAC component to estimate capacity

Access data base to identify actual capacity

- Similar or Equal → workload assessment were accurate
- Different → workload assessment were accurate

Compare both values

Estimate actual capacity using workload
Assessment of the coherency of mental workload results through the comparison of Predicted and Perceived Workload

**Record ISA (Instantaneous Self Assessment)**
- Normalized values

**Calculate workload using WAC**

**Issues**
- Low correlation ($R = 0.75, p = 0.35$)

**Causes:**
- Time shift
- Need to improve calibration of non-nominal events

**With correction**
- Strong correlation ($R = 0.93, p = 0.14$)
Do we think that the validation work is completed?

**NO**

**SESAR EXE-04.07.01-VP-003**
Resolving complexity by dynamic management of airspace

- December 2014

**EXPERIMENT RESULTS BETWEEN WORKLOAD MEASURES**

<table>
<thead>
<tr>
<th>Correlation factors</th>
<th>Objective Measures</th>
<th>Blink-related parameters</th>
<th>Fixation-related parameters</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>NASA-TLX</td>
<td>MCH score</td>
<td>Blink frequency</td>
</tr>
<tr>
<td>Information flow rate</td>
<td>R</td>
<td>0.908</td>
<td>0.904</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>NASA-TLX</td>
<td>R</td>
<td>0.894</td>
<td>0.878</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.003</td>
<td>0.004</td>
</tr>
<tr>
<td>MCH score</td>
<td>R</td>
<td>0.902</td>
<td>0.858</td>
</tr>
<tr>
<td></td>
<td>p</td>
<td>0.002</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Ha, Kim and Seong (2006)
Estimating complexity

How to improve the model

CONCLUSIONS
Estimating complexity

Key enabler for several SESAR concepts

Using workload as an indicator of air traffic complexity

Mental Workload framework:
- Demanded resources
- Available resources
- Thresholds.

Workload estimation algorithm (MWM)

Workload Analysis Component (WAC)
Validation

On-going

Needs to be improved
• More calibration experiments
  • Identifying more direct workload methods

Results
• Workload estimations are accurate
• Useful for ATM
• Suggest relationship between perceived & predicted mental workload

But...
• Improvements must be made on both the framework and the algorithm
Areas of improvement

- Introducing psychological factors (fatigue, stress & emotion)
- Introducing dynamic thresholds
- Enhancement of the operating mode definition
- Impact of system automation features
- Full development and integration of situational awareness and decision making processes
Centro de Referencia I+D+i ATM