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TYNA - an automated notification tool for operations in human space flight

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For more than seven years, the Belgian User Support and Operations Centre (B.USOC) is operating the Solar Monitoring Observatory (SOLAR) – an experiment of the European Space Agency (ESA), hosted on one of the external platforms of the Columbus module on the International Space Station (ISS). Since the beginning of SOLAR operations, B.USOC has invested in developing tools to support and to guarantee high quality operations. The Yet Another Mission Control System (Yamcs) software, a lightweight Mission Control System (MCS) developed and deployed at B.USOC as an extension of the standard ESA Columbus MCS, allows the SOLAR Operators to monitor the telemetry, to quickly browse the data archive, and to perform replays of events. Due to cost saving measures at the Columbus Control Centre in Munich, from January 2014 on the B.USOC team was obligated to provide 24/7 on-console service, demanding a huge effort from the small team. Therefore, the Yamcs software was extended with a notification tool which allowed B.USOC to return to nominal shift coverage. The papers presents this software extension called "The Yamcs Notification Add-on" (TYNA). TYNA actively monitors all the SOLAR telemetry data and the connections between the different servers and notifies the on-call Operators in case of anomalies. Via a web-interface it is possible to define different monitoring rules, as well as the type of notification, and who will be notified. One can choose between notification via e-mail, text message, phone call, or a combination. The monitoring rules define the content of the TYNA message, which allows a quick assessment of the occurred anomaly by the on-call Operator. As the SOLAR telemetry can be accessed remotely from any workstation with the Yamcs software, the SOLAR Operator can quickly assess the nature of the anomaly as being a payload issue, an on-board system anomaly, or a ground segment problem, and inform the counterparts and take adequate countermeasures. TYNA started monitoring the SOLAR payload on 15th July 2014 and allowed to reduce the on-console service from 24/7 to 16/7 shift coverage when the payload is generating science data, and nominal working hours during periods when the payload is in idle mode. While currently only applied for the SOLAR payload, the TYNA software has been validated to interface with the commonly used ESA MCS tools applied in the Columbus Payload Data Center (CD-MCS) and to monitor the other ESA payloads and Columbus System Telemetry. Both Yamcs and TYNA, developed with the support of ESA, are open source software and free of use for the ISS payload community.

I. Introduction

The Yamcs[1] Notification Add-on, TYNA, is an operations support tool which was developed to cope with a change in the operations concept for the support of the SOLAR payload operations at the Belgian User Support and Operations Centre (B.USOC) while maintaining the original resource allocation in terms of number of Operators. The tool was initiated from the specific need for a 24/7 telemetry monitoring of SOLAR, but was, in agreement with ESA, developed for a broader use such as payload operations in general.

This paper presents the operational and technical aspects of TYNA. In section II, the SOLAR Payload and the operational concepts evolution are briefly described, as well as TYNA functionalities to support these SOLAR

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operations. Section III then provides the technical details of TYNA and Section IV provides a brief overview of its use.

II. The SOLAR Operations

A. SOLAR Payload

SOLAR (see Fig.1) is an integrated platform accommodating three instruments complementing each other. The SOLAR mission has the aim to provide accurate measurements of the Solar Spectral Irradiance, covering a wide spectral range from the Infra-Red (IR) to the Extreme Ultra-Violet (EUV).

The scientific objectives of the SOLAR mission cover different fields of research, such as solar physics, atmospheric physics, and climatology[2, 3]. The SOLAR payload contains three instruments, each designed to observe the Sun in a specific wavelength range. These instruments are mounted on a Coarse Pointing Device (CPD) providing Sun pointing and tracking capabilities. The SOLAR Control Unit (CU) provides power, collects, formats and dispatches to ground the instruments generated telemetry data in telemetry packets. It receives ISS ancillary data and processes the ground issued telecommands. SOLAR was launched together with the European Columbus laboratory in February 2008 and has been operating since that time.

Figure 1: SOLAR Payload *(courtesy ESA)*

B. SOLAR Operations Concept

1. SOLAR Operations concept and on console coverage

Due to thermal constraints of the instruments and the motors of the platform, the SOLAR payload has to be continuously powered and must not be left unmonitored. These temperature constraints, as depicted in the ISS Flight Rule B19-104, should be respected and manual action from ground is required whenever these temperatures are out of limit. Furthermore, in case of an anomalous situation where the telemetry cannot be monitored, the SOLAR Operator shall support recovery actions or set up a work-around to put SOLAR in a nominal state again and, if possible, to regain telemetry. Therefore, since the start of the SOLAR Mission, the Belgian User Support Centre (B.USOC) ensures a 24/7 support for the SOLAR operations. The B.USOC is located on the premises of the Belgian Institute for Space Aeronomy in Uccle (Brussels), Belgium.

Due to ISS orbital mechanics and due to the mechanical range of the SOLAR CPD, the Sun is not always observable by SOLAR. In practice, this leads to so-called Sun Visibility Windows (SVWs) lasting typically 10 to 15 days. During these SVWs, SOLAR is tracking the Sun with its instruments and is performing measurements according to the inputs from the scientific Principal Investigators of the SOLAR instruments. Within those 10 to 15 days, the science requirements state that an average of 8 measurements per day are required.

At the beginning of the SOLAR operations back in 2008, an agreement was established between ESA, the Columbus Control Centre (COL-CC), responsible for the Columbus laboratory, and the B.USOC, to optimize the SOLAR on console support in the light of the science requirements[4]. Since the Columbus Flight Control Team at the COL-CC is in charge of the Columbus Laboratory, the COL-CC has visibility only of a limited number of Health and Status data of all payloads, such as power consumption, critical temperature sensor readings, etc., including those SOLAR temperature readings listed in the Flight Rule B19-104. In the light of the science requirements the agreed console support for SOLAR was:

- during science operations the BUSOC provides the SOLAR on console support;
- outside periods of science measurement the Columbus Control Centre (Col-CC) monitors the payload and contacts the SOLAR Operator on call whenever the platform shows an out of limit telemetry or whenever an external event occurs which could impact the SOLAR payload.

This set-up was implemented in July 2008 and applied until December 2013.

2. TYNA Implementation

The B.USOC was informed by ESA in November 2013 that from January 15 2014 onwards, SOLAR would no longer be monitored by COL-CC outside periods of science measurements. Therefore from January onwards, with the agreement of ESA, B.USOC supported a full 24/7 console coverage for a period of time limited to six months. It was also agreed with ESA that, during this transition period, a notification tool would be developed in order to allow automated monitoring of the payload when not performing science measurements. In the light of the development of such a tool, the B.USOC Operators drafted an initial set of requirements which replaces the critical 24/7 monitoring. Additionally, a set of requirements have been identified to have a tool that provides more capabilities adapted to the reality of the SOLAR operations. As part of the larger USOC cost saving exercise, ESA have finally requested to extend the SOLAR Automated Notification Tool to a more generic notification tool, usable by all USOCs, hence not relying on the Yamcs mission control system as for the B.USOC/SOLAR case.

III. TYNA Tool

A. TYNA Project

For general payload operations, the purpose of the TYNA Automated Notification Tool is to detect predefined anomalous ISS ESA payload activities. Once the notification tool detects an anomaly, and depending of the anomaly criticality, it triggers a notification to the defined on-call contact person. Different contact types can be associated to the notification rules, and are typically USOC operators and Ground Controllers. This contact information is provided by an external planning tool. The notification tool continues to notify the on-call contact until the contact acknowledges the notification(s). This acknowledgment is done by entering a confirmation code. Notifications by SMS and email provide additional information on the detected anomalies. There are three types of events that can be monitored by TYNA:

- Telemetry out of limits.
- Telemetry delays.
- TYNA Status: Mission Control System connection, external systems connection (phone, email).

A TYNA instance is connected to one Mission Control System instance, and therefore one mission database. To monitor several payload activities simultaneously, there should be one TYNA instance per mission database.

In the light of the urgency to deploy an automated notification tool and ESA's request to develop a generically usable tool, the project applied a phased approach:

- Phase 1 of TYNA focused on the critical features necessary to perform notifications for Flight rule B19-104. It provides robust features to notify against specific SOLAR parameters, via phone notifications. For phase 1, telemetry was received via the Yamcs mission control system. Planning was received by the B.USOC Predictor tool[5].
- Phase 2 relied on the features developed for phase 1 and extended the capabilities of TYNA to be able to notify against additional parameters of the SOLAR mission and to allow users of the tool to define their own notification rules against any parameters of the mission database. It also provided a web interface to users and additional options for notifications (SMS and emails).
- Phase 3 aimed at making the notification tool generic, usable by all USOCs. Based on phase 2 it provides a connector to an additional Mission Control System (CD-MCS), a connector API to third party planning tools, and ensure TYNA is operational in the Payload Data Centre (PDC) environment.

Phase 3 Acceptance Review was successfully completed in July 2015, whereas TYNA Phase 1 was deployed at B.USOC and operationally used since July 2014 and the extension, Phase 2, since October 2014.

B. TYNA Model

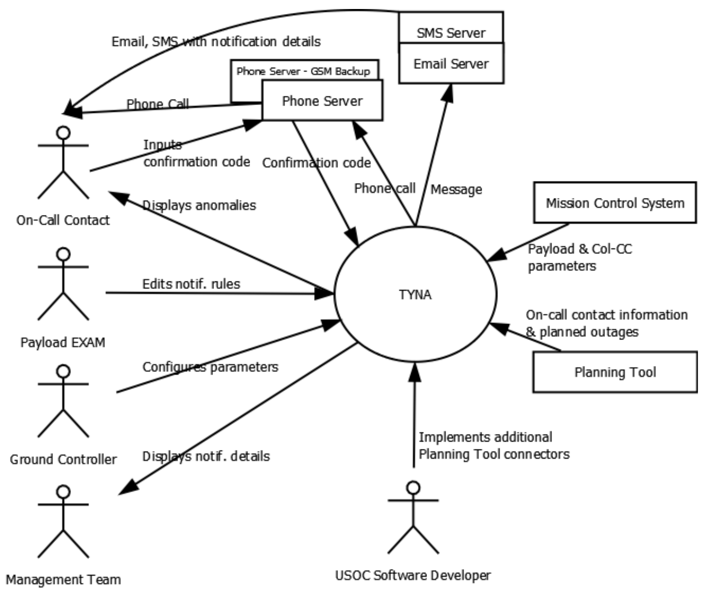
1. TYNA User Characteristics and Context

Although TYNA is mostly developed to support the USOC Operators, it should be accessible for a variety of users, all with different needs and responsibilities. Based on the basic USOC concept, permissions are defined for each of the functionalities; users have access within TYNA and user roles are defined as a collection of permissions. The following roles have been identified for the B.USOC deployment:

- The user role “Operator”, with following permissions:
    - Receive notification from the TYNA system: phone call, SMS or email.
    - Input confirmation code during phone notification call.
    - Display system information: System status, current and past anomalies.
    - Display notification rules.
- The user role “Payload EXAM”, with following permissions:
    - Receive notification from the TYNA system: phone call, SMS or email.
    - Input confirmation code during phone notification call.
    - Display system information: System status, current and past anomalies.
    - Display notification rules.
    - Edit notification rules.
- The user role “Ground Controller”, with following permissions:
    - Receive notification from the TYNA system: phone call, SMS or email.
    - Input confirmation code during phone notification call.
    - Display system information: System status, current and past anomalies.
    - Display notification rules.
    - Edit notification rules.
    - Display and edit TYNA settings.
- The user role “Manager”, with following permissions:
    - Display system information: System status, current and past anomalies.
    - Display notification details.
    - Display notification rules.

Figure 2 provides a context diagram of TYNA and its interfaces with other systems. The planning tool provides the necessary information on the persons to contact, including name, phone number and confirmation code. For the B.USOC, this system also provides information on the planned outages, avoiding unnecessary calls to the operator on call when no telemetry is received due to ground segment activities.

The Mission Control System is the system that provides the incoming telemetry to monitor, which can be CD-MCS or Yamcs. Other MCSs can be connected by implementing the appropriate connector. The concept of TYNA also foresees two VoIP phone servers: a prime phone server, and a backup phone server. For the B.USOC the backup is a VoIP-GSM box located in the internal network of the TYNA server. It is used in case of failure of the primary phone server. Additionally interfaces include an SMTP email server for notification via email and an SMS server.



TYNA - Context Diagram v3.1.0 dated 13 November 2014

Figure 2. TYNA Context Diagram

2. TYNA System Overview

The following diagram (Figure 3) illustrates the interaction between the components of which TYNA is composed.

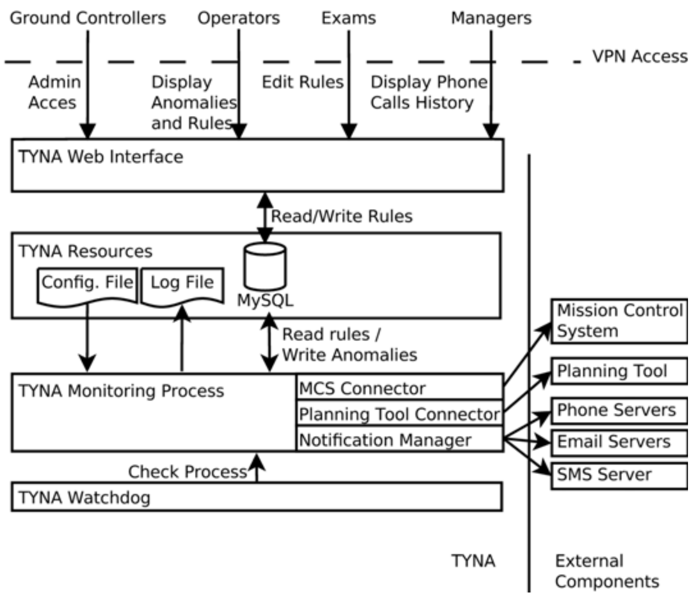


Figure 3. TYNA System Overview

The TYNA Monitoring Process is the core of the notification tool. It is responsible for checking the Telemetry and for notifying operators. It comprises the following elements:

- Rules: They define what should be monitored, and how users are notified in case of anomaly.
- Anomalies: As soon as a rule is executed by TYNA, if the rule finds an issue according to its definition, it produces an anomaly. An anomaly can be in a state Detected, Confirmed or Glitch.
- Notifications: As soon as an anomaly is in a Confirmed state, TYNA triggers a notification accordingly to the settings defined in the rule. Notification can be triggered via Phone call, SMS or Email. They are triggered to Operators and Ground Controllers following the notification.

The TYNA Web Interface is the main interface for users. Depending of their roles, it allows users to:

- Define and activate rules that will check the telemetry.
- Display the system status, current and past anomalies, and notification details.
- Display and update the configuration of the TYNA Monitoring Process.

The TYNA Resources are composed of the following elements:

- Configuration file: It defines the settings needed to run the monitoring process.
- Log File: The log file contains information on events in the monitoring process. It is accessible by Ground Controllers.
- Data Storage: The data storage is used by TYNA to store the rule definitions, anomalies found and notification details. The Web Interface component reads and writes the definition of rules (according to user's inputs) and reads the anomalies and notifications. The Monitoring Process read the definitions of rules and writes anomalies and notifications.

The TYNA Watchdog is a distinct component that ensures that the Monitoring Process is always up and running. Its goal is to ensure the reliability of TYNA.

3. TYNA Software Frameworks

The TYNA software is built upon industry standard frameworks. This has the advantage to increase reliability by reusing proved frameworks and patterns and to ease the development of additional connectors to connect TYNA to additional external tools (MCS and planning tools) by other USOCs.

A connector to an external tool is a Java class implementing a defined interface. This connector is then selected in the TYNA configuration to be loaded as the selected connector.

TYNA Service uses the following technologies: Java 7 as the programming language, Voice over IP (VoIP): SIP (Session Initiation Protocol) and RTP (Real-time Transport Protocol) using Jain-SIP. The database framework is a combination of Hibernate and MySQL.

TYNA Web Interface uses Grails, Groovy, Spring Security and MySQL.

4. Single Points of Failure

The reliability of the TYNA process has been the priority from the beginning of the project. It has been ensured in its design that it does not present a Single Point of Failure (SPOF). This implies that:

- The TYNA server and process itself are monitored by a ‘TYNA watchdog’ located on separate hardware and ensuring the TYNA server is running and performing as expected. This watchdog sends notifications itself in case the TYNA server is not running.
- External components have backup instances or default fallback values;
    - Phone servers have a primary server and a backup server. TYNA switches from the primary server to the Backup in case of phone server failure At B.USOC the primary server is VoIP server accessed through the network and internet. The backup server is a GSM VoIP box that is directly connected to the TYNA server. Advantages and drawbacks need to be take in consideration to choose the primary and backup servers: cost, voice quality, network access, GSM coverage, redundancies of connections.
    - Email backup servers are used in case of failure of the primary email server.
    - In case of failure of the external planning tool, default contacts are set in TYNA configuration and are used to notify anomalies until the planning tool is back.
    - Failures on any of these external components are themselves notified to the Ground Controller or the Operator as system failures.

C. TYNA Anomaly Detection and Notification Process

1. Phone Notification

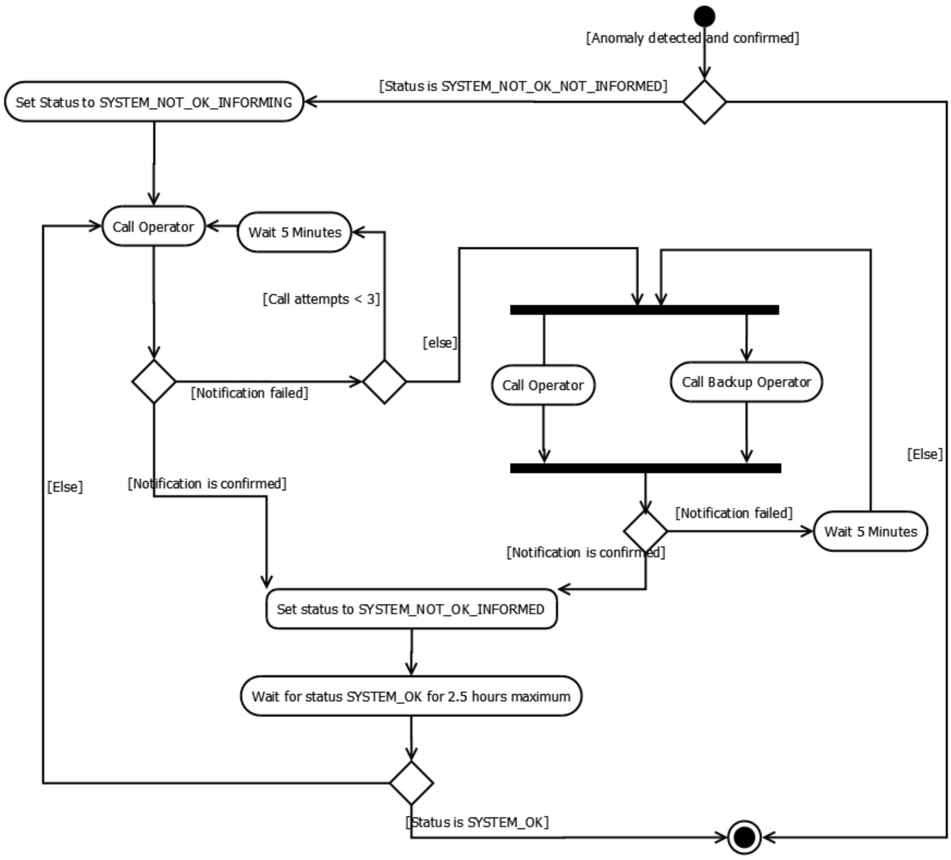


Figure 4: Phone Notification Process

The notification by phone is the preferred way to notify the Operator for critical anomalies. The process needs to be robust in order to ensure an Operator receives the notification. The Figure 4 describes the process used by the phone notification. TYNA first calls the Operator on call (as provided by the external planning tool) and requests a confirmation code that need to be dialed on the phone keys. TYNA keeps calling until it gets the confirmation code. After a number of attempts, TYNA calls in parallel a backup Operator (as provided by the external planning tool) until it receives the confirmation code.

Once the anomaly notification has been confirmed by the Operator, TYNA monitors the anomaly status and triggers a reminder notification if the anomaly has not been solved after a defined period of time.

Waiting time between phone call attempts and reminder are configurable, and can be set from 5 to 90 minutes at B.USOC for the SOLAR payload.

2. Anomaly Detection, Avoiding Annoying Notifications

Having a notification tool is useful to be aware of current anomalies of the system. However, it is very important that only meaningful anomalies are actually identified as an anomaly. The risk with an automatic notification system is to identify a number of anomalies that is too high. This can lead to the situation where the recipients of the notifications do no longer pay full attention - or worse ignore - the incoming notifications. If a meaningful anomaly is sent in such a batch of non-meaningful anomalies, it could escape the attention of the recipient.

TYNA has been developed with the aim to help operators in their 24/7 support, and not to be an annoyance. A set of mechanisms (see Fig.5) have been implemented to ensure that each detected anomaly gets the proper attention from the Operator or the Ground Controller.

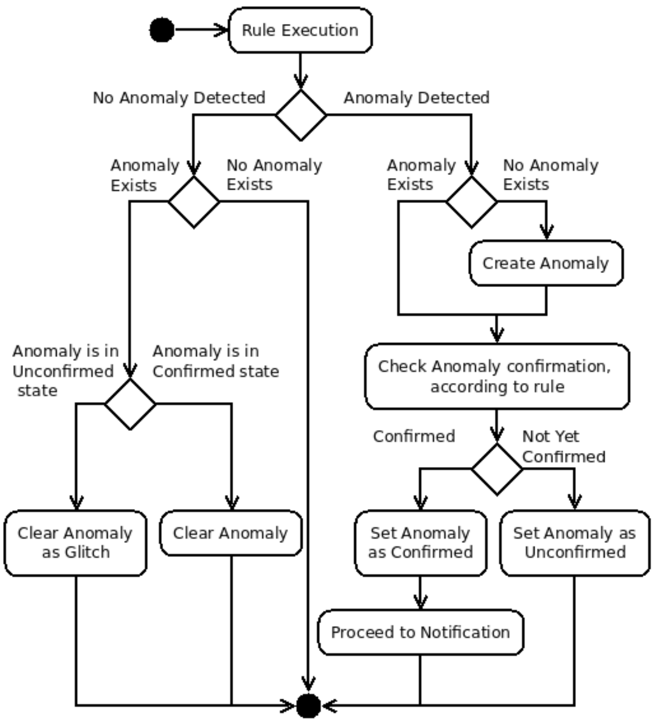


Figure 5: Notification rule execution process

Notification rules definitions encompass glitches tolerances. This can be defined as a number of consecutives values received for a parameter, or as a time of observation of the anomaly once detected. Following the glitches definitions, an anomaly is detected and then confirmed. Here, only confirmed anomalies are notified to the Operator.

Contexts can be defined for a notification rule to be valid. This allows to avoid notifications when a parameter is out-of-limit in a wrong context, and this allows creating more complex notification rules. For example a parameter delay notification rule could be defined as an anomaly if: 1) the payload has booted 2) there is not Ku band LOS, etc.

The notification vector is configurable for each rule: phone calls are reserved for critical anomalies. Less critical anomalies can be sent by email only.

The type of contact is defined for each rule which ensures that the right person is notified. At B.USOC, two types of contacts are defined: Operators and Ground Controllers. Operators receive notifications related to Flight Rule violations, Payload telemetry delays, etc. Ground Controllers receives notifications related to ground system anomalies such as general telemetry delays, MCS connectivity, etc.

IV. TYNA for Operations

1. Setup of TYNA

After the installation, the user with the role of 'Ground Controller' can fully configure the TYNA tool from a web interface; namely providing the details of the SIP configuration, the SMS server, the email server and the planning tool. Figure 6 shows an example of the configuration page of the planning tool. All these connections can be tested from the web page via the possibility to make a test call, SMS, email or to load the planning as a test.

Based on the actual operations concept, the Ground Controller can then define the notification parameters as to reflect the actual operations concept. This refers to which boundary constraints should be taken into account for monitoring. For example whether monitoring is required when an outage is scheduled in the planning, choose if a notificiation should be sent in case an anomaly is cleared. This covers also the generic settings of the notification, such as the timings between the phone calls, the number of calls required before starting to call a backup contact on-call, if any.

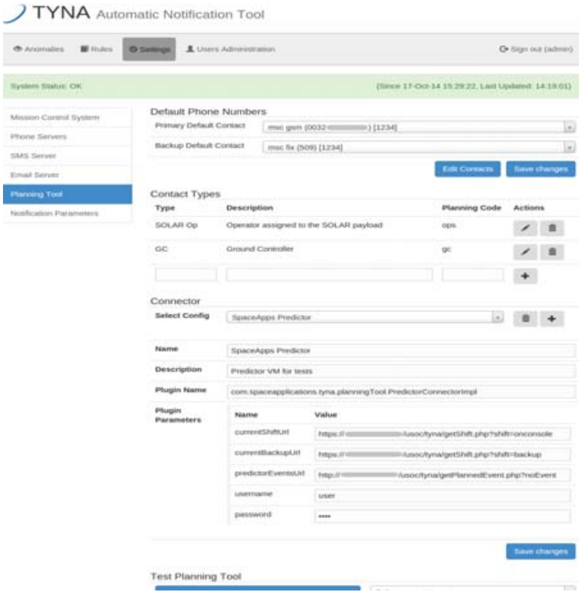


Figure 6: TYNA Planning Tool Configuration

2. Anomaly detection

As explained above, there are three types of notification rules: TYNA Status, Telemetry Out-of-Limit, and Telemetry Delay.

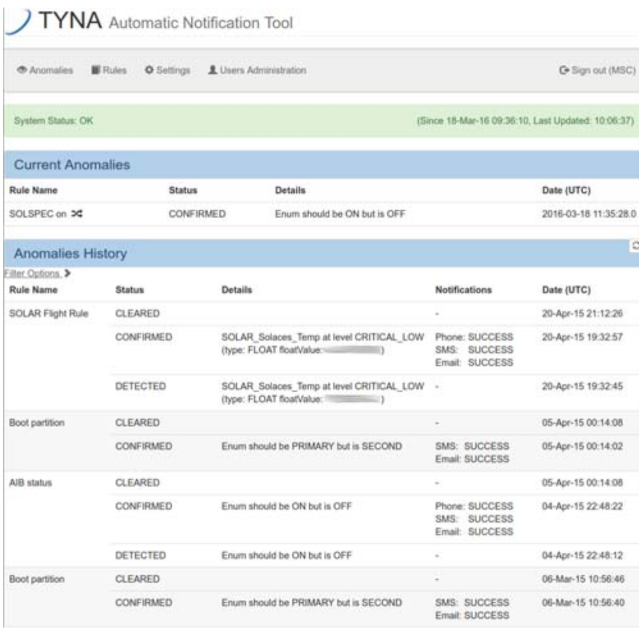


Figure 7: TYNA Anomalies Overview Web page

The TYNA Status are defining those rules to check that the TYNA system is properly connected to the external components it needs.

The Telemetry Out-Of-Limits rules check that the telemetry values are within the nominal ranges set by the Experiment Activity Manager (user role Payload EXAM). For each rule, a list of telemetry parameters can be defined. Each of the parameters is associated with a notification level or a configurable (custom) range. The Notification level is checked against the monitoring result provided by the Mission Control System. If a custom range is defined, the incoming values of the parameter are checked against the custom range defined in the rule. If one of a rules' parameters is out of limit, an anomaly is detected.

Finally, the Telemetry Delay rules allows to configure the notification tool as glitch tolerant. If the anomaly is detected for more occurrences than the glitches tolerance value, TYNA sets the anomaly as confirmed.

A rule can be set as self-standing or as a conditional rule. For example, to only monitor a certain parameter in a specific situation such only monitor a temperature when the instrument is actually switched on.

The TYNA Anomaly web page as shown in Figure 7 shows the current anomaly and the previous ones, including details of the anomaly such as the actual operations name of the parameter and the measured out of limit. Additionally, the notification details can be viewed depending on the user's role. The role 'Manager' can see all the details of the calls performed by TYNA, while the other roles will see limited information.

IV. Conclusion

In support of the B.USOC SOLAR operations, TYNA has now performed close to 17,000 hours of automated monitoring. The availability of the tool has been more than 99.99% during on-call coverage. During this period, forty-six SOLAR failures have been detected, 100% have been notified and resolved. With the implementation of TYNA an average of 5200 hours per year of on console support by the SOLAR Operators has been saved.

While currently only applied for the SOLAR payload, the software has been validated to interface with CD-MCS in the ESA Payload Data Centre and to monitor other ESA Payloads and Columbus System Telemetry. Additionally, TYNA is designed to be extended, using its connector mechanism, to any other MCS and Planning Tools or Systems. For the B.USOC future operations, the monitoring of payload telemetry by TYNA during non science critical periods is part of the proposed operations concepts.

Both Yamcs and TYNA are open source software and free of use for the ISS payload community.

Acknowledgments

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