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Department of Air Transportation

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Roadmap

• A | Introduction
  • Performance Measurement
  • Role of Interdependencies

• B | Methods
  • Analytical Approach
  • Operational Approach

• C | System Integration
  • Comparison & Integration
  • Application Example

• D | Conclusions
A | Introduction – Problem Statement

• Air Traffic Management = complex System-of-Systems (SoS)
  • System – Subsystems – Subsubsystems - …
  • Relationships and interactions (interdependencies) between all system elements
• Global optimum depends on accounting a local system`s influence on other parts

--> Discussion of system interdependencies and their criticality
--> Introduction of two approaches to analyze interdependencies
--> Proposition of an integration concept of both approaches
A | Introduction – Performance Measurement

- Performance Measurement = Process of collection, analysis and representation of system information

- Key Performance Area
  • Global categorization framework

- Key Performance Indicator
  • Express the intension of the performance object

- Performance Indicator

- Metric

- Common definitions for data aggregation
Introduction – Role of Interdependencies

- Idea: uncover relationships between (sub-)systems and their component's influences on each other
- Complex dynamic effects depending on system actions
- Relationships can be:
  - Directly between two systems
  - Indirect via third (fourth, …, n-th) system
- Complex paths through whole system possible
  --> structured models required for identification and quantification
A | Introduction – Role of Interdependencies

- Interdependencies on both system level and performance level (between KPI instead of system components)
- **ATM:**
  - Insufficient coordination between stakeholders (ANSPs, airports, airspace, manufacturers, …)
  - Sparse interdependencies have been recognized
    - \( \rightarrow \) non-optimum performance
- Pattern recognition between KPI & KPA improves systematical benchmarking process
B | Methods – Overview

Analytical Approach
- Level of KPI
- Structure: Benchmarking Framework
- Input:
  - Emitted performance data
- Output:
  - Correlations between KPI/KPA
  - System behavior approximation

Operational Approach
- Hierarchical perspective
- Structure: implied system architecture
- Input:
  - Process model
- Output:
  - Meta level-independent real-system approximation
B | Methods – Analytical Approach

- Incomplete availability of performance data
- Inclusion of non-measurable elements
- Consideration of faulty measurements
- Merging of different scales in
  - Time
  - Unit
B | Methods – Analytical Approach

• General approach: Multivariate Regression Analysis

• Problems:
  • High complex system
  • Hard to postulate causal link between variables
  • Non-linear functions
  • dependent inputs

• Required effects:
  • Identification of transitivity
  • Automated Principle Component Analysis (PCA)
    --> Master KPI(s)?
B | Methods – Analytical Approach

- Using Artificial Neural Networks (ANN) for analysis and (non-linear) regression
- Adaptive, automated analysis and self-parameterizing control system

- Recurrent Neural Networks (RNN):
  - Sequential information
  - Dependent inputs
  - Memorable information over time
Given a comprehensive network $\text{NET}_{KPI}$ with $n$ output devices ($(K)PI$) and $X$ and $Y$ are state spaces for all recorded outputs of $(K)PI_x$ and $(K)PI_y$:

- Identification of correlations at all not sufficient
- $f: X \rightarrow Y$ between $(K)PI_x$ and $(K)PI_y \in \text{NET}_{KPI}$ injective, but not bijective (state $D$ is matched by another correlation)

\[ \Delta (K)PI_y \rightarrow \mu_x (K)PI_x \text{ AND } \mu_y (K)PI_z \]
B | Methods – Analytical Approach

• Fuzzy Controller representing noise correlations
  (parameterized by RNN --> Neuro-Fuzzy-System)

• Fuzzy Rules (fictive examples):
  **IF** KPI\(_x\) = increasing **AND** KPI\(_y\) = decreasing
  **THEN** KPI\(_z\) = decreasing
  **WITH** high certainty

**IF** FLOW = increasing
**THEN** DELAY = increasing
**WITH** weight \(k\)

Neuro-Fuzzy-System
### Analytical Approach

- **Level of KPI**
- **Structure: Benchmarking Framework**
- **Input:**
  - Emitted performance data
- **Output:**
  - Correlations between KPI/KPA
  - System behavior approximation

### Operational Approach

- **Hierarchical perspective**
- **Structure: implied system architecture**
- **Input:**
  - Process model
- **Output:**
  - Meta level-independent real-system approximation
B | Methods – Operational Approach

- Aviation is a complex, dynamic system comprised of many sub-systems.
- Systems interact with each other on different levels of abstraction (i.e. hierarchy of systems) so they can fulfill their higher goals.
- Operational approach focuses on the processes involved.
B | Methods – Operational Approach

- Systems perform multiple process steps (actions) to transform inputs to outputs
- Each process-step might consist of sub-processes
- Such a de-composition can be repeated until further break-downs are not possible or feasible
- Result of process view is a *dynamic systems architecture*
- Relations between systems on the same level of abstraction
- As well as between different layers of abstraction
This creates interdependencies between systems and throughout the systems hierarchy:

- A single process step might be dependent on steps prior or after itself.
- A process step might be dependent on an exogenous system.
- A higher level process, integrating sub-processes, is directly measured and defined over the performance of that sub-processes.
B | Methods – Operational Approach

- Performance characteristics are directly dependable from the constituting sub-processes.
- To assess performance of a given process: need to quantify each step with a valid (K)PI.
- Challenging because of the dynamic, interdependent nature of the described system architecture.
- Consequences Operational Approach:
  - (K)PIs / Measurements are directly attributable to local process steps.
  - Interdependencies are the result of the created model of systems and processes.
  - Can explain correlations measured on a higher level through underlying process performance.
### Data Level Analysis

- Interdependencies between KPI through statistical analysis
- Heuristical approximation of system structure
- Opportunity to derive functional relationships for quantification

- Cannot explain underlying structure

### Process Level Analysis

- Interdependencies through the modeled system, relationships and attributes
- Performance benchmarking via direct measurement of processes
- PI/KPI directly attributable to specific system and processes

- Cannot formalize functional relationship
C | System Integration – Combination

- Integration of both methods generates better understanding of interdependencies and relationships
- Self-similarity (methods applicable from high-level to low level)
- Non-isolated hierarchy layers
- Integration scheme:
  1. Process model as the starting point
  2. Benchmarking scheme has to be defined
  3. KPIs have to be mapped to process model
C | System Integration – Application in Example

• Simplified example process „Aircraft Final Approach“
  
  • Final Approach = Lowest Level system
  
• Possibility to map (K)PI from lower levels to higher levels (e. g. Manage Arrival Queue) of comprising system
  
  • All emitted data of Final Approach mapped in superior system Implement Arrival Queue
  
• Through mapping parameters are not absolute, but relative

  --> representing average behavior of approach
C | System Integration – Application in Example

- **Entities:**
  - Aircraft
  - Tower

- **General Structure:**
  - Runway
  - Terminal Maneuvering Area (TMA)

- **Begin:**
  - Contact ATC

- **End:**
  - Exiting Taxiway

1. Process model as the starting point
C | System Integration – Application in Example

• Higher level (K)PI defined from absolute sub-(K)PI

• Description of time and distance components

2. Benchmarking scheme has to be defined

<table>
<thead>
<tr>
<th>Sub-KPI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PI_A: Time for Final Approach</td>
<td>$t_{\text{begin}}$ to $t_{\text{end}}$</td>
</tr>
<tr>
<td>PI_B: Time for rolling</td>
<td>$t_{\text{begin}}$ to $t_{\text{end}}$</td>
</tr>
<tr>
<td>PI_C: Absolute distance for Final Approach</td>
<td>Pos (Aircraft) to Pos (touchdown point)</td>
</tr>
<tr>
<td>PI_D: Absolute distance for rolling</td>
<td>Pos (touchdown point) to Pos (exit point)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KPI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(K)PI_{\text{TotalTime}}$</td>
<td>Total time taken to complete final approach</td>
</tr>
<tr>
<td>$(K)PI_{\text{FuelConsumed}}$</td>
<td>Total amount of fuel consumed during process</td>
</tr>
<tr>
<td>$(K)PI_{\text{FuelConsumationTime}}$</td>
<td>Fuel consumed during final approach per unit of time</td>
</tr>
<tr>
<td>$(K)PI_{\text{FuelConsumationDistance}}$</td>
<td>Fuel consumed during finale approach per unit of distance covered</td>
</tr>
</tbody>
</table>
C | System Integration – Application in Example

- "t"-parameters define time slots
- "Pos"-parameters define entity positions

Example Contact ATC (Tower):
- Initiated by entity "Aircraft"
- Begin $t_{begin}$ and end $t_{end}$
- Overall time $t = t_{end} - t_{begin}$
- Absolute position = $\text{Pos} (\text{Aircraft, } t_{end}) - \text{Pos} (\text{Aircraft, } t_{begin})$

3. KPIs have to be mapped to process model

<table>
<thead>
<tr>
<th>Subprocess</th>
<th>Entity</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact ATC (Tower)</td>
<td>Aircraft</td>
<td>$t_{begin}$, $t_{end}$, $\text{Pos}(t_{begin})$, $\text{Pos}(t_{end})$</td>
</tr>
<tr>
<td>Landing Clearance</td>
<td>Tower</td>
<td>$t_{begin}$, $t_{end}$, $\text{Pos}(t_{begin})$, $\text{Pos}(t_{end})$</td>
</tr>
<tr>
<td>Final Approach</td>
<td>Aircraft</td>
<td>$t_{begin}$, $t_{end}$, $\text{Pos}(t_{begin})$, $\text{Pos}(t_{end})$</td>
</tr>
</tbody>
</table>
D | Conclusions

• Both analytical and operational approach enable deeper system understanding
• The proposed hybrid scheme model creates new potential for the analysis of system performance
  • Not only view on abstract KPI representing measured data
  • Attributing each measurement to a local process
  • Analysing and backtracking of special effects in the dynamic system ATM

• Upcoming steps:
  • Data Analysis / Data Mining through ANN
  • Application of methods for complex systems modeling based on system-of-systems (SoS)
Thank you for your attention!

contact:

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