CONCEPTUALISATION FOR EVALUATING THE CURRENT RESILIENCE STATUS OF A HUMAN-IN-THE-LOOP CONTROLLER SUPPORT SYSTEM

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Abstract

Currently the resilience in air traffic management is evaluated by comparing the usage of an enhanced or new system to the baseline without this system. Our idea is to assess the resilience of a system without comparing it to a baseline. Therefore, appropriate performance indicators and their thresholds are to be selected to evaluate the current resilience of the system itself in real-time. A system consisting of an air traffic controller support system and the air traffic controller operating it is selected as use case. The paper describes the concept of current resilience and applies it to the use case. To investigate the validity of this approach for the selected use case a dashboard visualizing the necessary parameters is proposed.

1. INTRODUCTION

1.1. What is resilience?

Resilience is an ability of an ecosystem that enables its quick recovery. This means, if the system leaves its nominal state e.g. after disturbances occur, it is able to return quickly to it. This characteristic of the ecosystem makes resilience a very desirable property of socio-technical systems. The framework that incorporates concepts of robustness and resilience (1) has been adapted and applied to evaluate resilience of a human-in-the-loop controller support system. As illustrated in Figure 1 and Figure 2 in this framework a socio-technical system is resilient over the determined time horizon T, if its performance is outside of a specified nominal or reference state (maybe with some acceptable deviation level l and/or deviation time Δt) and returns to it again during the determined time horizon T and, if defined, during the acceptable deviation time Δt. When the performance of the considered system stays at the nominal state over determined time horizon T the system is robust over T (1).

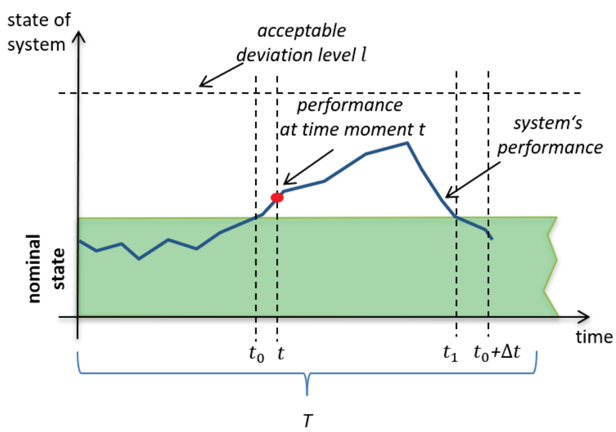

Figure 1. Evaluation of systems performance in the case of minimization of its performance indicators

Figure 1 and Figure 2 visualize the performance of a system illustrated by the blue line and given by some specified performance indicators during a time horizon T. The green area represents the defined nominal state of the considered performance indicators. Figure 1 illustrates the case when a performance indicator should be as small as possible, for instance delay. Figure 2 addresses the case where a performance indicator should stay as high as possible, for instance throughput.

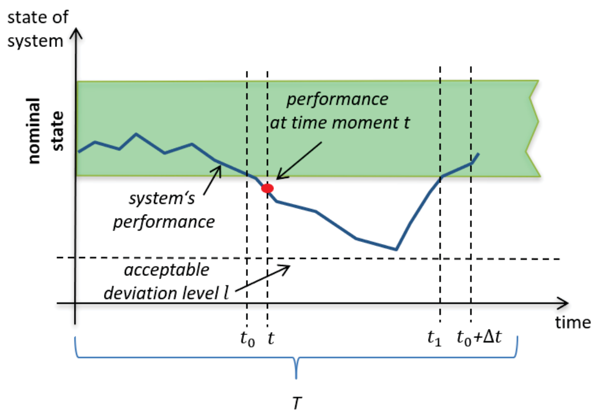

Figure 2. Evaluation of systems performance in the case of maximization of its performance indicators

As one can notice, an evaluation of the same system's performance represented by a specified set of performance indicators very strongly depends on the defined nominal state, time horizon, acceptable deviation level and deviation time, which in turn depend on the current operational conditions. For instance, a nominal state can be itself a disturbance factor for a system in the case when the defined nominal state calls for unrealistic performance indicator values under given operational.

1.2. Issue of current resilience

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(TraMICS) is a tactical air traffic controller support system consisting of two components: a) a surface management component, planning, monitoring and adapting conflict-free and optimized taxi trajectories and b) a security component, collecting specified alerts and deriving the Security Situations Indicator (SSI) which gives the controller an overview of the current security situation. TraMICS is a research prototype which was validated in a simulation environment (2). Looking at the performance of the surface management component and at the SSI, which is recalculated periodically considering alerts from the most recent time interval, the following question arises: Using TraMICS in a controller working position, how can we assess the current resilience applying the resilience definition mentioned before?

2. CONCEPT OF CURRENT RESILIENCE

In order to enable investigation of resilience in the case of a human-in-the-loop controller support system, the algorithm described in (1) was taken as a basis to assess the current resilience. It is slightly adapted, since it is not yet necessary at the planned investigations to classify and to characterize disturbances which may lead to a performance leaving the defined nominal state. The modified algorithm is the following:

1. Define and describe the system and its boundary to the environment;
2. Specify the scale and/or the level of hierarchy of subsystems constituting the system to observe;
3. Define the performance indicators of the system, if applicable their hierarchy and (weighted) dependency/priority, or performance function(s) involving selected performance indicators;
4. Specify the corresponding nominal state of the selected performance indicators or/and to specify the nominal state of the considered system's performance;
5. Set the time horizon T and optionally acceptable deviation level l as well as deviation time Δt for which the performance of the system can be outside of the defined nominal state to perform still resiliently. l and Δt can be chosen for each involved performance indicator separately;
6. Analyse whether the system is resilient or not according to the definition and all the values specified at the previous steps of the algorithm;
7. Investigate why the system is resilient or not and what should be done to improve its resilience.

Let us discuss and visualize step 6 that represents the central point of the algorithm to investigate the current resilience. To illustrate resilience evaluation, we assume that the performance of the considered system is expressed by means of a single performance indicator or of one performance function as shown in Figure 1 and Figure 2. The performance of the system leaves the nominal state at the time moment t_0. For the case the deviation time Δt and the deviation level l are defined, one can investigate resilience of the system at the time moment $t_0 + \Delta t$ if it belongs to the time horizon T or otherwise at the end of the time horizon T. If the values of the performance indicators at this moment are again at the reference area and they do not exceed the deviation level l within the time interval $[t_0, t_0 + \Delta t]$, we can state that the system is resilient. For instance, Figure 1 and Figure 2 illustrate resilient performance of the considered system because from the moment $t_1 \in [t_0, t_0 + \Delta t]$ the system performance is back again to the nominal state and within the time interval $[t_0, t_0 + \Delta t]$ the deviation level l is not exceeded.

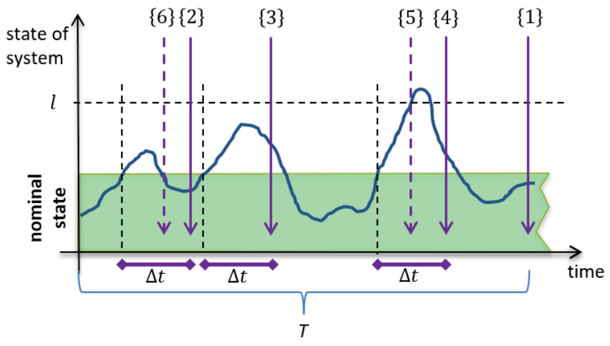

Figure 3. Moments where evaluation of resilience can be performed on an example of system's performance in the case of minimization of its single performance indicator or of its performance function.

Resilience of the system can be evaluated with respect to the definition given in section 1.1 either at the end of the time horizon T (moment {1} in Figure 3), or at the end of each time interval of the length Δt (moments {2}-{4} in Figure 3), which begins when the performance leaves the nominal state (dashed black vertical lines without numbers). T is understood as a fixed time interval, for instance one day of operation, and Δt represents a variable time interval that begins as soon as a performance indicator is outside of its nominal state. At any moment in time resilience can be analysed for these completed time intervals as well as at the moment where performance violates acceptable deviation level l (moment {5} in Figure 3) or returns back to the nominal state within the time interval Δt (moment {6} in Figure 3). In case the performance of the system is represented by multiple performance indicators/functions having corresponding nominal states, interval lengths Δt and deviation levels l, for each performance indicator the above described time moments (moment {1}-{6}) can occur. Depending on the defined system's performance nominal state, the moments for evaluating the current resilience depend on the set containing all time moments of all single performance indicators.

To summarize, although the current resilience of the system should be investigated during the time horizon T, a statement about the current resilience can be done for each involved performance indicator or function either

- at the end of the time horizon T;
- or at the end of each time interval of the length Δt if it is defined and belongs to the time horizon T;
- or at the moment where the performance violates the acceptable deviation level l, if defined;
- or at the moment the performance indicator or function returns back to the nominal state within its corresponding time interval Δt, if Δt is defined and belongs to the time horizon T.

3. USE CASE TRAMICS

In the following we will apply the algorithm described in chapter 2 to a use case of a human-in-the-loop controller support system.

3.1. System definition and hierarchy

As first step of the algorithm described in chapter 2 the system whose current resilience should be investigated is defined. It consists of the air traffic controllers support tool TraMICS integrated in the controller working position and the air traffic controller operating it. We call this system TraMICS-ecosystem in the following. Within the TraMICS-ecosystem, „air traffic controller“ is a role, which is fulfilled by different humans, one at a time. Next, step 2 of the algorithm, within the TraMICS-ecosystem there is an implicit hierarchy, as the controller keeps being responsible and in charge of his work all time.

3.2. Performance indicators

The next crucial step (step 3 of the algorithm) is the specification of indicators providing performance of the TraMICS-ecosystem. Already well-defined performance indicators were analysed to find candidates that are applicable to the TraMICS' use case in principle. The setting of the TraMICS-ecosystem within its human-in-the-loop simulation environment is explored to determine how the candidate performance indicators can be calculated or if they have to be adapted. This led to a slightly adapted calculation in all cases. From SESAR's PJ19.04 (3) Key Performance Area Safety the following candidate performance indicators were determined to be applicable:

- SAF4.1 Taxiway Collisions
- SAF4.2 Imminent Taxiway Collisions
- SAF4.3 Imminent Taxiway Infringements

The ICAO GANP Portal (4) delivered the following candidate performance indicators:

- KPI01 Departure punctuality
- KPI02 Taxi-out additional time
- KPI11 Airport throughput efficiency
- KPI13 Taxi-in additional time
- KPI14 Arrival punctuality

As TraMICS is a research prototype and running in a simulation environment, the performance indicators could not be applied one-to-one, but need adaptations as described in the following. Each TraMICS-ecosystem's performance indicator is evaluated within the time horizon T. This time horizon has a fixed, but configurable length and is the same for all TraMICS-ecosystem's performance indicators.

The formulas describing the calculations use the abbreviations listed in Table 1. We use scheduled times, as those are available in traffic scenarios configured for our human-in-the-loop simulation environment. We also assume, that arrivals land at $ELDT$, that $EIBT = SIBT$ and $EOBT = SOBT$. We do not intent to model turn-around processes in traffic scenarios for this research topic, so there will be no dependences of a late arrivals provoking connected late departures.

Abbreviation	Name
$AIBT$	Actual In-Block Time
$ALDT$	Actual Landing Time
$AOBT$	Actual Off-Block Time
$ATOT$	Actual Take-Off Time
$EIBT$	Estimated In-Block Time
$ELDT$	Estimated Landing Time
$EOBT$	Estimated Off-Block Time
$ETOT$	Estimated Take-Off Time
$SIBT$	Scheduled In-Block Time
$SOBT$	Scheduled Off-Block Time

Table 1. Abbreviations used within performance indicator definition.

3.2.1. SAF4.1_TraMICS - Taxiway Collisions

SAF4.1 Taxiway Collisions should be calculated as "% change in count of events or Frequency of occurrence per flight or movement" (3). SAF4.1_TraMICS is defined as the number of occurred collisions during movements on taxiways per time interval.

3.2.2. SAF4.2_TraMICS - Taxiway Conflicts

SAF4.2 Imminent Taxiway Collisions is defined as "% change in count of events or frequency of occurrence per flight or movement" (3). This is adapted to SAF4.2_TraMICS as number of conflicts during movements on taxiways per time interval.

3.2.3. SAF4.3_TraMICS - Route Deviations

SAF4.3 Imminent Taxiway Infringement's calculation "% change in count of events or frequency of occurrence per flight or movement" (3) is used as base for SAF4.3_TraMICS which is the number of route deviations (cases according to (5)) per time interval.

3.2.4. KPI01_TraMICS - Departure Punctuality

KPI01 is the percentage of flights departing from the gate on-time compared to schedule (4). KPI01_TraMICS is defined as the number of on-time departures divided by the total number of scheduled departures per time interval. According to the four variants described in (4), on-time is specified as:

A) $|AOBT - SOBT| \leq 5$ minutes
B) $0 \leq AOBT - SOBT \leq 5$ minutes
C) $|AOBT - SOBT| \leq 15$ minutes
D) $0 \leq AOBT - SOBT \leq 15$ minutes

3.2.5. KPI02_TraMICS - Taxi-out Additional Time

KPI02 is defined in (4) as actual taxi-out time compared to an unimpeded/reference taxi-out time. KPI02_TraMICS is calculated as sum of additional taxi-out times divided by number of flights per time interval. The additional taxi-out time per flight is calculated as ($ATOT - AOBT -$ unimpeded taxi time between flight's gate and flight's runway).

3.2.6. KPI11_TraMICS - Airport Throughput Efficiency

KPI11 is described according to (4) as “airport throughput (accommodated demand) compared to capacity or demand, whichever is lower.”. KPI11_TraMICS is calculated as $throughput$ divided by $demand$ (both per configurable time interval), where

- $demand$ is the number of departures with $ETOT$ within the time interval plus the number of arrivals with $EIBT$ within the time interval, where $ETOT = EOBT +$ unimpeded taxi time between flight’s gate and flight’s runway and $EIBT = ELDT +$ unimpeded taxi time between flight’s runway and flight’s gate;
- $throughput$ is the number of departures with $ATOT$ within the time interval, plus the number of arrivals with $ALDT$ in the time interval.

3.2.7. KPI13_TraMICS - Taxi-in Additional Time

The key performance indicator KPI13 is defined in (4) as actual taxi-in time compared to an unimpeded/reference taxi-in time. KPI13_TraMICS is calculated as sum of additional taxi-in times divided by number of flights per time interval. The additional taxi-in time per flight is calculated as ($AIBT - ALDT -$ unimpeded taxi time between flight’s runway and flight’s gate).

3.2.8. KPI14_TraMICS - Arrival Punctuality

KPI14 is the percentage of flights arriving at the gate on-time compared to schedule (4). KPI14_TraMICS is defined as the number of on-time arrivals divided by total number of scheduled arrivals per time interval. According to the four variants given in (4), on-time is defined as:

A) $|AIBT - SIBT| \leq 5$ minutes
B) $0 \leq AIBT - SIBT \leq 5$ minutes
C) $|AIBT - SIBT| \leq 15$ minutes
D) $0 \leq AIBT - SIBT \leq 15$ minutes

3.3. Nominal state, time horizon and further steps

The declared performance indicators describe the state of the TraMICS-ecosystem. In order to assess current resilience of this system, its nominal state should be specified. Therefore, according to the adapted algorithm, thresholds of the performance indicators depending on their hierarchy and priority are needed to be defined. Although being confident that the performance indicators are not completely independent, we do not yet consider potential dependencies. Nevertheless, all eight nominal states of the considered performance indicators together constitute the nominal state of the TraMICS-ecosystem’s performance. Since resilience is time dependent, it is necessary to set up the time horizon T and the deviation times Δt as well as the deviation levels l of the individual performance indicators to explore this property of the considered system (steps 4-5 of the algorithm). These values have to be selected carefully and in-line with operational needs. As those parameters did not catch our attention in the trials we did before, we are not yet able to set them realistically. Instead we want to visualize the measured performance according to the specified performance indicators, with artificial thresholds defining the nominal state. Even though the thresholds are artificial, they should already imply dependencies of the different punctuality variants. e.g. a punctuality threshold for a deviation up to 5 minutes should be less than the corresponding threshold for a difference to the schedule time up to 15 minutes. The visualization is assumed to assist in discussions with potential users to find proper settings of the performance indicators’ hierarchy and priority as well as their thresholds and the described time intervals. The following section describes the resulting requirements for the dashboard implementing the visualisation. As the nominal state is not yet set realistically, step 7 of the algorithm listed above is out of scope and not addressed in this work.

3.4. Visualization requirements

Since our goal is to follow the progress and course of the TraMICS-ecosystem performance including but not limited to the potentiality of a performance indicators dependency evaluation, it is necessary to be able to observe the progress of the selected performance indicators at once. Hence, all eight selected performance indicators should be visualized and displayed at comparable scales and preferably simultaneous. The performance progress as well as the thresholds defining the nominal state should be noticeable clearly. There should be a possibility to zoom in/out i.e. showing a longer or shorter time range and to slide a specified time range along the time line. Moreover, it should be possible to synchronize time and zoomed scales of the considered performance indicators and to have input options for changing of thresholds. The latter is deemed necessary, as changed operational conditions may require a different nominal state. This means, that the thresholds need to be changeable for specific time intervals in the past, but also in the near future e.g. the next hour.

4. DASHBOARD

The resilience dashboard is implemented as an interactive web interface designed to effectively visualize and assess the resilience parameters described in the previous chapter. Developed as a Python Dash app, the dashboard offers a comprehensive visualization through eight dynamic graphs as well as centralized control elements at the top (Figure 4). Central to its functionality is a RabbitMQ interface, which seamlessly ingests the performance data from the TraMICS software at specific intervals. By default, this time interval is set to 15 minutes, but can be configured. This data is then systematically stored within a dedicated database, which feeds the dashboard enabling users to evaluate the various resilience metrics for the current time as well as past intervals.

Each graph corresponds to one performance indicator. Figure 6 shows the graph of Departure Punctuality as example. The blue line is representing the value of the performance indicator. Since the performance indicators are calculated for discrete time intervals, their graphs have the shape of step-line functions with markers at the end of each time interval representing the time of evaluation. The colours of the threshold lines and the areas below represent whether the threshold indicates an upper (green) or lower (red) limit. Specifically, the thresholds for Arrival Punctuality, Departure Punctuality and Airport Throughput Efficiency indicate a lower limit, so the blue line should

Figure 4. Screenshot of the dashboard with all eight performance indicators and control elements at the top.

remain outside the red-shaded area, while for the other performance indicators the blue line should remain inside the green-shaded area. To change the threshold of each performance indicator, the user can use the Edit-button in the top right of each graph and enter new target values for the time-intervals as can be seen in Figure 5. Afterwards, the threshold line is automatically updated in the graph (cf. Figure 6).

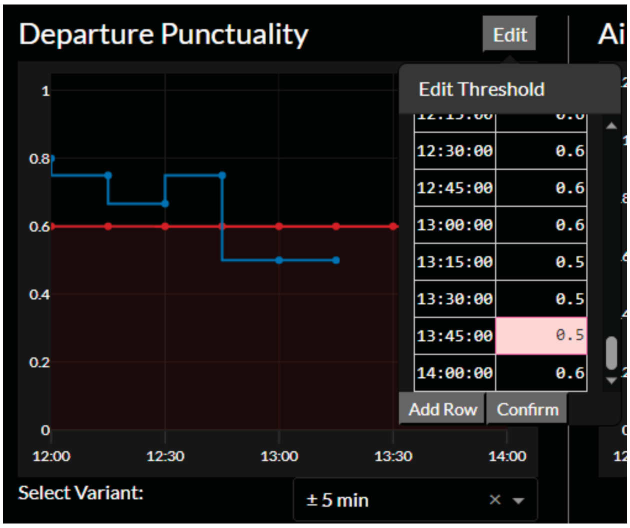

Figure 5. Edit window to adapt thresholds for each past and future time interval separately.

Another feature of the dashboard is the incorporation of a range slider (see at the top of Figure 4and in Figure 7), enabling users to select a specific time range within the last six hours for visualization. It is possible to zoom in or out on a certain timeframe, by changing the width of the range slider. Figure 8 shows the resulting range slider after a combined zooming and sliding action. This temporal customization empowers users to delve into e.g. critical timeframes, facilitating a detailed analysis of resilience dynamics. For specific analysis of one performance indicator, it is also possible to change the visualization time range for each graph individually by simply dragging along the x-axis of the graph, to either view past values or add new target thresholds for future intervals. After changing the visualization time range of one or more graphs, the Sync-button next to the range slider allows to resynchronize the displayed visualization time range of all graphs.

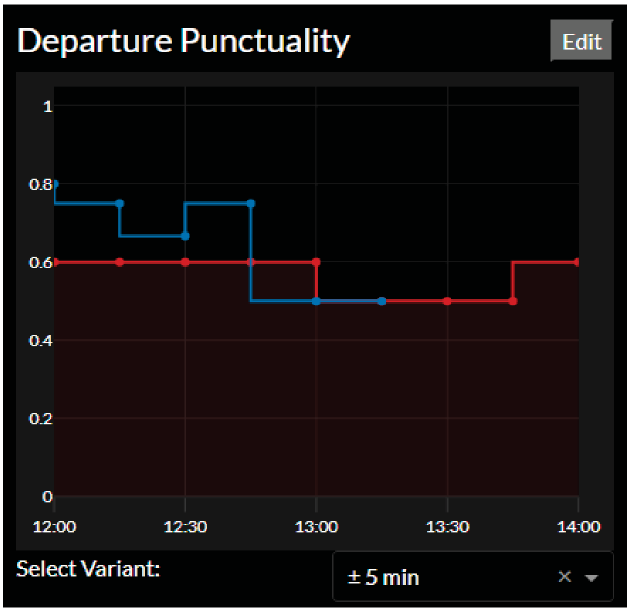

Figure 6. Single performance indicator graph showing the threshold (red) and the performance indicator progress (blue).

Figure 7. The range slider is configured by default to show a time range of two hours (in this example 12:30 to 14:30).

Figure 8. By adjusting the range slider, the visualized time range of all graphs can be changed to show a past time range or to zoom in and out to a specific time range.

Overall, the presented dashboard implements the requirements and serves as a tool for real-time monitoring and assessment of resilience parameters, underpinned by its sophisticated data integration and time scale exploration capabilities.

5. CONCLUSION AND FURTHER WORK

The paper describes the idea of assessing current resilience and applies it to the TraMICS-ecosystem. To familiarize experts with the concept of current resilience as well with the chosen performance indicators, their progress and their thresholds defining a nominal state, a dashboard is proposed. The dashboard visualizes the performance of the considered system by means of performance indicators and their nominal state over time. Thresholds can be changed over time and thereby the nominal state of the corresponding performance indicators according to operational conditions. As next step potential users have to be involved to discuss as well the choice as the specific calculation of the performance indicators, define their dependencies and/or hierarchies and find realistic thresholds setting the nominal state. In parallel the dashboard and the concept of current resilience in general should be validated. Another further research question would be, if and what impact the air traffic controllers might have to the system's performance and on the other hand, if the air traffic controllers are aware of the current resilience, if they might act differently.

6. REFERENCES

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