CTA Architecture

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List of Abbreviations			
AO	Announcement of Opportunity	SysML	Systems Modeling Language
CTA	Cherenkov Telescope Array	UML	Unified Modeling Language
CTAO	CTA Observatory	VO	Virtual Observatory
CTAC	CTA Consortium		
MM	Multi-messenger		
MWL	Multi-wavelength		

History		
Version	Date	Observation
1.0	14.04.2018	First release

Distribution	Project Commitee

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1 Introduction

CTAO will be a major astronomical facility serving a wide user community, offering unprecedented performance at the highest photon energies [R1]. CTAO faces many challenges compared to existing Cherenkov telescope arrays, in terms of increasing complexity with its large number of telescopes that are operated at the two CTA sites, the large number of interfaces between the components that make up the whole CTAO system and the operation of CTA as an open observatory with a large user base. The design of the instrumentation of the Cherenkov Arrays, and the concepts for operating them as part of an Observatory, have been developed over an extended period by many individuals. Whilst the overall concept for the CTAO system was established early in the project, and many areas have now been developed in great detail, it was felt that a formal approach towards a system architecture was needed, in particular in the area of software, but also much more generally in terms of operation as an observatory.

It is the goal of the system architecture to cope with this complexity, structuring the systems and enabling seamless integration of the developed units into a whole. The system architecture aims to cover the full scope of the CTA Observatory, i.e. all hardware and software systems, the processes and workflows of CTAO as well as all user aspects. While the system architecture has many applications in the project, the primary goals for the current architecture efforts are (i) to enable and improve communication and vision sharing among all CTA stakeholders involved in the pre-construction phase, (ii) to identify sub-systems (including scoping) to support assignment of responsibilities (e.g. work package definition), and (iii) to identify high-level interfaces between the main building blocks of CTAO. It serves as a vehicle and integration point for the complementing subsequent sub-system architectures.

The range of further applications is broad and includes support for interface management, staging scenarios for development and support for the integration, verification and validation. The development of the system architecture goes hand in hand with the requirements [R2] and use case refinement. This document presents the current status of the system architecture, for the purpose of discussion with all CTA stakeholders.

1.1 Readers Guide

The executive summary (Section 2) presents an overview of the architecture approach and its outcome.

Sections 3 and 4 provide a reference documentation of the system architecture for the whole CTAO system and its main building blocks in a self-consistent way. Section 3 presents the outcome for the CTAO system and its context, while Section 4 presents the details, i.e. scope, users, functionality and first-level functional decomposition, for each of the individual systems that make up the CTA Observatory as a whole and as currently captured in the architecture.

For those interested in formal aspects of the model derivation, Section 5 gives an overview of the approach and the used notation used.

2 Executive Summary

2.1 Top-level Architecture

The methodology for the CTA architecture was developed during this work with the support of Fraunhofer IESE [R3] and follows a defined methodology tailored for CTA needs using input from various architecture frameworks [R4, R5, R6, R7]. The top-level architecture follows a model-based approach and is described in a notation build on UML [R8] and the Systems Modelling Language (SysML) [R9]. The model is implemented in the Enterprise Architect tool [R10].

Figure 1 gives a view of the CTA architecture model. It consists of a top-level CTA architecture (top row) that provides an integrated view of all sub-systems (bottom row) with their logical and physical connections and processes which are executing across system boundaries. The top-level architecture focuses on what to build (not how to build it) and the identification of the main building blocks of the CTAO and their interconnections, among each other and with the internal and external users of the CTAO systems. As a system architecture, the top-level architecture gives an envelope to both hardware and software. It serves to define the scope of the main building blocks and to identify the main interfaces and provides input for further analysis (e.g. for the product level requirements). It shows all interactions of the sub-systems, defines their boundaries, their functionality, what information is exchanged and captures all user interactions.

The main drivers of the top-level architecture (top left in Figure 1) are the project objectives and requirements at observatory and system level [R2]. The top-level architecture is based on a process-driven analysis of the CTAO workflows with the primary goals to create a common understanding of the workflows and to derive the main building blocks of the CTAO system.

The top-level architecture model (top right in Figure 1) consists of different views capturing different aspects of CTA. For this release, the major goal of the top-level architecture is the scoping of CTA and of the individual sub-systems. Consequently, the focus of the current version is to identify the processes of CTA and the individual activities and actions that stakeholders and systems perform during the lifetime of the CTAO. The corresponding views are highlighted in green in Figure 2. Each view organises different modelling elements as detailed in Table 1. Traces between the elements in the different views allow the analysis of consistency and completeness of the model and enable reasoning about process and system decomposition and give scope to the various elements.

The top-level architecture serves as an envelope for and gives context and specifications to the various sub-systems and sub-system architectures (bottom row in Figure 1).
The detailed sub-system architectures complement the top-level architecture and focus on how to build the respective system. Here, the specifications of the individual components of the sub-system and its interfaces are derived. The separation of top-level architecture and sub-system architecture enables the sub-system teams to select their most suitable architecture approach that considers the specific needs of the sub-system (e.g. the SPES 2020 methodology [R6] has been chosen for the architecture approach of the Observation Execution System, one of the sub-systems of CTAO [R11]), while a coherent overall description of the integrated CTAO system is kept in the top-level architecture throughout the project.

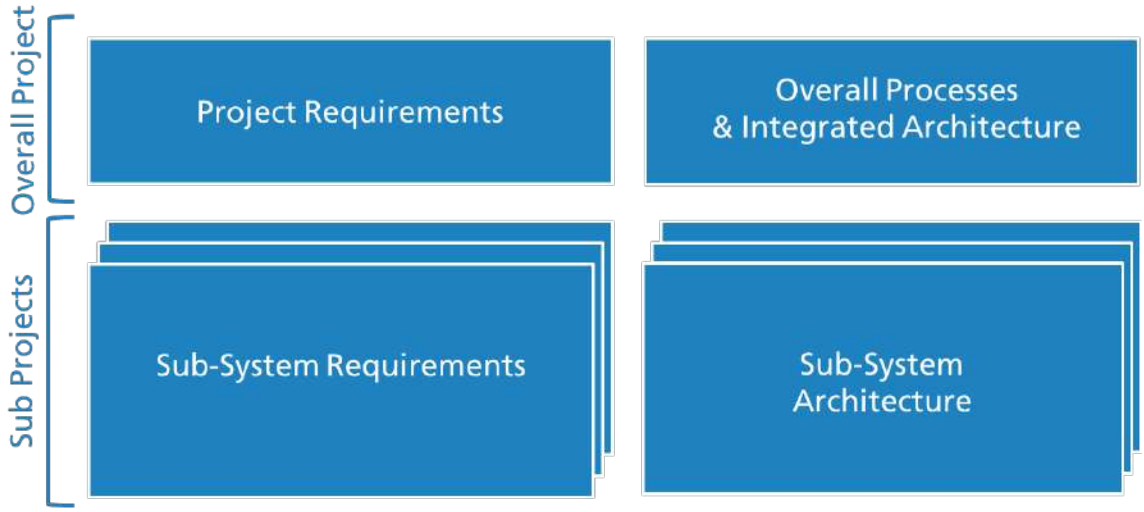

Figure 1: Overview of the modelling approach for CTA

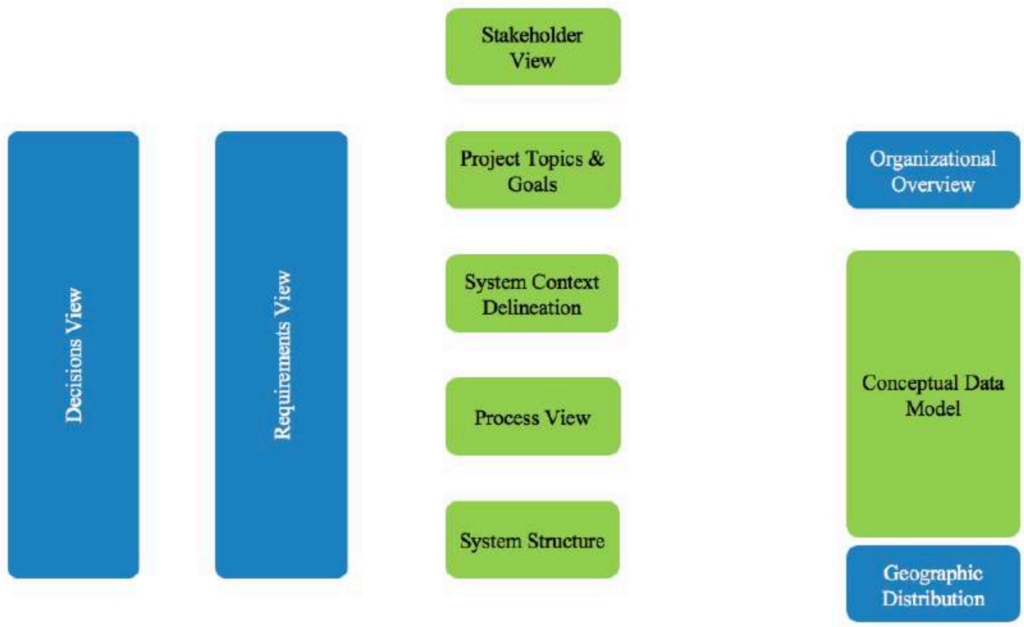

Figure 2: Views of the top-level architecture. The views highlighted in green are already existing in this release of the CTA top-level architecture model with the goal to derive a system structure. The views in blue are currently under construction.

Architecture View	Definition
Project Objectives	Collection of the project objectives of CTA, which are the one of the major architecture drivers.
Stakeholder View	Collection of stakeholders and organisations interacting with the CTAO system. They are the users of the CTAO systems and both external and internal stakeholders are captured here.
System Context Delineation	Depiction of the CTAO system as a black box and its interactions with the surrounding world, i.e.

Architecture View	Definition
	external stakeholders and organisations, external systems and physical objects.
Process View	Collection of the processes and internal activities that describe the CTAO workflow and relates the (internal and external) stakeholders and systems with the actions they perform in the processes and the data elements that flow between the actions. The processes are captured as activity diagrams.
System Structure	Functional decomposition of the CTAO system into a structure of systems, that interact with each other to serve the external interfaces and to implement the full scope of functionality of CTAO. In this view, the systems are shown with the main dataflow connections between them and to the external interfaces.
Conceptual Data Model	Collection presenting an abstract view of all data elements and their relations at high level, i.e. without the details.

Table 1: Overview on the architecture views used in the current version of the top-level CTA architecture.

2.2 The CTA Observatory and its Context

The system context of CTAO, where CTAO as a whole is treated as a black box, helps to define the boundaries of the CTAO, to identify the users of the CTAO and their interactions with CTAO and the interactions of CTAO with the surrounding world. It helps to identify the main interaction points with the surrounding world. Understanding the intent of the interactions of users with the CTAO and the CTAO objectives drive the definition of the processes and workflows that CTAO needs to implement.

The objectives of CTAO and observatory and system level requirements [R2] are the main drivers for the architecture. The objectives are shown in Figure 3 and are collected in the project objectives view. One example is the *'Dynamic Response to Scientific Opportunities'* that links to the functionality of CTAO to generate alerts and rapidly respond to external alerts. Appropriate functionality and interaction points have to be provided by CTAO. More information on the project objectives can be found in the architecture reference documentation in Section 3.1.

Other drivers for the architecture include the external stakeholders, the external systems and physical objects of the surrounding world with which CTAO interacts. They have been largely derived from the business plan [R12] and Observatory Model [R13]. Examples are given in Table 5. The external entities can benefit from or support CTAO objectives. The *Collaborating Scientific Facilities*, for instance, both benefit from and support the CTA objective of a *'Dynamic Response to Scientific Opportunities'*. They interact with the CTAO to exchange e.g. science alerts to coordinate observations of such fast phenomena. The stakeholders are collected in the *Stakeholder View* and more information on the external entities can be found in the architecture reference documentation in Sections 3.2 and 3.3.

In the system context view, CTAO is shown as a black box together with all external stakeholders and systems that it interacts with and the objects of the physical world that CTA observes. This view helps us to understand what interactions happen and enables us to identify the interfaces between CTAO and its context. The CTAO shown here encompasses all systems (hardware and software) and functionality needed such that CTAO can produce and/or consume the data elements exchanged with the external world. All these interactions are shown on the system context view in Figure 4.

The CTAO system is shown in the middle as a grey box with its boundary to the surrounding world. The context of the CTAO is arranged outside the CTAO system (in no particular order), where the different types are represented in with different symbols (external stakeholders as a stick figure, external organisations as a group of stick figures, external systems as a grey box, physical objects as an orange box). Interactions between CTAO and its context are captured as information flow between them, represented as a labeled dashed line with an arrow, where the direction of the arrow corresponds to the direction of the data exchange and the exchanged data element included as a label. The *Collaborating Scientific Facilities*, as one example of an external system interacting with CTAO, exchanges the data elements *'Science Alert'* and *'Imminent Observation Schedule'* with CTAO. As this information flows in both directions, the arrow is bidirectional. The information is exchanged via ports (the blue boxes on top of the boundary of the CTAO system), which correspond to interfaces that the CTAO system must provide to the outside world. The ports correspond one or more interfaces of all kinds (software, mechanical, electrical, etc.). These interfaces are identified in the top-level architecture and are served by the CTAO systems (contained inside the CTAO system black box). The interfaces are further specified in the subsystem architectures. The port *'Inter-Facility Collaboration'* is an example for such an interaction point of CTAO with the *Collaborating Scientific Facilities*, that needs to be served by one or more internal CTAO systems. Other examples are physical objects that are observed by CTAO as it acquires information from the outside world, for example to detect the Cherenkov light emitted by the Universe or to obtain weather information from the environment. CTAO also interacts with external stakeholders, e.g. the *Science User* that submits proposals, and organisations. For more information on the CTAO system context and the interactions of CTAO with the surrounding world see Section 3.4 in the architecture reference documentation.

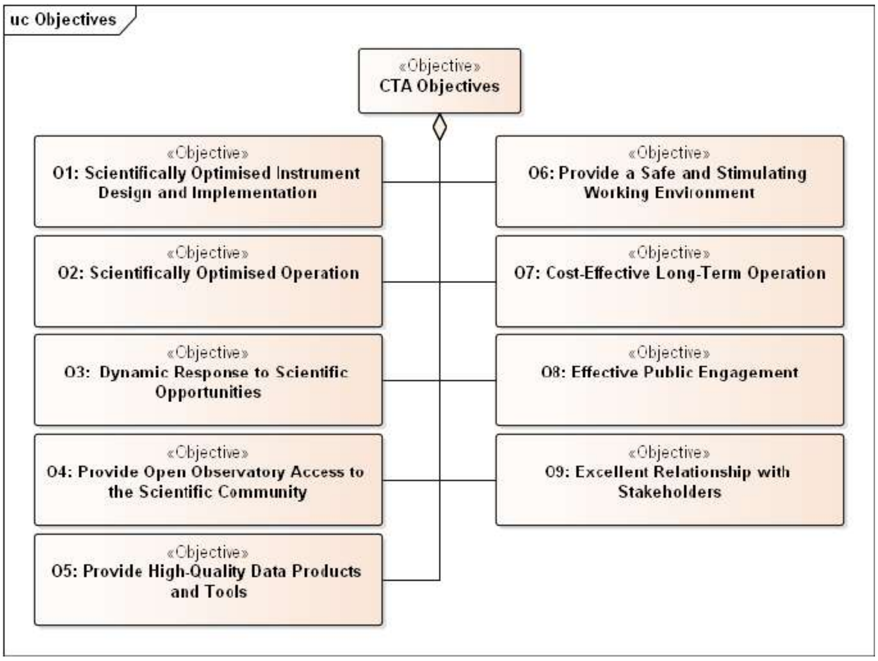

Figure 3: The CTAO objectives, taken from [R2].

Name	Type	Definition
Science User	Stakeholder Role	Someone who uses CTAO data products, with access determined according to proprietary data rights, and who uses CTAO tools and support.
Hosts and Neighbours	Organisation Role	Hosts are entities that accommodate the CTA Observatory installations at the respective site as stipulated within legal agreements. Neighbours are other organisations that occupy land close to the CTA sites and with whom the CTA Observatory communicates regularly to ensure harmonious co-existence.
Collaborating Scientific Facilities	External System	Scientific facilities, e.g. observatories, with which CTA collaborates to exchange information on observation schedules and scientific alerts e.g. to coordinate target of opportunity (ToO) observations. The information exchange can be direct or via public (ToO) networks.
Site Environment	Physical Object	Physical environment (e.g. weather) of the CTA array sites.

Table 2: Examples for entities of the context of CTAO that interact with the CTAO system. An example is given for an external stakeholder role, an external organisation role, an external system and a physical object.

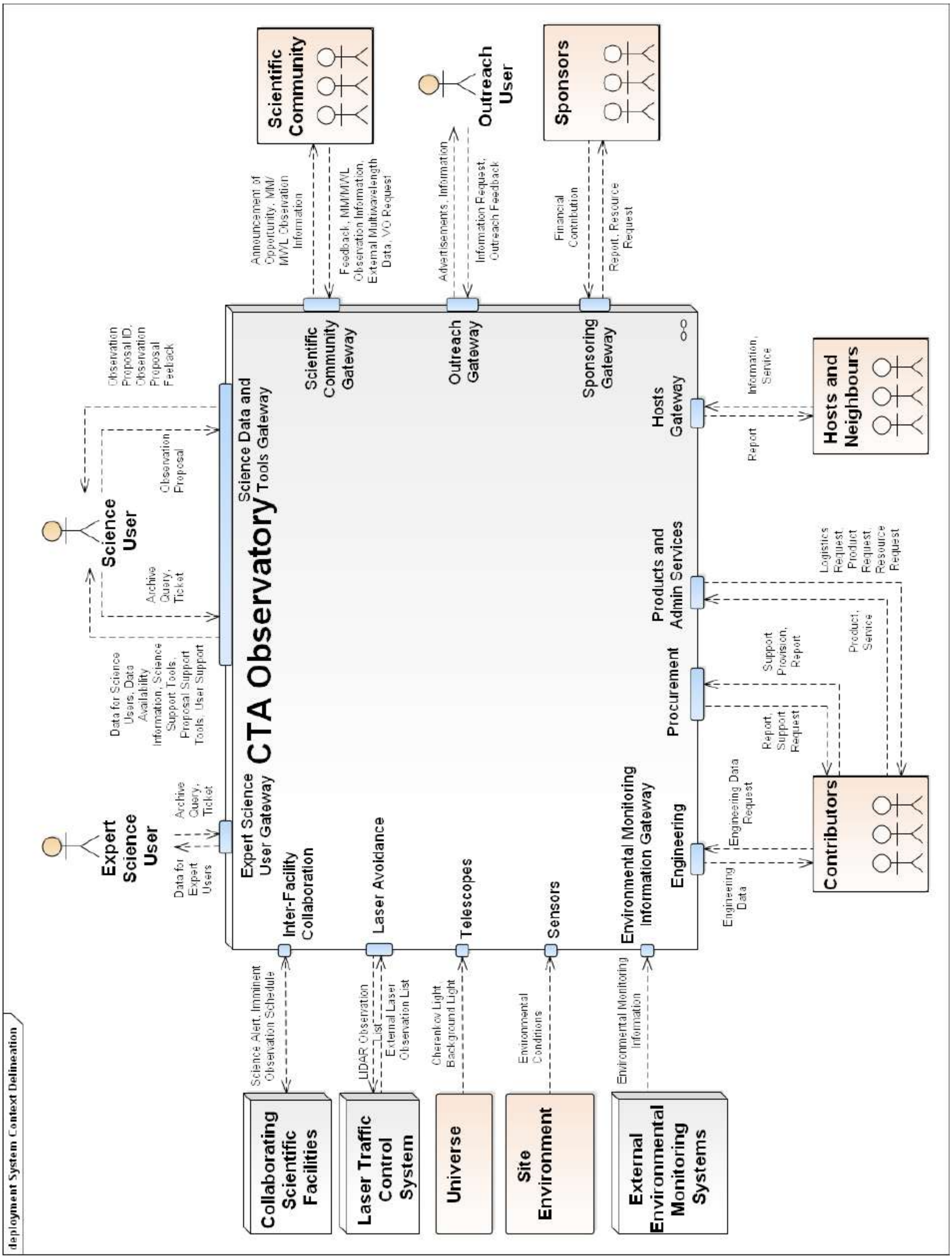

Figure 4: System Context Delineation of the CTAO system (grey box in the middle) and the main interactions with the outside world (external stakeholders and organisations, external systems and physical objects) through ports (blue boxes at the boundary of the CTAO system), the interaction points between the CTA Observatory and its environment. Further details of the interactions are given in Sections 3.4.1-3.4.3.

2.3 The Processes of the CTA Observatory

The definition of the processes that reflect the CTAO workflows is the first view of the architecture where the focus is put onto the internal details of CTAO and is one of the major steps of the modelling approach. CTAO has certain objectives and interactions with the external entities, that it wants to achieve, requiring interactions with the external entities. How this is achieved is modelled in the process view following a process-based analysis of the functionality that CTAO needs. A process can be most generally defined as a set of actions that provides functionality to consume and/or produce data elements that are exchanged over the interfaces. A process at top level typically starts with an external stakeholder that triggers some internal activities within CTA. While describing the processes and the internal activities, we identify the actions that CTAO-internal systems and stakeholders perform during their execution and the data elements that connect them. The actions are used for system scoping, since they describe what a CTAO system is supposed to do while the data-exchange between the actions can be used to identify the dataflow to and from the systems. The processes are collected in the process view and are the first place where the interactions between the individual CTAO systems and with the internal and external stakeholders are documented. It can be regarded as a link between the CTAO system context, where the top-level processes start, and the internal CTAO system structure (see also Section 2.4).

Figure 5 shows the top-level processes as identified for CTAO. These processes cover the full scope of CTAO and different areas from science and observatory operations to engineering and maintenance. The top-level use cases [R14] were used as an important input for the definition of the science and observatory operations processes. One of the main top-level processes is '*Observe with CTA*' which covers the overall science and observatory operations of CTAO from the Announcement of Opportunity issued to the *Scientific Community* to the high-level scientific products provided to the *Science User*. The top-level processes are decomposed in a hierarchical structure from the top-level down to a set of elementary atomic actions. Three layers of abstraction have been used in the architecture to group and organise the process hierarchy. An example for such a process decomposition is shown in Figure 6 for one process (*'Submit Proposal'*) that is derived from the top-level process *'Observe with CTA'* as:

- *'Observe with CTA: from Announcement of Opportunity to Scientific Result'* that is decomposed into a set of processes, among them:
  - *'Observation Request: from Announcement of Opportunity to Validated Proposal'* that contains the two processes:
    - *'Announcement of Opportunity'*
    - *'Submit Proposal'*

The final level of decomposition for *'Submit Proposal'*, modeled as a customized UML activity diagram, is shown in Figure 7 as a set of actions that are performed either by a single (internal or external) stakeholder (manual action), a single system (system-automated action) or stakeholder and system (system-supported action). Actions are not further decomposed but are most likely refined in the detailed system architectures and/or described in use cases. The processes in the final step of decomposition allow us to identify the set of actions needed to reach a certain objective or interaction, the internal stakeholders (or users) and systems that are needed to complete the process and the data elements that flows between them. The actions (orange boxes), internal and external stakeholders (stick figures), systems (blue boxes) and data elements (beige boxes) are depicted in Figure 7.

The process is triggered by an external event (‘*Begin of new proposal round’*), depicted as a red flag, followed by a sequence of actions. From the process analysis, the involved data

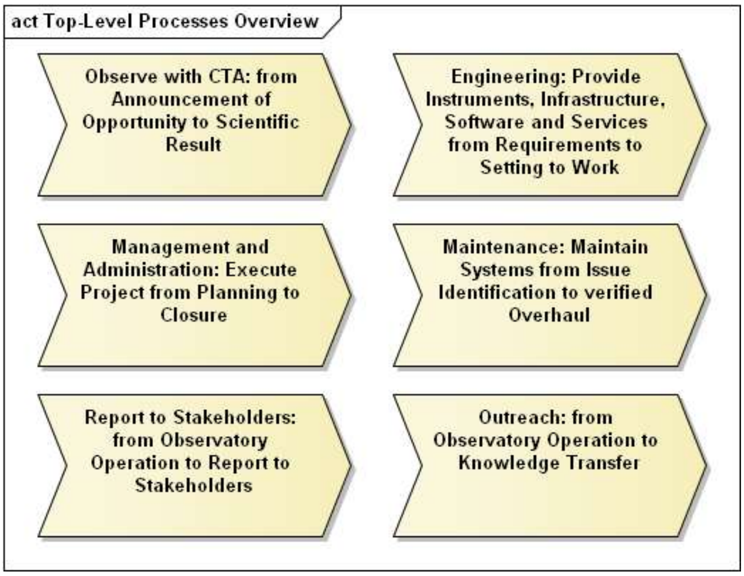

Figure 5: Overview of the top-level Processes.

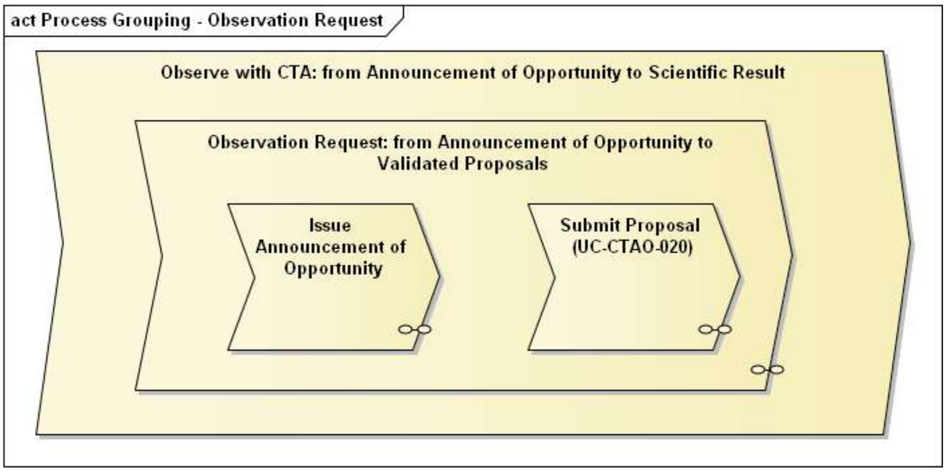

Figure 6: Example of a process decomposition.

elements can be inferred. The ‘*Science User*’ creates an *‘Observation Proposal Draft’* that after verification and submission becomes the *‘Observation Proposal’*. The main outcome of the process chain are the data elements ‘*Observation Proposal’* and linked ‘*Observation Proposal ID*’, the main business objects of this process, that are available for further processing. These data elements are handled (e.g. stored) by the respective system; in this case the *Science User Support System*. This system is defined as the system that supports these actions, in supporting the ‘Science User’ (*prepare the proposal, authenticate, modify an existing proposal* etc.) or performing the actions in an automated way (*verify proposal, store proposal, notify the Science User*). These actions imply a certain functionality of the system and interfaces that the system must provide (e.g. to the *Science User*). In a similar way, internal stakeholders can be identified that are needed to perform certain actions in either manual or system-supported way.

The elements identified in these processes are then collected in the different architecture views, the internal stakeholders in the stakeholder view, the systems in the system structure view (see next section) and the data elements in the conceptual data model. The conceptual data model contains the data element at a conceptual level, i.e. without going into the details, and their relations. It therefore connects the system context, the process view and the system structure view.

More information on the CTAO processes can be found in Section 3.5.

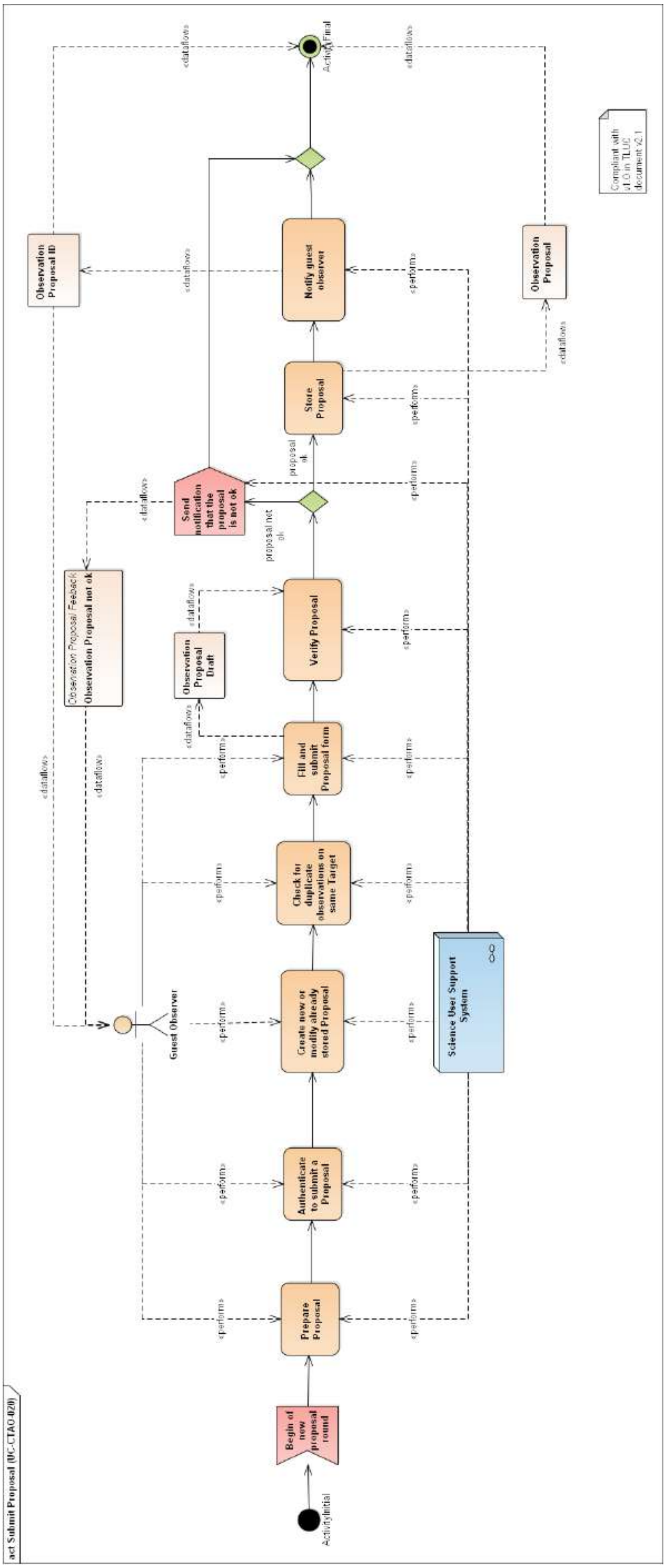

Figure 7: Example Process - Submit Proposal

2.4 The CTA Observatory Systems

The system context of CTAO and the analysis of the process decomposition allow us to identify the CTAO-internal systems with their scope and interconnections. In the process of this analysis, each system is derived with its context, i.e. the stakeholders and systems (internal and external to CTAO) that it interacts with, the interfaces it needs to realize for these interactions, the main data elements that flow in or out of the system, and the main functionality that is either executed automatically or where it supports a user. The grouping of these elements (e.g. based on the users of a system or actions that a system must perform) helps to identify the system structure.

Figure 8 gives an overview of the CTAO systems structure, with their definitions provided Table 3. The CTAO system is shown as a grey box in Figure 8, where the outer boundary corresponds to the boundary shown in Figure 4 with the exchanged data via the ports for the external interfaces (blue boxes). The CTAO systems at top level are shown as blue and green boxes with their ports (blue boxes at the boundary of the systems) and information flow between them (dashed arrows). The top-level CTAO systems can be grouped into two main categories:

- Systems that consist of software or a combination of hardware and software and where sub-systems are relatively well-integrated in the top-level system (blue boxes in Figure 8)
- Systems that consist of software and hardware/software sub-systems that are more loosely connected and are rather a collection of independent individual sub-systems (green boxes in Figure 8)

The systems exchange information and coordinate with each other to organise the full scope of the CTAO. In addition, they provide information and interfaces to both internal[1] and external users and support them in their activities. The interaction with the *Collaborating Scientific Facilities* via the port *Inter-Facility Collaboration* is, for instance, served by one single CTAO-internal system, the *Observation Execution System*, that implements the functionality and realizes the necessary interfaces to produce and consume the respective data elements *Science Alert* and *Imminent Observation Schedule*.

More information on the CTAO processes can be found in Section 4.1.

[1] Interaction points with the internal CTAO stakeholders or users of that system are not shown in the system structure view but have been added to the context view of each individual system in Section 4.3.

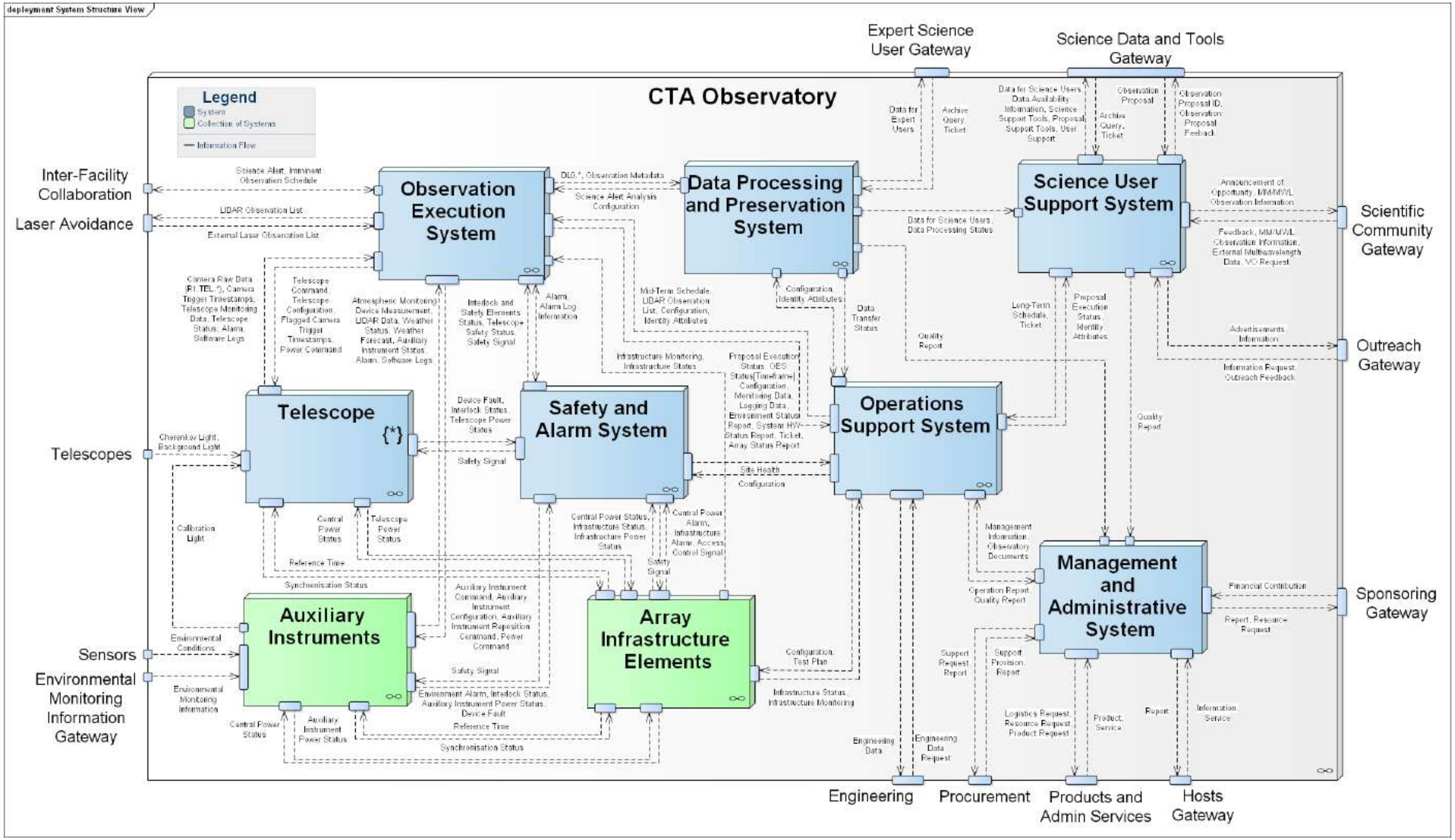

Figure 8: System Structure View of the CTA Observatory System.

System	Summary Description
Array Infrastructure Elements	A collection of infrastructure hardware and software systems supporting the systems running on-site. Includes systems for central power management, time synchronisation, on-site ICT infrastructure, test facilities and access control.
Auxiliary Instruments	A collection of auxiliary hardware and software systems associated with major data sources and devices at a CTA array site that are not Cherenkov Telescopes, for example instruments for the atmospheric monitoring or calibration.
Data Processing and Preservation System	A software system responsible for producing the science data products; including therefore the production and analysis of simulation data, (re)processing and the long-term preservation of data products and related information that will facilitate reproducibility of results as well as their transfer from the array sites.
Management and Administrative System	A collection of software systems associated with the administration of CTA. Includes procurement, logistics, human resources management and systems supporting the generation of performance/status reports for external stakeholders.
Observation Execution System	A software system responsible for the control and monitoring of telescopes and auxiliary (non-telescope) instruments at a CTA site, for the efficient scheduling and execution of pre-scheduled observations and those triggered dynamically, for the monitoring of the system performance, for the data acquisition and volume reduction as well as the automatic generation of science alerts.
Operations Support System	A collection of software systems supporting CTA operations. Includes configuration management, issue tracking, maintenance planning, authentication and authorization systems.
Safety and Alarm System	The hardware and software system for monitoring and control of the primary safety-relevant aspects (incl. interlocks) of the Telescopes and Infrastructure elements at a CTA array site. Includes an integrated alarm system.
Science User Support System	A software system providing the main point of access for proposal submission and to high-level CTA data products and corresponding sets of CTA tools to support data analysis. Provides support for proposal evaluation, for generation of the long-term schedule and for user support. Also includes outreach services.
Telescope	The hardware and software system associated with the control and data collection for a single Cherenkov Telescope at a CTA array site.

Table 3: Overview of the CTA Observatory systems.

2.5 Reference Documentation for the individual CTA Observatory Systems

Sections 4.3 introduces each individual CTAO system with its derived properties from the top-level architecture. For each system, the following items are presented:

SUMMARY
Summary table
NAME AND ACRONYM
Name and acronym of the system used throughout the section.
SCOPE
Summary of the main responsibilities and functionalities of the system under discussion.
CONTEXT
Environment of the system under discussion showing the main interactions and information flow with the surrounding internal and external systems and stakeholders.

USERS/STAKEHOLDERS	
-	**EXTERNAL USERS**
	External users of the system which interact with the system and are supported by the system to execute certain actions. The users can be external or internal to the CTAO.
-	**INTERNAL USERS**
	Internal users of the system which interact with the system and are supported by the system to execute certain actions. The users can be external or internal to the CTAO.
MAIN DATA ELEMENTS	
	Main conceptual data elements that are exchanged with the users and other systems (either as produced or consumed data) and are handled and/or stored within the system under discussion.
FUNCTIONALITY	
-	**USER-SUPPORTED PROCESSES AND ACTIONS**
	Main actions and related processes in which the system supports an internal or external stakeholder.
-	**AUTOMATIC PROCESSES AND ACTIONS**
	Main actions and related processes that are performed by the system.
INTERFACES	
	List of all the main interfaces with their purpose.
DEPLOYMENT	
	Number of instances of the system currently envisaged to run simultaneously (single or multiple instances) and its deployment location (either on site, off site or both).
NOTES	
	Additional notes.

3 The CTA Observatory and its Context

3.1 CTA Observatory Objectives

One of the major drivers for the architecture are the objectives of the CTA Observatory; these are reproduced in Table 4 from [R2]. The objectives help to identify the processes and the functionality that need to be implemented in the CTA Observatory.

Project Objective	Description
O1: Scientifically Optimised Instrument Design and Implementation	CTA shall be designed and implemented to cost-effectively provide dramatic performance improvements with respect to current ground-based gamma-ray telescopes, with improved sensitivity, resolution, larger field-of-view, wider energy range and full sky access.
O2: Effective Scientific Operation	Effective Scientific operation of CTA shall be ensured through optimised time allocation, effective scheduling, flexible and efficient operation and proposal support.
O3: Dynamic Response to Scientific Opportunities	CTA shall be able to rapidly generate alerts and rapidly respond to external alerts.
O4: Provide Open Observatory Access to the Scientific Community	CTA shall operate as an open observatory, providing access to CTA observation time, data products and support for the whole scientific community.
O5: Provide High-Quality Data Products and Tools	CTA shall provide reliable data products and comprehensive science tools to end users.
O6: Provide a Safe and Stimulating Working Environment	CTA shall prioritise the safety of personnel and visitors at CTA sites and provide opportunities for training and development, promoting the well-being of all personnel.
O7: Cost-Effective Long-Term Operation	CTA arrays must be efficiently maintained and operated, CTA data efficiently processed and archived, and the CTA organisation efficiently administered.
O8: Effective Public Engagement	CTA shall inform and excite public interest in its activities.
O9: Excellent Relationship with Users and Other Stakeholders	CTA shall strive for an excellent relationship with scientific users, sponsors and contributors, site hosts, other observatories and the scientific community as a whole.

Table 4: Overview of the CTA Observatory objectives. The objectives have been taken from [R2].

3.2 External Stakeholder and Organisational Roles

The external stakeholders and organisations, i.e. human entities or bodies interacting with the CTAO, constitute another main driver for the architecture of the CTAO. In their interactions with the CTAO, they have their own objectives and have expectations on the response from the CTAO. The external stakeholders receive or provide information, products and/or services from or to the CTAO. In addition, stakeholders can perform tasks by using the CTAO according to their rights. Understanding these interactions is essential to shed light on the functionality, the interfaces and the information that the CTAO system as a whole needs to provide and/or consume.

An overview of the external stakeholder and organisational roles is given in Figure 9 and in Table 5 together with their definition. Relationships between the stakeholders and organisations allow us to group the interactions. For instance, the stakeholder role *Science User* is the generalisation[2] of the stakeholders *Proposer*, *Guest Observer*, *Principal Investigator* and *Archive User* each having a specific scope and interaction with the CTAO.

It is important to note that the CTA Consortium (CTAC) and its members may take many roles of the external stakeholders and organisations. CTAC members may for example take the role of *Science User*, *Expert Science User*, *Contributors*, *Scientific Community* or *Outreach User*. While the interactions are the same as for a non-Consortium Member, different rights may apply. For instance, the CTAC members may take the role of the Expert Science User, while this will be only very rarely the case for a non-CTAC member.

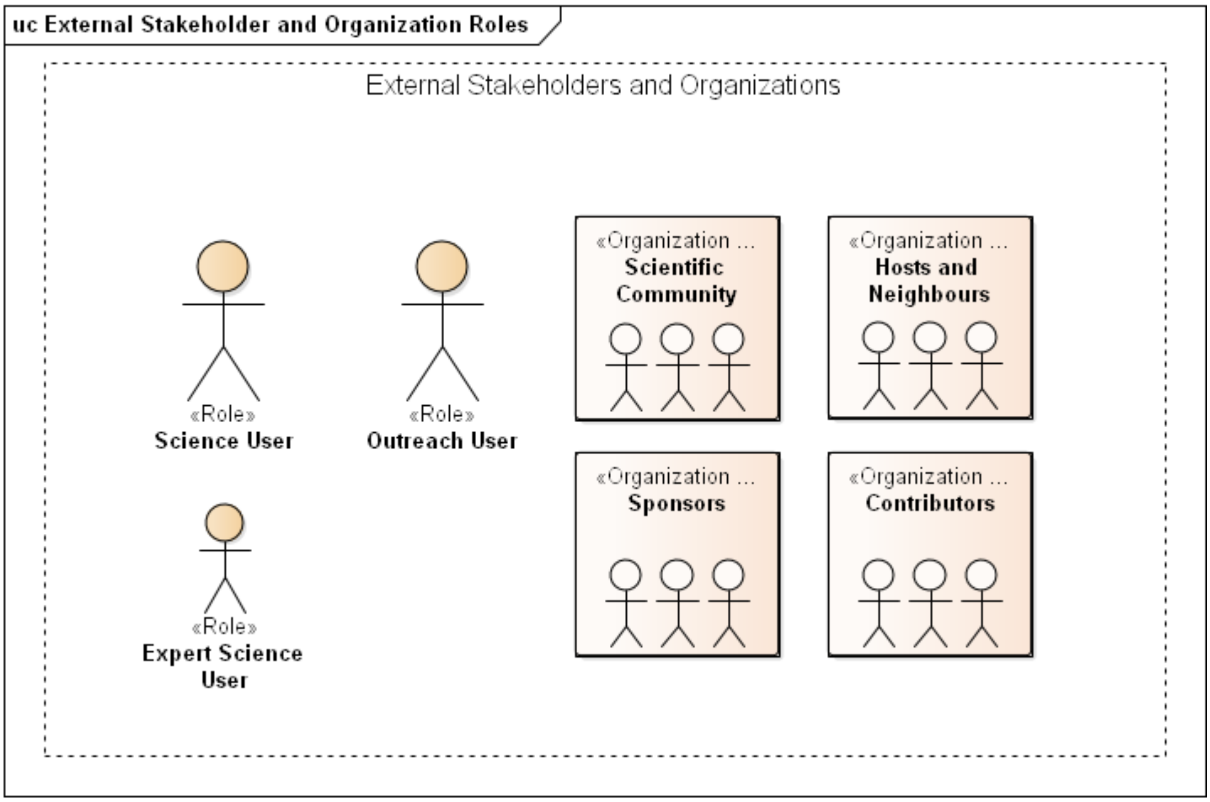

Figure 9: Overview of External Stakeholder and Organisational Roles. Specialisations are not shown here.

Name	External Stakeholder or Organisation Role	Definition
Science User	Stakeholder Role	Someone who uses CTAO data products, with access determined according to proprietary data rights, and who uses CTAO tools and support.
Specialisations of the Science User:		
- *Archive User*	*Stakeholder Role*	*Someone who accesses the CTA Observatory to obtain CTA data products, with access determined according to proprietary data rights, and CTAO tools to perform an analysis. The Archive User forms a specialisation of the Science User.*
- *Proposer*	*Stakeholder Role*	*Someone who submits a proposal in response to an Announcement of Opportunity. The Proposer forms a specialisation of the Science User.*
- *Guest Observer*	*Stakeholder Role*	*Someone whose proposal for an observation has been accepted. A Guest Observer forms a specialisation of the Proposer.*
- *Principal Investigator*	*Stakeholder Role*	*Contact person for a scientific programme (includes Guest Observer Programme, Key Science Projects, Director's Discretionary Time) that has the scientific responsibility for the related proposal. The Principal Investigator forms a specialisation of the Guest Observer.*
Expert Science User	Stakeholder Role	Someone who uses CTAO data at a lower level than the standard distributed data products. May submit technical proposals.
Scientific Community	Organisation Role	The scientific community of astrophysicists, astroparticle physicists, particle physicists, plasma physicists and cosmologists that will use CTAO services and its data products. The Scientific Community may respond to Announcements of Opportunity and/or use data made publicly available.
Outreach User	Stakeholder Role	Someone who uses CTAO outreach services and products.
Hosts and Neighbours	Organisation Role	Hosts are entities that accommodate the CTA Observatory installations at the respective site as stipulated within legal agreements. Neighbours are other organisations that occupy land close to the CTA sites and with whom the CTA Observatory communicates regularly to ensure harmonious co-existence.
Sponsors	Organisation Role	Organisations that provide financial support for construction and operation of CTA.
Contributors	Organisation Role	Organisations that provide products, components, parts, devices and/or services to the CTA Observatory.
Specialisations of the Contributors:		
- *Service Providers*	*Organisation Role*	*Organisations that provide a service to the CTA Observatory. Service Providers form a specialisation of Contributors.*
- *Product Providers*	*Organisation Role*	*Organisations that deliver a product to the CTA Observatory. Product Providers form a specialisation of Contributors.*
- *CTAO In-Kind Contributors*	*Organisation Role*	*Organisations that deliver a product or a service in-kind to the CTA Observatory. CTAO In-Kind Contributors form a specialisation of Contributors.*

Table 5: External Stakeholder and Organisational Roles together with their definition. The external stakeholders and organisations in italic and indented mode are specialisations of the preceding stakeholder, e.g. General Public and Media are both a specialisation of Outreach User. The stakeholders and organisational roles have been collected from [R12] and [R13].

3.3 External Systems and Physical Objects

Systems and physical objects external to the CTA Observatory are shown in Figure 10 and are summarized in Table 6. External systems can be hardware and/or software systems that provide an interface for information exchange with CTAO. Such interactions between external systems and CTAO are established to support the objectives and functionality of CTAO.

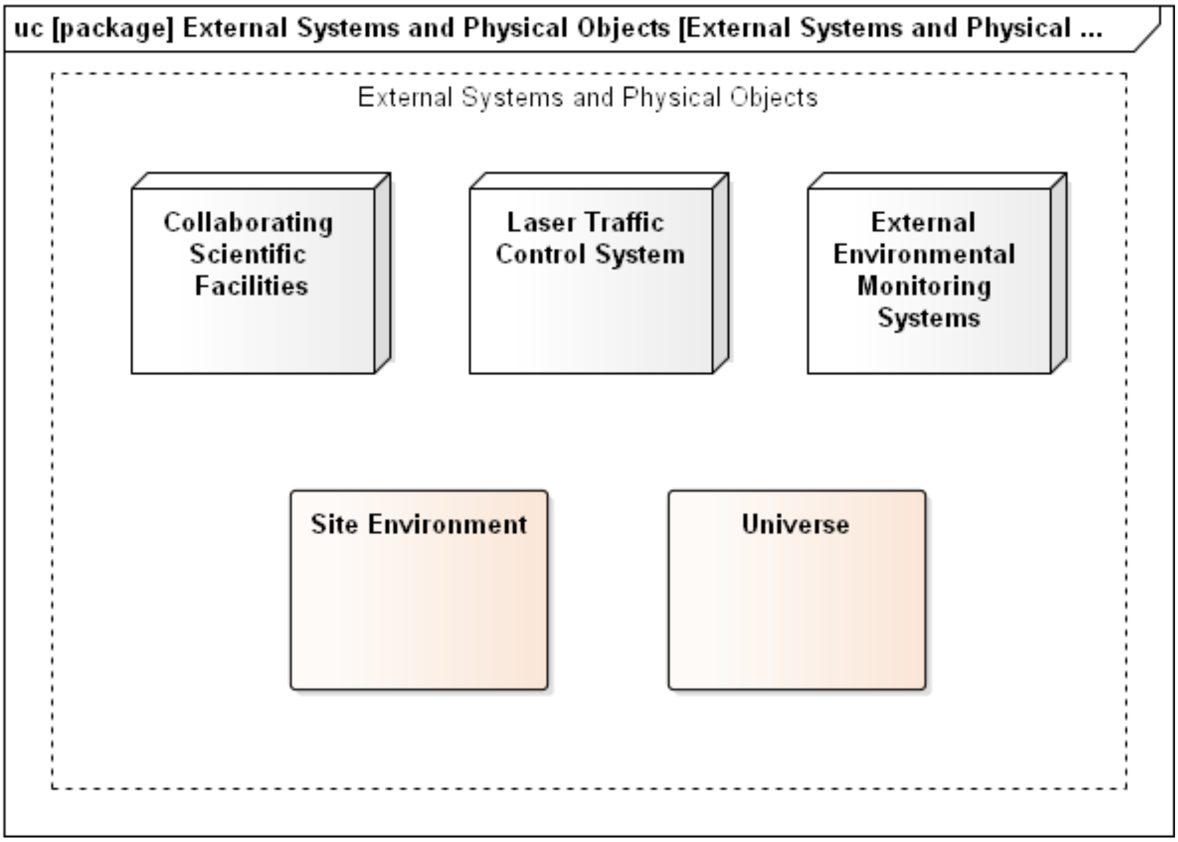

Figure 10: Overview of the External Systems and Physcial Objects interacting with the CTA Observatory.

Name	External Systems or Physical Objects	Definition
Collaborating Scientific Facilities	External System	Scientific facilities, e.g. observatories, with which CTA collaborates to exchange information on observation schedules and scientific alerts e.g. to coordinate target of opportunity (ToO) observations. The information exchange can be direct or via public (ToO) networks.
Laser Traffic Control System	External System	The Laser Traffic Control System is an external system used to coordinate the usage of lasers between neighbouring facilities to avoid collisions.
External Environmental Monitoring Systems	External System	External systems that provide information about the environment at the CTA array sites.
Universe	Physical Object	All natural light sources detectable at the CTA array sites.
Site Environment	Physical Object	Physical environment (e.g. weather) of the CTA array sites.

Table 6: Overview of External Systems and Physical Objects external to the CTAO.

3.4 The CTA Observatory System

The system context delineation (see Figure 11) is a diagram showing the CTA Observatory system as a black box together with all external stakeholders and organisations, external systems and physical objects and the information that flows between them. The system context delineation helps to define the boundary of the CTAO system, i.e. what is inside and under control of the CTAO – and what is outside. In addition, it describes who uses the CTAO system and for what purpose and what kind of information is exchanged.

In this view, the internal details of the CTAO system are not shown. The CTAO system contains all hardware and software systems that provide all functionality needed to serve the interactions with the external systems and users, to consume the inputs (e.g. *Cherenkov light* from the *Universe*) and produce the required output to the external stakeholders (e.g. *High-level data products* for the *Science User*). However, the internals of the CTAO system are not of interest here.

The information flow between external entities (e.g. *Science User*) with the CTAO is shown as a dashed line. The identification of the interaction points with the external entities, represented as ports (blue boxes in Figure 11), is the first step towards the identification of the system and user interfaces of the CTAO systems. The interactions with the outside world cover all aspects of the CTA Observatory, e.g. Science (at the top and top right of the CTAO system box in Figure 11), Operations (at the left), Engineering and administration (at the bottom and bottom right) and Outreach (at the right). Most interaction points are realized with software interfaces, except for telescopes and sensors to physical objects that are realized by hardware.

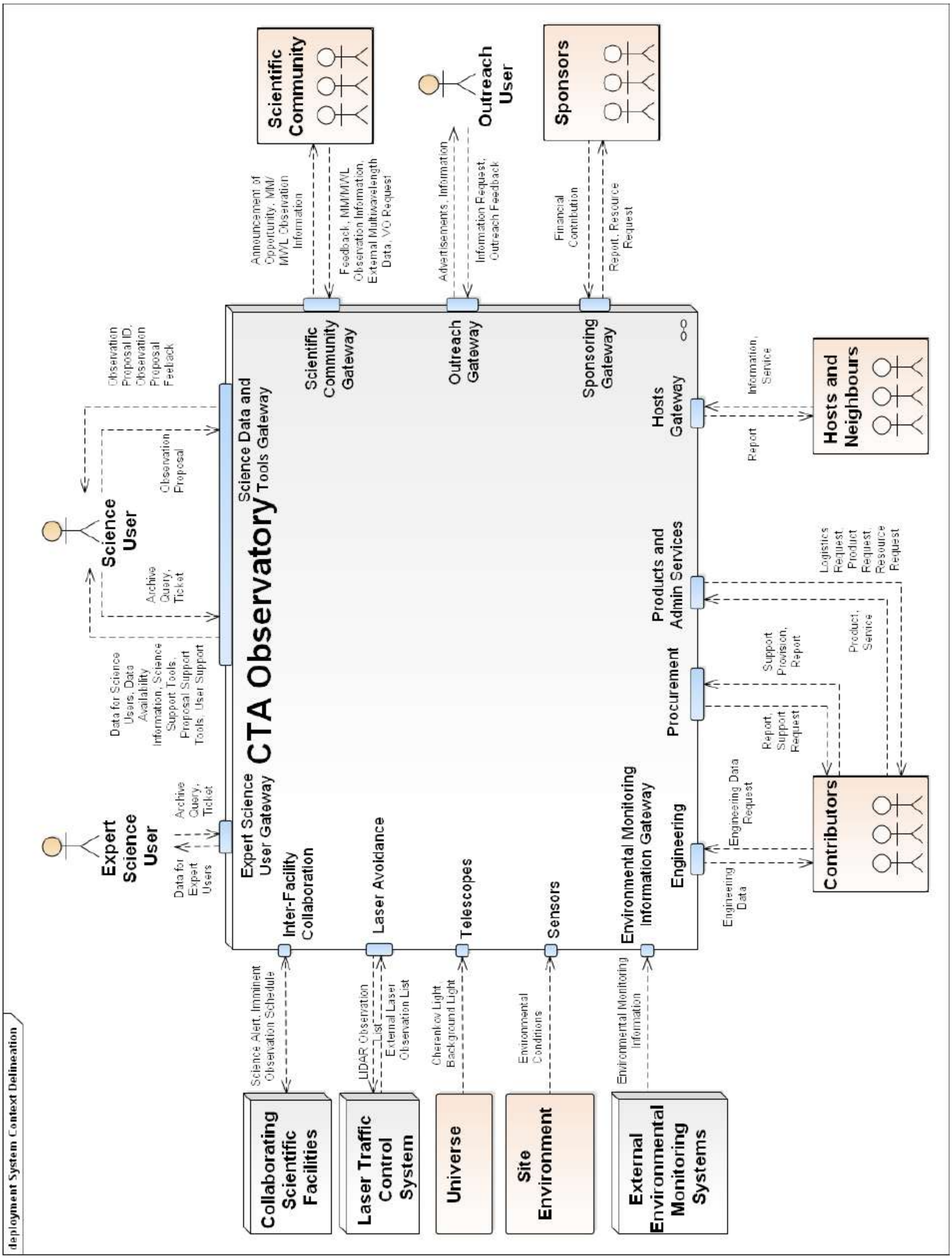

Figure 11: System Context Delineation of the CTA Observatory System (big grey box in the middle) and the main interactions with the outside world (external stakeholders and organisations, external systems and physical objects) through ports (blue boxes), the main interaction points between the CTA Observatory and its environment. Further details of the interactions are given in Sections 3.4.1-3.4.3. See also Section 6.3 for a reading guide.

Further details on the individual interactions are given below, grouped for the different types of external entities.

3.4.1 Main Interactions with External Stakeholders and Organisations

See Section 3.2 for an overview of the external stakeholders and organisational roles.

3.4.1.1 Interactions with *Science User*

The *Science User* is the generalisation of several science-related stakeholder roles (*Proposer, Guest Observer, Principal Investigator, Archive User*). The interactions with the CTAO system fall into two main categories.

The first group of interactions describes the proposal handling for CTA – the submission of proposals, the feedback for the success of the submission and the updates on the observation status in case of a successful proposal are some of the information items that are exchanged between the *Science User* and the CTAO. For the proposal preparation, appropriate tools are available for access and/or download by the *Science User*.

The second group of interactions describes the access to and analysis of high-level data products according to the appropriate data access rights. When data becomes available, the *Science User* is informed and can query and download the data together with science analysis tools for the scientific exploration of the data.

Additionally, user support is given in various forms by the CTAO and services exist for the *Science User* to give feedback (e.g. through help-desk and issue ticket systems) and to access documentation.

3.4.1.2 Interactions with *Expert Science User*

In addition to the interactions of a *Science User*, the *Expert Science User* has access to lower-level data with, for example, the goal of developing and testing new algorithms for reconstruction and/or calibration.

3.4.1.3 Interactions with *Scientific Community*

The *Scientific Community* receives directed information on science and operation-related topics from the CTAO, most notably the Announcements of Opportunity. In addition, special ports exist for the *Scientific Community* to share multi-wavelength (MWL) and multi-messenger data (MM) with the Observatory as well as to search and access CTA data in Virtual Observatory (VO) format.

3.4.1.4 Interactions with *Outreach User*

The *Outreach User* is the generalisation of several outreach-related stakeholder roles (Media, General Public). CTAO provides services to address the needs of the *Outreach User*, to actively engage the *Outreach User* with advertisements and exchange of information and to enable an efficient channel for providing feedback and requests for information.

3.4.1.5 Interactions with *Sponsors*

CTAO provides access to information and reports to the sponsors (e.g. funding agencies) that are the financial contributors to the CTAO. The reports cover the full scope of the CTAO, evaluating its performance.

3.4.1.6 Interactions with *Hosts and Neighbours*

The *Hosts* (e.g. the hosts of the CTA array sites) and *Neighbours* (e.g. other observatories near a CTA array site) is a group that is related to the operation of the CTA array sites. *Hosts* may provide services to and are engaged in continuous information exchange with the Observatory (e.g. service-related reports and/or warnings). *Neighbours* exchange information with CTAO on, for example, the usage of lasers or notices on upgrade work that may impact the operation of the CTA arrays.

3.4.1.7 Interactions with *Contributors*

The contributors (e.g. an in-kind contributor from within the CTAC or an external company) are providers of services and/or products to the CTAO. To provide these services and/or products, the contributors need access to e.g. engineering information and support from the CTAO for e.g. logistics and procurement. Regular information exchange with the contributors over the lifetime of the provided service and/or product is expected.

3.4.2 *Main Interactions with External Systems*

External systems are hardware and/or software systems that are outside of the CTAO boundary and are in interaction and/or coordination with the CTAO.

3.4.2.1 Interactions with *External Environmental Monitoring Systems*

Information on the environmental conditions can be provided by external systems (e.g. satellite systems) and is used by the CTAO as an input for its operation or planning of on-site maintenance work.

3.4.2.2 Interactions with *Laser Traffic Control System*

Both the CTAO and neighbouring scientific installations regularly use laser beams to e.g. monitor the atmospheric conditions. The coordination of the usage of the laser beams between the CTAO and *Neighbours* to minimize impact on their observations is envisaged to be done via an external laser traffic control system. In a similar way, air traffic can be informed of the usage of the laser beams or the usage of it regulated according to the traffic needs.

3.4.2.3 Interactions with *Collaborating Scientific Facilities*

Exchange of scientific alerts and imminent observation schedules e.g. via a ToO network or directly with collaborating scientific facilities is of key importance for the CTAO to maintain a coordinated and scientifically optimized observation programme and react dynamically to scientific opportunities. A dynamic coordination of the two CTA sites can be organised based on a similar information exchange.

3.4.3 *Main Interactions with the Environment*

The environment is a direct input to the CTAO.

3.4.3.1 Interactions with *Universe*

The main purpose of the CTAO is to detect Cherenkov light from the *Universe* for which specific systems are built as part of the CTAO System.

3.4.3.2 Interactions with *Site Environment*

The characterisation of the site environment (e.g. weather) is an important functionality of the CTAO system for various reasons, among them the safety of the CTAO systems at the CTA array sites and an accurate calibration of the scientific data of CTAO.

3.5 Processes

The main means for capturing the functionality of the CTA Observatory systems and to describe the interactions of the CTAO system with the external world are *processes*. A process is a self-contained sequence of steps that has one or more kind of input and has an expected outcome, which supports the CTAO in reaching a certain objective and/or interaction with external stakeholders. The processes cover all aspects of CTAO and help to identify the internal stakeholders (i.e. users of the CTAO systems) of CTA, the CTAO systems and the data elements which are exchanged between the CTAO systems and stakeholders.

The processes are organised in a hierarchical order and an overview of the top-level processes covering all aspects of the CTAO is given in Section 3.5.1. The top-level processes are further decomposed to various level of detail in Section 3.5.2. An example process is given in Section 3.5.3.

3.5.1 Top-Level Processes

The top-level processes listed in Table 7 and in Figure 12 cover all aspects of the CTA Observatory, including science and observatory operations, maintenance, management and administration.

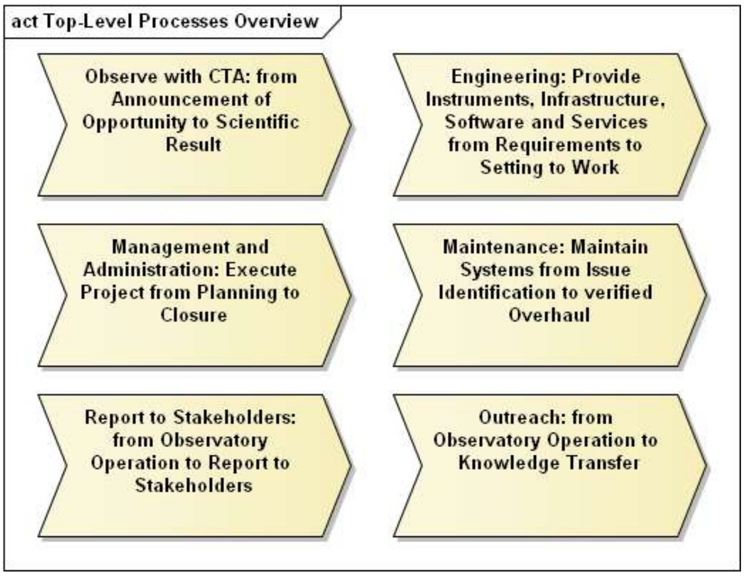

Figure 12: Overview of the top-level Processes.

Process	Summary Description
Observe with CTA: from Announcement of Opportunity to Scientific Result	Covers the overall process describing the science and operation part from the announcement of opportunity (issued to the *Scientific Community*) to the provision of high-level scientific products (provided to the *Science User*).

Process	Summary Description
Maintenance: Maintain Systems from Issue Identification to verified Overhaul	Covers maintenance of the hardware and software systems and the identification, book-keeping and reaction to identified issues. Includes the calibration of instrumentation, the verification of performance and interaction with those users that identify issues.
Engineering: Provide Instruments, Infrastructure, Software and Services from Requirements to Setting to Work	Covers operational aspects of the CTA Observatory. Related to the design, implementation, configuration and installation of instruments, infrastructure, software and services needed for the CTA Observatory to operate.
Report to Stakeholders: from Observatory Operation to Report to Stakeholders	Covers reporting functionality, from all main systems to the stakeholders. The reporting to identified stakeholders (internal or external to CTA) follows all steps from engineering to the collection of data and its processing and dissemination and includes all quality reporting from the different systems.
Outreach: from Observatory Operation to Knowledge Transfer	Covers outreach activities of the observatory, as a dedicated path for information and reporting to external stakeholders.
Management and Administration: from Project Planning to Observatory Operation	Covers all management and administration activities to build up and/or operate the CTA Observatory.

Table 7: Overview of the top-level processes with their definitions.

3.5.2 Process Decomposition

The top-level processes are further decomposed into activities (i.e. a groups of actions) and actions at lower level of abstraction and higher level of detail. Processes and activities can be arranged in process/activity chains or grouped according to certain criteria, e.g. day and night activities, on-site and off-site procedures, etc. The processes and activities might overlap, might be sequential or simultaneous, might be orthogonal to each other or share certain activities that are common between the processes and activities, which allows for different perspectives on a certain CTAO aspect. For the area of the science and observatory operations, the top-level use cases [R14] have been used as the major input and an overview of the first layer of decomposition of the top-level process 'Observe with CTA' is given in Figure 13.

The process decomposition stops when actions, the leaf elements, are identified for each process. The actions are characterized by either being executed by exactly one system (without any user involvement), by exactly one person (without any system involvement), or by exactly one person with the support of exactly one system. In this way, the decomposition of the processes allows us to identify and scope the (internal and external) stakeholders and the CTAO systems as well as the exchanged data elements. With the decomposition, the individual CTAO systems can be identified with their functionality (actions), their interfaces and data elements exchanged with their environment. In this way, the systems acquire clear responsibilities and boundaries to the external world.

In total, about 150 process and activities have been modelled, of which ~100 are related to science and observatory operations which is the main focus of the current work. The list of processes and activities is not complete and continuous work is being done to complete and refine them.

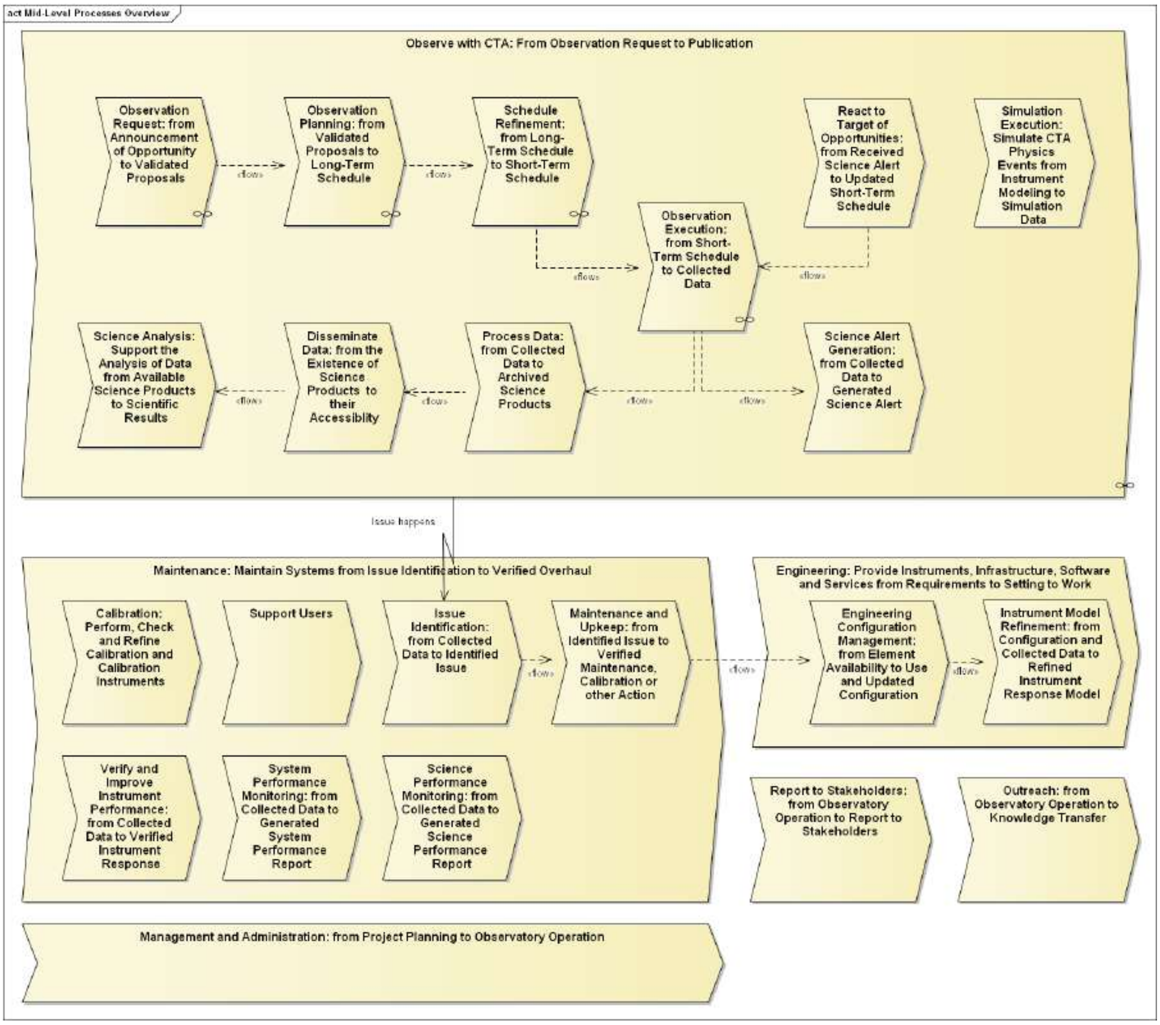

Figure 13: Overview of the first level of process decomposition.

Process	Summary Description
Observe with CTA: from Announcement of Opportunity to Scientific Result	
Observation Request: from Announcement of Opportunity to Validated Proposals	Covers the proposal request, proposal preparation, proposal submission and evaluation.
Observation Planning: from Validated Proposals to Long-Term Schedule	Covers the generation of an approved long-term observation plan from the validated proposals.
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Covers the planning of observations on different timescales (mid-term schedule on week/month basis, short-term schedule during the night) from a long-term schedule. Includes the planning of calibration and maintenance work, the reaction to target of opportunities, and coordination with other observatories for multi-messenger/multi-wavelength campaigns.
Observation Execution: from Short-Term Schedule to Collected Data	Covers the execution of the planned observations and data acquisition. Includes calibration, monitoring and reaction to alarms.
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Covers the reaction to internal and external Science Alerts. Includes their reception, filtering and updating of the observation plan.

Process	Summary Description
Science Alert Generation: from Collected Data to Generated Science Alert	Covers the generation of Science Alerts during data acquisition.
Process Data: from Collected Data to Archived Science Products	Covers all steps for the processing of low-level data to the production of the high-level Science Products. Includes calibration and data quality monitoring.
Disseminate Data: from the Existence of Science Products to their Accessibility	Covers the dissemination of the high-level Science Products.
Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Covers the support for the external users of CTAO services and products (e.g. Science User, Scientific Community). Includes support for the science analysis and publications.
Simulation Execution: Simulate CTA Physics Events from Instrument Modeling to Simulation Data	Covers the simulation steps needed for the generation of the instrument response and generation of the information needed for the operation of the CTAO.
Maintenance: Maintain Systems from Issue Identification to Verified Overhaul	
Verify and Improve Instrument Performance: from Collected Data to Verified Instrument Performance	Covers the activities to verify and improve instrument performance, including the detection of issues and their fixing
System Performance Monitoring: from Collected Data to Generated System Performance Report	Covers the monitoring, diagnosis and generation of reports for the relevant stakeholders related to the operational performance of the CTAO.
Science Performance Monitoring: from Collected Data to Generated Science Performance Report	Covers the monitoring, diagnosis and generation of reports for the relevant stakeholders related to the science performance of the CTAO.
Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Covers all activities to improve the calibration of the instruments at the CTA array sites and operation of the calibration instruments
Support Users	Covers the support of external users of CTA data and products, including the tools for data analysis and proposal preparation
Issue Identification: from Collected Data to Identified Issue	Covers the identification of issues and generation of related reports during the operation of the CTAO.
Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Covers all steps necessary to react on identified issues, including the generation of work orders, their execution and related reports.
Engineering: Provide Instruments, Infrastructure, Software and Services from Requirements to Setting to Work	
Engineering Configuration Management: from Element Availability to Element Use and Updated Configuration	Covers the activation of instruments, and their update, at the CTA array sites and the related instrument configuration.
Instrument Model Refinement: from Configuration and Collected Data to Refined Instrument Response Model	Covers the steps to update and verify the instrument response based on the actual configuration and the data collected at the array sites

Table 8: Overview of the processes at 1st level of decomposition together with their definitions.

3.5.3 Process Example

Processes and activities are modelled with activity diagrams using SysML/UML notation (see also the reading guide in Section 6.3). An example for such an activity diagram is given in Figure 15.

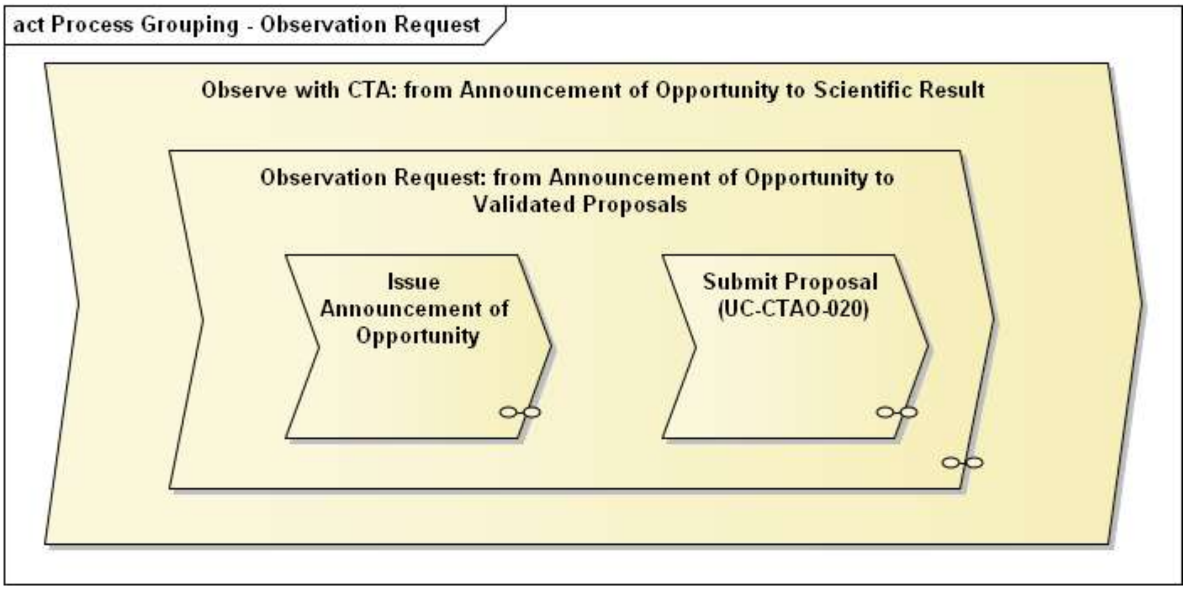

Figure 14: Overview of an example of a process decomposition.

Process	Summary Description
Observe with CTA: from Announcement of Opportunity to Scientific Result	Covers the overall process describing the science and operation part from announcement of opportunity (issued to the *Scientific Community*) to the provision of high-level scientific products (provided to the *Science User*).
Observation Request: Propose CTA Observations from Announcement of Opportunity to validated Proposals	Covers the proposal request, proposal preparation, proposal submission and evaluation.
Submit Proposal	Covers the submission of a proposal.

Table 9: Related definitions for the example of a process decomposition.

The activity has the title *'Submit Proposal'* and is part of the activity *'Observation Request'* (see Section 3.5.2), which in turn is part of the process '*Observe with CTA*' (see Section 3.5.1). It is modeled following the description given in the top-level use case UC-CTAO-020 [R14]. The goal of the activity is the submission of a proposal with the expected outcome of a stored observation proposal that can be further used and processed by other activities. Execution of the activity is done from left to right and several actions are executed that are performed either by a human with system support or by a system automatically. The person identified to contribute to the execution of this activity is the *Proposer* (which is part of *Science User*) who submits an observation proposal draft and the *Science User Support System* that supports the *Proposer* in doing so. In addition, the *Science User Support System* executes some actions ('*verify proposal'*, '*store proposal'*, *'notify Proposer'*) fully automatically. The expected outcome of the activity is the creation of a stored *Observation Proposal* and an *Observation Proposal ID*, that serve as input for the next activity in the chain.

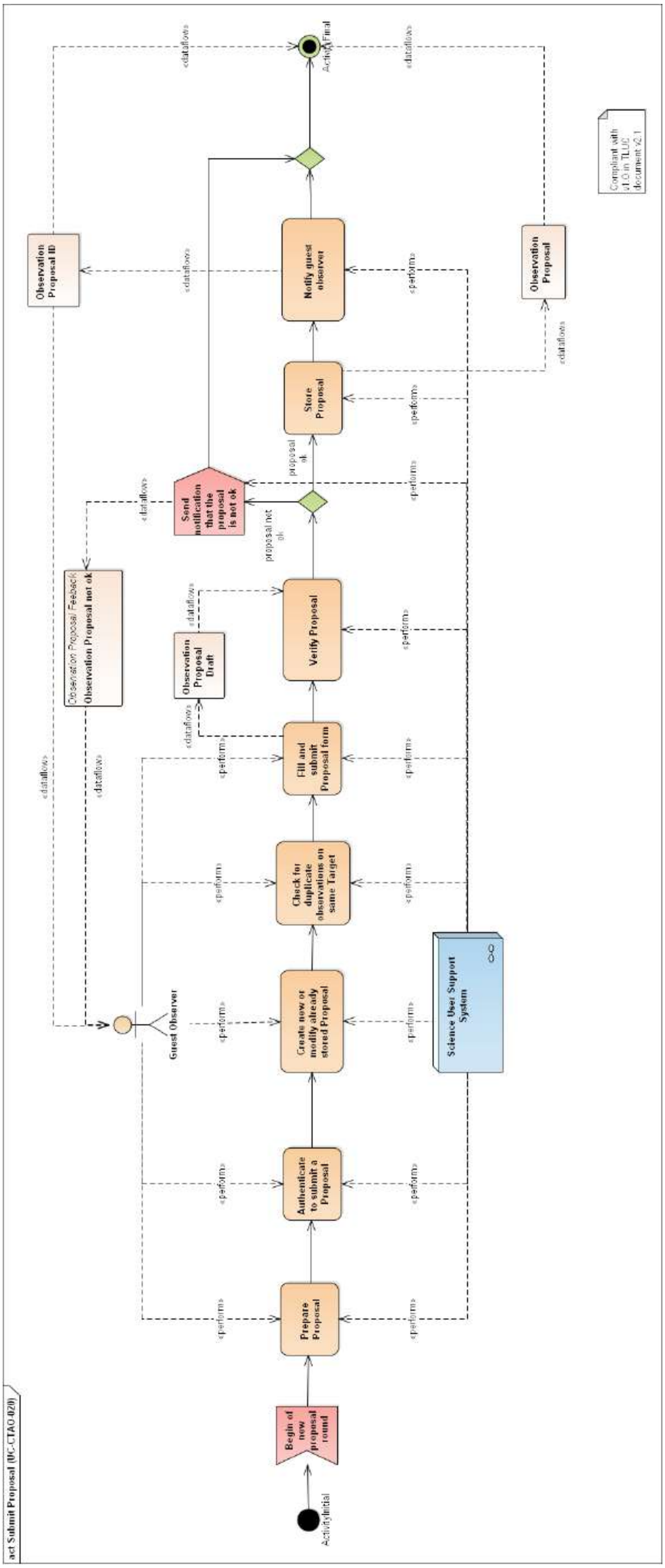

Figure 15: Example Process - Submit Proposal

4 The CTA Observatory Systems

In this chapter, a summary of the individual top-level systems of the CTA Observatory is given. The chapter starts with an overview of the top-level systems of CTAO, organized in the system structure and presented in Section 4.1, followed by the presentation of the internal stakeholders and organisations in Section 4.2. Each individual system is described in more detail in Section 4.3, addressing the following questions:

- What is the functionality and responsibility of the system?
- Who are the users of the systems and how do they interact with the system?
- How do the systems interact and what are the main interfaces?
- Which data is exchanged?
- What is the internal functional sub-structure (or decomposition) that can satisfy the required functionality and interfaces?

From the architectural description of each system, functional product-level requirements and specifications (incl. interface definitions) will be derived for each system in the future.

4.1 System Structure

The CTAO system is composed of a set of top-level systems that each provides certain functionality to the CTAO system and have certain interfaces. The aggregation of these systems and their interplay cover the full functionality of the CTAO necessary and serve its interactions. The first layer of the decomposition of the CTAO system into top-level systems is shown in Figure 16. This decomposition is valid for the operation phase of CTAO.

The system structure shows the top-level systems, the information that flows between them and to the external world and the interfaces through which the systems interact with each other and the external world. The top-level systems are composed of only software or a hardware/software combination to provide the required functionality and interfaces. In Table 10, an overview of the top-level systems is given, and the individual systems are further detailed in Section 4.3.

System	Summary Description
Array Infrastructure Elements	A collection of infrastructure hardware and software systems supporting the systems running on-site. Includes systems for central power management, time synchronisation, on-site ICT infrastructure, test facilities and access control.
Auxiliary Instruments	A collection of auxiliary hardware and software systems associated with major data sources and devices at a CTA array site that are not Cherenkov Telescopes, for example instruments for the atmospheric monitoring or calibration.
Data Processing and Preservation System	A software system responsible for producing the science data products; including therefore the production and analysis of simulation data, (re)processing and the long-term preservation of data products and related information that will facilitate reproducibility of results as well as their transfer from the array sites.

System	Summary Description
Management and Administrative System	A collection of software systems associated with the administration of CTA. Includes procurement, logistics, human resources management and systems supporting the generation of performance/status reports for external stakeholders.
Observation Execution System	A software system responsible for the control and monitoring of telescopes and auxiliary (non-telescope) instruments at a CTA site, for the efficient scheduling and execution of pre-scheduled observations and those triggered dynamically, for the monitoring of the system performance, for the data acquisition and volume reduction as well as the automatic generation of science alerts.
Operations Support System	A collection of software systems supporting CTA operations. Includes configuration management, issue tracking, maintenance planning, authentication and authorization systems.
Safety and Alarm System	The hardware and software system for monitoring and control of the primary safety-relevant aspects (incl. interlocks) of the Telescopes and Infrastructure elements at a CTA array site. Includes an integrated alarm system.
Science User Support System	A software system providing the main point of access for proposal submission and to high-level CTA data products and corresponding sets of CTA tools to support data analysis. Provides support for proposal evaluation, for generation of the long-term schedule and for user support. Also includes outreach services.
Telescope	The hardware and software system associated with the control and data collection for a single Cherenkov Telescope at a CTA array site.

Table 10: Overview of the CTA Observatory systems.

These top-level systems make up the whole of the CTAO system and cover all areas from science and observatory operations to engineering and maintenance.

The systems that take part in and support the science and observatory operations of the observatory are the Telescopes that produce the bulk data from incoming Cherenkov and background light, the Observation Execution System that incorporates the data acquisition from the Telescopes as well as their control and monitoring, the Data Processing and Preservation System, where the bulk data is processed and archived and the Science User Support System that provides the high-level data and tools for the *Science Users* as well as the main access point for the *Science Community*. The science and observatory operations are supported by systems that cover operational aspects of the Observatory – the Safety and Alarm System, the Operations Support System, the Auxiliary Instruments and the Array Infrastructure Elements. Management and Administration aspects are covered by the corresponding Management and Administrative System.

The top-level systems can be grouped into two main categories:

- Systems that consist of software or a combination of hardware and software and where sub-systems are relatively well-integrated in the top-level system (blue boxes in Figure 16)
- Systems that consist of software and hardware/software sub-systems that are more loosely connected and are rather a collection of independent individual sub-systems (green boxes in Figure 16)

The systems exchange information and coordinate with each other to organise the full scope of the CTAO. In addition, they provide information and interfaces to both internal and external users and support them in their activities.

While almost all systems have users from within CTAO, external users can only access a limited number of systems for specific purposes:

- All science-related interfaces to the external world (*Science Users*, *Scientific Community*) are provided by the Science User Support System, except for lower-level data access for specific purposes for the *Expert Science User* that is provided by the Data Processing and Preservation System
- Contributors and Sponsors will interface with the Operations Support System and Management and Administrative System for reporting, engineering and management purposes

The system structure does not show the deployment of the systems (e.g. at the CTA array sites, off-site) or number of instances (e.g. single instance, multiple instances). Such views will be added in future versions of the document.

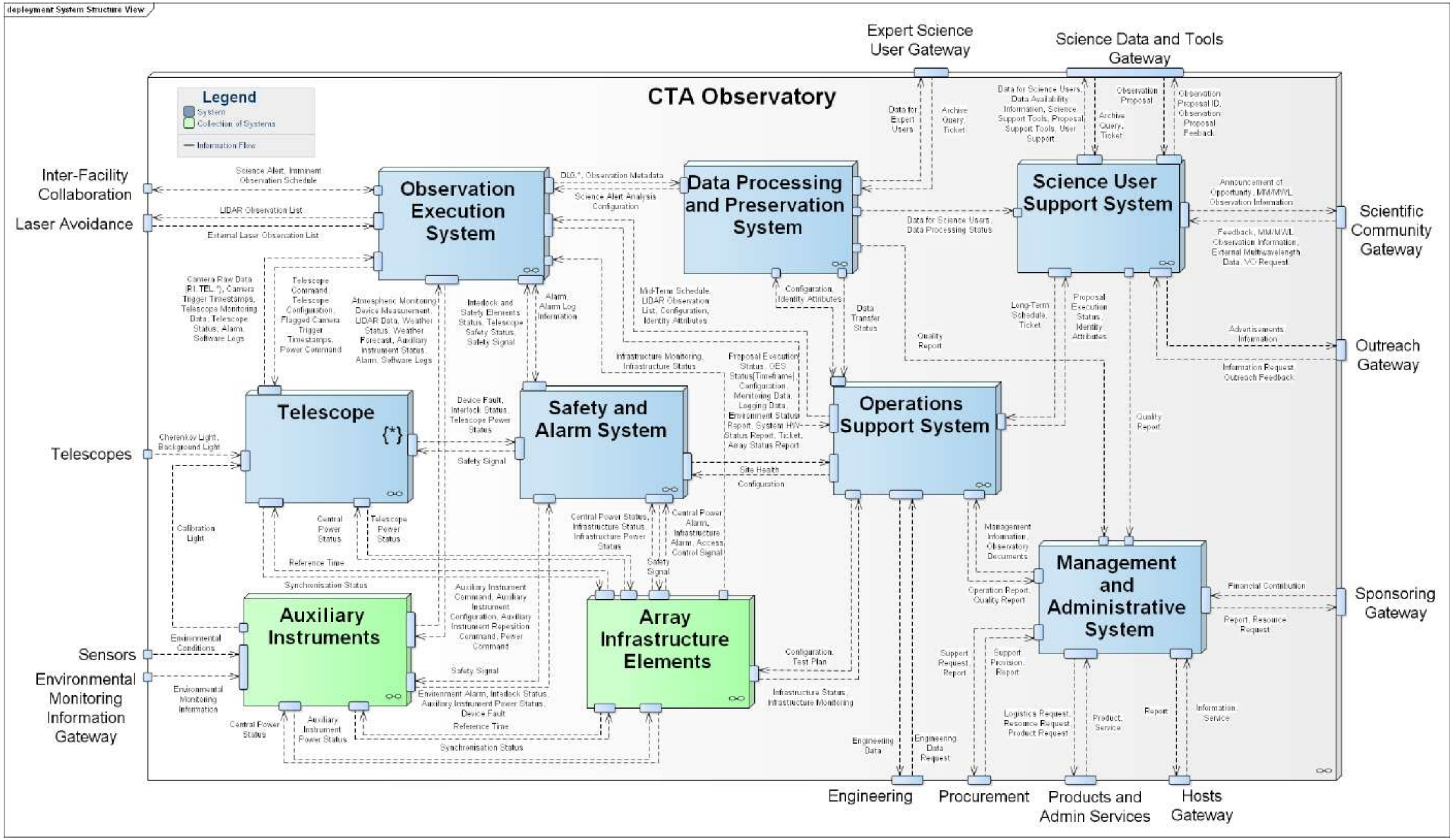

Figure 16: System structure of the CTAO system. Throughout the document the data level definitions of [R15] are used and are reproduced in Section 5.

The system structure as shown in Figure 16 enables one to follow the flow of the high-level data and its processing steps through the systems. Two examples are given below in Figure 17 and Figure 18.

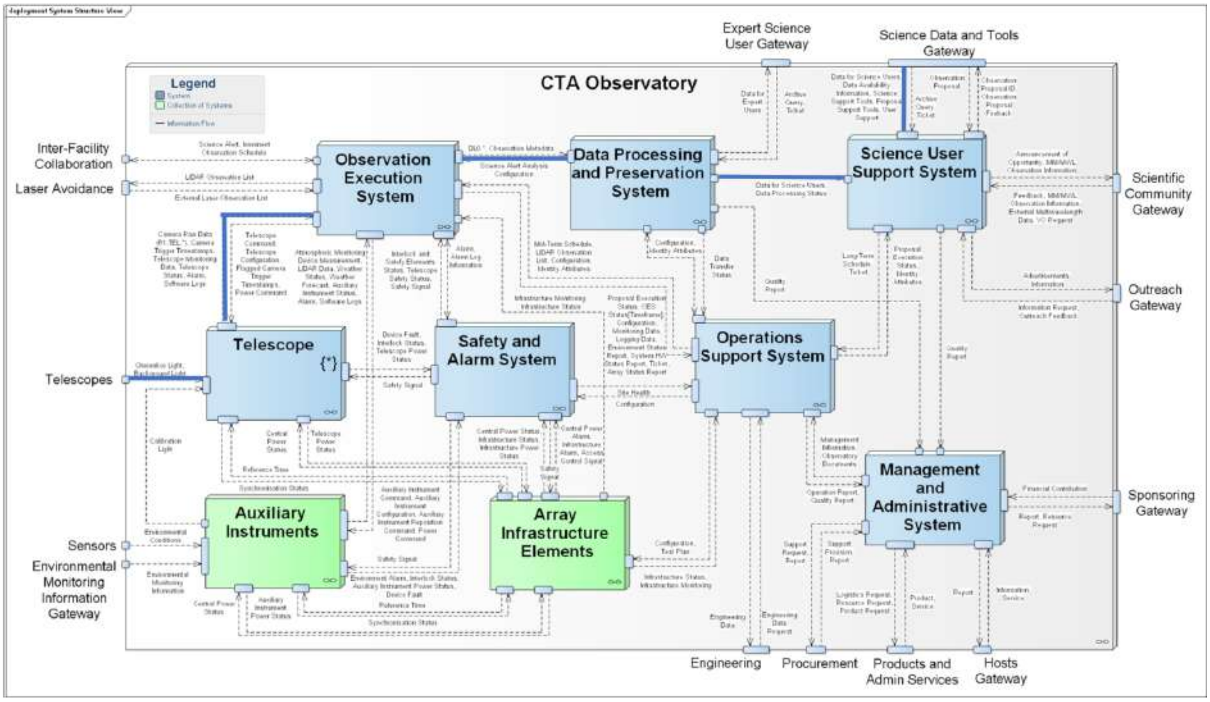

Figure 17: Overview of the main data flow through the system structure, from Cherenkov light to high-level science product.

The bulk data flow from observations to dissemination is shown in Figure 17. Cherenkov and background light are detected at the individual *Telescope* systems, with data transferred to the *Observation Execution System*, where it is processed, reduced and temporarily stored. The data at data level 0 [R15] is then transferred off-site by the *Data Processing and Preservation System*, further processed into higher-level data products and archived long-term. The higher-level data products are then made available to the external *Science Users* by the *Science User Support System* that also contains the information on data access rights.

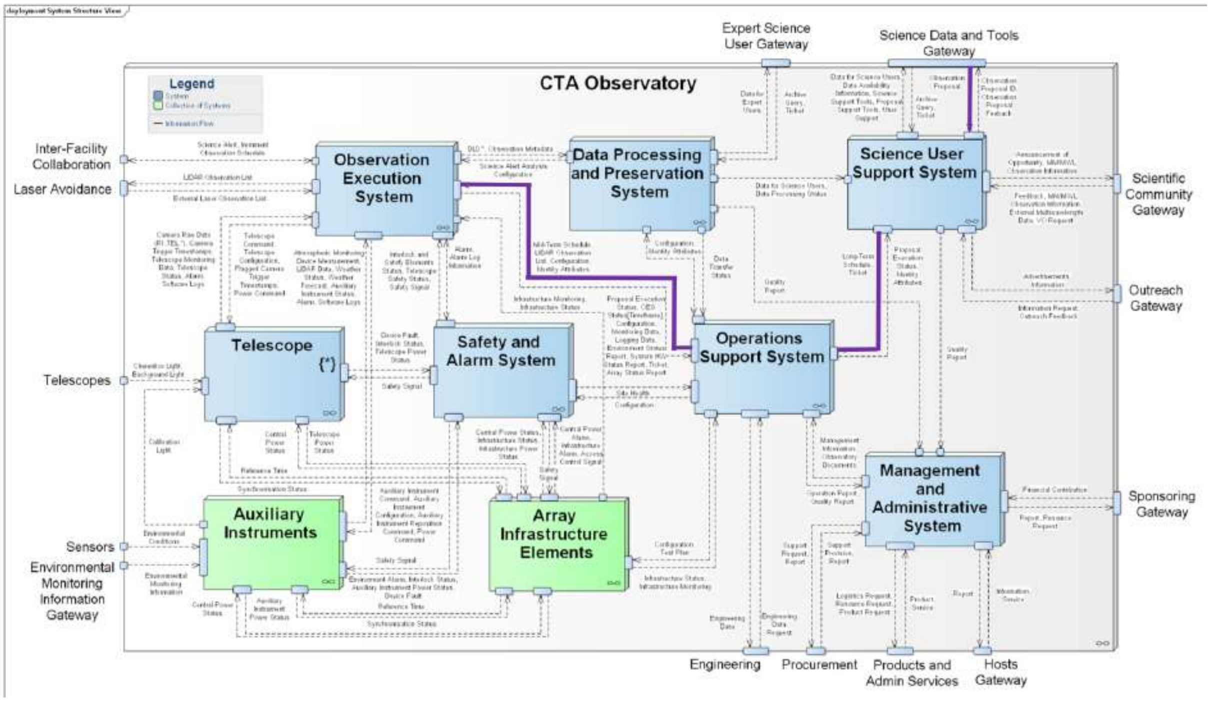

Figure 18: Overview of the main scheduling path through the system structure, from observation proposals to short-term schedule.

The flow of the planned observations from proposal submission to observation execution is shown in Figure 18. The observation proposals are submitted by the external *Science Users* to CTA via the *Science User Support System*, where the proposals are reviewed, and a long-term schedule is built. The long-term schedule can be altered at the *Operations Support System* to incorporate daily to weekly plans for calibration and maintenance work. Finally, a short-term schedule is created at the *Observation Execution System* that incorporates further input from e.g. the actual site environment conditions or received scientific alerts. The short-term schedule is translated into a sequence of planned observations that are then executed by the *Observation Execution System*.

More details on the top-level systems are given in Section 4.3, where functionality, users, and interfaces are given for each system.

4.2 *Internal Stakeholders and Organisational Roles*

An overview of the internal stakeholders of the CTA Observatory systems is given in Table 11. These stakeholders take part in the execution of the processes and are supported by the CTAO systems to perform certain actions to reach their goals and are the users of the CTAO systems. The stakeholders are from many different areas such as science and observatory operations, user support, maintenance and administration. The stakeholders have been identified from the Business Plan [R12] and Observatory Model [R13] and from those modelled processes where they are needed for the process to be successfully executed. A role definition has been assigned to each user, based on the actions that they perform during the processes. CTAO systems support the stakeholders to perform certain actions. The actions and stakeholders are listed for each system individually in Section 4.3.

The current version of the CTAO system architecture presented in this document is mainly focused on the science and observatory operations part of the CTAO, leaving the work to complete and to detail the processes mainly for engineering and administration for a future version of this document.

Role Name	Internal Stakeholder or Organisation Role	Definition	Uses which systems
Administrative Director	Stakeholder	Leads the Administration Division.	
Configuration Manager	Stakeholder	Keeps track of the configuration of all instruments, part replacements etc. Responsible for the central management of all documentation, logging and configurations.	OES, OSS
Data Processing Manager	Stakeholder	Responsible for running the data processing pipelines and for monitoring the data processing and archiving status as well as the data transfer and pipelines performance at all stages of data processing.	DPPS
Data Quality Scientist	Stakeholder	Responsible for monitoring the quality of pipeline-produced data products and calibrations. Will discuss quality fixes with Instrument Scientists and Maintenance Engineers.	DPPS
Director General	Stakeholder	Director of the CTA Observatory. Is accountable for the overall direction of the Observatory, has overall responsibility for safety within CTAO and for the time allocation.	SUSS
Director of Operations	Stakeholder	Leads the Operations Division.	
Director of Science Management	Stakeholder	Leads the Science Data Management Division.	
Expert Operator	Stakeholder	Has expert access to the instruments and software at the CTA array sites, executes debugging and engineering activities in case of reported problems.	AIE, OES, SAS
Instrument Scientist	Stakeholder	A CTA instrument expert, capable of diagnosing problems and devising investigative/calibration actions/interventions based on recorded data. Supports maintenance and operation in a flexible manner according to specific needs. Oversees and advises calibration activities and data evaluation.	OSS
Maintenance Engineer	Stakeholder	Manages and executes maintenance activities and conducts on-site preventive and corrective maintenance tasks.	AIE, OSS, SAS, TEL
Operations Support	Stakeholder	Responsible for the support of all instrument operations and maintenance activities. Assists operations and maintenance personnel on-site.	OSS
Operator	Stakeholder	Responsible for supervising and carrying out scheduled observations and calibrations during the night. Troubleshoots problems, can modify schedule if necessary (e.g. weather/ToO) and logs all activities.	AIE, OES, SAS
Outreach Officer	Stakeholder	Responsible for all educational and public outreach activities.	SUSS
Simulation Scientist	Stakeholder	Liaison with Configuration Manager, ensures that simulations and instrument response	DPPS

Role Name	Internal Stakeholder or Organisation Role	Definition	Uses which systems
		functions produced are an accurate description of the CTA configuration.	
Site Manager	Stakeholder	Responsible for local on-site management, on-site science operations, and technical operations, as well as for construction activities.	
Software Maintenance Engineer[3]	Stakeholder	Responsible for overseeing and executing the maintenance (e.g. bug fixes and maintaining compatibility) and development (e.g. requested new features) all software associated with CTA observatory and science operations.	OSS, SUSS
Support Astronomer	Stakeholder	Oversees and supports scheduling of observations from long-term to short-term, supervises reactions to external and internal science alerts.	OES, OSS, SUSS
Time Allocation Committee	Organisation	Appointed by the Director General, the Time Allocation Committee (TAC) will review proposals, provide a ranking of and recommendations on the proposals to the Director General and, where appropriate, comment on specific issues.	SUSS
User Group	Organisation	Advises the Director General on all matters relevant to Science Users, acting as liaison between the user community and the Observatory.	

Table 11: Overview of the users of the CTA Observatory systems in alphabetical order. The internal stakeholder and organisational roles are given together with their definition and which system is used in the current version of the architecture.

[3] It should be noted that software maintenance is performend on all systems containing software (OES, DPPS, SUSS, TEL, etc.), but related processes are not yet detailed in this release.

4.3 Reference Documentation for the CTA Observatory Systems

This section introduces the various top-level systems of the CTA Observatory. The systems are characterized using a common template. The system profiles will be updated as the system requirements and process descriptions evolve. Throughout the document the data level definitions of [R15] are used and are reproduced in Section 5.

The reference documentation reflects the current architecture model where the relevant processes have been defined. It is not complete in all areas and/or contains the same level of detail (e.g. maintenance). These will be added in future releases according to project needs.

4.3.1 System Profile Template

SUMMARY
Summary table
NAME AND ACRONYM
Name and acronym of the system used throughout the section.
SCOPE
Summary of the main responsibilities and functionalities of the system under discussion.
CONTEXT
Environment of the system under discussion showing the main interactions and information flow with the surrounding internal and external systems and stakeholders.
USERS or STAKEHOLDERS[4]
- **EXTERNAL USERS**
External human users of the system which interact with the system and are supported by the system to execute certain actions. The users can be external or internal to the CTAO.
- **INTERNAL USERS**
Internal human users of the system which interact with the system and are supported by the system to execute certain actions. The users can be external or internal to the CTAO.
MAIN DATA ELEMENTS
Main conceptual data elements that are exchanged with the users and other systems (either as produced or consumed data) and are handled and/or stored within the system under discussion.
FUNCTIONALITY
- **USER-SUPPORTED PROCESSES AND ACTIONS**
Main actions and related processes in which the system supports an internal or external stakeholder.
- **AUTOMATIC PROCESSES AND ACTIONS**
Main actions and related processes that are performed by the system.
INTERFACES
List of all the main interfaces with their purpose.
DEPLOYMENT
Number of instances of the system currently envisaged to run simultaneously (single or multiple instances) and its deployment location (either on site, off site or both).
NOTES

[4] Throughout the document, human users of the systems and stakeholders are used synonymously.

Additional notes.

4.3.2 Array Infrastructure Elements

4.3.2.1 Summary

NAME AND ACRONYM
Array Infrastructure Elements (AIE)
SCOPE
A collection of infrastructure hardware and software systems supporting the systems running on-site. Includes systems for the central power management, time synchronisation, on-site ICT infrastructure, test facilities and access control.
CONTEXT
External systems: none[5] Internal systems: Auxiliary Instruments, Observation Execution System, Operations Support System, Safety and Alarm System, Telescope
USERS
External users: none Internal users: Expert Operator Operator
DECOMPOSITION
Access Control System, Central Power System, On-site ICT Infrastructure, Test Facilities {*}, Time Synchronization System
DEPLOYMENT
Instances at both CTA array sites
NOTES

4.3.2.2 Name and Acronym

Array Infrastructure Elements (AIE)

4.3.2.3 Scope

The AIE is a collection of on-site sub-systems which facilitate the smooth running of the CTAO. There are two main categories of infrastructure elements; core elements, that are required to be fully functional for the array telescopes and auxiliary devices to operate; and supporting facilities.

Core infrastructure elements include the on-site Access Control System (for example key cards at gates), the Central Power System for global power control and management, the Time Synchronisation System for the distributed reference system clock and the network and on-site Information and Communication Technologies (ICT) infrastructure. The on-site Access Control System ensures that only personnel with the correct authorization are permitted to operate certain systems and/or enter certain areas. The distributed system clock, network and on-site ICT infrastructure are key elements without which observations with Cherenkov Telescopes are not possible. Additional, specified Auxiliary Instruments may also require the distributed clock and connection to the network. All devices require the global power control.

Aside from the core infrastructure elements, there are at least three supporting facilities, classified as Array Infrastructure Elements as, similarly to the core infrastructure elements, they are self-contained hardware (and associated software) systems that are used by all telescopes. The on-site Camera Test Facility, Mirror Test Facility and Mirror Re-coating Facility fulfil this role.

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[5] External systems such as GPS, WAN, etc. will be added in a next release of the architecture.

All Array Infrastructure Elements are connected to the Safety and Alarm System, with monitoring information also passed to the Observation Execution System and Operation Support System as appropriate. Alarms may be raised in the case of failure or degraded performance of part of a core infrastructure element and/or in case of a conflict or violation raised by the Access Control system.

4.3.2.4 Main Processes

The main processes to which the AIE contributes are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
    a. *Observation Execution: from Short-Term Schedule to Collected Data*

In addition, the array infrastructure elements support the on-site operation and maintenance of the Observatory with their sub-systems and provide important infrastructure for the other CTAO systems to function properly.

4.3.2.5 Context and User Interactions

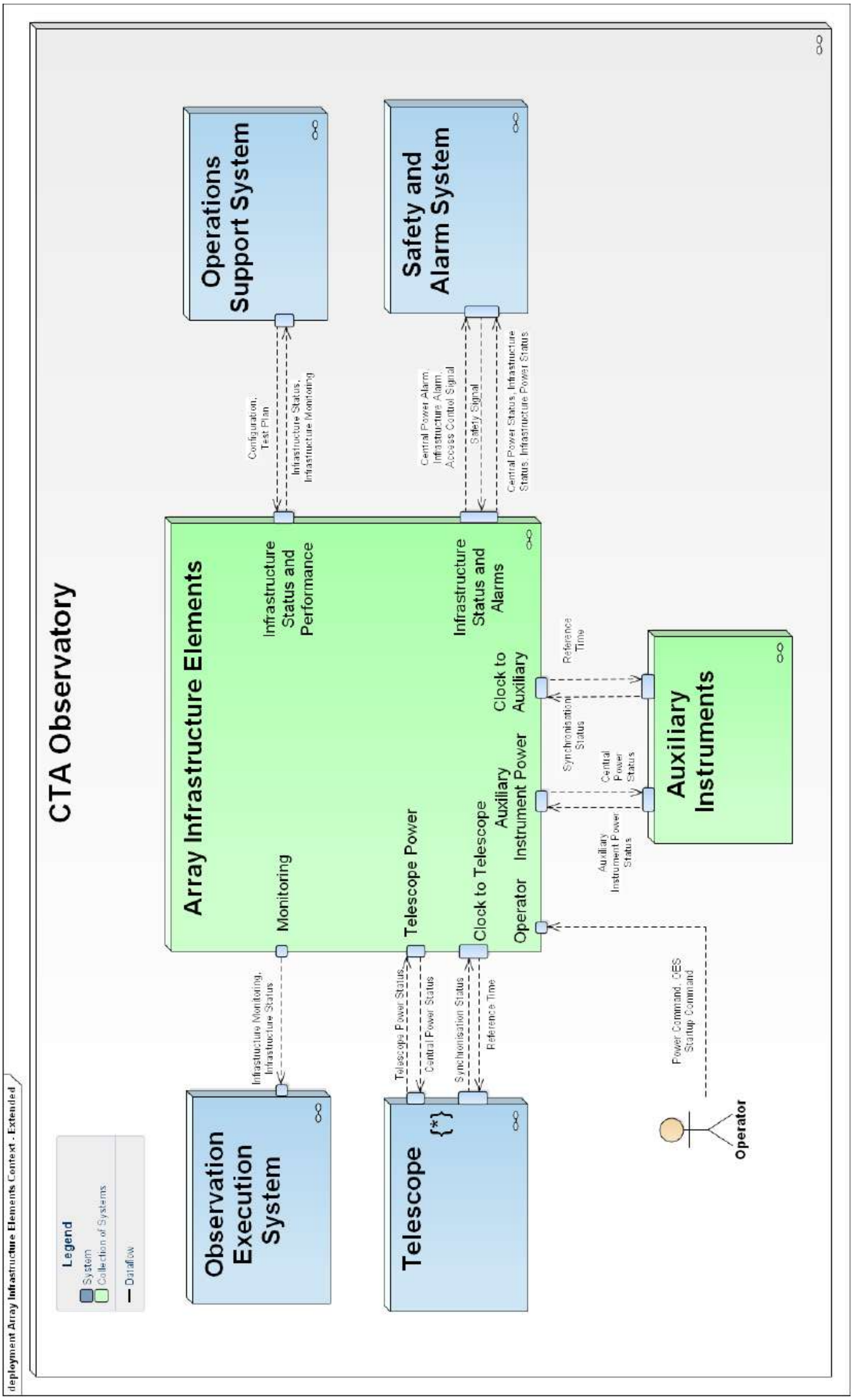

Figure 19: Context of the Array Infrastructure Elements. Shown are the interactions with other systems of the CTAO. Please note that the Expert Operator uses the same interfaces as the Operator.

Figure 19 shows the context of the AIE, i.e. the systems internal to the CTAO that the AIE interacts with for exchange of information. In addition to the information flow between the systems, the AIE provide resources, such as power or computing and networking resources, to the other on-site CTAO systems. These resources are not shown here.

The main interactions between the CTAO systems for information exchange are:

Interactions with Internal Systems

- *Observation Execution System*

  Continuous provision of monitoring and status information of array infrastructure elements, most notably of the Time Synchronisation System

- *Telescope*

  Continuous provision of a reference time signal and exchange of information on the time synchronisation status

- *Operations Support System*

  Frequent exchange of configuration, documentation (e.g. procedures, calibration strategies) and plans (e.g. test plans), provision of status and monitoring reports on the array infrastructure elements

- *Safety and Alarm System*

  Provision of alarms when the safety of the array is concerned (esp. access alarm, power failure, ...) and general status information

- *Auxiliary Instruments*

  Continuous provision of a reference time signal (mainly for those calibration devices that need high-precision timing) and exchange of information on the time synchronisation status

4.3.2.6 Users

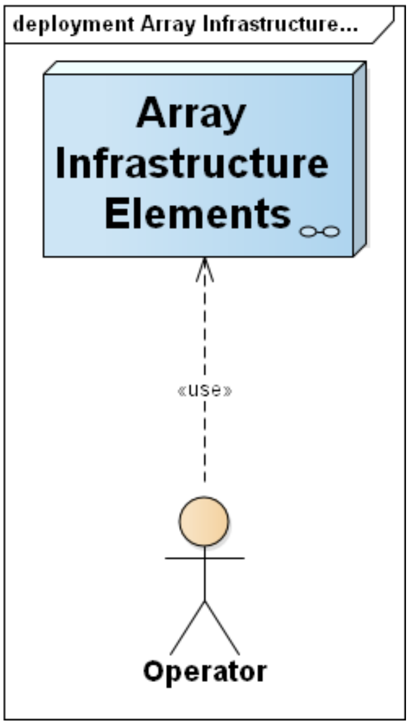

Figure 20: Overview of the internal and external users of the AIE.

This section lists the users of the AIE and their interactions with the system. An overview of the users is given in Figure 20 and their definition in Table 12. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Internal Stakeholders
Expert Operator Has expert access to the instruments and software at the CTA array sites, executes debugging and engineering activities in case of reported problems. **Operator** Responsible for supervising and carrying out scheduled observations and calibrations during the night. Troubleshoots problems, can modify schedule if necessary (e.g. weather/ToO) and logs all activities.

Table 12: Internal and external users of the AIE.

Interactions with Internal Stakeholders

- *Operator and Expert Operator*

  Power on/off of array elements and OES

4.3.2.7 Main Data Elements

Table 13 lists the main data elements that are produced/consumed and stored/logged by the AIE.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Access Control Signal	Signal notifying that a person accessed the area within the CTA array sites	Produced	Logged
Central Power Alarm	Alarm about failure of the central power	Produced	Logged
Central Power Status	Status information on the central power	Produced	Logged
Clock System Monitoring	Monitoring information on the central timing system and clock synchronisation	Produced	Logged
Configuration	Configuration of the arrays, including all instrument and infrastructure configuration	Consumed	Logged
Infrastructure Alarm	Alarm from one of the array infrastructure elements	Produced	Logged
Infrastructure Monitoring	Monitoring information of the array infrastructure elements	Produced	Stored
Infrastructure Power Status	Status information on the power of the array infrastructure element	Produced	Logged
Infrastructure Status	Status information on the array infrastructure element	Produced	Logged
OES Startup Command	Startup of OES	Consumed	Logged
Power Command	Command to control the power of the system and its elements	Consumed	Logged
Power Monitoring	Monitoring information of the central power	Produced	Logged
Reference Time	Reference time signal for clock distribution	Produced	Logged
Synchronisation Status	Status of time synchronisation to the distributed clock at the array element	Consumed	Logged
Test Plan	Plan including the test strategy and work order for executing a test	Consumed	Stored

Table 13: Main data elements exchanged with the AIE.

4.3.2.8 Decomposition

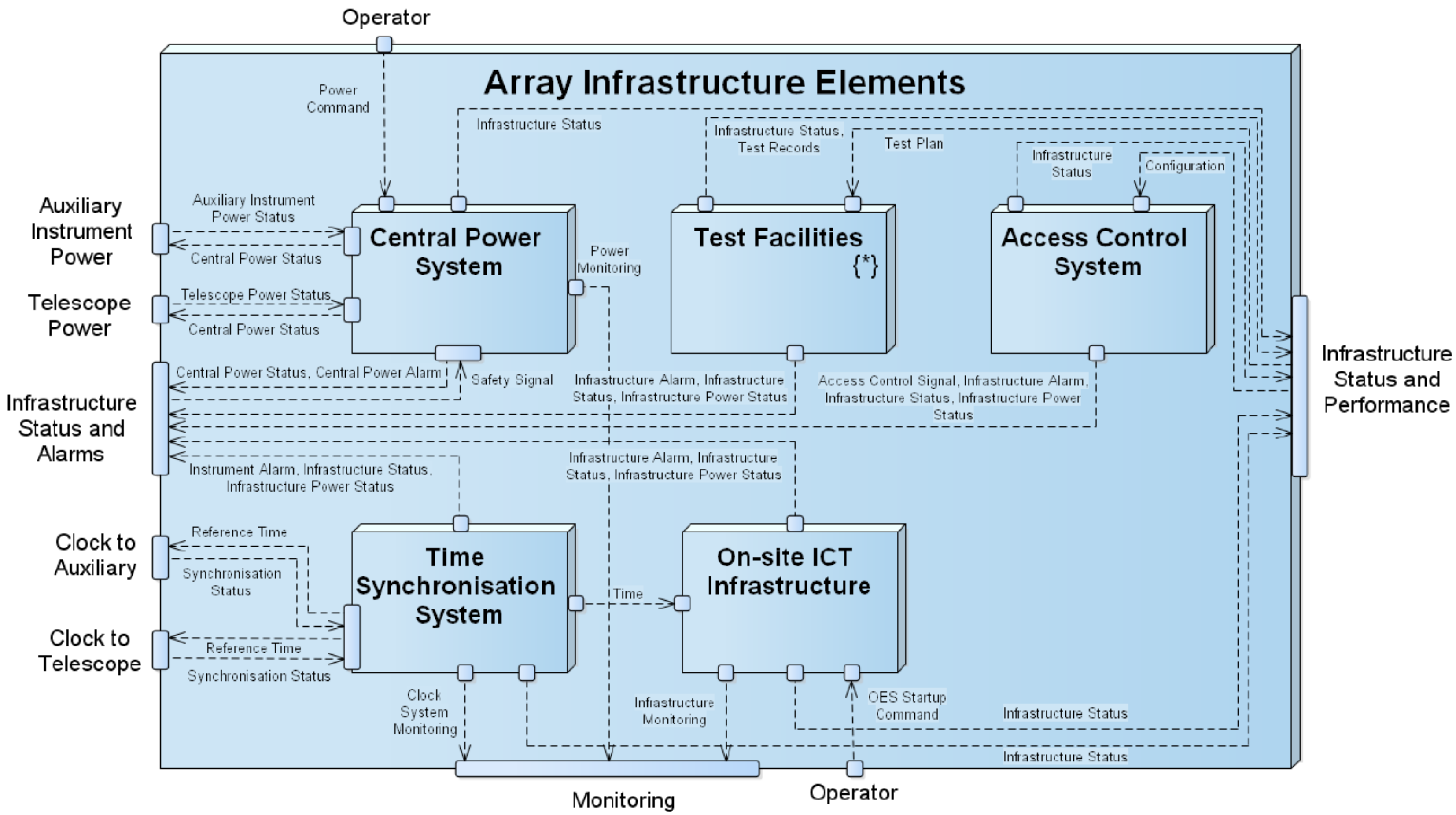

Figure 21: First-level functional decomposition of the Array Infrastructure Elements.

A preliminary *functional* decomposition of the AIE at the first level is shown in Figure 21. The AIE is composed of the following main sub-systems that group functionality in relation to:

- *Central Power System*

  All hardware and software to provide power to the CTA array sites, including power management, and generation of alarms.

- *Test Facilities*

  All hardware and software for the on-site Camera Test Facility, Mirror Test Facility and Mirror Re-coating Facility, including the test bench setup and necessary equipment and software to run and evaluate the tests on-site and to report the results.

- *Access Control System*

  All hardware and software for organizing and monitoring the access control at the CTA array sites.

- *Time Synchronisation System*

  Central hardware and software for the provision of a distributed clock and for the monitoring of the synchronization the distributed timing system at the location of each array element.

- *On-site ICT Infrastructure*

  All hardware and software for the operation of the network and computing infrastructure on-site.

4.3.2.9 Functionality

4.3.2.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system.

External Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action

Table 14: Overview of the actions in which the external stakeholders are supported by the AIE.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Shutdown System Array Elements	Switch down array element power

Supported User	Supported Process	Process/Activity	User-Supporting Action
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Startup Array Elements in Cold Startup Mode	Request power-up of array elements
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Startup Array Elements in Cold Startup Mode	Startup OES Manager

Table 15: Overview of the actions in which the internal stakeholders are supported by the AIE.

4.3.2.9.2 Automated Processes and Actions

This section lists the processes where the AIE takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Make power available to telescope

Table 16: Overview of the actions, which are automatically performed by the AIE.

4.3.2.10 Main Interfaces

This section provides an overview of the ports that the AIE provides to the other systems and stakeholders internal to CTAO. Each port may be implemented by one or more interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Auxiliary Instrument Power	Auxiliary Instrument Power Status, Central Power Status	Provide availability and status information on the central power to the Auxiliary Instruments and monitor the status of their power	
Monitoring	Infrastructure Monitoring	Monitoring of the array infrastructure elements, most notably the central monitoring of the clock distribution status	
Clock to Telescope	Synchronisation Status, Reference Time	Clock distribution to Telescopes and monitoring of its synchronisation status	

Port	Main Data Element Exchanged	Purpose	Notes
Clock to Auxiliary	Synchronisation Status, Reference Time	Clock distribution to Auxiliary Instruments and monitoring of its synchronisation status	Some Auxiliary Instruments (e.g. LIDAR) may need a high-precision reference time signal
Infrastructure Status and Alarms	Central Power Alarm, Infrastructure Alarm, Central Power Status, Infrastructure Status, Infrastructure Power Status, Access Control Signal	Provide basic status information on the infrastructure elements and related alarms (power, infrastructure, access control) to the Safety and Alarm System	
Infrastructure Status and Performance	Configuration, Test Plan, Infrastructure Status, Infrastructure Monitoring	Receive input of the CTAO (e.g. configuration, documentation, test plans) Provide long-term monitoring of the performance of the Array Infrastructure Elements	
Operator	Power Command, OES Startup Command	Power on/off array elements and OES startup	
Telescope Power	Telescope Power Status, Central Power Status	Provide availability and status information on the central power to the Telescopes and monitor the status of their power	

Table 17: Overview of the main interfaces for the AIE.

4.3.2.11 Deployment

The Array Infrastructure Elements are deployed at both CTA array sites.

4.3.2.12 Additional Notes

4.3.3 Auxiliary Instruments

4.3.3.1 Summary

NAME AND ACRONYM
Auxiliary Instruments (AUX)
SCOPE
A collection of auxiliary hardware and software systems associated with major data sources at a CTA array site that are not Cherenkov Telescopes, for example instruments for the atmospheric monitoring or calibration.
CONTEXT
Physical Object: Site Environment External systems: External Environmental Monitoring Systems Internal systems: Array Infrastructure Elements, Observation Execution System, Safety and Alarm System, Telescope
USERS
External users: none Internal users: none
DECOMPOSITION
Environmental Monitoring Device {*}, Illuminating Calibration Device {*}, Lidar {*}
DEPLOYMENT
Instances at both CTA array sites
NOTES

4.3.3.2 Name and Acronym

Auxiliary Instruments (AUX)

4.3.3.3 Scope

The AUX is a collection of independent hardware and software systems located on-site, that are controlled and monitored via the Observation Execution System, with power control and safety-relevant fault notification provided via the Safety and Alarm System. These systems relate to the overall calibration, monitoring and characterization of the telescope arrays and the atmosphere above the arrays during regular operations.

The Auxiliary Instruments can be generally classified as either calibration devices external to the Telescope system or equipment for monitoring and characterization of the environmental conditions on-site.

Calibration devices may interact with the Telescopes via illumination using a reference light source. The equipment for environmental monitoring is comprised of passive devices (such as typical weather station equipment), with LIDARs for atmospheric characterization purposes classified amongst the calibration devices. Operation of both calibration and environmental monitoring devices will be via the OES. Operation of the LIDARs is regulated by the Laser Traffic Control System (LTCS), which is an external system coordinating all lasers in CTAO and in neighbouring observatories. Certain Auxiliary Instruments, such as LIDARs and calibration devices which externally illuminate Telescopes, may require the distributed reference clock and information on the Telescopes pointing direction. The data from environmental monitoring devices supports the short-term scheduling via the provision of real-time weather monitoring information. Environmental alarms may be raised by the environmental monitoring devices, in cases where these may have implications for safe array operation.

4.3.3.4 Main Processes

The main processes to which the AUX contribute are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
    a. *Schedule Refinement: from Long-Term Schedule to Short-Term Schedule*
    b. *Observation Execution: from Short-Term Schedule to Collected Data*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
    a. *Calibration: Perform, Check and Refine Calibration and Calibration Instruments*

4.3.3.5 Context and User Interactions

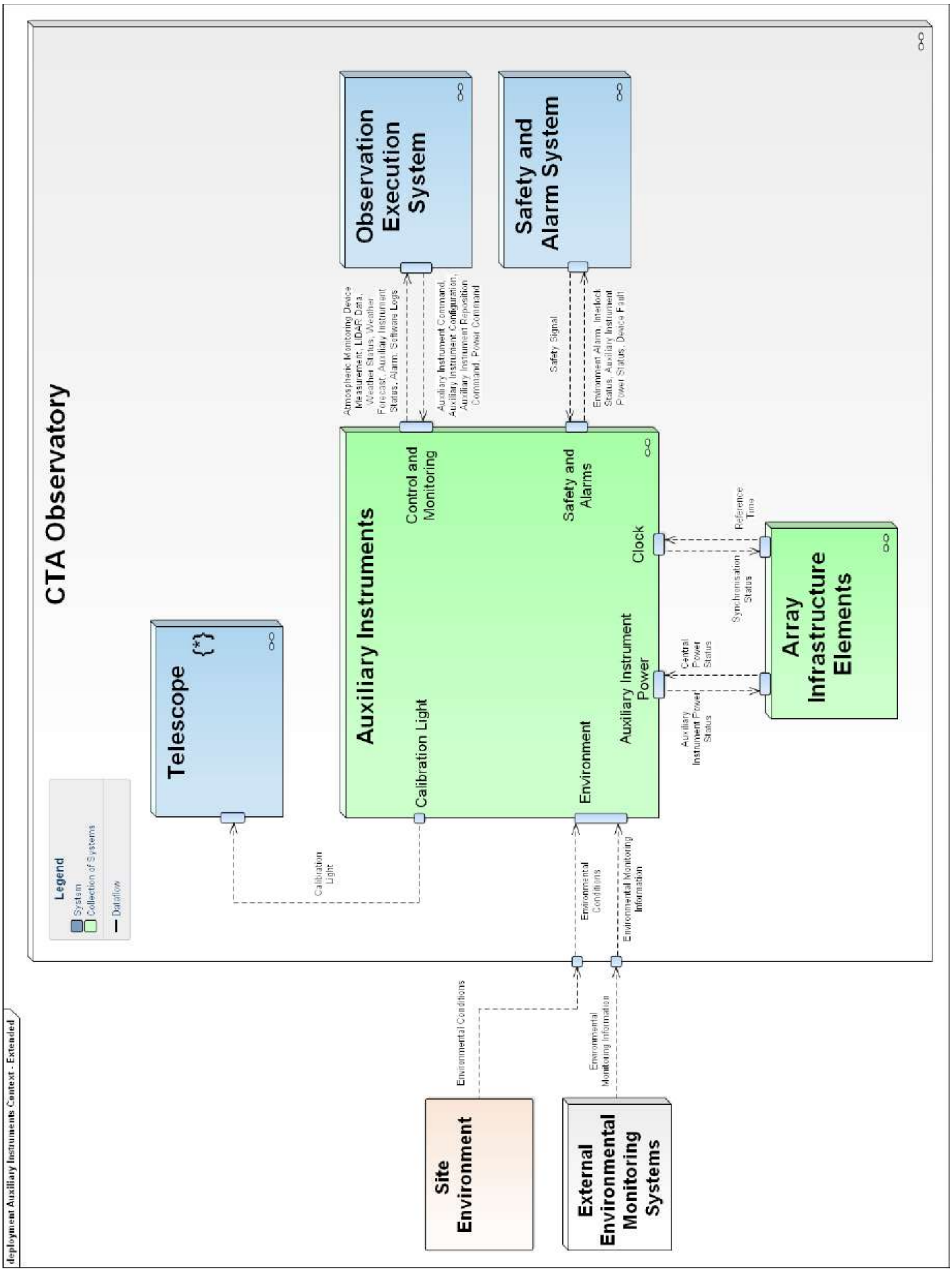

Figure 22: Context of the AUX. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the AUX. The main interactions with the systems are:

Interactions with External Systems

- *External Environmental Monitoring Systems*

Continuous receiving of preformatted environmental monitoring information, provided by the external systems (e.g. satellite images, weather reports)

Interactions with Physical Objects

- *Site Environment*

  The changing characteristics of the site environment (e.g. weather) are continuously probed and measured with dedicated campaigns.

Interactions with Internal Systems

- *Observation Execution System*

  The Auxiliary Instruments are monitored, operated and readout by the OES, which also provides all information (e.g. pointing direction, configuration) necessary for their operation.

- *Telescope*

  The Auxiliary Instruments are the sources of the calibration light for the Telescopes.

- *Safety and Alarm System*

  In addition to the frequent exchange of status information on both the Auxiliary Instruments and central elements (e.g. central power status), the Auxiliary Instruments provide alarms to the Safety and Alarm System in the situations, where the safety of humans and that of the array is at risk (e.g. earthquake).

- *Array Infrastructure Elements*

  Continuous receiving of the reference time and provision of the time synchronisation status for some elements of the Auxiliary Instruments and of the status and availability of central power

4.3.3.6 Users

There are no processes with users in the current architecture description; the Auxiliary Instruments operate fully automatically. Please note that maintenance of the components itself are implicit for all hardware and software systems.

4.3.3.7 Main Data Elements

Table 18 lists the main data elements that are produced/consumed and stored/logged by the AUX.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Alarm	Problem or condition that should be reported to the operator and may require his/her action	Produced	Logged
Atmospheric Monitoring Device Measurement	Data readout from the atmospheric monitoring device	Produced	Logged
Auxiliary Instrument Command	Command to operate the auxiliary instrument	Consumed	Logged
Auxiliary Instrument Configuration	Configuration of the auxiliary instrument	Consumed	Logged
Auxiliary Instrument Power Status	Status information on the power of the auxiliary instrument	Produced	Logged
Auxiliary Instrument Reposition Command	Command to change the pointing direction of the auxiliary instrument	Consumed	Logged
Auxiliary Instrument Status	Status information on the auxiliary instrument	Produced	Logged
Calibration Light	Artificial light collected and recorded by the telescope and used for calibration purposes	Produced	Logged
Central Power Status	Status information on the central power	Consumed	Logged
Device Fault	Information in case of a failure of the device	Produced	Logged
Environment Alarm	Alarm about a critical environmental condition (e.g. earthquake)	Produced	Logged
Environmental Conditions	Site environment, e.g. weather	Consumed	Logged
Environmental Monitoring Information	Processed monitoring information on the site environment provided by external systems	Consumed	Logged
Interlock Status	Status information on the interlocks at the related system	Produced	Logged
LIDAR Data	Measurement data readout from the LIDAR	Produced	Logged
Power Command	Command to control the power of the system and its elements	Consumed	Logged

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Reference Time	Reference time signal for clock distribution	Consumed	Logged
Safety Signal	Signal to alert on a safety-relevant issue	Consumed	Logged
Software Logs	Logging information from the system	Produced	Logged
Synchronisation Status	Status of time synchronisation to the distributed clock at the array element	Produced	Logged
Weather Forecast	Weather forecast information	Produced	Logged
Weather Status	Status information on the weather	Produced	Logged

Table 18: Main data elements exchanged with the AUX.

4.3.3.8 Decomposition

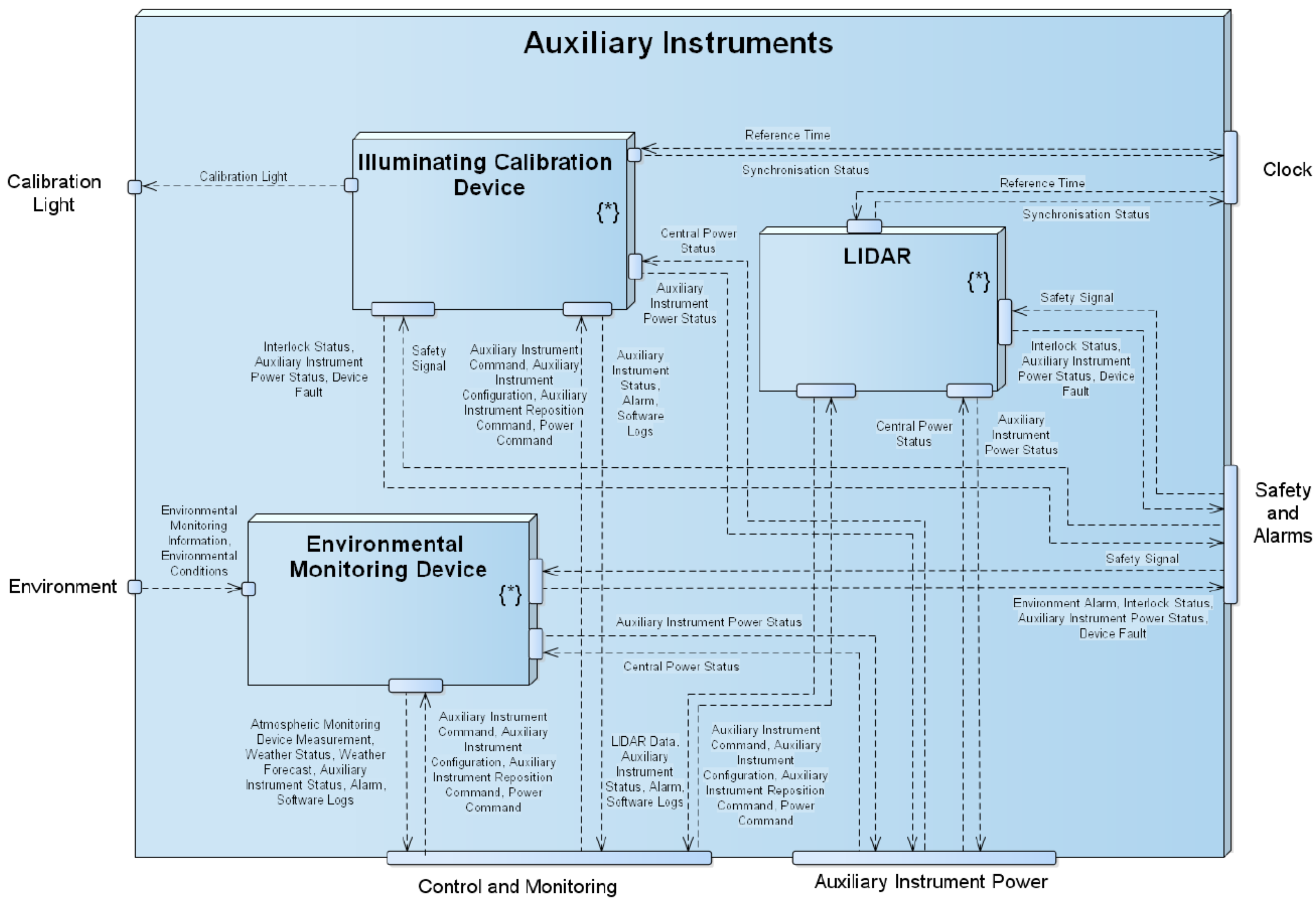

Figure 23: First-level functional decomposition of the Auxiliary Instruments.

A preliminary functional decomposition of the AUX at the first level is shown in Figure 23. The AUX is composed of the following main sub-systems that group functionality in relation to:

- *Illuminating Calibration Device {*}*

  Devices (includes hardware and software) used for the illumination of (individual or arrays of) Telescopes for the purpose of their calibration

- *Environmental Monitoring Device {*}*

  Devices (includes hardware and software) used for the monitoring of the environment

- *LIDAR {*}*

  LIDAR (includes hardware and software)

This first-level decomposition is planned to evolve to show the final list of all individual auxiliary instruments to be deployed at the CTA sites with all their main interfaces.

4.3.3.9 Functionality

This section lists all actions that the AUX performs or in which it supports a user.

4.3.3.9.1 *User-Supported Processes and Actions*

The auxiliary instruments run fully automatic and direct user interaction is only expected during commissioning and maintenance.

4.3.3.9.2 Automated Processes and Actions

This section lists the processes where the AUX takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	**Process/Activity**	**Automated Action**
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Acquire data from instruments characterizing the atmosphere in the pointing direction
	Create Atmospheric Devices Software Logs	Produce software logs
	Execute Observing Mode	Receive next pointing direction and observation mode
	Perform a Calibration Run and Store Raw Calibration Data	Generate Calibration Light
	Perform Night Lidar Shots	Take LIDAR Measurement

Supported Process	**Process/Activity**	**Automated Action**
	Produce Atmospheric Devices Measurements	Acquire atmospheric and weather monitoring data
	Put the Array to Safe State	Go to Safe (Auxiliary Instrument)
	Startup Array Elements in Cold Startup Mode	Startup Auxiliary Instrument in Cold Startup Mode
	Warmup Array	Auxiliary instrument goes to Ready state
	Warmup Array	Auxiliary instrument goes to Standby state
	Warmup Array	Auxiliary instrument performs internal calibrations
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Acquire atmospheric and weather monitoring data
		Analyse the atmospheric transmission with LIDAR data
		Monitor for earthquakes
		Perform Weather Forecasting
		Take LIDAR Measurement
	Schedule Programmes Online	Obtain environment and sky conditions
Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Calibrate a Calibration Instrument	Record results of calibration of a calibration instrument onboard of an Auxiliary Instrument
Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Prepare a Calibration Run	Prepare calibration instruments for calibration

Table 19: Overview of the actions, which are automatically performed by the AUX.

4.3.3.10 Main Interfaces

This section provides an overview of the ports that the AUX provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	**Main Data Element Exchanged**	**Purpose**	**Notes**
Auxiliary Instrument Power	Auxiliary Instrument Power Status, Central Power Status	Receive availability and status information of the central power and provide the status of the power of the Auxiliary Instruments	
Calibration Light	Calibration Light	Provide a source of calibration to the Telescopes	
Environment	Environmental Conditions, Environmental	Measure and collect information the site environment	

Port	Main Data Element Exchanged	Purpose	Notes
	Monitoring Information		
Clock	Synchronisation Status, Reference Time	Synchronise the clock of the Auxiliary Instruments to the global reference time and provide information on the synchronisation status	
Safety and Alarms	Safety Signal, Power Command, Central Power Status, Environmental Alarms, Interlock Status, Auxiliary Instrument Power Status, Device Fault	Provision of alarms based on the environmental status at the CTA array sites, provision of safety-relevant information (interlock and power status)	
Control and Monitoring	Atmospheric Monitoring Device Measurement, LIDAR Data, Weather Status, Weather Forecast, Auxiliary Instrument Status, Alarm, Software Logs, Auxiliary Instrument Command, Auxiliary Instrument Configuration, Auxiliary Instrument Reposition Command, Power Command	Main interface for the control, monitoring and readout of all Auxiliary Instruments, provision of all information relevant to assess the site environment and weather	

Table 20: Overview of the main interfaces for the AUX.

4.3.3.11 Deployment

The Auxiliary Instruments will be deployed at both CTA array sites with many sub-systems as auxiliary instruments.

4.3.3.12 Additional Notes

The AUX use cases are not yet modeled in the architecture and will follow with an update of this section in a future version.

4.3.4 Data Processing and Preservation System

4.3.4.1 Summary

NAME AND ACRONYM
Data Processing and Preservation System (DPPS)
SCOPE
A software system responsible for producing the science data products given to Science Users; including therefore the production and analysis of simulation data, (re)processing and the long-term preservation of data products and related information that will facilitate reproducibility of results as well as their transfer from the array sites.
CONTEXT
External systems: none[6] Internal systems: Management and Administrative System, Observation Execution System, Operations Support System, Science User Support System
USERS
External users: Expert Science User Internal users: Data Processing Manager, Data Quality Scientist, Simulation Scientist
DECOMPOSITION
Bulk Data Archive, Computing Resource and Workflow Management System, Data Analysis and Processing Pipelines, Expert User Portal, File Transfer System, Reporting and Diagnosis, Simulation System
DEPLOYMENT
runs at multiple sites: a slimmed-down version runs at the CTA sites to enable on-site, off-line automated science analysis (level B) analysis (incl. data quality evaluation) and file transfer to the off-site data centre(s), multiple instances of the DPPS run at the CTA data centre(s) for data processing, preservation, and simulation
NOTES

4.3.4.2 Name and Acronym

Data Processing and Preservation System (DPPS)

4.3.4.3 Scope

The DPPS is the system responsible for all workflow steps for the generation of the science data products from the low-level data produced at the CTA array sites. Therefore, the DPPS provides all the functionality for:

- the production and analysis of simulation data, including the derivation of instrument response information,
- the processing of telescope data including its (re)calibration and transformation into science data products, including annual re-processing with updated algorithms and calibration
- the monitoring of data quality at all levels, including the production of data quality reports,
- the management of computing resources, including the automated launching and monitoring of data-processing and simulation pipeline jobs across the CTA data centre(s),

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[6] Depending on the chosen CTA computing model, off-site data centre(s) may be external systems. The off-site data centre(s) are not included in the current release.

- the long-term preservation of data products and related information that will facilitate reproducibility of results, including the management of multiple versions and replicas of the resulting products, and their distribution among the data centre(s),
- the management of meta-data information to enable queries of archived data for various observation, simulation, and data-related parameters, and dependant on the user's data access rights,
- the provision of an on-site, off-line automated science analysis (level B) used for science data quality and system performance evaluation,
- the transfer of data from the sites to the CTA data centre(s), and the mirroring between data centre(s),
- the provision of a user interface (expert's gateway) to all DPPS sub-systems

As with all CTA systems, the DPPS provides monitoring information for its sub-systems, which are deployed at the CTA data centre(s) and array sites and produces quality metrics and reports related to the services provided.

4.3.4.4 Main Processes

The main processes to which the DPPS contributes are related to the science-related observatory workflow for the (re)processing of data from low-level to high-level data products, including the off-line calibration and data quality monitoring, as well as simulation of data (main process 'Observe with CTA'), and those related to the Maintenance (data quality monitoring, calibration, instrument performance) and Engineering (refinement of the instrument response). The relevant processes are (only top two levels listed):

1. Observe with CTA
   a. *Process Data: from collected Data to archived Science Products*
   b. *Simulation Execution: Simulate CTA physics events from Instrument Modeling to Raw Data*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
   a. *Issue Identification: from collected Data to identified Issue*
   b. *Calibration: Perform, Check and Refine Calibration and Calibration Instruments*
   c. *Verifying and Improving Instrument Performance: from collected Data to verified Instrument Response*
3. Engineering: Provide Instruments, Infrastructure, Software and Services from Requirements to Setting to Work
   a. *Instrument Model Refinement: from configuration and collected Data to refined Instrument Response Model*

4.3.4.5 Context and User Interactions

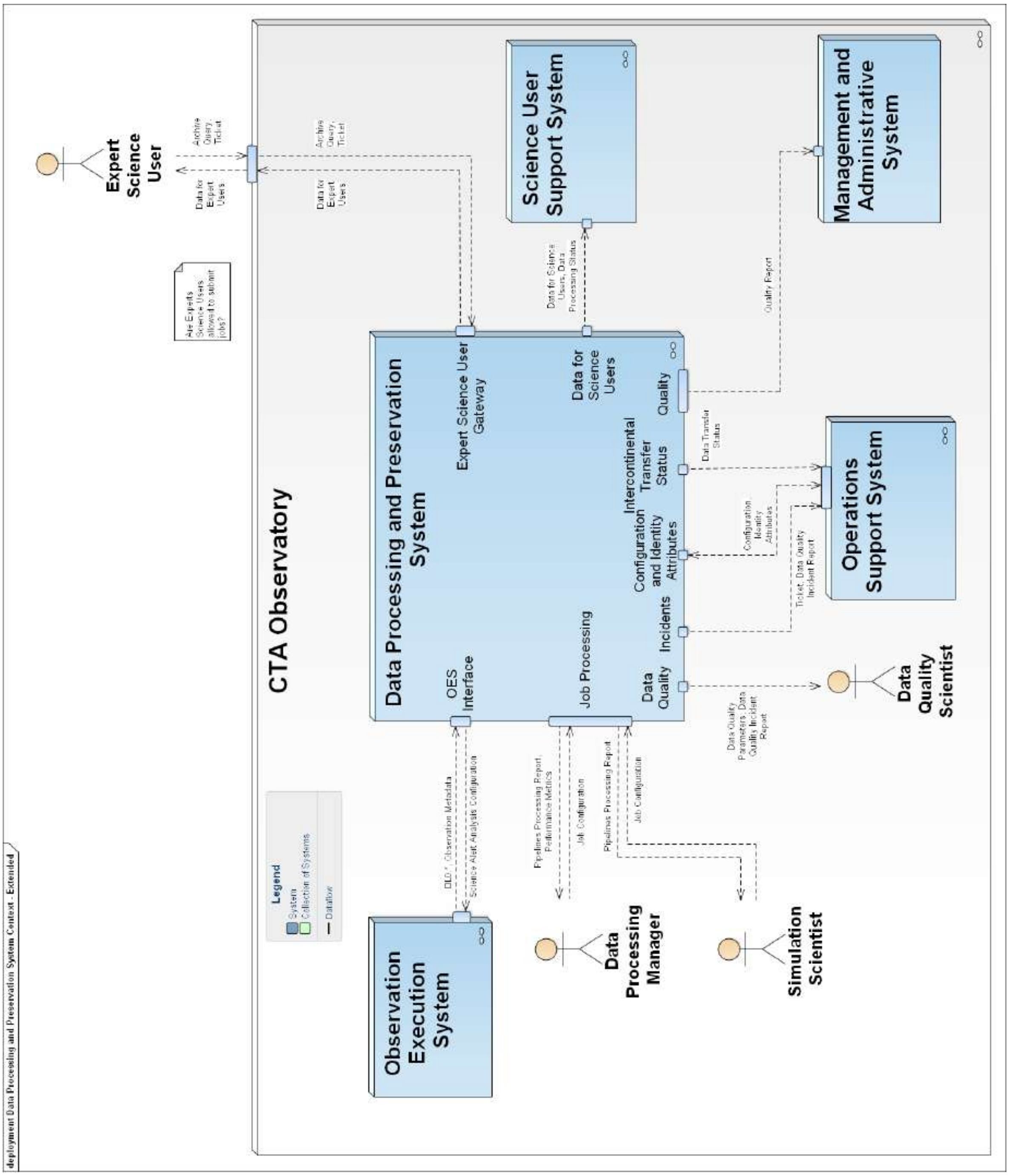


Figure 24: Context of the DPPS. Shown are the interactions with other systems and stakeholders of the CTAO and of the external world.

Figure 19 shows the context of the DPPS, i.e. the interactions with the stakeholders and systems internal and external to the CTAO.

The DPPS is the system of CTA where the bulk-data processing is done, low-level data is archived and algorithms for data processing applied. The DPPS provides the main access point for the low-level data, the simulated data and related processing for use by other CTAO systems.

It interacts with only internal CTAO systems, for which it consumes and provides data (OES, SUSS) or information on the data quality and reports (OSS, MAS). Interactions with users are mostly for internal organisation/monitoring of the processing (data, simulations) and data quality. The DPPS provides access to the low-level data and its processing information only to one external stakeholder, the Expert Science User.

Interactions with Internal Systems

- *Observation Execution System*

  Access to low-level data for an on-site, off-line automated science analysis (level B) analysis on-site and continuous transfer of all low-level data and all relevant observation metadata from the array sites to the data centre(s)

- *Science User Support System*

  Frequent provision of high-level science products for the Science User and related information on the data processing

- *Operations Support System*

  Continuous synchronisation of the instrument configuration and provision of identified issues (tickets) and data quality reports to support the maintenance work, synchronisation of user profiles and attributes for the authentication and authorization

- *Management and Administrative System*

  Frequent provision of reports on the performance of the DPPS

4.3.4.6 Users

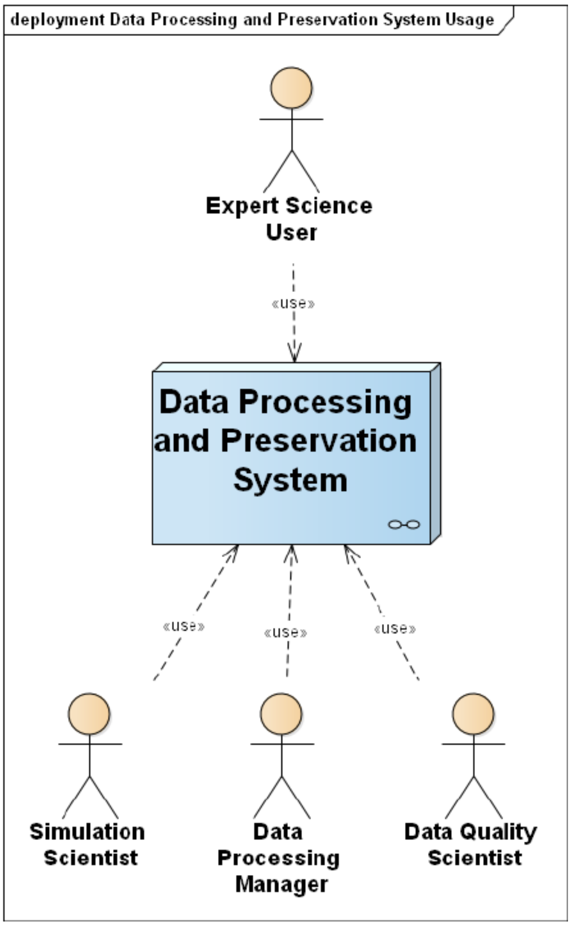


Figure 25: Overview of the internal and external users of the DPPS.

This section lists the users of the DPPS and their interactions with the system. An overview is given in Figure 25 and their definition in Table 21. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Expert Science User Someone who uses CTA data at a lower level than the standard distributed data products. May submit technical proposals.
Internal Stakeholders
Data Processing Manager Responsible for running the data processing pipelines and for monitoring the data processing and archiving status as well as the data transfer and pipelines performance at all stages of data processing. **Data Quality Scientist** Responsible for monitoring the quality of pipeline-produced data products and calibrations. Will discuss quality fixes with Instrument Scientists and Maintenance Engineers. **Simulation Scientist** Liaison with Configuration Manager, ensures that simulations and instrument response functions produced are an accurate description of the CTA configuration.

Table 21: Definition of the internal and external Users of the DPPS.

Interactions with External Stakeholders

- *Expert Science User*

  Provision of access to lower-level data compared to the standard high-level science products (for the Science User) to allow for the Expert Science User for further investigation of the data and processing algorithms

Interactions with Internal Stakeholders

- *Data Quality Scientist*

  Provision of all relevant calibration and data quality parameters produced during the processing and reprocessing of the low-level data for monitoring the data quality

- *Data Processing Manager*

  Provision of command and monitoring information to configure and run the data processing pipelines and for monitoring the data processing and archiving status as well as the data transfer and pipelines performance at all stages of data processing.

- *Simulation Scientist*

  Provision of command and monitoring information to configure and run the simulation pipelines and for monitoring the processing and archiving status of the simulation as well as the production of the instrument response information.

4.3.4.7 Main Data Elements

Table 22 lists the main data elements that are produced/consumed and stored/logged by the DPPS.

Main Data Element Exchanged	**Definition**	**Produced/Consumed**	**Stored/Logged**
Archive Query	Query for archived data related to a proposal, time period, target, etc. depending on the context of the query (e.g. Science User, Expert Science User) and data access rights	Consumed	Logged
Configuration	Configuration of the arrays, including all instrument and infrastructure configuration	Produced/Consumed	Stored
Data for Expert Users	Data products at various levels for the Expert Science User	Produced	Stored
Data for Science Users	High-level science products for the Science User,	Produced	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	grouping contains event lists, instrument response function and science analysis results		
Data Processing Status	Status of the production of the low-level and simulation data	Produced	Logged
Data Quality Incident Report	Report on identified issues of data quality	Produced	Logged
Data Quality Parameters	Parameters describing the quality of the processed data	Produced	Logged
Data Transfer Status	Status of the data transfer from array sites to the data centre(s)	Produced	Logged
*DL0.**	Low-level data produced at the array sites	Consumed	Stored (Archived)
Identity Attributes	User identification and attributes for authentication and authorization (e.g. for data access rights)	Consumed	Stored
Job Configuration	Configuration of the processing jobs to be executed automatically, includes calibration configuration	Consumed	Logged
Observation Metadata	Parameters of the observations relevant for the low-level data (includes the logical file names of the data files)	Consumed	Stored (Archived)
Performance Metrics	Report on the metric of observables describing the performance of the related system and its elements	Produced	Stored (Archived)
Pipelines Processing Report	Status information on the performance of the pipelines used for production of the low-level and simulation data	Produced	Logged
Quality Report	Status information on the performance of the system	Produced	Logged
Science Alert Analysis Configuration	Support information required for the data analysis steps within	Produced	Logged

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	OES, at a minimum this information must include: instrument configurations, image cleaning configurations, background model, instrument response functions		
Ticket	Ticket providing the description of an issue related to problems with the software, hardware, data quality or user experience	Produced	Logged

Table 22: Overview of the main data elements consumed or produced by the DPPS.

4.3.4.8 Decomposition

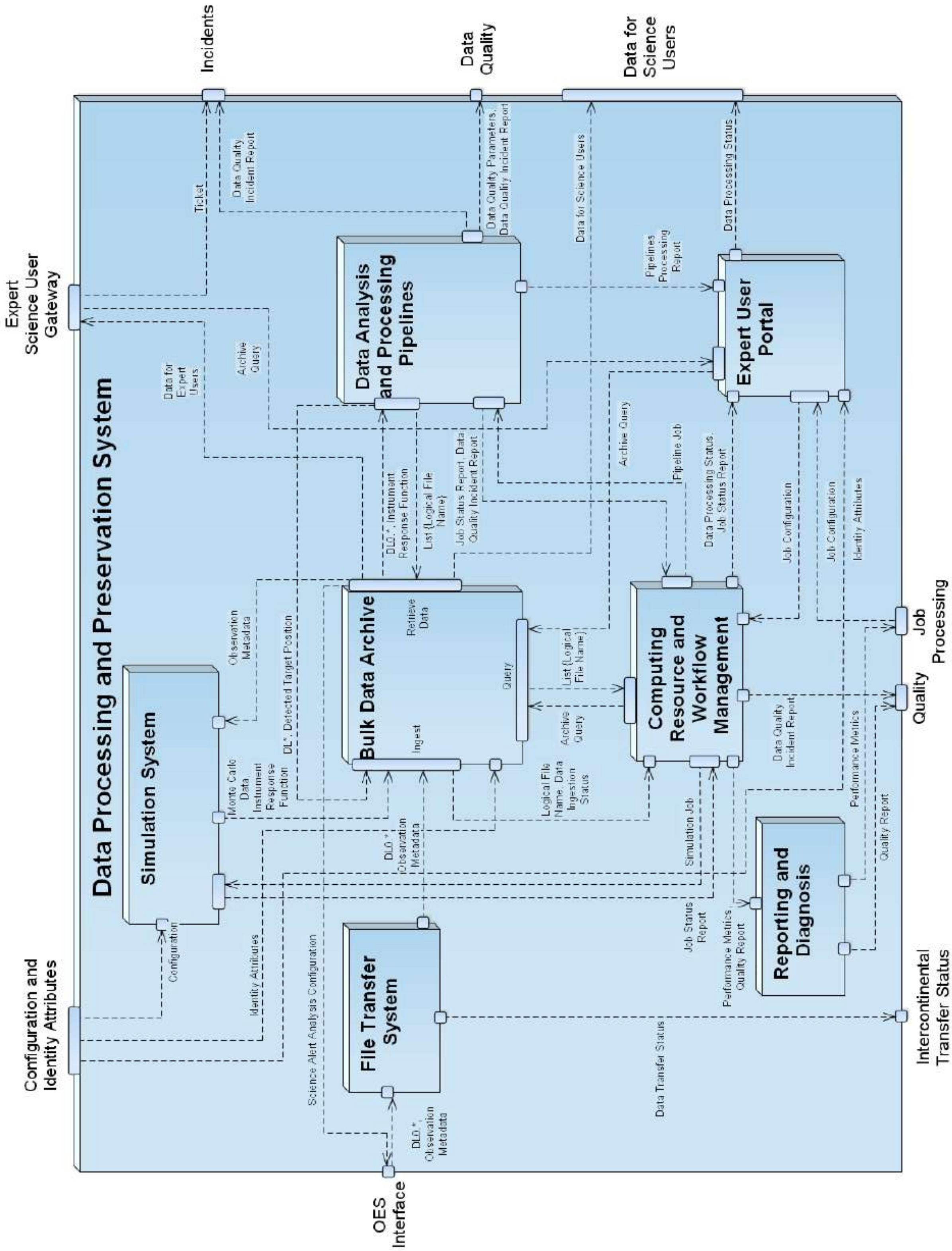


Figure 26: First-level functional decomposition of the DPPS.

A preliminary functional decomposition of the DPPS at the first level is shown in Figure 26. The DPPS is composed of the following main sub-systems that group functionality in relation to:

- *Bulk Data Archive*

  Software responsible for the long-term preservation of the low-level data, observation metadata and all relevant information for reproducibility of results

- *Computing Resource and Workflow Management System*

  Software system to organise, coordinate and monitor the processing of the simulation and low-level data at the data centre(s)

- *Data Analysis and Processing Pipelines*

  Software system responsible for the calibration and processing of the low-level data to produce the high-level science data products and associated data quality checks, includes the on-site, off-line automated science analysis (level B) pipeline

- *Expert User Portal*

  Web-based user interface for interaction with the DPPS sub-systems, providing access to archive queries and retrievals, pipelines launching and monitoring, data quality monitoring, and status information

- *File Transfer System*

  Software responsible for the transfer of data between the array sites and the data centre(s)

- *Reporting and Diagnosis*

  Software responsible for the monitoring of the performance of the DPPS system and generation of quality reports

- *Simulation System*

  Software system responsible for the simulation of Cherenkov data and instrument response

A version of DPPS is envisaged to run at the CTA array sites (on-site), with the minium functionality of Computing Resource and Workflow Management System, Data Analysis and Processing Pipelines (for the on-site off-line automated science analysis, level B), File Transfer System (for transfer of the data from on-site to off-site via the intercontinental line) and, depending on the interface implementation to OES, a (potentially slimmed-down) version of the Archive.

4.3.4.9 Functionality

This section lists all actions that the DPPS performs or in which it supports a user. These actions provide a behavioral description of the system.

4.3.4.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system.

External Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Expert Science User	Maintenance: Maintain System from Issue Identification to verified Overhaul Issue Identification: from collected Data to identified Issue	Search Lower Level Data	Connect to system and authenticate user Define search query Download data

Table 23: Overview of the actions in which the external stakeholders are supported by the DPPS.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Data Processing Manager	Process Data: from collected data to archived Science Products	Monitor Execution of Pipelines	Select data to explore
		Execute automatic Quality Checks on Data Level 1 to 3	Allow user exploration of data Issue incident report
		Execute standard data processing	Search for observations that need (re)processing
		Reprocess Data: from Archived Data to Reprocessed Archived Science Products	Configure pipeline software with recommended options Install new pipeline software on DPPS
Data Quality Scientist	Process Data: from collected data to archived Science Products	Check Scientific Data Quality Offline	Check data quality parameters
			Issue quality incident report

Table 24: Overview of the actions in which the internal stakeholders are supported by the DPPS.

4.3.4.9.2 Automated Processes and Actions

This section lists the processes where the DPPS takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Ingest data
Observation Planning: Plan Observations from validated Proposals to Long-Term Schedule	Define new Observing mode	Store the new Instrument Response Function
Process Data: from collected data to archived Science Products	Archive Data	Check the data integrity
		Extract and validate metadata
		Insert Metadata and logical file name into database

Supported Process	Process/Activity	Automated Action
		Store file and get logical filename
		Transfer file
	Check Scientific Data Quality Offline	Detailed offline data processing
	Configure Auxiliary Instrument pipeline	Retrieve current configuration parameters
		Update any required SVC data files
		Update configuration parameters
		Update database for configuration
		Write SVC changes storage
	Configure Pipeline workflow	Select predefined stage configuration from database
		Update configuration parameters
		Validate configuration
		Write new configuration to database
	Derive and apply calibration coefficients for Image Reconstruction	Transfer calibration data to offsite archive Transfer muon data to offsite archive
	Execute automated Science Analysis	Perform automatic science analysis
	Execute automatic Quality Checks on Data Level 1 to 3	Bin DLN monitoring data in time or another axis
		Check quality: generate histograms
		Generate quality report and write it to storage
		Retrieve DLN monitoring products from storage
		Select subset of observations or time range
		Summarize monitoring data bin (average statistics + histograms)
	Execute Auxiliary Instrument Pipeline	Validate Auxiliary Instrument pipeline results
	Execute Main Data Processing Pipeline (DL0 --> DL3)	Validate data processing results
	Execute Monte-Carlo Production Pipeline	Configure Monte-Carlo production pipeline
		Launch Monte-Carlo production
		Validate Monte-Carlo production results
	Execute standard data processing	Ingest data products into storage
	Launch Auxiliary Instrument pipeline	Retrieve auxiliary instrument data for time range
		Run specialized pipeline to process device data

Supported Process	Process/Activity	Automated Action
		Select time range (night or hour etc.)
		Write processed data to storage (if exists)
		Write processed monitoring data to database
	Launch Pipeline workflow	Produce processing report
		Select observations or MC data to process
		Select predefined configuration
	Monitor and Control off-site Distributed ICT infrastructure	Administration & monitoring of data archive
	Monitor Execution of Pipelines	Display details for individual observations
		Display summary of subset
		Extract pipeline type (e.g. Main Data Processing
		Observation subset (production name
		Pipeline stage or task
	Produce Instrument Response Function	Analyse the Monte Carlo Events
		Calculate the Instrument Response Function
		Evaluate computing needs and compare with available resources
		Launch and execute the Monte Carlo production pipeline
		Prepare the Monte Carlo production pipeline
		Publish the Instrument Response Function (i.e. make it discoverable and/or inform the user)
		Report that available resources are not sufficient
		Report that available resources are not sufficient
		Store the Instrument Response Function
		Validate the Instrument Response Function
	Provide Instrument Response Function	Issue a report for invalid IRF
		Issue a report for missing IRF
		Issue request to produce new Instrument Response Function
		Query the CTA archive for existing Instrument Response Functions
		Validate Instrument Response Function

Supported Process	Process/Activity	Automated Action
	Reprocess Data: from archived Data to reprocessed archived Science Products	Analyse and combine Monte-Carlo Runs to generate necessary science support files
		Process all real DL0 data
		Process Monte-Carlo Runs
		Process subset of real data and check quality and validate and optimize results
		Retrieve Existing Monte Carlo Products
		Transfer DL3 data to science archive
	Retrieve Data	Validate existence of file and check authorization
	Search Lower Level Data	Process query
		Validate query and check authorization
	Submit job(s)	Check job(s) result status until finished
		Execute jobs on computing resources
		Locate the logical file names that are needed for the job
		Prepare job(s) associated with LFNs
		Query common instrument configuration and other global info from database and write to local file that can be distributed to job
		Relaunch or continue Job
		Submit Job
	Transfer DL0 data to off-site Archive	Transfer DL0 data
	Synchronise Science Alert Generation Analysis Configuration	Provide science alert generation configuration to OES
Science Analysis: Support the Analysis of Data from available Science Products to Scientific Results	Perform a Scientific Analysis	Determine Array Performance
		Fit model to the data
		Produce a light-curve
		Produce a source spectrum
		Produce a sky image
		Select and apply event selection
		Select data to analyse
		Store high-level data products
		Store high-level data products

Table 25: Overview of the actions, which are automatically performed by the DPPS.

4.3.4.10 Main Interfaces

This section provides an overview of the ports that the DPPS provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of the relevant information. Please note that the DPPS functionality covers the data transfer between the CTA on-site arrays and the off-site data centre(s) as well as between the off-site data centre(s). These interfaces do not appear in this list as they are not external to DPPS. Special care will be taken in a future release to cover the interfaces between the DPPS on-site and off-site systems.

Port	Main Data Element Exchanged	Purpose	Notes
Configuration and Identity Attributes	Configuration, Identity Attributes	Synchronise the configuration and user identification attributes with the OSS	
Data for Science Users	Data for Science Users, Processing Status	Provide high-level science products and inform about processing status	
Data Quality	Data Quality Parameters, Data Quality Incident Report	Monitor and report on data quality	
Expert Science User Gateway	Data for Expert Users, Archive Query, Ticket	Provide access to low-level data to Expert Science User	
Incidents	Ticket, Data Quality Incident Report	Report issues	
Intercontinental Transfer Status	Data Transfer Status	Monitor and report status of data transfer	
Job Processing	Pipelines Processing Report, Job Configuration	Organise and coordinate the processing of the simulations and the low-level data, incl. calibration and data quality monitoring	
OES Interface	DL0, Observation Metadata	Access to low-level data for processing on-site (level B analysis) and transfer of low-level data from array sites to the data centre(s)	Please note that this interface implies a an interface between on-site and off-site through the intercontinental link between the DPPS on-site and DPPS off-site.
Quality	Quality Report	Report performance of the DPPS system	

Table 26: Overview of the main interfaces for the DPPS.

4.3.4.11 Deployment

The DPPS runs at multiple sites. A reduced version of the DPPS runs at the CTA sites with the main functionality of an on-site, off-line automated science analysis (level B) analysis (incl.

data quality evaluation) and file transfer to the off-site data centre(s). Multiple instances of the DPPS run at the CTA data centre(s) for data processing and simulation.

The instances of DPPS on-site (at the CTA array sites) and the DPPS off-site are interfaced via the intercontental data link using the File Transfer System. A dedicated view will be added in a future release of this document.

4.3.4.12 Additional Notes

It is envisaged that the software and algorithms for the analysis pipelines are reused by the OES.

It is envisaged that the software for Science Tools provided by SUSS are reused within the DPPS.

The section will be updated following the chosen CTA computing model and related definition of off-site data centre(s).

4.3.5 Management and Administrative System

4.3.5.1 Summary

NAME AND ACRONYM
Management and Administrative System (MAS)
SCOPE
A collection of software systems associated with the administration of CTA. Includes procurement, logistics, human resources management and systems supporting the generation of performance/status reports for external stakeholders.
CONTEXT
External systems: none Internal systems: Data Processing and Preservation System, Operations Support System, Science User Support System
USERS
External users: Contributors, Hosts and Neighbours, Sponsors Internal users:
DECOMPOSITION
Logistics, Operation Management System, Risk Management, Financial Planning and Administration, Human Resources, Outreach and Information, Performance Reporting and Analysis
DEPLOYMENT
NOTES

4.3.5.2 Name and Acronym

Management and Administrative System (MAS)

4.3.5.3 Scope

The Management and Administrative System is a collection of systems associated with the management and administration of CTAO that includes procurement, logistics, human resources management, risk management and other systems supporting the generation of quality reports to stakeholders, the relationship with hosting entities and sponsors and the definition of the business strategy / planning.

4.3.5.4 Main Processes

In the current architecture model, no processes are modeled that are linked directly to the Management and Administrative System; these will be added in a future version of the architecture.

4.3.5.5 Context and User Interactions

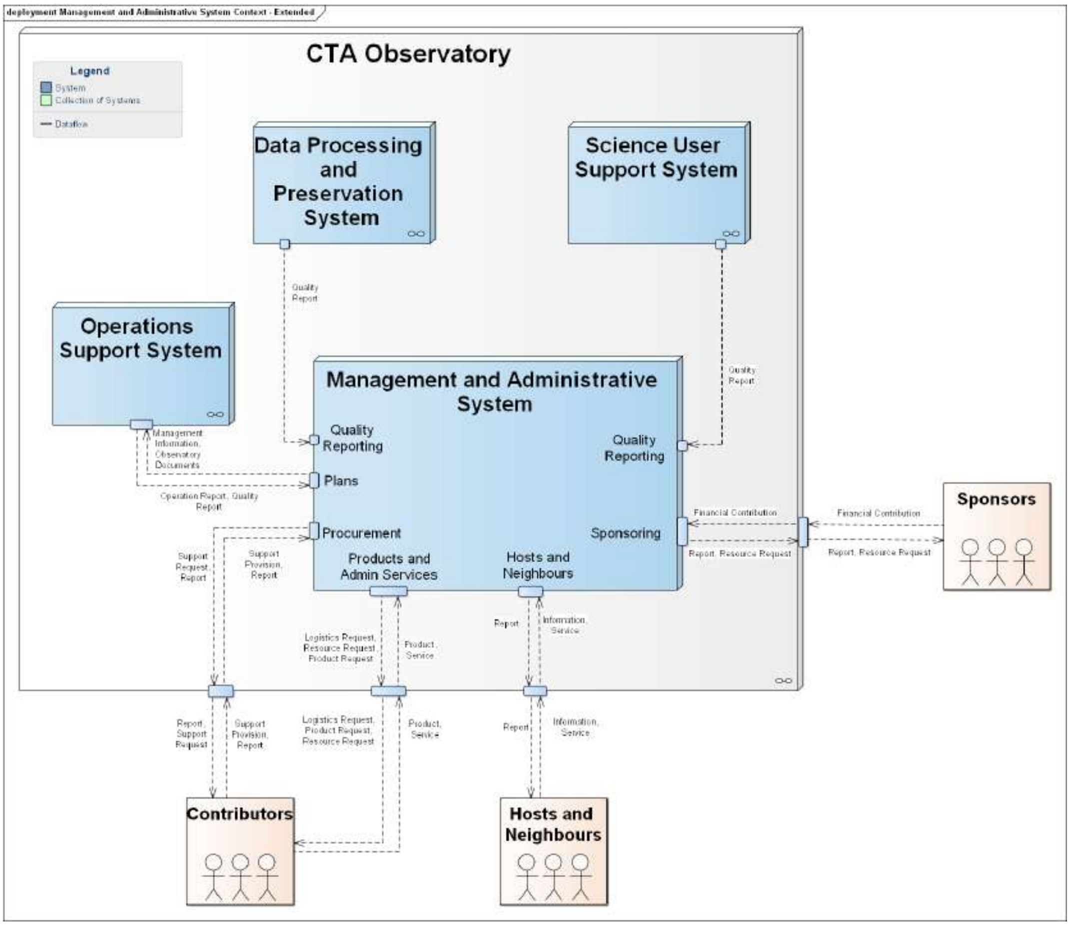


Figure 27: Context of the MAS. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the MAS.

Interactions with Internal Systems

- *Operations Support System*

  Regular provision of management information and Observatory documentation (e.g. test plans) to support the Observatory operation and maintenance activities, receiving of reports characterizing the Observatory performance

- *Data Processing and Preservation System*

  Receiving of reports characterizing the Observatory performance

- *Science User Support System*

  Receiving of reports characterizing the Observatory performance

4.3.5.6 Users

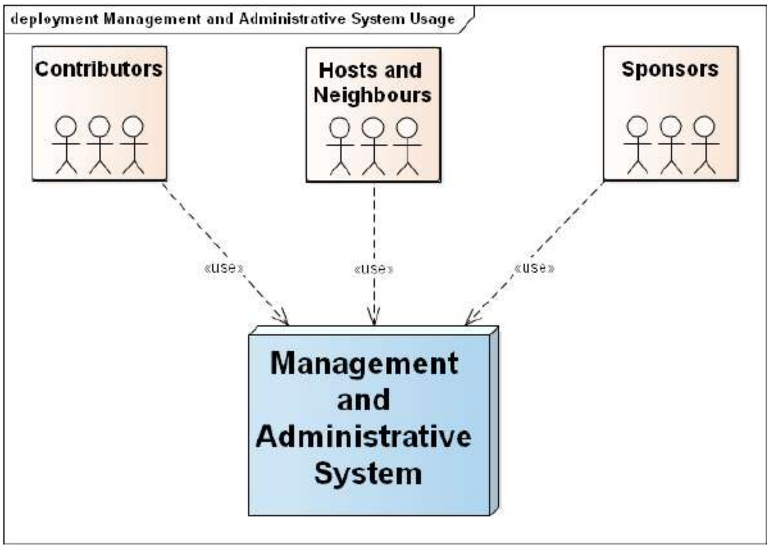


Figure 28: Users of the MAS.

This section lists the users of the MAS and their interactions with the system. An overview is given in Figure 28 and their definition in Table 27. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Contributors Organisations that provide products, components, parts, devices and/or services to the CTA Observatory.
Hosts and Neighbours Hosts are entities that accommodate the CTA Observatory installations at the respective site as stipulated within legal agreements. Neighbours are other organisations that occupy land near to the CTA sites and with whom the CTA Observatory communicates regularly to ensure harmonious co-existence.
Sponsors Organisations that provide financial support for construction and operation of CTA.
Internal Stakeholders

Table 27: Internal and external users of the MAS.

Interactions with Internal Stakeholders

- *Contributors*

  Frequent exchange of information and services with the Contributor to facilitate the procurement and logistics procedures, and to organise all steps from request to delivery of products and services

- *Hosts and Neighbours*

  Frequent exchange of information and reports with the Hosts and Neighbours of the CTA array sites

- *Sponsors*

  Frequent reporting to Sponsors and organisation of the financial contributions received for the operation and construction of the CTA Observatory

4.3.5.7 Main Data Elements

Table 28 lists the main data elements that are produced/consumed and stored/logged by the MAS.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Financial Contribution	Information related to the funding of the CTA Observatory	Consumed	Stored
Information	Information provided by the Hosts and Neighbours of the CTA array sites relevant for its construction and operation	Consumed	Stored
Logistics Request	Request for information and support on the logistics of a certain product or service	Produced	Stored
Management Information	Documentation and decisions provided by the CTA management group for the operation and construction of the CTA Observatory	Produced	Stored
Observatory Documents	Documents covering the CTA Observatory elements and tasks (e.g. calibration strategy, test plan)	Produced	Stored
Operation Report	Report on the CTA Observatory operation performance	Produced	Stored
Product	An element (e.g. system or sub-system) of the CTA Observatory	Consumed	Stored
Quality Report	Report on the performance of the systems and quality of services of the CTA Observatory	Produced	Stored
Product Request	Request for a product	Produced	Stored
Report	Report on the provided services and/or products	Produced/Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Resource Request	Request for the provision of a resource	Produced	Stored
Service	Provision of a service	Consumed	Stored
Support Provision	Provision of support	Produced	Stored
Support Request	Request for support	Produced	Stored

Table 28: Main data elements exchanged with MAS.

4.3.5.8 Decomposition

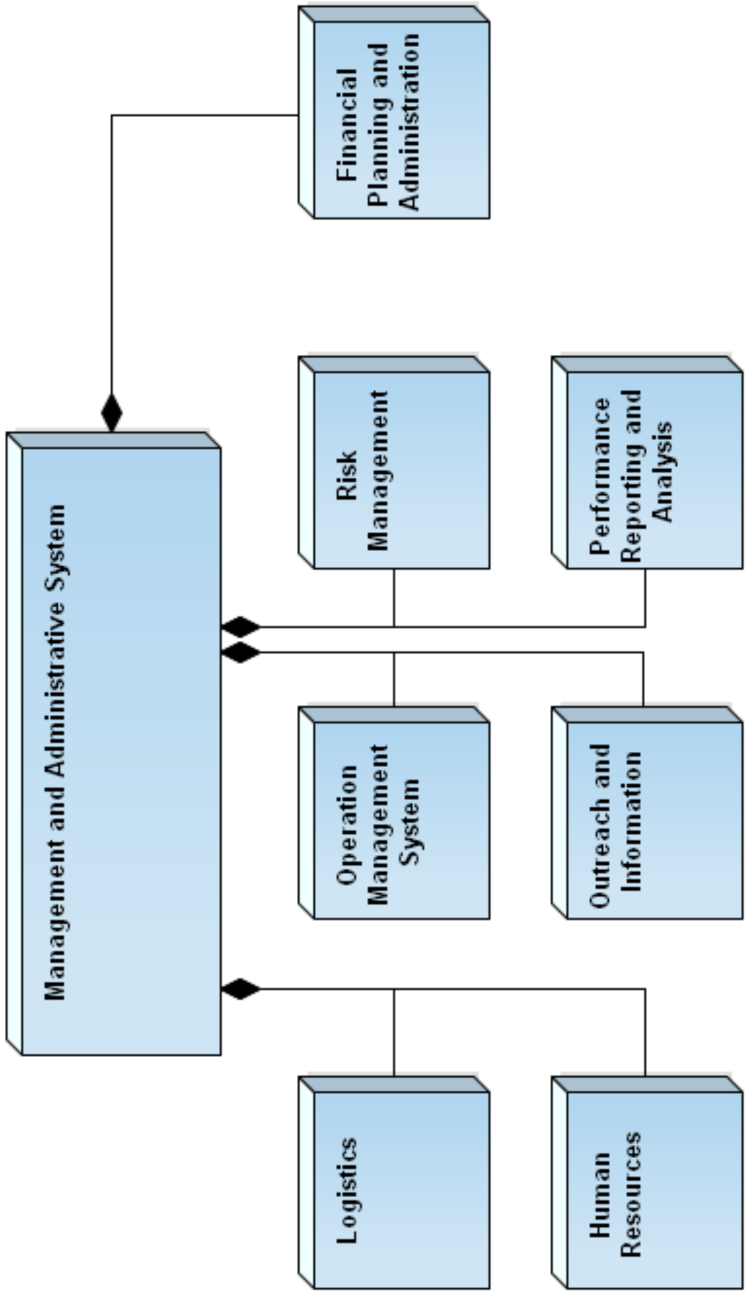


Figure 29: First-level functional decomposition of the MAS.

A preliminary functional decomposition of the MAS at the first level is shown in Figure 29. The functional decomposition is shown with the dataflow and interconnections between the systems, which is not yet defined. The MAS is composed of the following main sub-systems that group functionality in relation to (their defintion will be added in a future release):

- *Logistics*
- *Human Resources*

- *Operation Management System*
- *Outreach and Information*
- *Risk Management*
- *Performance and Reporting Analysis*
- *Financial Planning and Administration*

4.3.5.9 Functionality

In this version of the architecture model, no processes are modeled that directly link to the MAS. This section, intended to list all actions that the MAS performs or in which it supports a user, will be added in future version of the architecture.

4.3.5.10 Main Interfaces

This section provides an overview of the ports that the MAS provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Quality Reporting	Quality Report	Receive and evaluate all reports from the individual systems	
Plans	Management Information, Observatory Documents, Operation Report, Quality Report	Central hub for all Observatory-wide documentation	
Procurement	Support Request, Support Provision	Support from CTAO for the contributors for the procurement	
Products and Admin Services	Logistics Request, Resource Request, Product Request, Product, Service	Services of CTAO related to the provision of products	
Host and Neighbours	Information, Service, Report	Information exchange with host and neighbours	
Sponsoring	Report, Resource Request, Financial Contribution	Services of CTAO related to its funding	

Table 29: Overview of the main interfaces for the MAS.

4.3.5.11 Deployment

The MAS will be deployed in a single instance off-site.

4.3.5.12 Additional Notes

The work on management and administrative processes was not the focus of the current release and further details will be added in a future release, following the project needs

4.3.6 Observation Execution System

4.3.6.1 Summary

NAME AND ACRONYM
Observation Execution System (OES)
SCOPE
A software system responsible for the control and monitoring of telescopes and auxiliary (non-telescope) instruments at a CTA site, for the efficient scheduling and execution of pre-scheduled observations and those triggered dynamically, for the monitoring of the system performance, for the data acquisition and volume reduction as well as the automatic generation of science alerts.
CONTEXT
External systems: Collaborating Scientific Facilities, Laser Traffic Control System Internal systems: Array Infrastructure Elements, Auxiliary Instruments, Data Processing and Preservation System, Operations Support System, Safety and Alarm System, Telescope {*}
USERS
External users: none Internal users: Operator, Expert Operator, Configuration Manager, Support Astronomer
DECOMPOSITION
Configuration, Data Handling, Manager and Central Control, Monitoring and Logging, OES Alarms, Operator Interfacing, Reporting and Diagnosis, Short-Term Scheduling and ToO Handling
DEPLOYMENT
One instance at each of the CTA array sites
NOTES

4.3.6.2 Name and Acronym

Observation Execution System (OES)

4.3.6.3 Scope

The Observation Execution System is a software system that governs the efficient scientific operation and data acquisition of the CTA systems during observation nights and engineering operations during day time. The main functionality of the OES is:

- interprets the mid-term schedule, extracting the necessary information to plan and execute the observations,
- splits the telescopes of a site into functional groups (sub-arrays) according to the schedule needs and telescope availability, and then send commands to those telescopes that compose each sub-array to configure and perform the data acquisition,
- monitors all the processes involved during the execution of night operations and presents them in a meaningful way to the night operators,
- gathers and stores monitoring information from telescopes and auxiliary devices, as well as real-time performance indicators that ensure the quality of the acquired data and the status of the instrumentation, raising alarms when problems arise,
- provides support for gathering and logging information for basic observing-oriented metrics,
- provides the operations-focused user interface for the operator to monitor and operate the CTAO systems during the observing operations.

The Observation Execution System provides the framework for the integration of all other on-site systems involved in the scientific operations: Auxiliary Instruments, Array Infrastructure

Elements, Data Processing and Preservation System, Telescopes; and is connected to the Operations Support System and Safety and Alarm System.

4.3.6.4 Main Processes

The main processes to which the OES contributes are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
    a. *Schedule Refinement: from Long-Term Schedule to Short-Term Schedule*
    b. *Observation Execution: from Short-Term Schedule to Collected Data*
    c. *React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule*
    d. *Science Alert Generation: from Collected Data to Generated Science Alert*
    e. *Process Data: from Collected Data to Archived Science Products*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
    a. *Calibration: Perform, Check and Refine Calibration and Calibration Instruments*
    b. *Issue Identification: from Collected Data to Identified Issue*
    c. *Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action*

4.3.6.5 Context and User Interactions

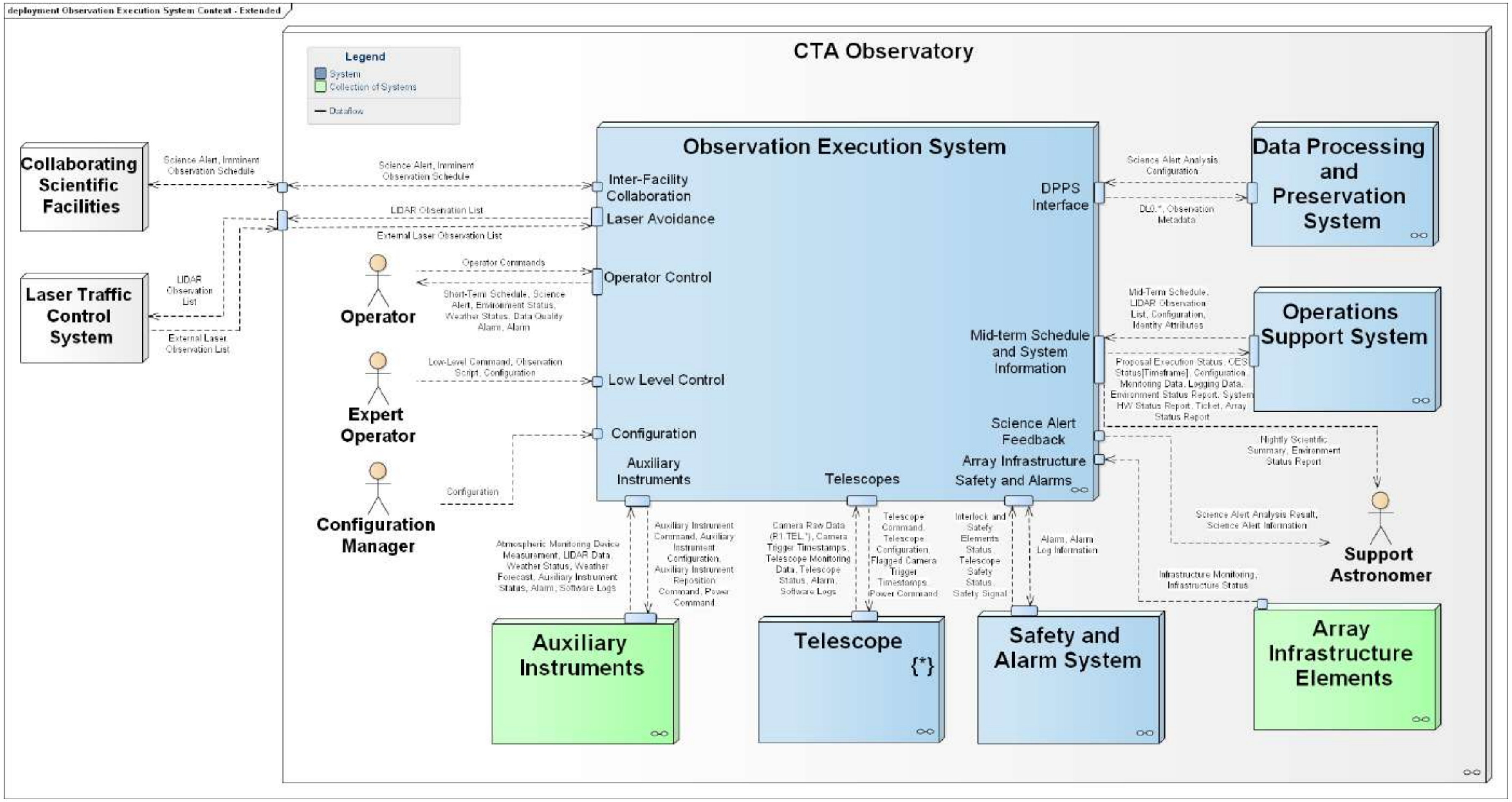


Figure 30: Context of the OES. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the OES. The Observation Execution System interfaces with all systems running on-site. It provides interfaces to external systems for observation coordination (e.g. exchange of science alerts and imminent observation schedules with external scientific facilities and between the two CTA sites) and coordination of laser usage (e.g. with neighbouring scientific facilities) via the laser traffic control system.

Interactions with External Systems

- *Collaborating Scientific Facilities*

  Continuous exchange of Science Alerts and information on the imminent observation schedule to facilitate ToO follow-ups and coordination of observations

- *Laser Traffic Control System*

  Continuous exchange of planned operation of the lasers at the CTA array and neighbouring sites to minimize the impact on the observations

Interactions with Internal Systems

- *Auxiliary Instruments*

  Collection of monitoring data from the auxiliary instruments characterizing the site environment, control, monitoring and logging of the various devices and handling of alarms, provision of pointing direction of the telescopes

- *Array Infrastructure Elements*

  Monitoring of the clock system and its time synchronisation status with the various CTA systems

- *Telescope*

  Control, monitoring and logging of the individual telescopes and handling of alarms, data acquisition of the raw Cherenkov data and flagging of camera trigger timestamps for coincidences

- *Safety and Alarm System*

  Monitoring of the safety-relevant status information from the individual systems (e.g. interlocks), handling of safety signals produced by the SAS, provision of safety-relevant alarms and information collected by the OES

- *Data Processing and Preservation System*

  Provision of DL0 and observation metadata, receiving of analysis support information (e.g. instrument response function) from the DPPS

- *Operations Support System*

Synchronisation of the configuration, provision of monitoring and logging data as well as performance and failure reports, synchronisation of user profiles and attributes for the authentication and authorization

4.3.6.6 Users

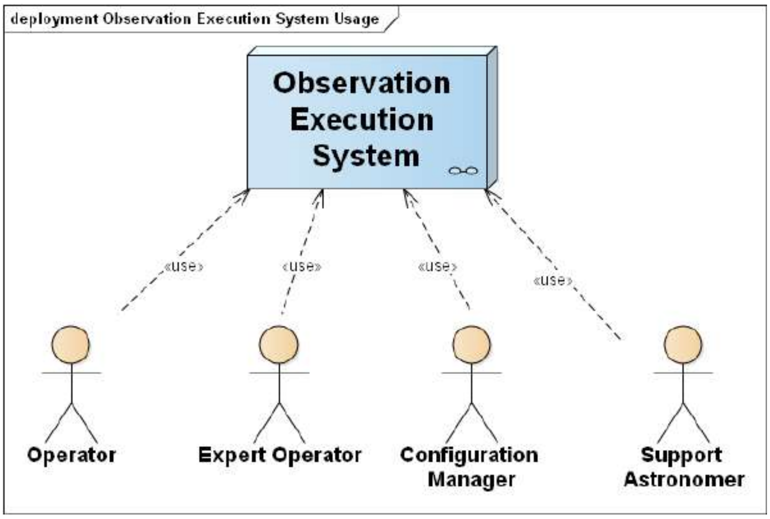


Figure 31: Users of the OES.

This section lists the users of the OES and their interactions with the system. An overview is given in Figure 31 and their definition in Table 30. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Internal Stakeholders
Operator Responsible for supervising and carrying out scheduled observations and calibrations during the night. Troubleshoots problems, can modify schedule if necessary (e.g. weather/ToO) and logs all activities. **Expert Operator** Has expert access to the instruments and software at the CTA array sites, executes debugging and engineering activities in case of reported problems. **Configuration Manager** Keeps track of the status of all instruments, part replacements etc. Responsible for the central management of all documentation, logging and configurations. **Support Astronomer** Oversees and supports scheduling of observations from long-term to short-term, supervises reactions to external and internal science alerts.

Table 30: Internal and external users of the OES.

Interactions with Internal Stakeholders

- *Operator*

  Functionality for the operation of the Observatory with full access to control, monitoring and logging information from the various on-site systems

- *Expert Operator*

Additional functionality to allow for low-level commands and observation scripts for expert to operate the telescopes

- *Configuration Manager*

  Change of configuration of software and hardware elements

- *Support Astronomer*

  Provision of a summary on the nightly science results and results of the science alert generation to support the handling of ToOs

4.3.6.7 Main Data Elements

Table 31 lists the main data elements that are produced/consumed and stored/logged by the OES.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Alarm	Problem or condition that should be reported to the operator and may require his/her action	Produced/Consumed	Stored
Alarm Log Information	Additional information on each alarm.	Produced/Consumed	Stored
Array Status Report	Report on the status of the array on different time scales	Produced	Logged
Atmospheric Monitoring Device Measurement	Data readout from the atmospheric monitoring device	Consumed	Stored
Auxiliary Instrument Command	Command to operate the auxiliary instrument	Produced	Logged
Auxiliary Instrument Configuration	Configuration of the auxiliary instrument	Produced	Stored
Auxiliary Instrument Reposition Command	Command to change the pointing direction of the auxiliary instrument	Produced	Logged
Auxiliary Instrument Status	Status information of the auxiliary instrument	Consumed	Logged
Camera Raw Data (R1.TEL.)*	Low-level data readout from the camera of a telescope	Consumed	Stored
Camera Trigger Timestamps	Timestamp of a camera trigger	Consumed	Stored
Clock System Monitoring	Monitoring information on the central timing system	Consumed	Logged

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	and clock synchronisation		
Configuration	Configuration of the arrays, including all instrument and infrastructure configuration	Produced/Consumed	Stored
Data Quality Alarm	Alarm notification on a data quality problem	Produced	Logged
*DL0.**	Low-level data produced at the array sites	Produced	Stored
Environment Status	Collected status information on the site environment	Consumed	Stored
Environment Status Report	Report on the collected status information on the site environment	Produced	Stored
External Laser Observation List	List of planned observations with lasers operated by external observatories	Consumed	Logged
Flagged Camera Trigger Timestamps	Camera trigger timestamps flagged for coincidence	Produced	Stored
Identity Attributes	User identification and attributes for authentication and authorization (e.g. for data access rights)	Consumed	Stored
Imminent Observation Schedule	List of observations on a certain target or region planned for the night	Produced/Consumed	Stored
Interlock and Safety Elements Status	Status information on the interlocks and safety status of all elements at the array site	Consumed	Logged
LIDAR Data	Measurement data readout from the LIDAR	Consumed	Stored
LIDAR Observation List	List of planned observations with the LIDAR	Produced	Stored
Logging Data	Logging information from the on-site elements	Produced	Stored
Low-Level Command	Control command on expert level	Consumed	Logged
Mid-Term Schedule	Collection of scheduling blocks, on the timescale of weeks to days	Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Monitoring Data	Monitoring information from the on-site elements	Produced	Stored
Nightly Scientific Summary	Summary of the scientific results of each observation night	Produced	Stored
Observation Metadata	Parameters of the observations relevant for the low-level data (includes the logical file names of the data flies)	Produced	Stored
Observation Script	Series of commands that define an observation task	Consumed	Stored
OES Status [Timeframe]	Information from the logs, noted events and operator logbook	Produced	Stored
Operator Commands	Commands to control site operations and exposed to the Operator and Expert Operator	Consumed	Logged
Proposal Execution Status	Status of the execution of a certain proposal	Produced	Stored
Safety Signal	Signal to alert on a safety-relevant issue	Consumed	Logged
Science Alert Analysis Configuration	Support information required for the data analysis steps within OES, at a minimum this information must include: instrument configurations, image cleaning configurations, background model, instrument response functions	Consumed	Stored
Scientific Alert	Alert related to a scientifically interesting event (e.g. a ToO) or observation (e.g. detection of a signal within the field of view)	Consumed/Produced	Stored
Scientific Alert Analysis Result	Information on the results of an analysis for a specific scientific alert	Produced	Stored
Scientific Alert Information	Supporting information related to a specific scientific alert, e.g. data	Produced	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	quality, array status, correlation with other scientific alerts		
Short-Term Schedule	Collection of scheduling blocks on the timescale of an observation night	Produced	Stored
Software Logs	Logging information from the system	Produced/Consumed	Stored
System HW Status Report	Report on the status of individual hardware systems and devices at the CTA array site	Produced	Stored
Telescope Command	Command to control a telescope and its elements	Produced	Logged
Telescope Configuration	Configuration of a telescope and its elements	Produced	Stored
Telescope Monitoring Data	Monitoring data collected from a telescope and its elements	Consumed	Stored
Telescope Safety Status	Safety status of a telescope and its elements	Consumed	Stored
Telescope Status	Status information of a telescope and its elements	Consumed	Stored
Ticket	Ticket providing the description of an issue related to problems with the software, hardware, data quality or user experience	Produced	Logged
Weather Forecast	Weather forecast information	Consumed	Stored
Weather Status	Status information on the weather	Consumed	Stored

Table 31: Main data elements exchanged with OES.

4.3.6.8 Decomposition

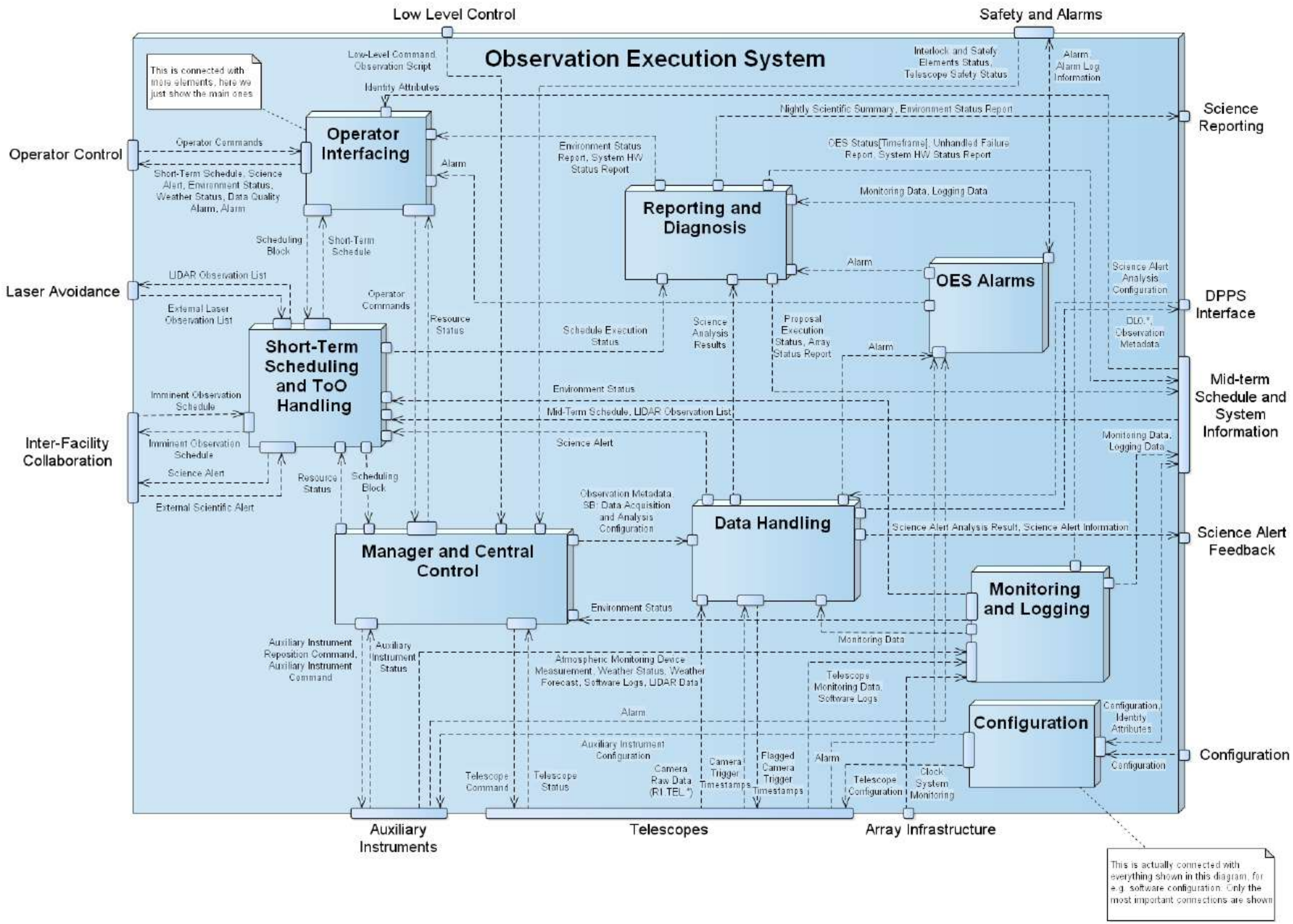


Figure 32: First-level functional decomposition of the OES.

A preliminary functional decomposition of the OES at the first level is shown in Figure 32. The OES is composed of the following main sub-systems that group functionality in relation to:

- *Operator Interfacing*

  The user interface for the Operators deployed in the control room, providing to the operator crew the control and monitoring of the system. It is interfaced to the Observation Execution System and other relevant systems such as the Safety and Alarm System. Only one instance of the OES exists per site and is running throughout the day and night.

- *Manager and Central Control*

  This sub-system interprets the scheduling blocks received from the Short-Term Scheduler sub-system, creates sub-arrays and sends commands to the Telescopes and the Data Handling sub-systems. It uses the Monitoring and on-site logging sub-system to oversee the conditions to continue the execution of a scheduling block and cancel that execution if the conditions become adverse. This sub-system is also the master for the start-up, shutdown, supervision and registry functionalities. In addition, it provides the standardized entry point for instrument control, configuration, monitoring, logging, and alarms for telescopes and auxiliary devices, as well as the start-up and shutdown procedures for these. It accesses the devices via standardized control interfaces. One instance of the OES Manager and Central Control exists per OES system.

- *Short-Term Scheduling and ToO Handling*

  This sub-system creates the short-term schedule based on the mid-term schedule, environment conditions and, when applicable, on any internal or external scientific alert. This sub-system also comprises the ToO alert functionality to filter, process and rank internal and external scientific alerts. The short-term schedule is sent as scheduling blocks to the OES Manager and Central Control sub-system. One instance per OES system exists.

- *OES Alarms*

  Service that gathers, filters and exposes the alarms raised by the Observation Execution System processes, the Telescope and the Auxiliary Instruments. These alarms are then sent to both the Operator Interface and to the Safety and Alarm System.

- *Data Handling*

  This sub-system includes the data acquisition, array trigger and science alert functionalities. The Data Handling sub-system is initiated by the OES Manager and Central Control whenever it receives a new scheduling block. The duty of the Data Handling sub-system is to get the scientific data and event timestamps from the telescopes, group the data in terms of sub-arrays, perform the first steps of data volume reduction, first level of data quality at real-time and to apply the analysis that generates internal science alerts. This sub-system includes the temporary storage of raw scientific data that is later transferred to the Data Processing and Preservation

System. Meta-data obtained from the Monitoring and Central Control sub-systems is added to the raw scientific data.

- *Monitoring and Logging*

  Service that gathers monitoring (time series data from instruments sensors and statuses at typically ~1 Hz rates) and software logging, mainly from the telescopes and other instruments like environment monitoring devices and stores them in a local database. The monitoring system works continuously to record any monitoring data made available by scientific instrumentation. The monitoring system also collects the engineering data from the telescopes.

- *Configuration*

  Service that contains the configuration of the Observation Execution System software deployment, as well as the device configurations. It synchronizes with the Operations Support System for the configuration of the array hardware and the user profiles and attributes for the authentication and authorization.

- *Reporting and Diagnosis*

  This sub-system generates nightly reports on performance indicators for various stakeholders.

4.3.6.9 Functionality

This section lists all actions that the OES performs or in which it supports a user. These actions provide a behavioural description of the system.

4.3.6.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Configuration Manager	Maintenance and Upkeep: from Identified Issue to Verified	Fix Issue reported from Data Quality Inspection	Manage Configuration
Operator	Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Notify operator of status of the alarm and the automatic mitigation actions taken
Operator	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Perform a night drive test
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Manage Alarms during Operations	Operator implements a control action to fix alarm
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Manage Alarms during Operations	Request Maintenance
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Manage Alarms during Operations	Write explanation report on reaction to alarm
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Environment	Display environment status to operator
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Status of the Operations in a CTA Site	Display on-site system to operator
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Request Power-up telescopes
Operator	Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Start-up all telescope-specific processes running in the central computing system
Operator	Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Request a LIDAR shot to zenith
Support Astronomer	React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Manage Internal Scientific Alerts	Inform support astronomer that an internal science alert was triggered
Support Astronomer	React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Execute on-line data processing and analysis	Validate on-line data processing results

Table 32: Overview on actions in which the internal Stakeholders are supported by the OES.

4.3.6.9.2 Automated Processes and Actions

This section lists the processes where the OES takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Activity/Process	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Command cameras to prepare for data taking
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Enable array level event identification
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Ensure that all Raw Data from Cameras and Atmospheric Measurements are properly stored
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Request Camera triggering
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Inform Cameras to disable triggering
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Stop data taking
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Metadata	Store observation metadata
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Muon Data	Compress image data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Muon Data	Store data in temporary store
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Compress image data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Find trigger data coincidence and flag data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Store data in temporary store
Observation Execution: from Short-Term Schedule to Collected Data	Check for Telescope Alarms	Insert alarm
Observation Execution: from Short-Term Schedule to Collected Data	Check Scientific Data Quality at Real Time	Check the data quality parameters real-time
Observation Execution: from Short-Term Schedule to Collected Data	Check Scientific Data Quality at Real Time	Send data quality alarm
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Create a human readable weather report
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Establish the environment
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Evaluate from environment whether observations are still safe and appropriate
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Determine Atmospheric Conditions	Perform a common weather monitoring

Supported Process	Activity/Process	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Determine the pointing direction for each Telescope of the sub-array
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Issue a repointing position command to Atmospheric Instruments
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Read the requested Observing Mode and associated details for the next Scheduling Block
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Send pointing directions to Telescopes
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Acquire and archive Data and create internal science alerts when necessary
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Acquire atmospheric monitoring data
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Cancel execution of SB
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Check environmental and instrumental conditions online
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Divide the array into sub-arrays
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Evaluate Data and Instrument Quality
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Execute Observation Mode (Move the Telescopes to the Specified Conditions)
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Process and Analyse data Online
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Stop data taking
Observation Execution: from Short-Term Schedule to Collected Data	Execute Scheduling Block	Supervise execution of SB until scheduled time is over
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Execute ToO Scheduling Block	Interrupt and observe Fast
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Execute ToO Scheduling Block	Evaluate urgency of the SB
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Execute ToO Scheduling Block	Prolong Observations and join other Sub-arrays with or without updating (e.g. target coordinates)
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Check sanity of alert and update the list of alerts
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Define Observation Parameters and Pattern

Supported Process	Activity/Process	Automated Action
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Filter Alert (advanced filter)
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Process Alert
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Rank Alert and reassign priority
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Receive Alert
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Filter and Rank and Process ToOs	Validate and Filter Alert (basic filter) and assign priority
Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Fix Issue reported from Data Quality Inspection	Provide OES system status report
Science Alert Generation: from Collected Data to Generated Science Alert	Derive and Apply Calibration Coefficients for Online Image Reconstruction	Apply calibration coefficients on-line
Science Alert Generation: from Collected Data to Generated Science Alert	Derive and Apply Calibration Coefficients for Online Image Reconstruction	Derive on-line calibration coefficients
Science Alert Generation: from Collected Data to Generated Science Alert	Derive and Apply Calibration Coefficients for Online Image Reconstruction	Derive on-line muon calibration parameters
Science Alert Generation: from Collected Data to Generated Science Alert	Execute on-line data processing and analysis	Execute Online Stage 1 Data Processing (DL0 --> DL1)
Science Alert Generation: from Collected Data to Generated Science Alert	Execute on-line data processing and analysis	Execute Online Stage 2 Data Processing (DL1 --> DL2)
Science Alert Generation: from Collected Data to Generated Science Alert	Execute on-line data processing and analysis	Execute Online Stage 3 Data Processing (DL2 --> DL3)
Science Alert Generation: from Collected Data to Generated Science Alert	Execute on-line data processing and analysis	Execute Online Stage 4 Data Processing (DL3 --> DL4)
Science Alert Generation: from Collected Data to Generated Science Alert	Generate Scientific Alerts	Produce list of internal science alerts

Supported Process	Activity/Process	Automated Action
Science Alert Generation: from Collected Data to Generated Science Alert	Generate Scientific Alerts	Retrieve field of view information for the Science Alerts
Science Alert Generation: from Collected Data to Generated Science Alert	Generate Scientific Alerts	Make maps and look for significant sources
Observation Execution: from Short-Term Schedule to Collected Data	Manage Alarms during Operations	Insert Alarm
Observation Execution: from Short-Term Schedule to Collected Data	Manage Alarms during Operations	Filter Alarm (redundancy discarding)
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	Manage Internal Scientific Alerts	Filter ToO (basic filter)
Observation Execution: from Short-Term Schedule to Collected Data	Monitor Execution of Observations	Produce indicators on the proposal execution status during the night.
Observation Execution: from Short-Term Schedule to Collected Data	Monitor Execution of Observations	Retrieve the list of observed scheduling blocks during the night
Observation Execution: from Short-Term Schedule to Collected Data	Monitor Execution of Observations	Retrieve acquired data statistics
Observation Execution: from Short-Term Schedule to Collected Data	Monitor Execution of Observations	Send indicators of the proposal execution status to the OSS
Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Environment	Produce human-readable environment status report
Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Environment	Store environment monitoring data
Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Status of the Operations in a CTA Site	Produce human-readable on-site system status report
Observation Execution: from Short-Term Schedule to Collected Data	Monitor the Status of the Operations in a CTA Site	Transfer on-site system status report to OSS
Observation Execution: from Short-Term Schedule to Collected Data	Perform an Observation	Adapt Short-Term Schedule and trigger execution of a single Scheduling Block
Observation Execution: from Short-Term Schedule to Collected Data	Perform Calibration Run and Store Raw Calibration Data	Compress calibration data
Observation Execution: from Short-Term Schedule to Collected Data	Perform Calibration Run and Store Raw Calibration Data	Store calibration data
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night Lidar Shots	Check the target position with the Laser Traffic Control System
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night Lidar Shots	Pick next LIDAR position
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night Lidar Shots	Remove the LIDAR shot position from the list
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night Lidar Shots	Store LIDAR Data

Supported Process	Activity/Process	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night Lidar Shots	Verify the LIDAR positions with the Laser Traffic Control System and remove rejected positions
Observation Execution: from Short-Term Schedule to Collected Data	Prepare a Calibration Run with External Light Source	Request auxiliary instruments to prepare for calibration
Observation Execution: from Short-Term Schedule to Collected Data	Prepare a Calibration Run with External Light Source	Request telescope to prepare for calibration
Issue Identification: from Collected Data to Identified Issue	Put the Array to Safe State	Ask Array Elements to go to the Safe State
Issue Identification: from Collected Data to Identified Issue	Put the Array to Safe State	Raise an Alarm
Issue Identification: from Collected Data to Identified Issue	Put the Array to Safe State	Verify that all elements arrived in the Safe State
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Cancel the execution of the scheduling block and release telescopes of the sub-array
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Create a flag for the data quality monitoring
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Notify to the real time analysis process of a loss of a telescope
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Remove the telescope from the list of available telescopes
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Stop camera data acquisition and remove telescope from the sub-array data acquisition and triggering
Observation Execution: from Short-Term Schedule to Collected Data	React to a New External Laser Shot Request	Continue observations as planned
Observation Execution: from Short-Term Schedule to Collected Data	React to a New External Laser Shot Request	Continue planned observations and send feedback to the Laser Traffic Control System
Observation Execution: from Short-Term Schedule to Collected Data	React to a New External Laser Shot Request	Evaluate external laser shot proposal
Observation Execution: from Short-Term Schedule to Collected Data	React to a New External Laser Shot Request	Reschedule observations avoiding laser directions
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	React to Scientific Alert	Create Scheduling Block
React to Target of Opportunities: from Received Science Alert to Updated Short-Term Schedule	React to Scientific Alert	Update ongoing ToO observations (e.g. target coordinates) without prolonging observations
React to Target of Opportunities: from	React to Scientific Alert	Update Short-Term Schedule

Supported Process	Activity/Process	Automated Action
Received Science Alert to Updated Short-Term Schedule		
Observation Execution: from Short-Term Schedule to Collected Data	Report Night Performance in a Site	Merge all OES report results
Observation Execution: from Short-Term Schedule to Collected Data	Retrieve and Store Monitoring Data	Check the safety limits of the monitored elements
Observation Execution: from Short-Term Schedule to Collected Data	Retrieve and Store Monitoring Data	Extract downsampled monitoring data
Observation Execution: from Short-Term Schedule to Collected Data	Retrieve and Store Monitoring Data	Gather monitoring data
Observation Execution: from Short-Term Schedule to Collected Data	Retrieve and Store Monitoring Data	Produce an alarm based on the monitoring information
Observation Execution: from Short-Term Schedule to Collected Data	Retrieve and Store Monitoring Data	Store raw monitoring data
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Schedule Programmes Online	Calculate short-term schedule
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Schedule Programmes Online	Create list of scheduling blocks to be executed during the night
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Schedule Programmes Online	Retrieve mid-term schedule
Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Schedule Programmes Online	Store short-term schedule as executed during the night
Observation Execution: from Short-Term Schedule to Collected Data	Shutdown System Array Elements	Stop array element software
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Contact SAS to find safety and interlock status
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Receive telescope power-on completion signal
Observation Execution: from Short-Term Schedule to Collected Data	Startup Array Elements in Cold Startup Mode	Startup array elements software running in the computer cluster
Observation Execution: from Short-Term Schedule to Collected Data	Startup Array Elements in Cold Startup Mode	Startup remaining OES components
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Produce timeframe log summary
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Receive alarm log information
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Receive Operator Logbook entry
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Receive real-time data quality log (Results)

Supported Process	Activity/Process	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Receive on-site software log
Observation Execution: from Short-Term Schedule to Collected Data	Store Online Logging Information	Store on-site Logs
Science Alert Generation: from Collected Data to Generated Science Alert	Synchronise Science Alert Generation Analysis Configuration	Check for updates on science alert generation configuration
Science Alert Generation: from Collected Data to Generated Science Alert	Synchronise Science Alert Generation Analysis Configuration	Update configuration of the OES Science alert generation
Process Data: from Collected Data to Archived Science Products	Transfer DL0 data to off-site Archive	Make DL0 data available for transfer
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Instruct Array Element to go to Ready state
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Instruct Array Elements to go to the Standby State
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Verify Array Elements status

Table 33: Overview of the actions, which are automatically performed by the OES.

4.3.6.10 Main Interfaces

This section provides an overview of the ports that the OES provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Array Infrastructure	Infrastructure Monitoring, Infrastructure Status	Monitoring of the array infrastructure elements (most notably the clock synchronisation status)	
Auxiliary Instruments	Atmospheric Monitoring Device Measurement, LIDAR data, Weather Status, Weather Forecast, Auxiliary Instrument Status, Alarm, Software Logs, Auxiliary Instrument Command, Auxiliary Instrument Configuration, Telescopes Pointing Direction, Power Command	Control, monitoring and readout of the auxiliary instruments	

Port	Main Data Element Exchanged	Purpose	Notes
Configuration	Configuration	Update of the configuration of the instruments at the CTA array site	
DPPS Interface	DL0, Observation Metadata, Analysis Support Information	Provision of the bulk science and monitoring data and related metadata information, synchronisation of analysis support information (e.g. instrument response function)	
Inter-Facility Collaboration	Science Alert, Imminent Observation Schedule	Exchange of science alerts for ToOs and imminent observation schedules for coordination of observations	
Laser Avoidance	Lidar Observation List, External Laser Observation List	Coordination with neighbouring facilities on the usage of laser systems	
Low-Level Control	Low-Level Commands, Observation Script	Maintenance and engineering activities	
Mid-term Scheduler and System Information	Mid-Term Schedule, Configuration, LIDAR Observation List, Proposal Execution Status, OES Status, Monitoring Data, Logging Data, Environment Status Report, System HW Status Report, Ticket, Identity Attributes	Synchronisation of all information relevant for the science operations (mid-term schedule, configuration) and provision of all monitoring and engineering information relevant for site operations, user authentication and authorization	
Operator Control	Operator Commands, Short-Term Schedule, Scientific Alert, Environment Status, Weather Status, Data Quality Alarm, Alarm	Main interface for the Operator to control and monitor the operations at the CTA array site	
Safety and Alarms	Interlock and Safety Elements Status, Telescope Safety Status, Safety Signal, Alarm, Alarm Log Information	Exchange on safety-relevant information for resource management and reaction on safety alerts in case of an emergency	
Science Alert Feedback	Science Alert Analysis Result,	Exchange of science alert information for	

Port	Main Data Element Exchanged	Purpose	Notes
	Science Alert Information, Nightly Scientific Summary, Environment Status Report	ToO handling and summary information on the observation nights	
Telescopes	Telescope Raw Data (R1), Camera Trigger Timestamps, Telescope Monitoring Data, Telescope Status, Alarm, Software Logs, Telescope Commands, Telescope Configuration, Flagged Camera Trigger Timestamps, Power Command	Control, monitoring and readout of the Telescope and its elements	

Table 34: Overview of the main interfaces for the OES.

4.3.6.11 Deployment

The OES has two instances, located at each of the CTA sites. The two instances of the OES exchange information and coordinate among each other the execution of ToO observations.

4.3.6.12 Additional Notes

It is envisaged that the software and/or algorithms for the short-term scheduler sub-system is shared with mid-term and long-term scheduler.

It is envisaged that the software and/or algorithms for the science alert generation is shared with that of the off-line analysis software (pipelines).

4.3.7 Operations Support System

4.3.7.1 Summary

NAME AND ACRONYM
Operations Support System (OSS)
SCOPE
A collection of software systems supporting CTA operations. Includes configuration management, issue tracking, maintenance planning, authentication and authorization systems.
CONTEXT
External systems: none Internal systems: Array Infrastructure Elements, Data Processing and Preservation System, Management and Administrative System, Observation Execution System, Safety and Alarm System, Science User Support System
USERS
External users: Contributors Internal users: Configuration Manager, Instrument Scientist, Maintenance Engineer, Operations Support, Software Maintenance Engineer, Support Astronomer
DECOMPOSITION
Authentication and User Management, Computerized Maintenance Management System, Documentation Management and Engineering Information, Engineering and Logging Database, Internal Help Desk, Issue Tracking, Local Technical Resource Management and Planning, Master Configuration Database, Mid-Term Scheduler, Performance Tracking (Dashboard), Reporting and Diagnosis, Test Requirements Database, Warehouse Management System
DEPLOYMENT
Distributed system with multiple instances deployed at the CTA array sites and off-site centres and synchronized to each other
NOTES

4.3.7.2 Name and Acronym

Operations Support System (OSS)

4.3.7.3 Scope

The OSS is a software system that is mainly responsible for the access to information and services used for planning, monitoring, quality control and assurance, to support the Observatory operations and the CTA systems. Therefore, the OSS provides all functionality in support of:

- the management of the local maintenance at the two array sites,
- the management and tracking of spares and technical resources (e.g. vehicle use) at the two array sites and across the Observatory,
- the planning of medium-term activities, including Observatory operations, calibration and maintenance work,
- the management of documentation and engineering information,
- the assessment of the status of the Observatory and the reporting of the Observatory performance, including gathering of the needed information,
- the management of the user access to all CTA systems (authentication and authorization),

The OSS provides a means for information from these sub-systems to be incorporated into the evolving array configuration model that is needed for array response simulations (within the Data Processing and Preservation System).

4.3.7.4 Main Processes

The main processes to which the OSS contributes are related to Observatory operations and include the planning of Observatory operations and the support for its execution as well as the support for the engineering and maintenance activities across the Observatory's lifecycle. The relevant processes are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
   a. *Observation Planning: from Validated Proposals to Long-Term Schedule*
   b. *Schedule Refinement: from Long-Term Schedule to Short-Term Schedule*
   c. *Observation Execution: from Short-Term Schedule to Collected Data*
   d. *Process Data: from Collected Data to Archived Science Products*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
   a. *Calibration: Perform, Check and Refine Calibration and Calibration Instruments*
   b. *Support Users*
   c. *Issue Identification: from Collected Data to Identified Issue*
   d. *Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action*

4.3.7.5 Context and User Interactions

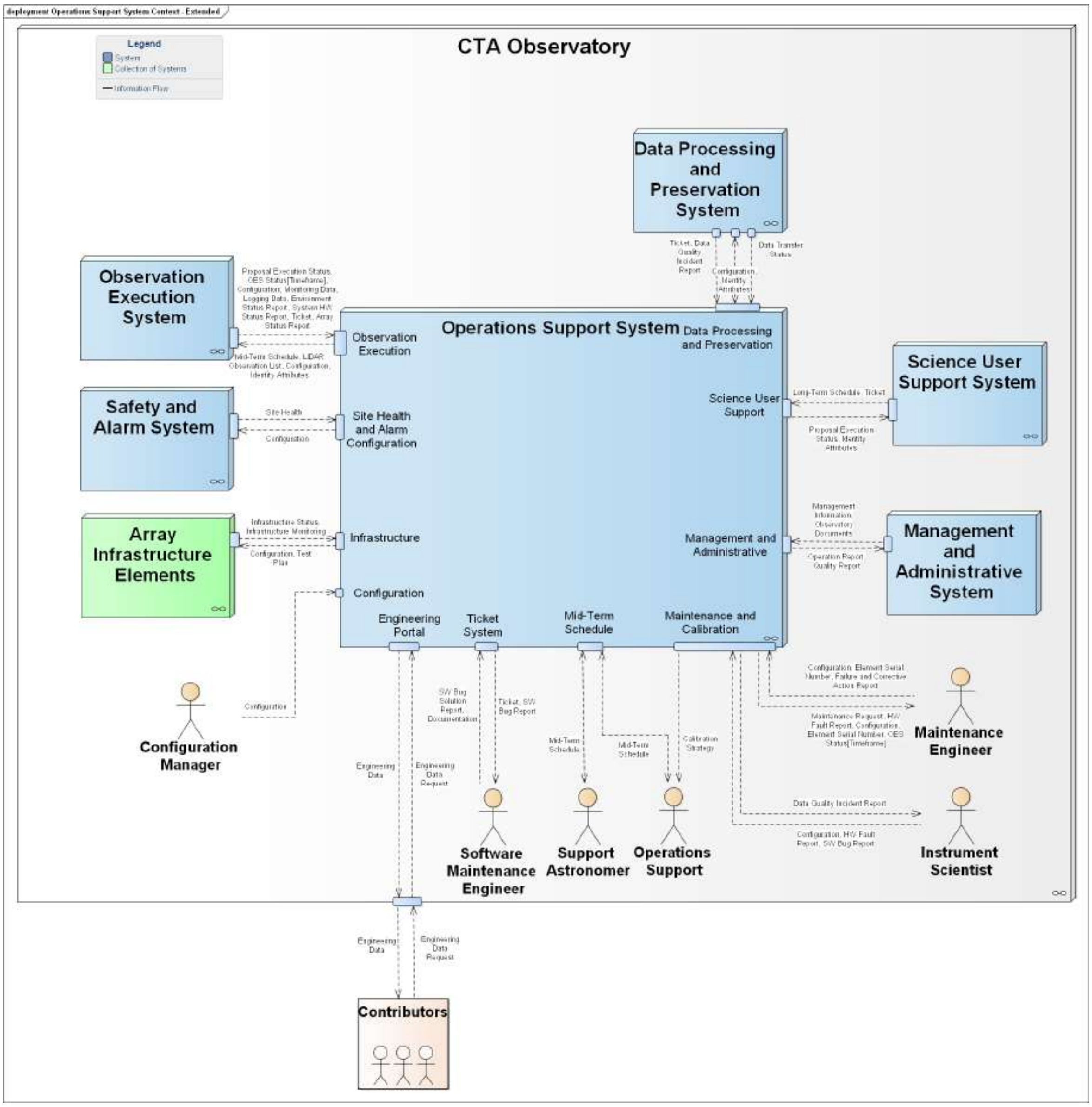


Figure 33: Context of the OSS. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the OSS and its interactions. The OSS interacts only with internal CTAO systems, mainly for the exchange and synchronisation of information across the Observatory (e.g. configuration, status information of the systems, issue tracking, documentation and engineering information). The OSS is used by many internal CTAO stakeholders mainly for the planning and execution of activities and resources to support maintenance. The OSS provides the main access point to the engineering information for external Contributors.

Interactions with Internal Systems

- *Observation Execution System*

Continuous synchronisation of configuration information, frequent provision of mid-term schedule, including maintenance activities, and planned LIDAR observations, access to all performance indicators (e.g. proposal execution status), monitoring and logging information and continuous receiving of tickets and reports, synchronisation of user profiles and attributes for the authentication and authorization

- *Science User Support System*

  Provision of proposal execution status and frequent access to long-term schedule, continuous receiving of tickets and reports, synchronisation of user profiles and attributes for the authentication and authorization

- *Safety and Alarm System*

  Receiving of performance indicators and site health information and continuous synchronisation of configuration information

- *Array Infrastructure Elements*

  Receives infrastructure status and monitoring information, provides access to engineering documents, e.g. test plan for testing facilities, and continuous synchronisation of configuration information

- *Data Processing and Preservation System*

  Continuous receiving of tickets and performance indicators and reports (e.g. data transfer status, data quality incident reports), and continuous synchronisation of configuration information, synchronisation of user profiles and attributes for the authentication and authorization

- *Management and Administrative System*

  Receiving of Management information and Observatory documentation (e.g. input to the planning activities, documentation database) and provision of operation and quality reports

4.3.7.6 Users

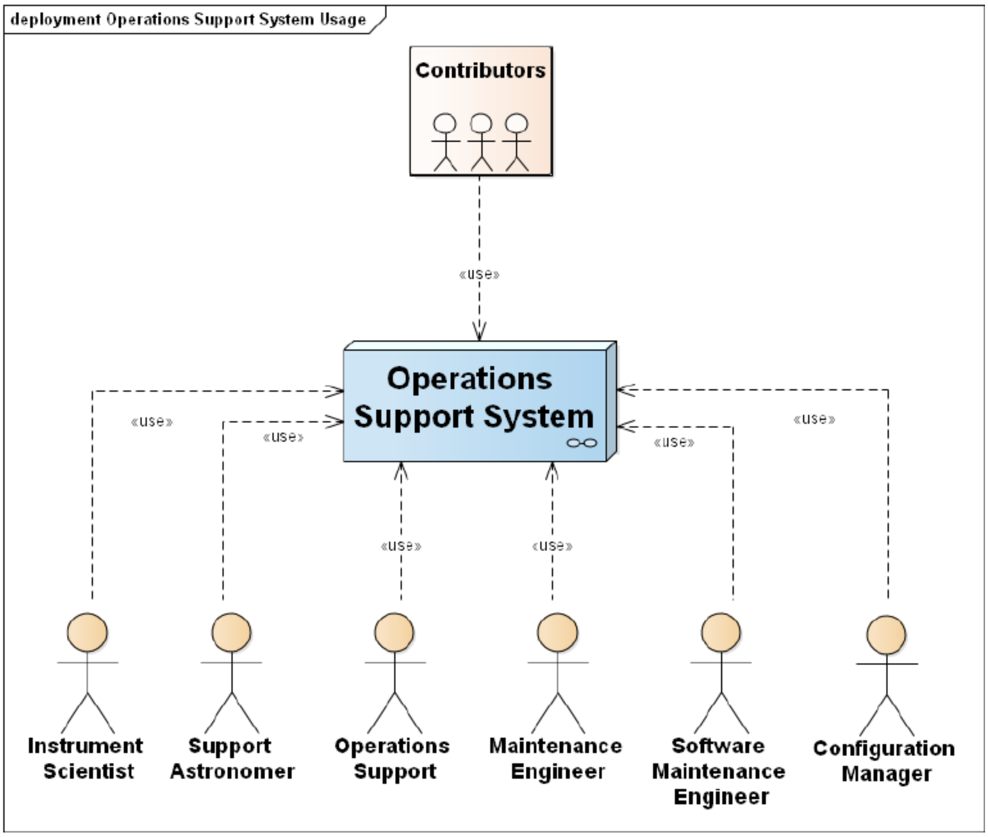


Figure 34: Overview of internal and external users of the OSS.

This section lists the users of the OSS and their interactions with the system. An overview is given in Figure 34 and their definition in Table 35. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Contributors Organisations that provide products, components, parts, devices and/or services to the CTA Observatory.
Internal Stakeholders
Instrument Scientist A CTA instrument expert, capable of diagnosing problems and devising investigative/calibration actions/interventions based on recorded data. Supports maintenance and operation in a flexible manner according to specific needs. Oversees and advises calibration activities and data evaluation. **Support Astronomer** Oversees and supports scheduling of observations from long-term to short-term, supervises reactions to external and internal science alerts. **Operations Support** Responsible for the support of all instrument operations and maintenance activities. Assists operations and maintenance personnel on-site. **Maintenance Engineer** Manages and executes maintenance activities and conducts on-site preventive and corrective maintenance tasks. **Software Maintenance Engineer** Responsible for overseeing and executing the maintenance (e.g. bug fixes and maintaining compatibility) and development (e.g. requested new features) all software associated with CTA observatory and science operations.

Configuration Manager	Keeps track of the status of all instruments, part replacements etc. Responsible for the central management of all documentation, logging and configurations.

Table 35: Internal and external users of the OSS with their definition.

Interactions with External Stakeholders

- *Contributors*

  Exchange of engineering data and documentation in support of the contributor's work

Interactions with Internal Stakeholders

- *Configuration Manager*

  Change of the CTAO configuration (e.g. configuration of instrumentation or of documentation) following e.g. updated instrument status information or parts replacement

- *Software Maintenance Engineer*

  Executes software maintenance procedures following identified issues/maintenance requests and provides relevant reports or updated documentation

- *Support Astronomer*

  Supports the mid-term scheduling for science-related observations and for reaction to internal and external Science Alerts

- *Operator*

  Issue reports and requests for maintenance activities

- *Operations Support*

  Supports calibration and maintenance activities and their scheduling, following defined guidelines and status information

- *Instrument Scientist*

  Identifies and supports identification of issues (e.g. data quality incident reports)

- *Maintenance Engineer*

  Provides failure action reports and updated configuration and element serial number following maintenance activities, receives maintenance requests together with relevant information (e.g. failure reports, current configuration and element serial number, monitoring information)

4.3.7.7 Main Data Elements

Table 36 lists the main data elements that are produced/consumed and stored/logged by the OSS.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Array Status Report	Report on the status of the array on different time scales	Consumed	Logged
Calibration Strategy	Documentation describing the required CTA Observatory calibration procedures	Produced/Consumed	Stored
Configuration	Configuration of the arrays, including all instrument and infrastructure configuration	Produced/Consumed	Stored
Data Quality Incident Report	Report on identified issues of data quality	Consumed	Stored
Data Transfer Status	Status of the data transfer from array sites to the data centre(s)	Consumed	Logged
Documentation	CTA Observatory documents	Consumed	Stored
Element Serial Number	Serial number of the products, components, parts, and/or devices	Produced/Consumed	Stored
Engineering Data	Data supporting the engineering activities (e.g. requirements, CAD models)	Produced	Stored
Engineering Data Request	Request for engineering data	Consumed	Logged
Environment Status Report	Report on the collected status information on the site environment	Consumed	Stored
Failure and Corrective Action Report	Report on taken actions following a maintenance activity	Consumed	Stored
HW Fault Report	Report on a fault related to hardware problems	Produced/Consumed	Stored
Identity Attributes	User identification and attributes for authentication and authorization (e.g. for data access rights)	Produced	Stored
Infrastructure Monitoring	Monitoring information of the array infrastructure elements	Consumed	Stored
Infrastructure Status	Status information of the array infrastructure element	Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
LIDAR Observation List	List of planned observations with the LIDAR	Produced	Stored
Logging Data	Logging information from the on-site elements	Consumed	Stored
Long-Term Schedule	Collection of all the observation programs in a cycle, with each program being a collection of scheduling blocks, on the timescale of years to months	Consumed	Stored
Maintenance Request	Request for the execution of a defined maintenance activity	Produced	Logged
Management Information	Documentation and decisions provided by the CTA management group for the operation and construction of the CTA Observatory	Consumed	Stored
Mid-Term Schedule	Collection of scheduling blocks, on the timescale of weeks to days	Produced/Consumed	Stored
Monitoring Data	Monitoring information from the on-site elements	Consumed	Stored
Observatory Documents	Documents covering the CTA Observatory elements and tasks (e.g. calibration strategy, test plan)	Consumed	Stored
OES Information [Timeframe]	Information from the logs, noted events and operator logbook	Consumed	Stored
Operation Report	Report on the Observatory operation performance	Consumed	Stored
Proposal Execution Status	Status of the execution of a certain proposal	Produced/Consumed	Stored
Quality Report	Report on the performance of the systems and quality of services of the CTA Observatory	Produced	Logged
Site Health	Performance report on the safety-related status of the CTA array site	Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
SW Bug Report	Ticket or report on a software-related identified issue	Produced	Stored
SW Bug Solution Report	Report or ticket on the fix of a software-related identified issue	Consumed	Stored
System HW Status Report	Report on the status of individual hardware systems and devices at the CTA array site	Consumed	Stored
Test Plan	Plan including the test strategy and work order for executing a test	Produced/Consumed	Stored
Ticket	Ticket providing the description of an issue related to problems with the software, hardware, data quality or user experience	Produced/Consumed	Stored

Table 36: Main data elements exchanged with OSS.

4.3.7.8 Decomposition

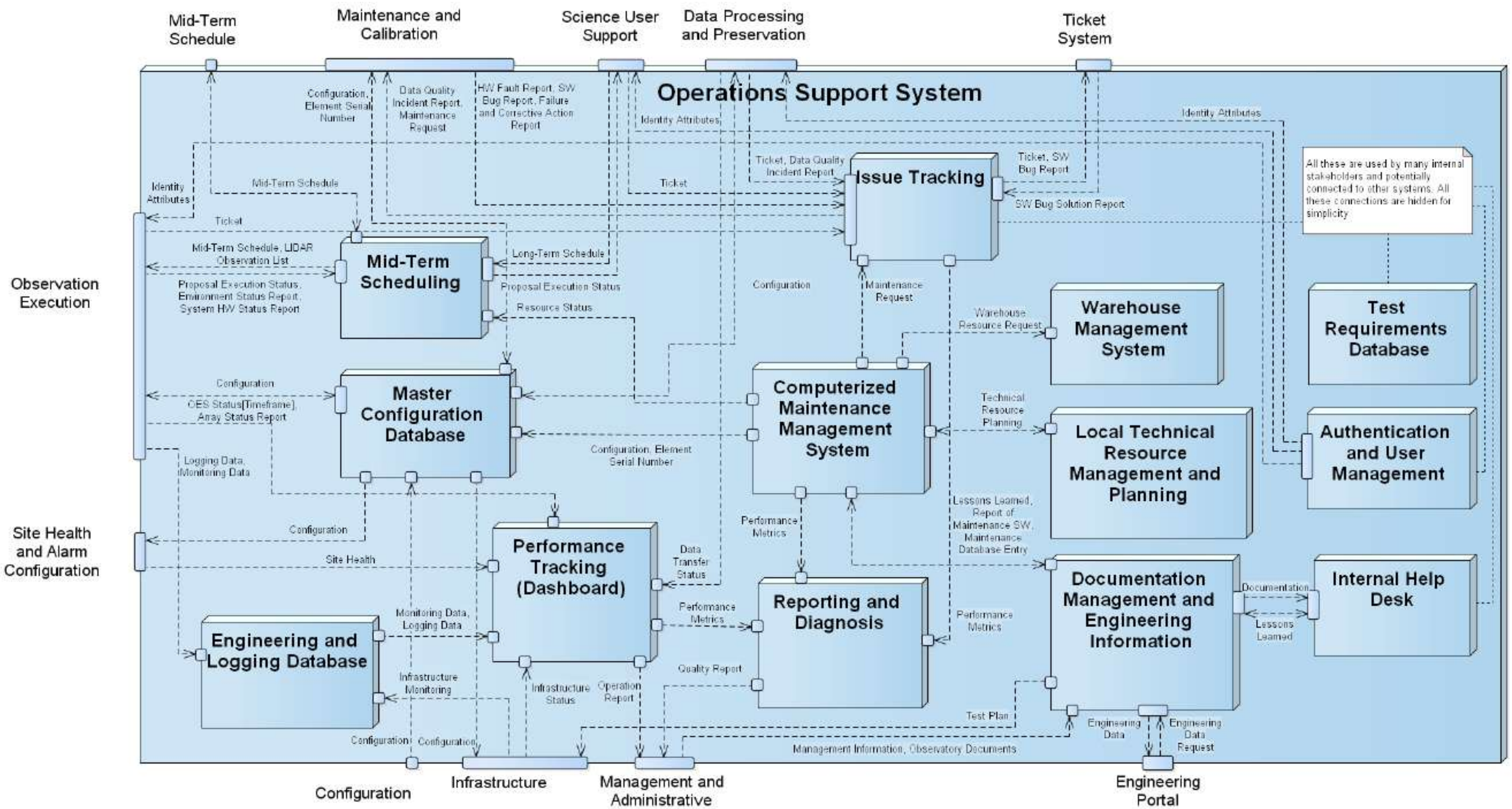


Figure 35: First-level functional decomposition of the OSS.

A preliminary functional decomposition of the OSS at the first level is shown in Figure 35. The OSS is composed of the following main sub-systems that group functionality in relation to:

- *Mid-Term Scheduler*

  Software system providing all functionality to schedule Observatory observations, calibration and maintenance activities on the timescale of weeks to days

- *Master Configuration Database*

  Software system containing the configuration of the Observatory, including the instrument configuration, and which is synchronised with the configuration used at other CTAO systems

- *Engineering and Logging Database*

  Software system providing access to engineering and logging information collected from the array sites

- *Performance Tracking (dashboard interface)*

  Software system providing access to performance indicators of the Observatory

- *Computerized Maintenance Management System*

  Software system to support the maintenance activities

- *Issue Tracking*

  Software system to manage and maintain the list of issues collected throughout the Observatory

- *Warehouse Management System*

  Software system to support the management of spares

- *Local Technical Resource and Management Planning*

  Software system to support the planning of resources at each site

- *Documentation Management and Engineering Information*

  Software system providing access to Observatory documentation and engineering information and to organise the associated workflow

- *Test Requirements Database*

  Software system providing access to all test-related documentation, including definition of procedures, test plans, work orders etc.

- *Authentication and User Management*

Software system to manage user accounts and their authentication for the CTA Observatory and to provide this service to the CTAO systems

- *Internal Help Desk*

  Software system implementing a help desk for internal usage at the various locations

4.3.7.9 Functionality

This section lists all actions that the OSS performs or in which it supports a user. These actions provide a behavioral description of the system.

4.3.7.9.1 *User-Supported Processes and Actions*

This section lists list all actions in which the system supports the users, and which are invoked by the users of the system.

External Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Contributor	Not yet modeled		

Table 37: Overview of the actions in which the external stakeholders are supported by the OSS.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Configuration Manager	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Manage configuration
Data Quality Scientist	Process Data: from Collected Data to Archived Science Products	Check Scientific Data Quality Offline	Issue quality incident report
Instrument Scientist	Observation Planning: from Validated Proposals to Long-Term Schedule	Define new Observing mode	Set up the instrumentation and software for this new observing mode
Maintenance Engineer	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Calibrate a Calibration Instrument	Prepare work order for calibration a calibration instrument
Maintenance Engineer	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Prepare a Calibration Run with External Light Source	Add Calibration Run to Mid-Term Schedule
Maintenance Engineer	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Prepare a Calibration Run with External Light Source	Extract Calibration Configuration

Supported User	Supported Process	Process/Activity	User-Supporting Action
Maintenance Engineer	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Prepare a Calibration Run with External Light Source	Extract Calibration Strategy
Maintenance Engineer	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Revise an Instrument Calibration Record	Revise instrument calibration record
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Extract information for further investigation
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Prepare work order for calibration a calibration instrument
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Manage maintenance
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform a Preventive Maintenance Task	Close Ticket
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform a Preventive Maintenance Task	Open Ticket
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform Corrective Maintenance	Close Ticket
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform Corrective Maintenance	Produce short report/incident report
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform Corrective Maintenance	Register a new Ticket
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform Corrective Maintenance	Retrieve Further Information

Supported User	Supported Process	Process/Activity	User-Supporting Action
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Create a log of the performed work and outcome
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Deliver the replaced component to the corresponding warehouse
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Enter both removed and new element serial number
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Identify the need of replacement of a mirror facet and assign replacement action
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Receive and update the ticket status
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Retrieve configuration and prepare a replacement method statement
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Retrieve the required equipment and spare instrumentation and bring it to the array
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Return the equipment and spare instrumentation and log its availability
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Create a log of the performed work and outcome
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Deliver the replaced component to the corresponding warehouse
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Enter both removed and new element serial number

Supported User	Supported Process	Process/Activity	User-Supporting Action
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Identify the need to replace a component of the drive system
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Receive and Update Ticket Status
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Retrieve configuration and prepare a replacement method statement
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Retrieve equipment and spare instrumentation and bring it to the array
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Create a log of the performed work and outcome
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Deliver the replaced component to the corresponding warehouse
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Enter both removed and new element serial number
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Identify the need of replacement of a camera component (e.g. a PMT Module)
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Receive and Update Ticket Status
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Retrieve configuration and prepare a replacement method statement
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Retrieve equipment and spare instrumentation and bring it to the array

Supported User	Supported Process	Process/Activity	User-Supporting Action
Operations Support	Calibration: Perform, Check and Refine Calibration and Calibration Instruments	Setup Equipment and Acquire Data for Calibration for Image Reconstruction	Schedule calibration scheduling block
Operations Support	Observation Execution: from Short-Term Schedule to Collected Data	Update Schedule to avoid External Laser Shots	Compare the proposed list of Laser Shots with Mid-Term Schedule and update list
Software Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Fix Software Bug
Software Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Fix Issue reported from Data Quality Inspection	Manage Software
Software Maintenance Engineer	Support Users	Support Users (Level 1)	Close Ticket
Software Maintenance Engineer	Support Users	Support Users (Level 1)	Close Ticket
Software Maintenance Engineer	Support Users	Support Users (Level 1)	Validate Answer
Software Maintenance Engineer	Support Users	Support Users (Level 1)	Write report and update FAQ
Software Maintenance Engineer	Support Users	Support Users (Level 2)	Close Ticket
Software Maintenance Engineer	Support Users	Support Users (Level 2)	Investigate issue (level 2 support)
Software Maintenance Engineer	Support Users	Support Users (Level 2)	Validate Answer
Software Maintenance Engineer	Support Users	Support Users (Level 2)	Write report and update FAQ
Software Maintenance Engineer	Support Users	Support Users (Level 2)	Close Ticket
Software Maintenance Engineer	Support Users	Support Users (Level 3)	Close Ticket
Software Maintenance Engineer	Support Users	Support Users (Level 3)	Investigate issue (level 3 support)
Software Maintenance Engineer	Support Users	Support Users (Level 3)	Validate Answer

Supported User	Supported Process	Process/Activity	User-Supporting Action
Software Maintenance Engineer	Support Users	Support Users (Level 3)	Write report and update FAQ
Support Astronomer	Schedule Refinement: from Long-Term Schedule to Short-Term Schedule	Prepare Mid-Term Schedule	Prepare Mid-Term Schedule

Table 38: Overview of the actions in which the internal stakeholders are supported by the OSS.

4.3.7.9.2 Automated Processes and Actions

This section lists the processes where the OSS takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Perform Night LIDAR Shots	Extract mid-term schedule
		Form a List of Lidar shot Positions and Times
	Monitor the Environment	Receive environment status report
	Monitor the Status of the Operations in a CTA Site	Receive on-site system status report
	Update Schedule to avoid External Laser Shots	Send updated list of laser shots to the Laser Traffic Control System
	Manage Alarms during Operations	Store explanation report on reaction to alarm
Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Transfer operation list of all replacements
	Replace electronic equipment in a telescope camera	Transfer operation list of all replacements
	Replace a mirror facet	Transfer operation list of all replacements

Table 39: Overview of the actions, which are automatically performed by the OSS.

4.3.7.10 Main Interfaces

This section provides an overview of the ports that the OSS provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Configuration	Configuration	Access to configuration database	
Data Processing and Preservation	Configuration, Data Transfer Status, Data Quality Incident Report, Ticket, Identity Attributes	Record the status of data processing and synchronisation of configuration, user	

Port	Main Data Element Exchanged	Purpose	Notes
		authentication and authorization	
Engineering Portal	Engineering Data, Engineering Data Request	Exchange of engineering information	
Infrastructure	Infrastructure Status	Record the status of the on-site infrastructure	
Maintenance and Calibration	Calibration Strategy, Maintenance Request, Configuration, Element Serial Number, Failure and Corrective Action Report, HW Fault Report, OES Status, Data Quality Incident Report, SW Bug Report	Planning and reporting of maintenance and calibration activities, access to maintenance and calibration-related information	
Management and Administrative	Management Information, Observatory Documents	Exchange of Observatory documentation	
Mid-Term Schedule	Mid-Term Schedule	Adaptation of the mid-term schedule to include e.g. calibration and maintenance activities	
Observation Execution	Mid-Term Schedule, LIDAR Observation List, Configuration, Proposal Execution Status, OES Status, Monitoring Data, Logging Data, Environment Status Report, System HW Status Report, Identity Attributes	Provide input for the on-site operation to organise the schedule, synchronize the configuration and to keep a record of the monitoring, logging and status information from all on-site systems, user authentication and authorization	
Science User Support	Long-Term Schedule, Ticket, Proposal Execution Status, Identity Attributes	Receiving of long-term schedule as basis for operations planning and report on status of the observations, user authentication and authorization	
Site Health and Alarm Configuration	Site Health, Configuration	Record the on-site health status (e.g. safety information) and synchronize the configuration	

Port	Main Data Element Exchanged	Purpose	Notes
Ticket System	Ticket, SW Bug Solution Report, Documentation	Report and resolving of reported software issues	

Table 40: Overview of the main interfaces for the OSS.

4.3.7.11 Deployment

Multiple instances will be deployed at the CTA array sites and off-site centres and synchronized to each other. However, the duplication of services should be reduced as much as possible.

4.3.7.12 Additional Notes

4.3.8 *Safety and Alarm System*

4.3.8.1 Summary

NAME AND ACRONYM
Safety and Alarm System (SAS)
SCOPE
The hardware and software system for monitoring and control of the primary safety-relevant aspects (incl. interlocks) of the Telescopes and Infrastructure elements at a CTA array site. Includes an integrated alarm system.
CONTEXT
External systems: none Internal systems: Array Infrastructure Elements, Auxiliary Instruments, Observation Execution System, Operations Support System, Telescope {*}
USERS
External users: none Internal users: Maintenance Engineer, Operator
DECOMPOSITION
Alarm and Control System, Local Interlock and Power Control {*}, Access Control Alarm System
DEPLOYMENT
One instance of the SAS is deployed at each CTA array site
NOTES

4.3.8.2 Name and Acronym

Safety and Alarm System (SAS)

4.3.8.3 Scope

The Safety and Alarm System is envisaged as a high-reliability/low-complexity hardware and software system for monitoring and control of the primary safety-relevant aspects of the telescope arrays at the two sites. It is independent from and supplementary to any safety systems and functionality that is contained within the other systems. The SAS:

- provides information for the Operators and Day Crew to monitor the basic status (for example: OK, Off, Fault) of all array elements and associated systems (possible alarm sources are e.g. Telescopes and the Array Infrastructure Elements such as on-site ICT components, cooling and power systems),
- collects and manages safety-relevant alarms generated by these systems (for example fire alarms, access alarms, telescope alarms) to present operators with the clear information needed to minimize the time taken to diagnose the root problem and decide on a response,
- collects and provides information on the status of interlocks and power at Telescopes down to Telescope sub-system level (e.g. Camera), Auxiliary Instruments and Array Infrastructure Elements,
- contains a system for monitoring which individuals are present within the array at a given time and, in case of unauthorized access, for generating alarms.

The Safety and Alarm System must be interfaced to the Observation Execution System to allow alarm information to flow between the Observation Execution System and the Safety and Alarm System and for power/fault/interlock status to be available to the Observation Execution

System for planning / resource management. The Safety and Alarm System must be interfaced to the Operations Support System to provide a long-term record of the basic status of array elements for use in planning and reporting.

4.3.8.4 Main Processes

The main processes to which the SAS contributes are related to support the safe execution of Observatory operations and maintenance. The relevant processes are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
    a. *Observation Execution: from Short-Term Schedule to Collected Data*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
    a. *Issue Identification: from Collected Data to Identified Issue*
    b. *Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action*

4.3.8.5 Context and User Interactions

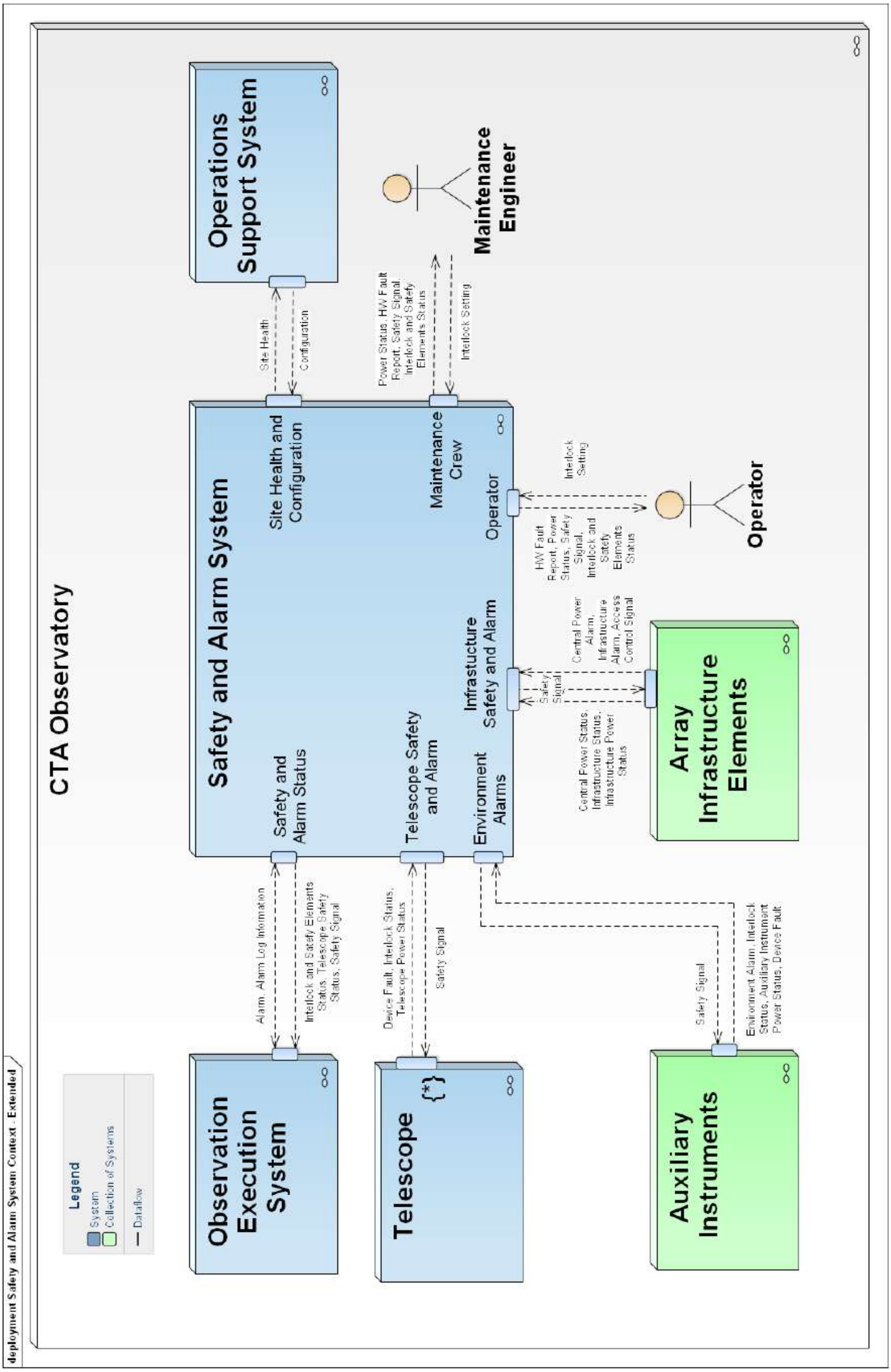


Figure 36: Context of the SAS. Shown are the interactions with other systems of the CTAO and with the internal Stakeholders. Please note that the Expert Operator uses the same interface as the Operator.

Figure 19 shows the context of the SAS. The SAS does not interact with the external world but has interfaces with all on-site systems and on-site personnel to support the safe operation and maintenance of the CTA arrays. The interactions of the SAS are summarized in this and the next section.

Interactions with Internal Systems

- *Observation Execution System*

  Continuously provides safety-relevant alarms and related information as well as the interlock and safety status from the various systems. Is informed of any safety-relevant alarm detected at the level of OES and informs in case a safety-relevant problem is detected.

- *Telescope*

  Continuously receives the interlock and power status of the Telescope and is informed of safety-relevant device faults. Informs the Telescope in case a safety-relevant problem is detected. The power of the Telescope can be controlled via the SAS in case of emergency or maintenance actions, which also provides the status of the central power system.

- *Auxiliary Instruments*

  Continuously receives the interlock and power status of the Auxiliary Instruments and is informed on safety-relevant device faults as well as safety-relevant alarms from the environment, e.g. earthquake alerts. Informs the Auxiliary Instruments in case a safety-relevant problem is detected. The power of the Auxiliary Instruments can be controlled via the SAS in case of emergency or maintenance actions, which also provides the status of the central power system.

- *Array Infrastructure Elements*

  Continuously receives the interlock and power status of the Array Infrastructure Elements as well as information on the access to the array sites. The power of the Array Infrastructure Elements can be controlled via the SAS in case of emergency or maintenance actions, which also provides the status of the central power system.

- *Operations Support System*

  Provision of reports on the general status of the site health and synchronisation of the configuration

4.3.8.6 Users

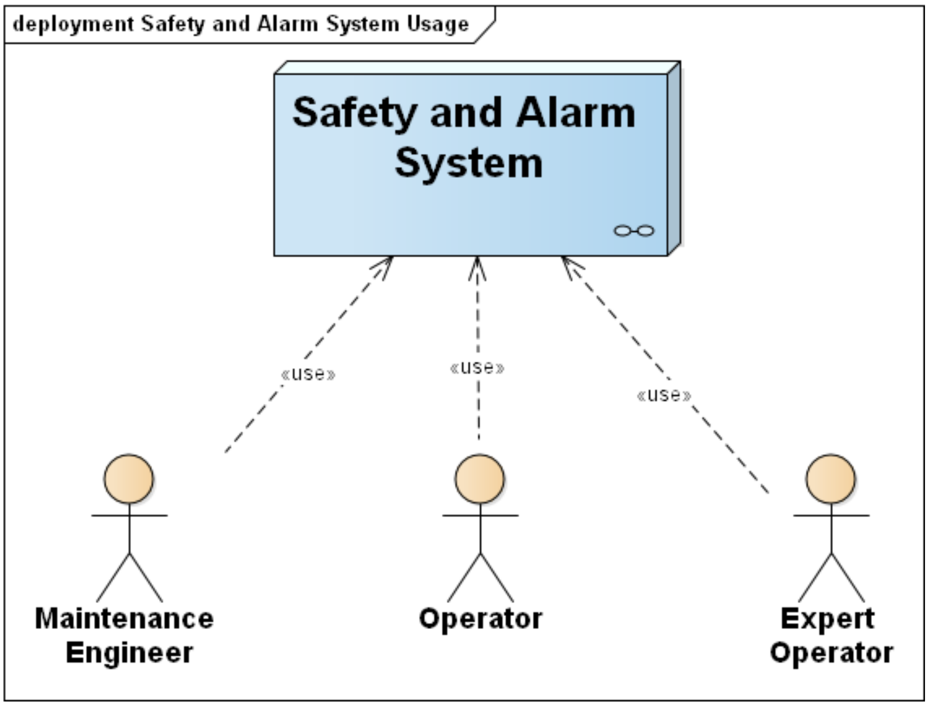


Figure 37: Overview of the users of the SAS.

This section lists the users of the SAS and their interactions with the system. An overview is given in Figure 37 and their definition in Table 41. Please note that maintenance of the components itself are implicit for all hardware and software systems. It should be noted that only personnel with appropriate rights will have access to the system.

External Stakeholders
Internal Stakeholders
Expert Operator Has expert access to the instruments and software at the CTA array sites, executes debugging and engineering activities in case of reported problems. **Maintenance Engineer** Manages and executes maintenance activities and conducts on-site preventive and corrective maintenance tasks. **Operator** Responsible for supervising and carrying out scheduled observations and calibrations during the night. Troubleshoots problems, can modify schedule if necessary (e.g. weather/ToO) and logs all activities.

Table 41: Internal and external users of the SAS.

Interactions with Internal Stakeholders

- *Operator and Expert Operator*

  Continuously provides information on the status of the interlocks and power of the various systems and informs on any safety-related problem. In addition, it provides a means to control the power at the various systems.

- *Maintenance Engineer*

Continuously provides information on the status of the interlocks and power of the various systems. In addition, provides means to control the power at the various systems.

4.3.8.7 Main Data Elements

Table 42 lists the main data elements that are produced/consumed and stored/logged by the SAS.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Access Control Signal	Signal notifying that a person accessed the area within the CTA array sites.	Consumed	Logged
Alarm	Problem or condition that should be reported to the operator and may require his/her action	Produced/Consumed	Stored
Alarm Log Information	Additional information on each alarm	Produced/Consumed	Stored
Auxiliary Instrument Power Status	Status information on the power of the auxiliary instrument	Consumed	Stored
Central Power Alarm	Alarm about failure of the central power	Consumed	Stored
Central Power Status	Status information of the central power	Produced/Consumed	Stored
Configuration	Configuration of the arrays, including all instrument and infrastructure configuration	Consumed	Stored
Device Fault	Information in case of a failure of the device	Consumed	Stored
Environment Alarm	Alarm about a critical environmental condition (e.g. earthquake)	Consumed	Stored
HW Fault Report	Report on a fault related to hardware problems	Produced	Logged
Infrastructure Alarm	Alarm from one of the array infrastructure elements	Consumed	Stored
Infrastructure Power Status	Status information of the power of the array infrastructure element	Consumed	Stored
Infrastructure Status	Information of the status of the array infrastructure element	Consumed	Stored
Interlock and Safety Elements Status	Status information on the interlocks and safety status of all	Produced	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	elements at the array site		
Interlock Status	Status information of the interlocks at the system	Produced/Consumed	Stored
Power Status	Status information of the power of the system and its elements	Produced	Stored
Safety Signal	Signal to alert on a safety-relevant issue	Produced	Stored
Site Health	Performance report on the safety-related status of the CTA array site	Produced	Stored
Telescope Power Status	Information on the power status of the telescope	Consumed	Stored
Telescope Safety Status	Information on the safety status of the telescope	Produced	Stored

Table 42: Main data elements exchanged with the SAS.

4.3.8.8 Decomposition

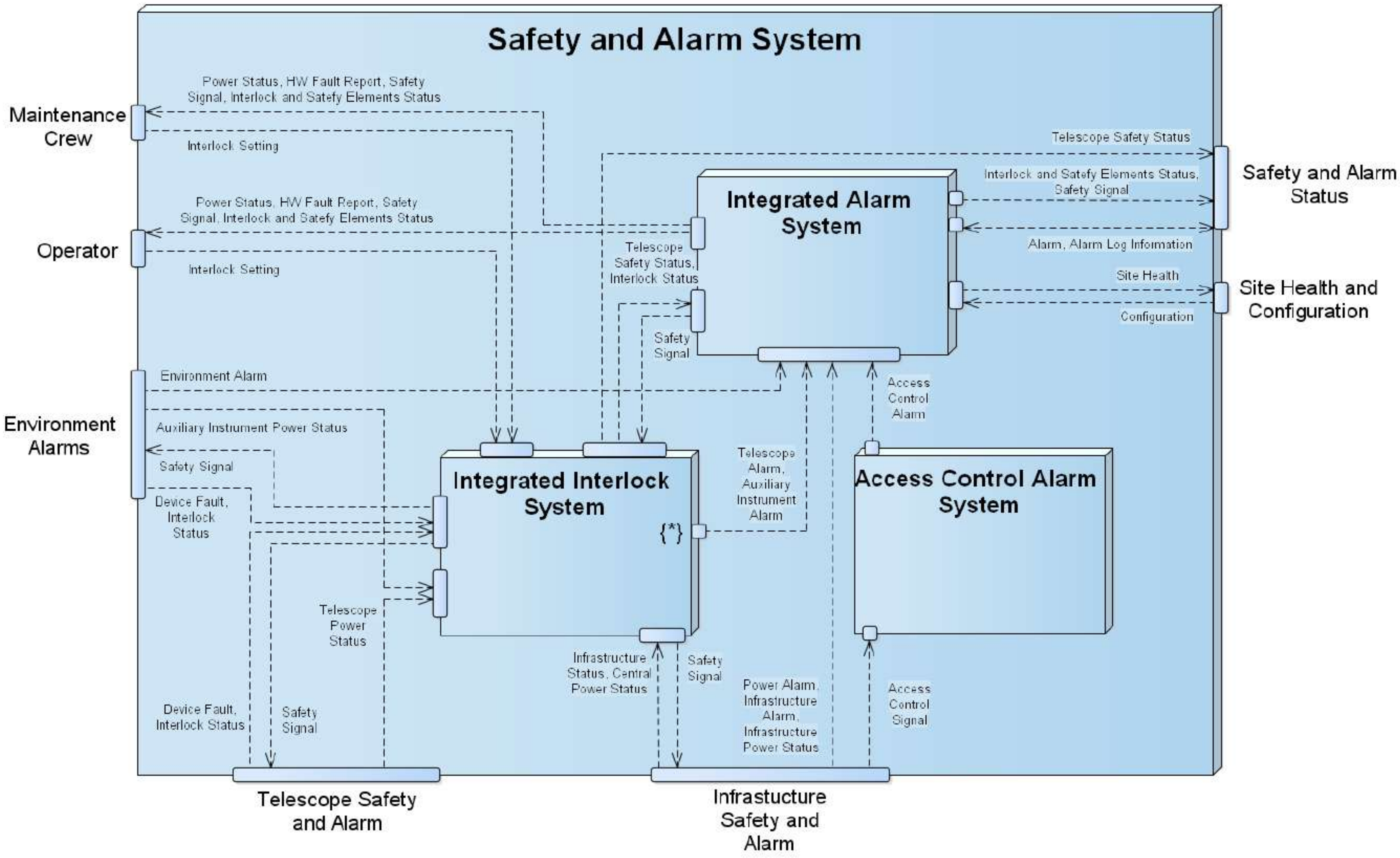


Figure 38: First-level functional decomposition of the SAS.

A preliminary functional decomposition of the SAS at the first level is shown in Figure 38. The SAS is composed of the following main sub-systems that group functionality in relation to:

- *Integrated Alarm System*

  Software system responsible for collecting all safety-relevant status and alarms from the various CTA systems and generate a signal in case of the detection of a safety issue

- *Integrated Interlock and Power Control System*

  Software system responsible for monitoring and controlling the status of local interlocks and the power supply to the deployed hardware systems within the array

- *Access Control Alarm System*

  Software system responsible for the monitoring of the access to the CTA array sites and generation of an alarm in case of unauthorized access

4.3.8.9 Functionality

This section lists all actions that the SAS performs or in which it supports a user. These actions provide a behavioral description of the system.

4.3.8.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system. Only internal stakeholders use the SAS.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Operator	Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Evaluate Level of Severity and eventually request operation action or open a ticket
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Activate interlock to prevent telescope motion / remove power from drives
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Check current power and network and parking situation of telescope
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Unlock telescope local park/power interlock at cabinet
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace a mirror facet	Visual inspection that telescope is correctly parked & confirming information from the system
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Activate interlock to prevent telescope motion / remove power from drives
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Check current power and network and parking situation of telescope
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Unlock telescope local park/power interlock at cabinet
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Visual inspection that telescope is correctly parked & confirming information from the system

Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Activate interlock to prevent telescope motion / remove power from drives
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Check current power and network and parking situation of telescope
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Unlock telescope local park/power interlock at cabinet
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Visual inspection that telescope is correctly parked & confirming information from the system

Table 43: Overview of the actions in which the internal stakeholders are supported by the SAS.

4.3.8.9.2 Automated Processes and Actions

This section lists the processes where the SAS takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Monitor Interlock and Safety Data Items
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Start monitoring Telescope sensors

Table 44: Overview of the actions, which are automatically performed by the SAS.

4.3.8.10 Main Interfaces

This section provides an overview of the ports that the SAS provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Environment Alarms	Environment Alarm, Interlock Status, Auxiliary Instrument Power Status, Device Fault, Safety Signal	Exchange on the safety-relevant information of the Auxiliary instruments and the site environment, and provision of safety alerts in case of an emergency	

Port	Main Data Element Exchanged	Purpose	Notes
Infrastructure Safety and Alarm	Central Power Status, Central Power Alarm, Infrastructure Status, Infrastructure Alarm, Infrastructure Power Status, Infrastructure Power Alarm, Safety Signal, Access Control Signal	Exchange on the safety-relevant information of the array infrastructure elements, and provision of safety alerts in case of an emergency	
Maintenance Crew	Power Status, HW Fault Report, Safety Signal, Interlock and Safety Elements Status, Interlock Setting	Safety-relevant information for the Operator on the site elements, possibility to reset interlocks	
Operator and Expert Operator	Power Status, HW Fault Report, Safety Signal, Interlock and Safety Elements Status, Interlock Setting	Safety-relevant information for the Operator on the site elements, possibility to reset interlocks	
Safety and Alarm Status	Alarm, Alarm Log Information, Interlock and Safety Element Status, Safety Signal	Exchange of alarms and their notifications with the OES and access to safety-relevant status information of the various CTA systems for the Operator	
Site Health and Configuration	Site Health, Configuration	Reporting on the status of the site and synchronisation of their configuration	
Telescope Safety and Alarm	Device Fault, Interlock Status, Telescope Power Status, Safety Signal	Exchange on the safety-relevant information of the Telescopes and their elements, and provision of safety alerts in case of an emergency	

Table 45: Overview of the main interfaces for the SAS>

4.3.8.11 Deployment

One instance of the SAS is deployed at each CTA site.

4.3.8.12 Additional Notes

This section will be revised following the on-going work on the SAS.

4.3.9 *Science User Support System*

4.3.9.1 Summary

NAME AND ACRONYM
Science User Support System (SUSS)
SCOPE
A software system providing the main point of access for proposal submission and to high-level CTA data products and corresponding sets of CTA tools to support data analysis. Provides means for proposal evaluation, for generation of the long-term schedule and for user support. Also includes outreach services.
CONTEXT
External systems: none Internal systems: Data Processing and Preservation System, Management and Administrative System, Operation Support System
USERS
External users: Outreach User, Scientific Community, Science User
Internal users: Director General, Outreach Officer, Software Maintenance Engineer, Support Astronomer, Time Allocation Committee
DECOMPOSITION
Documentation System, Long-Term Scheduling, Proposal Handling, Reporting and Diagnosis, Science Archive, Science Gateway, Science Help Desk, Science Support Tools
DEPLOYMENT
Single instance, off-site
NOTES
Long-Term Scheduler (algorithms and/or software) potentially reused by OSS and OES, Science Tools (algorithms and/or software) potentially reused by DPPS and OES, Science Archive synchronized to DPPS

4.3.9.2 Name and Acronym

Science User Support System (SUSS)

4.3.9.3 Scope

The Science User Support System (SUSS) is the system of CTA that provides the main access point for the exchange of science-related information with the external stakeholders and all functionality to support the science-related workflow. This includes software applications and services for the observation planning, including proposal preparation and submission, proposal review and evaluation up to the generation of the long-term schedule, as well as for the delivery of archived high-level science data products and analysis tools to the Science Users. Support for the users in all of these steps is an integral part of the provided services of the SUSS. In addition, it enables support for the multi-messenger/multi-wavelength observation coordination, and exchange of information via a common external astronomical standard (e.g. the Virtual Observatory standard), for the Scientific Community.

4.3.9.4 Main Processes

The processes supported by the SUSS are mainly related to the observation planning and the flow of high-level science data from the CTAO to the Science Users and support for their analysis.

1. Observe with CTA: from Announcement of Opportunity to Scientific Result

   a. *Observation Request: from Announcement of Opportunity to Validated Proposals*
   b. *Observation Planning: from Validated Proposals to Long-Term Schedule*
   c. *Science Alert Generation: from Collected Data to Generated Science Alert*
   d. *Process Data: from Collected Data to Archived Science Products*
   e. *Disseminate Data: from the Existence of Science Products to their Accessibility*
   f. *Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
   a. *Support Users*
3. Report to Stakeholders: from Observatory Operation to Report to Stakeholders
4. Outreach: from Observatory Operation to Knowledge Transfer

4.3.9.5 Context and User Interactions

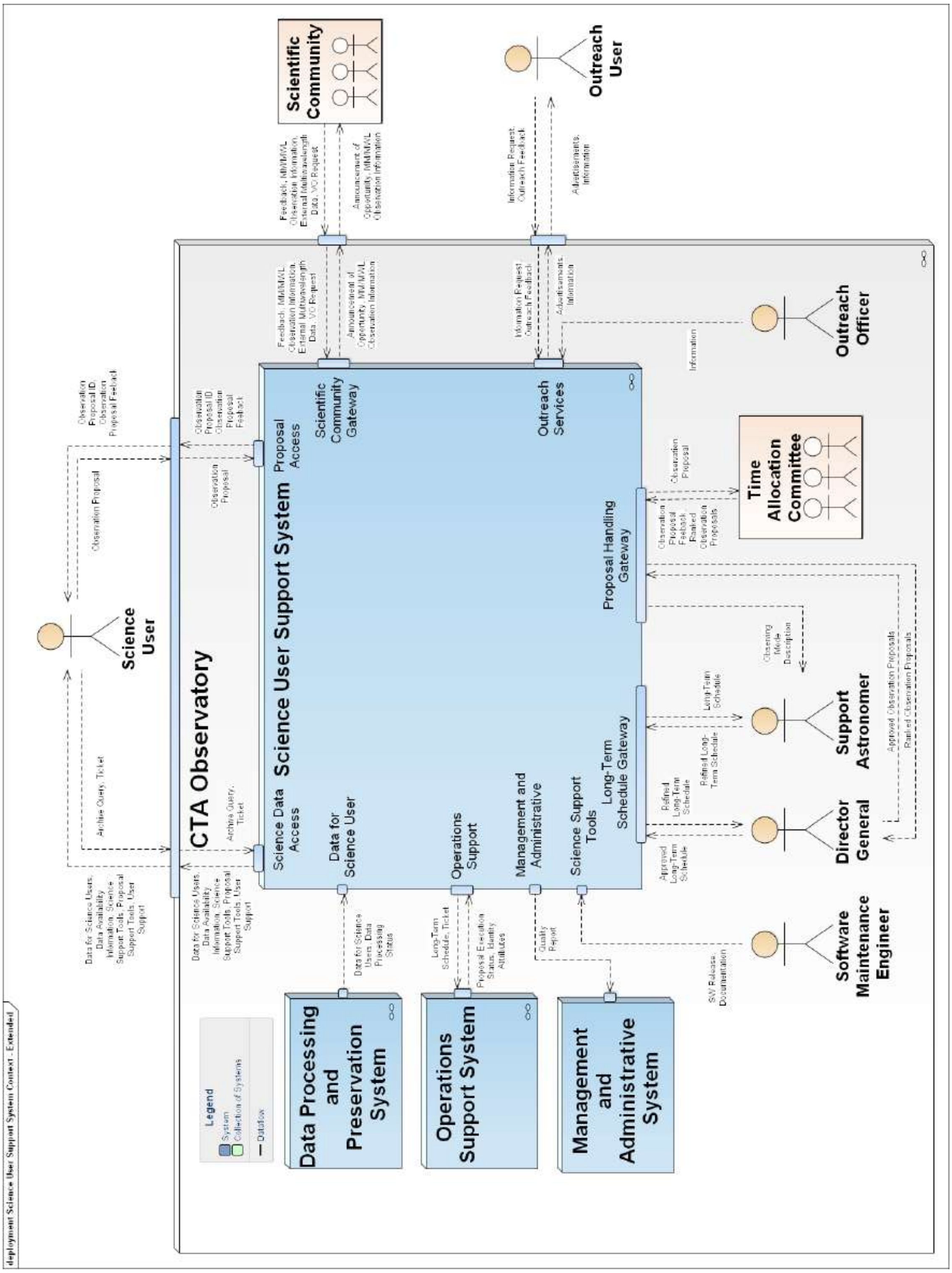


Figure 39: Context of the Science User Support System. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the SUSS, i.e. the stakeholders and systems internal and external to the CTAO that the SUSS interacts with. This section is hence divided into individual paragraphs for each of the entities that have interactions with the SUSS.

Interactions with Internal Systems

- *Data Processing and Preservation System*

  Receiving of the high-level science data and its processing status

- *Operations Support System*

  Provision of the long-term schedule and sub-sequent receiving of the execution status of the proposals, synchronisation of user profiles and attributes for the authentication and authorization

- *Management and Administrative System*

  Provides reports to the MAS containing quality and diagnostic information related to its performance and its interactions with the external stakeholders

4.3.9.6 Users

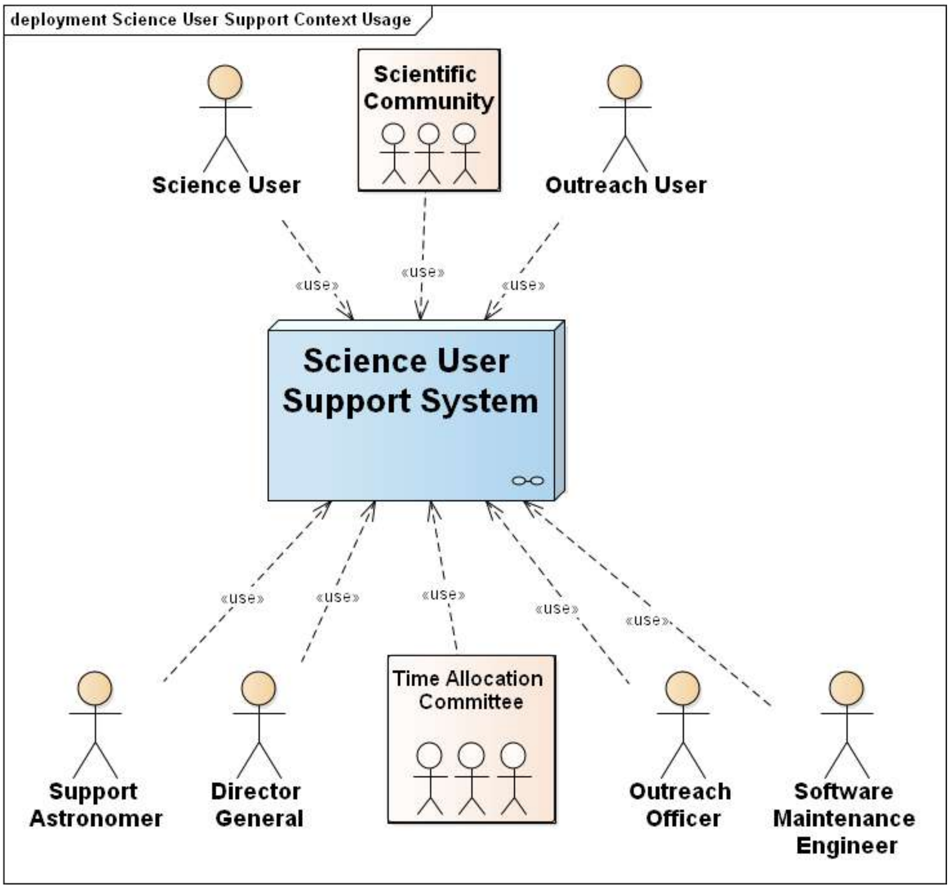


Figure 40: Users of the Science Support System. External stakeholders and organisations are shown in the top row, while internal stakeholders and organisations are shown in the bottom row.

This section lists the users of the SUSS and their interactions with the system. An overview is given in Figure 40 and their definition in Table 46. Please note that maintenance of the components itself are implicit for all hardware and software systems. The SUSS is the main gateway and access point for the external stakeholders and organisations (*Scientific Community, Science Users, Outreach User*) interacting with the CTAO. The second user group of the SUSS is internal to CTA and is mainly responsible for the preparation of the observation plan (long-term schedule) of CTAO (*Time Allocation Committee, Support*

Astronomer, Director General), the provision of updated science analysis and proposal preparation tools (*Software Maintenance Engineer*) or outreach information (*Outreach Officer*).

External Stakeholders
Outreach User Someone who uses CTA outreach services and products. **Scientific Community** The scientific community of astrophysicists, astroparticle physicists, particle physicists, plasma physicists and cosmologists that will use CTA services and its data products. The Scientific Community may respond to Announcement of Opportunities and/or use data made publically available. **Science User** Someone who uses CTA data products, with access determined according to proprietary data rights, and who uses CTA tools and support, for performing an analysis or submitting a proposal
Internal Stakeholders
Director General Director of the CTA Observatory. Is accountable for the overall direction of the Observatory, has overall responsibility for safety within CTAO and for the time allocation. **Outreach Officer** Responsible for all educational and public outreach activities. **Software Maintenance Engineer** Responsible for overseeing and executing the maintenance (e.g. bug fixes and maintaining compatibility) and development (e.g. requested new features) all software associated with CTA observatory and science operations. **Support Astronomer** Oversees and supports scheduling of observations from long-term to short-term, supervises reactions to external and internal science alerts. **Time Allocation Committee** Appointed by the Director General, the Time Allocation Committee (TAC) will review proposals, provide a ranking of and recommendations on the proposals to the Director General and, where appropriate, comment on specific issues.

Table 46: Internal and external users of the Science User Support System.

Interactions with External Stakeholders

- *Science User*

  The SUSS offers tools to help Science Users in the preparation of the observation proposals and tracking the subsequent status of the proposal and related observations. A second responsibility is related to the dissemination of data and associated science analysis tools for the science analysis. The Science User can query the SUSS based on predefined metadata and download the data to his personal storage. Associated analysis tools are also provided for download and to be executed in the users' personal environment. Additional user support is provided based on e.g. a help-desk, documentation or newsletters.

- *Scientific Community*

  The CTAO interacts with the Scientific Community to distribute the Announcement of Opportunity, to exchange information on MM/MWL observations used in the observation planning and data analysis. In addition, the Scientific Community can interact and exchange information with the CTAO based on the Virtual Observatory standard protocol.

- *Outreach User*

  The SUSS offers access to science-related information and dedicated services to engage Outreach Users and facilitate active exchange of information.

Interactions with Internal Stakeholders

- *Time Allocation Committee*

  The SUSS offers functionality to the Time Allocation Committee to retrieve, evaluate and rank the observation proposals and to submit related feedback to the CTAO and to the respective Science User.

- *Support Astronomer*

  The Support Astronomer uses the functionality provided by the SUSS to create a long-term schedule from the ranked proposals.

- *Director General*

  The SUSS provides means for the Director General to evaluate and approve the ranked list of observation proposals and the long-term schedule.

- *Outreach Officer*

  The Outreach Officer uses the services provided by the SUSS to insert science-related outreach information for the engagement of the public.

- *Software Maintenance Engineer*

  The Software Maintenance Engineer interacts with the SUSS to release new versions of the science analysis tools and documentation.

4.3.9.7 Main Data Elements

Table 47 lists the main data elements that are produced/consumed and stored/logged by the SUSS.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Advertisements	Advertisements on CTA Observatory and science-related topics, e.g. an exceptional scientific result	Produced	Logged
Announcement of Opportunity	Regular call for observation proposals	Produced	Logged
Approved Long-Term Schedule	Long-term Schedule after approval and basis for further observation planning	Consumed	Stored
Approved Observation Proposals	List of ranked observation proposals after approval and	Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	basis for generation of the long-term schedule		
Archive Query	Query for archived data related to a proposal, time period, target, etc. depending on the context of the query (e.g. Science User, Expert Science User) and data access rights	Consumed	Logged
Data Availability Information	Information on the availability of data for its use by the Science User and Scientific Community	Produced	Logged
Data for Science Users	High-level science products for the Science User, grouping contains event lists, instrument response function and science analysis results	Consumed	Stored
Data Processing Status	Status of the production of the low-level and simulation data	Consumed	Stored
Documentation	CTA Observatory documents	Produced	Stored
External Multiwavelength Data	Multiwavelength information and data relevant for the science operation of CTA	Consumed/Produced	Stored
Feedback	Feedback of the Scientific Community	Consumed	Logged
Identity Attributes	User identification and attributes for authentication and authorization (e.g. for data access rights)	Consumed	Stored
Information	General information on the CTA operations and performance for the general public	Produced	Logged
Information Request	Request for specific information on the CTA operations and performance from the general public	Consumed	Logged

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Long-Term Schedule	Collection of all the observation programs in a cycle, with each program being a collection of scheduling blocks, on the timescale of years to months	Produced	Stored
MM/MWL Observation Information	Information on multi-messenger and multi-wavelength observations relevant for the science operations	Consumed	Stored
Observation Proposal	Proposal for observations with the CTA Observatory	Consumed	Stored
Observation Proposal Feedback	Feedback on the approval of the observation proposal and related additional information	Produced	Stored
Observation Proposal ID	Unique identifier for an observation proposal	Produced	Stored
Observing Mode Description	Description of the proposed observation mode related to an observation proposal	Consumed/Produced	Logged
Outreach Feedback	Feedback from the general public	Consumed	Logged
Proposal Execution Status	Status of the execution of a certain proposal	Consumed	Stored
Proposal Support Tools	Tools to support the preparation of proposals	Produced	Stored
Quality Report	Report on the performance of the systems and quality of services of the CTA Observatory	Produced	Stored
Ranked Observation Proposals	Ranked list of observation proposals received after an announcement of opportunity and after evaluation by the TAC	Consumed	Stored
Refined Long-Term Schedule	Collection of all the observation programs in a cycle, with each program being a collection of scheduling blocks, on the timescale of years	Consumed	Stored

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
	to months after refinement by the Support Astronomer		
Science Support Tools	Tools to support the analysis of CTA data products	Produced	Stored
SW Release	Information on the release of CTA software	Consumed	Logged
Ticket	Ticket providing the description of an issue related to problems with the software, hardware, data quality or user experience	Consumed	Logged
User Support	Information and responses to support external users of CTA data and products	Produced	Logged
VO Request	Request for CTA data following the VO standards	Consumed	Logged

Table 47: Main data elements exchanged with the SUSS.

4.3.9.8 Decomposition

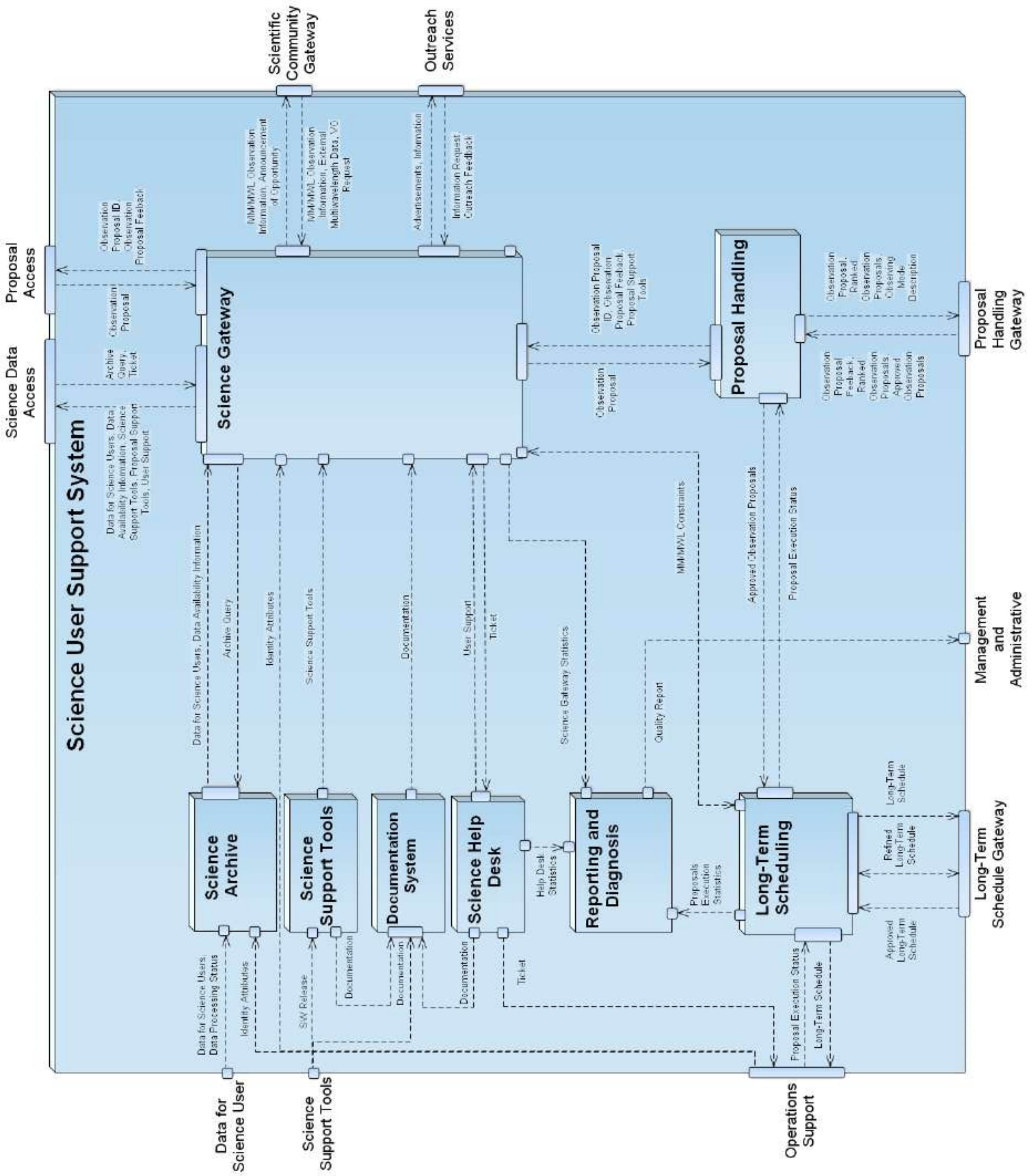


Figure 41: First-level functional decomposition of the SUSS.

A preliminary functional decomposition of the SUSS at the first level is shown in Figure 41. The SUSS is composed of the following main sub-systems that group functionality in relation to:

User Interaction and User Support:

- *Science Gateway*

  This sub-system is the main access point and interface for the external stakeholders (Science User, Scientific Community, Outreach User) for the access to the science data and analysis tools, for the proposal submission and related tools, to the science help desk and issue tracking system. It provides the interface to the users and provides a framework to integrate the internal CTAO systems.

- *Science Help Desk*

  This sub-system provides all tools to support the external stakeholders in performing a data analysis and in submitting proposals. Among others, it contains documentation, wiki pages, a well-integrated issue tracking system etc.

- *Documentation*

Science Analysis:

- *Science Archive*

  This sub-system organises the storage of the high-level science data products, the part of the CTA data that is accessed by the external Science User.

- *Science Support Tools*

  This sub-system provides all tools for the high-level data analysis (science analysis tools).

Observation Planning:

- *Proposal Handling System*

  This sub-system provides the means to submit, store and access observation proposals. It provides all tools supporting the proposal preparation for the Science User and the means for the Time Allocation Committee to evaluate and rank the submitted proposals.

- *Long-Term Scheduler*

  This sub-system provides all tools needed to create a long-term observation schedule from the list of ranked and accepted proposals. This sub-system includes tools to simulate and test different long-term observation schedules and strategies.

Reporting and Diagnosis:

- *Reporting and Diagnosis*

  This sub-system provides the means to collect reporting and diagnosis information from all other SUSS sub-systems and to create reports and metrics for internal and external stakeholders.

4.3.9.9 Functionality

This section lists all actions that the SUSS performs or in which it supports a user. These actions provide a behavioral description of the system.

4.3.9.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system.

External Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Guest Observer	Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Authenticate to submit a Proposal
Guest Observer	Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Check for duplicate observations on same Target
Guest Observer	Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Create new or modify already stored Proposal
Guest Observer	Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Fill and submit Proposal form
Guest Observer	Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Prepare Proposal
Outreach User	Outreach: from Observatory Operation to Knowledge Transfer	Provide Information to Outreach User	Request Outreach Information
Outreach User	Outreach: from Observatory Operation to Knowledge Transfer	Provide Information to Outreach User	Retrieve Outreach Information
Principal Investigator	Science Alert Generation: from Collected Data to Generated Science Alert	Generate an off-line Science Alert for the Region of Interest (ROI)	Receive Science Alert and notify Principal Investigator of the Proposal
Principal Investigator	Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Check the status of the program via a dashboard
Principal Investigator	Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Request Feedback from the Principal Investigator of the Proposal
Proposer	Observation Planning: from Validated Proposals to Long-Term Schedule	Define new Observing mode	Define a new Observing Mode
Science User	Process Data: from Collected Data to Archived Science Products	Check Scientific Data Quality Offline	Users Data Exploration
Science User	Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Allow user exploration of data
Science User	Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Issue incident report

Supported User	Supported Process	Process/Activity	User-Supporting Action
Science User	Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Select subset of observations or time range
Science User	Disseminate Data: from the Existence of Science Products to their Accessibility	Make Data Discoverable	Data Are Discovered
Science User	Disseminate Data: from the Existence of Science Products to their Accessibility	Release data	Download the Data
Science User	Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Retrieve Data	Connect to system and authenticate user
Science User	Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Search Science Data	Connect to system and authenticate user
Science User	Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Search Science Data	Define search query
Science User	Support Users	Support Users (Level 1)	Issue request (i.e. bug report and ticket)

Table 48: Overview of the actions in which the external stakeholders are supported by the SUSS.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Director General	Observation Execution: from Short-Term Schedule to Collected Data	Issue Announcement of Opportunity	Add documentation and link to relevant information hub to Announcement of Opportunity
Director General	Observation Execution: from Short-Term Schedule to Collected Data	Issue Announcement of Opportunity	Send Announcement of Opportunity
Director General	Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Approve final list of proposals
Instrument Scientist	Observation Execution: from Short-Term Schedule to Collected Data	Define new Observing mode	Check the technical feasibility of the new observing mode
Outreach Officer	Outreach: from Observatory Operation to Knowledge Transfer	Provide Information to Outreach User	Produce outreach information
Software Maintenance Engineer	Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Provide Data Analysis Package to User	Make data analysis package available

Supported User	Supported Process	Process/Activity	User-Supporting Action
Support Astronomer	Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Build a queue of Scheduling Blocks and setup the triggered observation proposals SBs set
Support Astronomer	Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Store the observation programs and create the Long-Term Schedule

Table 49: Overview of the actions in which the internal stakeholders are supported by the SUSS.

4.3.9.9.2 Automated Processes and Actions

This section lists the processes where the SUSS takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Science Alert Generation: from Collected Data to Generated Science Alert	Execute automated Science Analysis	Store DL4 Results
Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Bin DLN monitoring data in time or other axis
Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Check quality: generate histograms and apply cuts etc.
Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Generate quality report and write it to storage
Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Retrieve DL4 monitoring products from storage
Process Data: from Collected Data to Archived Science Products	Execute Automatic Quality Checks on data level 4	Summarize monitoring data bin (average statistics + histograms)
Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Create the Scheduling Blocks for Each Target
Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Perform technical validation of each Scheduling Block
Observation Planning: from Validated Proposals to Long-Term Schedule	Prepare Programmes and Long-Term Schedule	Retrieve Targets for a Proposal
Disseminate Data: from the Existence of Science Products to their Accessibility	Release data	Send e-mail Notification of data availability
Disseminate Data: from the Existence of Science Products to their Accessibility	Release data	Validate Data
Process Data: from Collected Data to Archived Science Products	Reprocess Data: from archived Data to reprocessed archived Science Products	Release data and documentation and science tool

Supported Process	Process/Activity	Automated Action
Process Data: from Collected Data to Archived Science Products	Reprocess Data: from archived Data to reprocessed archived Science Products	Update Science Tools
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Collect Proposal from Proposal storage
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Evaluate and grade Proposal
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Notify Observers about result of proposal review
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Prepare the list of acceptable and ranked proposals
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Review Proposal on basic (technical) parameters
Observation Planning: from Validated Proposals to Long-Term Schedule	Review Proposal	Store approved list of proposals with proposal ID and approval information (e.g. priority)
Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Search Science Data	Process query
Science Analysis: Support the Analysis of Data from Available Science Products to Scientific Results	Search Science Data	Validate query and check authorization
Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Notify guest observer
Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Prepare Proposal
Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Store Proposal
Observation Request: from Announcement of Opportunity to Validated Proposals	Submit Proposal	Verify Proposal
Support Users	Support Users (Level 1)	Forward Ticket to Operations Support
Report to Stakeholders: from Observatory Operation to Report to Stakeholders	Track Publications	Track Publication Status

Table 50: Overview of the actions, which are automatically performed by the SUSS.

4.3.9.10 Main Interfaces

This section provides an overview of the ports that the SUSS provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Data for Science Users	Data for Science Users	Provision of CTA data and products to the Science User	
Long-Term Schedule Gateway	Long-Term Schedule, Refined Long-Term Schedule, Approved Long-Term Schedule	Generation of the long-term schedule	
Management and Administrative	Quality report	Generation of quality reports for the relevant stakeholders	
Operations Support	Long-Term Schedule, Ticket, Proposal Execution Status, Identity Attributes	Provision of long-term schedule as basis for operations planning and report on status of the observations, user authentication and authorization	
Outreach Services	Advertisements, Information, Outreach Feedback	Communication with the Outreach User	Potentially integrated in one Science Gateway
Proposal Access	Observation Proposal, Observation Proposal ID, Proposal Execution Status	Proposal platform for the Science User	Potentially integrated in one Science Gateway
Proposal Handling Gateway	Observation Proposal, Observation Proposal Feedback, Ranked Observation Proposals, Observing Mode Description	Generation of a ranked and approved list of observation proposals	
Science Data Access	Data for Science Users, Data Availability Information, Science Support Tools, Proposal Support Tools, User Support, Archive Query, Ticket	Receiving of high-level science products and their processing status	Potentially integrated in one Science Gateway
Science User Support Tools	SW Release, Documentation	Release of new science analysis and proposal support tools and related documentation	
Scientific Community Gateway	Announcement of Opportunity, MM/MWL Observation Information, Feedback, External	Exchange of information on multi-messenger and multiwavelength observations and data, information for	Potentially integrated in one Science Gateway

Port	Main Data Element Exchanged	Purpose	Notes
	Multiwavelength Data, VO Request	the Scientific Community	

Table 51: Overview of the main interfaces for the SUSS.

4.3.9.11 Deployment

One instance of the SUSS is currently planned to run off-site.

4.3.9.12 Additional Notes

It is envisaged that the software related to the functionality of creating the long-term schedule is potentially (partly) re-used by the OSS (mid-term scheduling) and OES (short-term scheduling).

It is envisaged that the software related to the science analysis (Science Tools) is potentially re-used by the DPPS and the OES.

The Data for Science Users is envisaged to be synchronized between SUSS and DPPS.

4.3.10 Telescope

4.3.10.1 Summary

NAME AND ACRONYM
Telescope (TEL)
SCOPE
The hardware and software system associated with the control and data collection for a single Cherenkov Telescope at a CTA array site.
CONTEXT
Physical Objects: Universe External systems: none Internal systems: Array Infrastructure Elements, Auxiliary Instruments[7], Observation Execution System, Safety and Alarm System
USERS
External users: none Internal users: Maintenance Engineer
DECOMPOSITION
Camera, Telescope Manager, Structure
DEPLOYMENT
At run-time, there will be as many instances of these systems per site as telescopes are deployed on the site
NOTES

4.3.10.2 Name and Acronym

Telescope (TEL)

4.3.10.3 Scope

The Telescope is a system composed of hardware and software that represents a generic single CTA Cherenkov Telescope. The Telescope System implements high level operations like park, track, move to safe, take data, calibration, self-test and a state machine at the Telescope sub-system level (Camera, Structure) that are exposed to the Observation Execution System. The Telescope System is responsible for the coordination and control of the various sub-systems that comprise the Telescope System.

The main control and monitoring interface of the Telescope system is with the Observation Execution System using the integration services and software framework provided by the OES, but safety and power related communication is interfaced via telescope-wise cabinets to the Safety and Alarm System and Array Infrastructure Elements. The sub-system fault conditions are, however, managed internally in the Telescope System.

At run-time, there will be as many of these systems per site as telescopes are deployed on the site, the coordination of all these Telescope systems being achieved by means of the Observation Execution System in terms of scientific operations, and the Safety and Alarm System in terms of safety operations and Array Infrastructure Elements for power management. Low-level and technical operations are accessible by direct engineering user interfaces

[7] The Auxiliary Systems are a source of calibration light for the Telescopes and can be treated as a physical object in the context of a Telescope.

provided by the Telescope system and are used during commissioning and maintenance operations.

4.3.10.4 Main Processes

The main processes to which the TEL contributes are (only top two levels listed):

1. Observe with CTA: from Announcement of Opportunity to Scientific Result
   a. *Observation Execution: from Short-Term Schedule to Collected Data*
2. Maintenance: Maintain Systems from Issue Identification to verified Overhaul
   a. *Calibration: Perform, Check and Refine Calibration and Calibration Instruments*
   b. *Issue Identification: from Collected Data to Identified Issue*
   c. *Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action*

4.3.10.5 Context and User Interactions

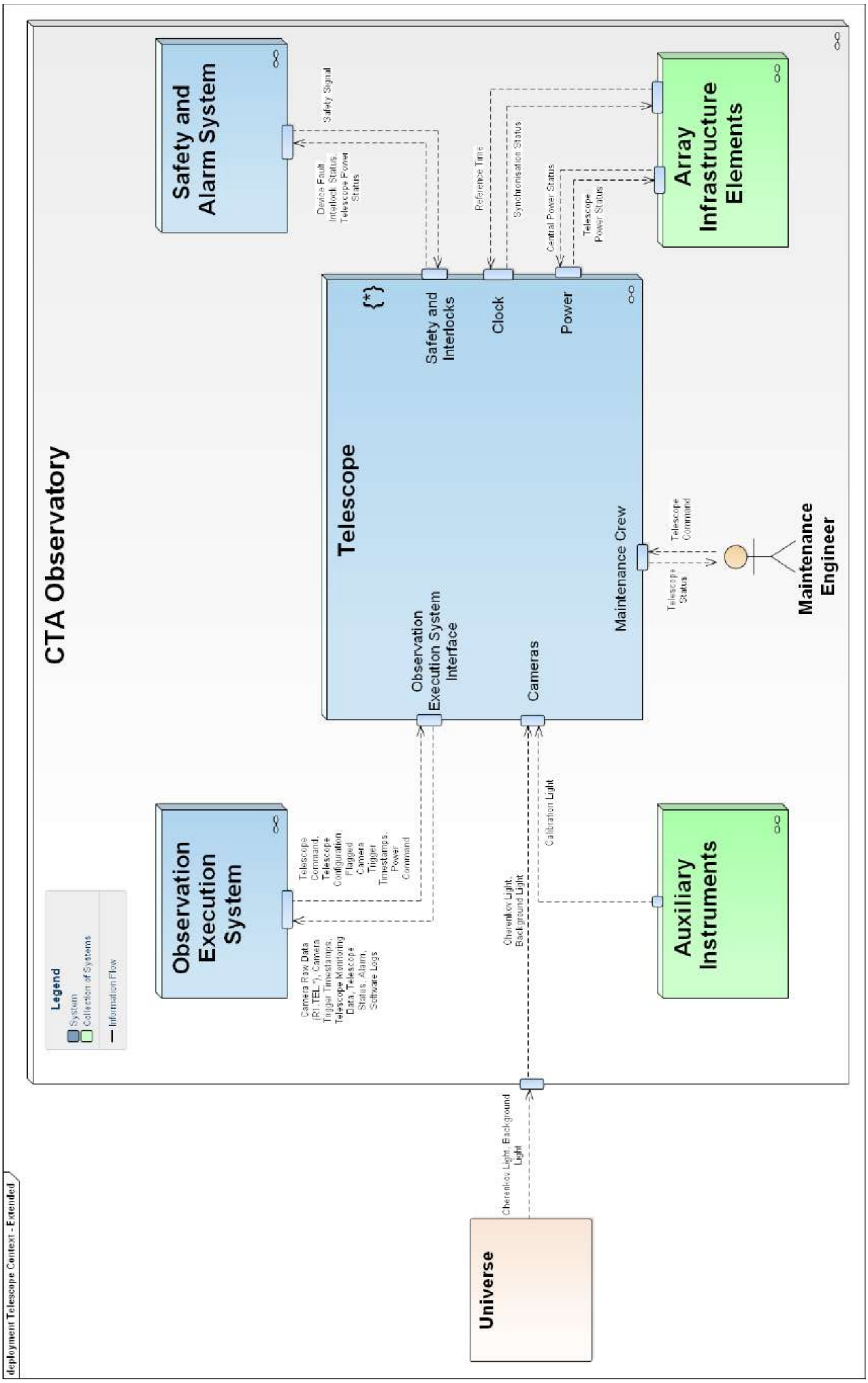


Figure 42: Context of the TEL. Shown are the interactions with other systems of the CTAO and with the external world.

Figure 19 shows the context of the TEL. The main interactions are:

Interactions with External Physical Objects

- *Universe*

  Source of the Cherenkov and Background Light collected by the Telescope

Interactions with Internal Systems

- *Observation Execution System*

  Control, monitoring and logging of the individual telescopes via the OES, provision of alarms, sending of Cherenkov data and camera trigger timestamps to the OES. Power on/off can be requested via the SAS.

- *Safety and Alarm System*

  Provision of status of the interlock and power and safety-relevant information to the SAS. The Telescope is informed via the SAS on any safety-relevant emergency situations.

- *Auxiliary Instruments*

  The Auxiliary Instruments are a source of calibration light for the Telescopes.

- *Array Infrastructure Elements*

  Continuous receiving of a reference time signal (mainly for the Camera) and exchange of information on the time synchronisation status. The Telescope receives availability and status information on the central power from the AIE.

4.3.10.6 Users

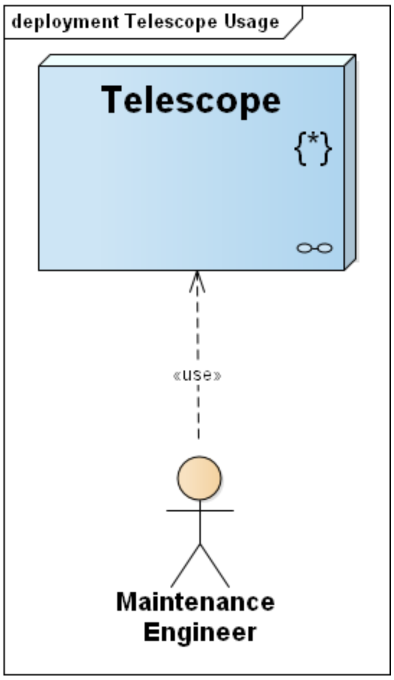


Figure 43: Users of the TEL.

This section lists the users of the TEL and their interactions with the system. An overview is given in Figure 43 and their definition in Table 52. Please note that maintenance of the components itself are implicit for all hardware and software systems.

External Stakeholders
Internal Stakeholders
Maintenance Engineer Manages and executes maintenance activities and conducts on-site preventive and corrective maintenance tasks.

Table 52: Internal and external users of the TEL.

Interactions with Internal Stakeholders

- *Maintenance Engineer*

  Steering of the telescope during maintenance activities

4.3.10.7 Main Data Elements

Table 53 lists the main data elements that are produced/consumed and stored/logged by the TEL.

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Alarm	Problem or condition that should be reported to the operator and may require his/her action	Produced	Logged
Calibration Light	Artificial light collected and recorded by the telescope and used for calibration purposes	Produced/Consumed	Logged
Camera Raw Data (R1)	Low-level data readout from the camera of a telescope	Produced	Logged
Camera Trigger Timestamps	Timestamp of a camera trigger	Produced	Logged
Central Power Status	Status information of the central power	Consumed	Logged
Cherenkov Light, Background Light	External light collected and recorded by the telescope	Consumed	Logged
Device Fault	Information in case of a failure of the device	Produced	Logged
Flagged Camera Trigger Timestamps	Camera trigger timestamps flagged for coincidence	Consumed	Logged
Interlock Status	Status information of the interlocks at the system	Produced	Logged

Main Data Element Exchanged	Definition	Produced/Consumed	Stored/Logged
Power Command	Command to control the power of the system	Consumed	Logged
Telescope Command	Command to control a telescope and its elements	Consumed	Logged
Telescope Configuration	Configuration of a telescope and its elements	Consumed	Logged
Telescope Monitoring Data	Monitoring data collected from a telescope and its elements	Produced	Logged
Telescope Power Status	Information on the power status of the telescope	Produced	Logged
Telescope Status	Status information of a telescope and its elements	Produced	Logged
Reference Time	Reference time signal for clock distribution	Consumed	Logged
Software Logs	Logging information from the system	Produced	Logged
Synchronisation Status	Status of time synchronisation to the distributed clock at the node	Produced	Logged
Safety Signal	Signal to alert on a safety-relevant issue	Consumed	Logged

Table 53: Main data elements exchanged with TEL.

4.3.10.8 Decomposition

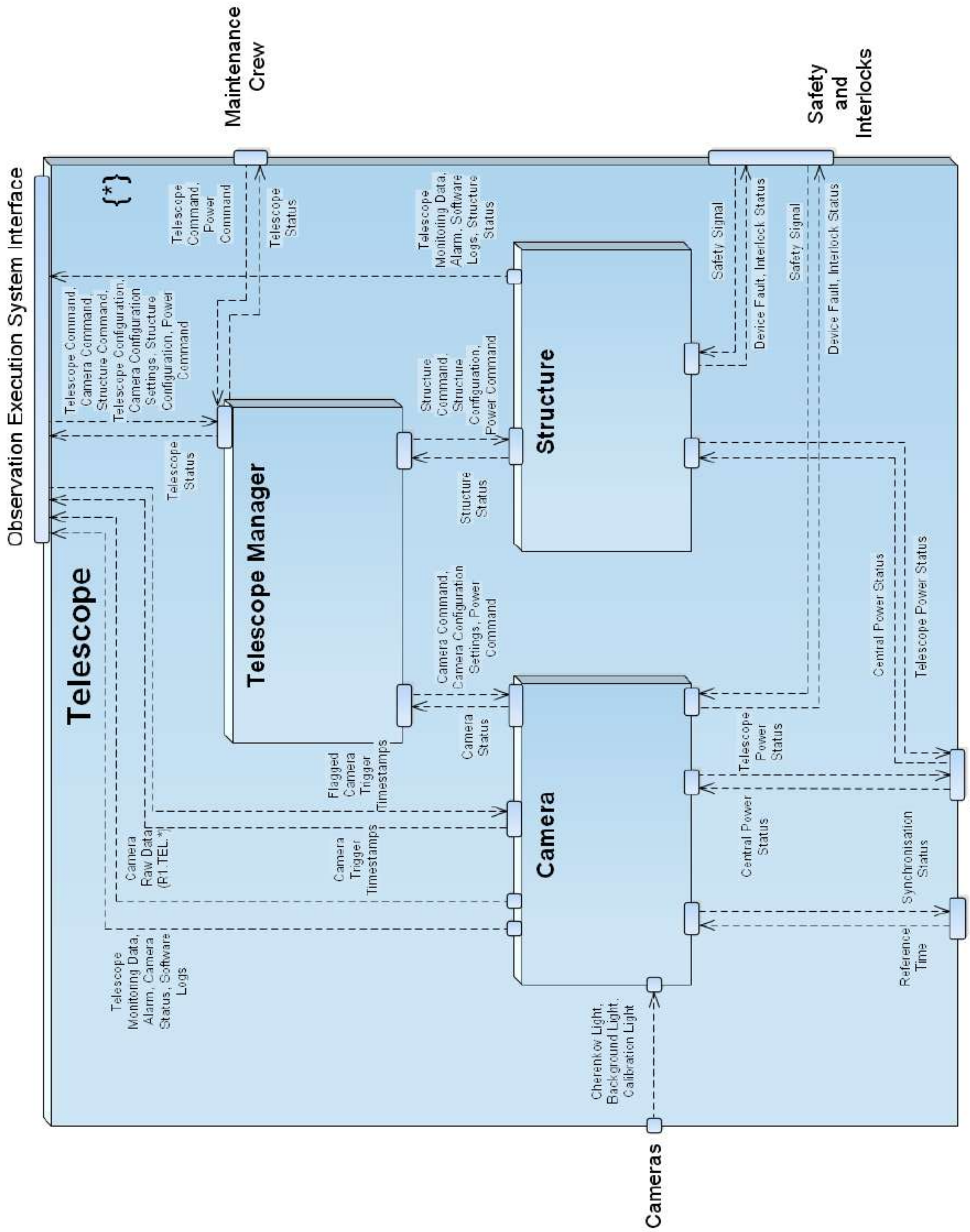


Figure 44: First-level functional decomposition of the TEL.

A preliminary functional decomposition of the TEL at the first level is shown in Figure 44. The TEL is composed of the following main sub-systems that group functionality in relation to:

- *Telescope Manager*

A relatively simple software sub-system, that coordinates the two other sub-systems and implements global telescope states and operations.

- *Camera*

  A hardware and software sub-system that gathers Cherenkov and calibration light and makes it available to the data acquisition in the Observation Execution System; and implements Camera states and operations

- *Structure*

  A hardware and software sub-system that allows the instrumentation to be pointed to a position in the sky and the light to be focused on the Camera; and implements Structure states and operations

4.3.10.9 Functionality

This section lists all actions that the TEL performs or in which it supports a user. These actions provide a behavioral description of the system.

4.3.10.9.1 *User-Supported Processes and Actions*

This section lists all actions in which the system supports the users, and which are invoked by the users of the system.

External Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action

Table 54: Overview of the actions in which the external stakeholders are supported by the TEL.

Internal Stakeholders

Supported User	Supported Process	Process/Activity	User-Supporting Action
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform a day drive engineering test	Power all telescope devices and close camera and power camera
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Perform a day drive engineering test	Power off the Telescope & activate drive
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Power all telescope devices

Supported User	Supported Process	Process/Activity	User-Supporting Action
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Power off the Telescope & activate drive
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace and test an element of the drive system	Deactivate camera power and open camera and replace camera component and close camera and power camera
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Replace electronic equipment in a telescope camera	Deactivate camera power and open camera and replace camera component and close camera and power camera
Maintenance Engineer	Maintenance and Upkeep: from Identified Issue to Verified Maintenance, Calibration or other Action	Calibrate a Calibration Instrument	Record results of calibration of a calibration instrument onboard of a Telescope

Table 55: Overview of the actions in which the internal stakeholders are supported by the TEL.

4.3.10.9.2 Automated Processes and Actions

This section lists the processes where the TEL takes part and lists the actions therein, which are done automatically by this system during the execution of the process or activity.

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Enable Camera Triggering
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Data	Prepare for data taking
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Muon Data	Convert and pre-calibrate image data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Muon Data	Detect local triggers and capture raw data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Muon Data	Select muon events

Supported Process	Process/Activity	Automated Action
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Convert & Pre-Calibrate Flagged Data
Observation Execution: from Short-Term Schedule to Collected Data	Acquire Raw Data from Scheduled Observation to Storage	Detect local triggers and capture raw data
Observation Execution: from Short-Term Schedule to Collected Data	Check for Telescope Alarms	Check the instrumentation status
Observation Execution: from Short-Term Schedule to Collected Data	Check for Telescope Alarms	Detect a problem
Observation Execution: from Short-Term Schedule to Collected Data	Check for Telescope Alarms	Raise a telescope alarm
Observation Execution: from Short-Term Schedule to Collected Data	Check for Telescope Alarms	Solve problem locally
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Load Camera configuration settings (calibration and voltage and trigger etc.)
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Move Telescopes to intermediate position
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Open Camera lids
Observation Execution: from Short-Term Schedule to Collected Data	Execute Observing Mode	Telescopes Move to the Target
Observation Execution: from Short-Term Schedule to Collected Data	Perform Calibration Run and Store Raw Calibration Data	Capture raw data
Observation Execution: from Short-Term Schedule to Collected Data	Perform Calibration Run and Store Raw Calibration Data	Convert/ Pre-calibrate data
Observation Execution: from Short-Term Schedule to Collected Data	Prepare a Calibration Run	Prepare telescope for calibration
Observation Execution: from Short-Term Schedule to Collected Data	Produce Telescope Monitoring Data	Produce telescope monitoring data
Observation Execution: from Short-Term Schedule to Collected Data	Produce Telescope Raw Data	Get the data from the camera front-end
Observation Execution: from Short-Term Schedule to Collected Data	Produce Telescope Raw Data	Transfer the raw image data to the camera server
Observation Execution: from Short-Term Schedule to Collected Data	Produce Telescope Software Logs	Produce telescope software logs
Observation Execution: from Short-Term Schedule to Collected Data	Put the Array to Safe State	Go to Safe (Telescope)
Issue Identification: from Collected Data to Identified Issue	Perform a day drive engineering test	Activate the Drive
Issue Identification: from Collected Data to Identified Issue	Perform a day drive engineering test	Start drive System engineering test

Supported Process	Process/Activity	Automated Action
Issue Identification: from Collected Data to Identified Issue	Perform a day drive engineering test	Telescope goes to Safe State
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Detect the fault and/or detect a sudden decrease of telescope power consumption and inform global safety system and raise a local alarm
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Drive the telescope to the two axes parking position and insert the stow-pins
Issue Identification: from Collected Data to Identified Issue	React to a Failure of a Drive System Component during the Night	Notify that telescope axes are parked
Issue Identification: from Collected Data to Identified Issue	Replace and test an element of the drive system	Start drive System engineering test
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Check contact to telescope element hardware controllers
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Communicate to OES that the telescope is in Safe state
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Power-up assemblies and local control units
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Power-up Camera
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Power-Up internal telescope switch
Observation Execution: from Short-Term Schedule to Collected Data	Startup a Telescope in Cold Startup Mode	Raise an alarm
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Telescope goes to Ready state
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Telescope goes to the Standby state
Observation Execution: from Short-Term Schedule to Collected Data	Warmup Array	Telescope warms up Camera and preforms internal calibrations

Table 56: Overview of the actions, which are performed by the TEL.

4.3.10.10 Main Interfaces

This section provides an overview of the ports that the TEL provides to the external stakeholders and to the systems and stakeholders internal to CTAO. Each port may be implemented by one or more software interfaces that allow the exchange of information.

Port	Main Data Element Exchanged	Purpose	Notes
Cameras	Cherenkov Light, Background Light, Calibration Light	Collection of light to produce CTA science	
Clock	Reference Time, Synchronisation Status	Clock distribution and monitoring of its	

Port	Main Data Element Exchanged	Purpose	Notes
		synchronisation status	
Maintenance Crew	Telescope Status, Telescope Command, Power Command	Maintenance operations of the telescope	
Observation Execution System	Camera Raw Data, Camera Trigger Timestamps, Telescope Monitoring Data, Telescope Status, Alarm, Software Logs, Telescope Command, Telescope Configuration, Flagged Camera Trigger Timestamps, Power Command	Control, monitoring and readout of the Telescope and its elements	
Power	Central Power Status, Telescope Power Status	Availability and status information on the central power and provision of the status of the Telescope power	
Safety and Interlocks	Device Fault, Interlock Status, Telescope Power Status, Safety Signal	Exchange of the safety-relevant information on the Telescope (incl. interlocks) and safety alerts in case of an emergency	

Table 57: Overview of the main interfaces for the TEL.

4.3.10.11 Deployment

At run-time, there will be as many instances of these systems per site as telescopes are deployed on the site.

4.3.10.12 Additional Notes

It is envisaged that the Telescope Manager sub-system will be standardized according to the commonalities between telescopes and fully integrated in the OES prior to the Science Operations Phase.

Work is ongoing on the use cases for a generic Telescope which will result in a major update of this section.

5 Appendix: Data Level Definitions

Throughout the document the data level definitions of [R15] are used and are repeated in for completeness.

Data Level	Definition
R0 *(raw low-level)*	camera data transmitted from telescope to central servers. R0 content and format is internal to each camera and is specified and coordinated between individual camera teams.
R1 *(raw common)*	data transmitted on-site by a camera or device in a common format, not intended for archival storage. This is the first level of data seen by the OES and is therefore as common as possible between all cameras/hardware/devices. Exceptionally, some R1 data may be stored for engineering purposes.
DL0 *(raw archived)*	all archival data from the data acquisition hardware/software. This is the first level of data that are stored in the bulk archive. This includes both camera event data and technical data from other subsystems, such as non-camera devices or software.
DL1 *(processed)*	processed DL0 data that may still include some TEL data and parameters derived from them. For example this includes calibrated image charge, Hillas parameters, and a usable telescope pattern. This is only optionally stored in the archive.
DL2 *(reconstructed)*	Reconstructed shower parameters such as energy, direction, particleID, and related signal discrimination parameters. At this point, no TEL information is stored. For each event this information may be repeated for multiple reconstruction and discrimination methods. This is only optionally stored in the archive. At this point, telescope-wise info is generally dropped.
DL3 *(reduced)*	Sets of selected (e.g. gamma-ray candidates, electron candidates, selected hadron candidates, etc.) events with a single final set of reconstruction and discrimination parameters, along with associated instrumental response characterizations and any technical data needed for science analysis.
DL4 *(science)*	binned data products like spectra, sky maps, or light curves, along with associated data (source models, fit results, etc).
DL5 *(high-level)*	high-level or “legacy” observatory data, such as CTA survey sky maps or the CTA source catalog.
DL5 *(high-level)*	CTA shall inform and excite public interest in its activities.

Table 58: Data level definitions as taken from [R15].

6 Appendix: CTA Architecture Methodology

6.1 Architecture Approach

The methodology for the CTA architecture developed during this work with the help of Fraunhofer IESE [R3], follows a defined methodology tailored for CTA needs and using input from various architecture frameworks [R4, R5, R6, R7]. The architecture is described in a notation build on the UML [R8] and Systems Modelling Language (SysML) [R9] and is implemented in the Enterprise Architect tool [R10].

Figure 45 gives a view of the CTA architecture model. The modelling approach consists of a top-level CTA architecture (top row) that provides an integrated view of sub-systems with their logical and physical connections and processes which are executing across system boundaries. It gives context and specifications to the various sub-systems and serves as an integration architecture for the different sub-system architectures (bottom row). This separation enables the sub-system teams to select their most suitable architecture approach that considers the specific needs of the sub-system. Individual models with adequate modelling approaches can be chosen, while a coherent overall description of the integrated CTAO system is kept throughout the project.

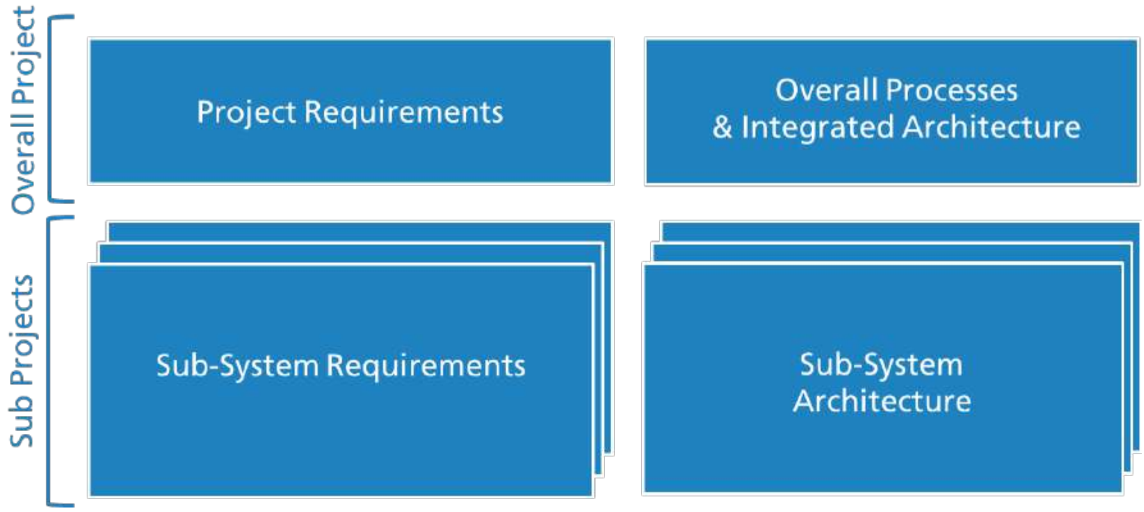


Figure 45: Overview of the modelling approach for CTA

The top-level architecture consists of different views (see Figure 46) capturing different aspects of CTAO. Currently the major goal of the top-level architecture is the scoping of CTAO and of the individual sub-systems. Consequently, the focus of the work is to identify the processes of CTAO and the individual activities and actions that stakeholders and systems perform during the lifetime of the CTAO. The corresponding views are highlighted in green in Figure 46. Each view organises different modelling elements, which are linked to each other via traces, and are shown in Figure 47. Traces between the elements in the different views allow the analysis of consistency and completeness of the model and enable reasoning about process and system decomposition and give scope to the various elements.

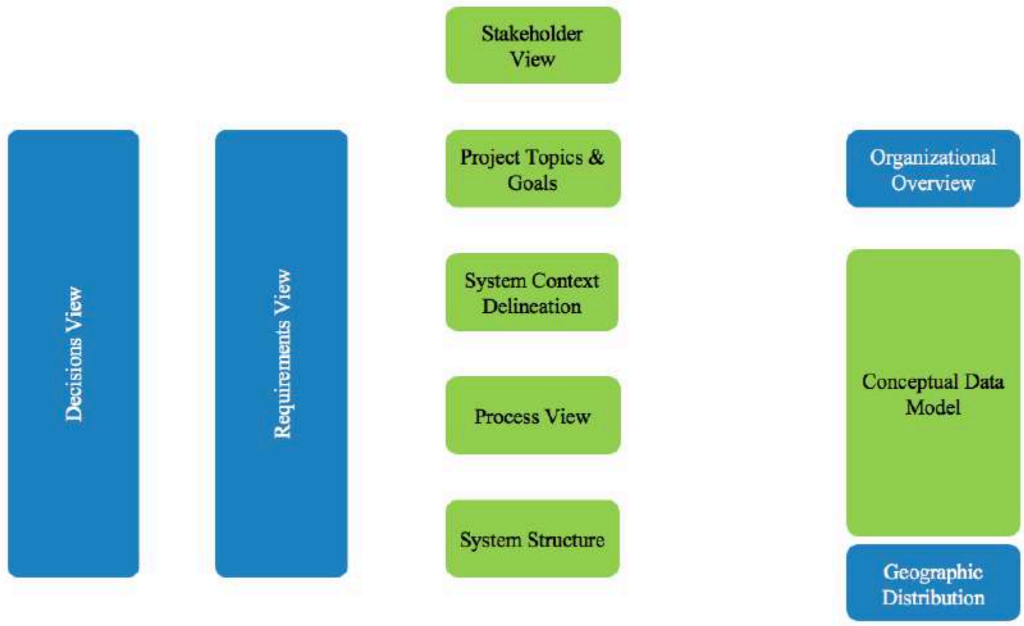


Figure 46: Views of the top-level architecture. The views highlighted in green have been mainly worked on in the first version of the CTA top-level architecture model with the goal to derive a system structure.

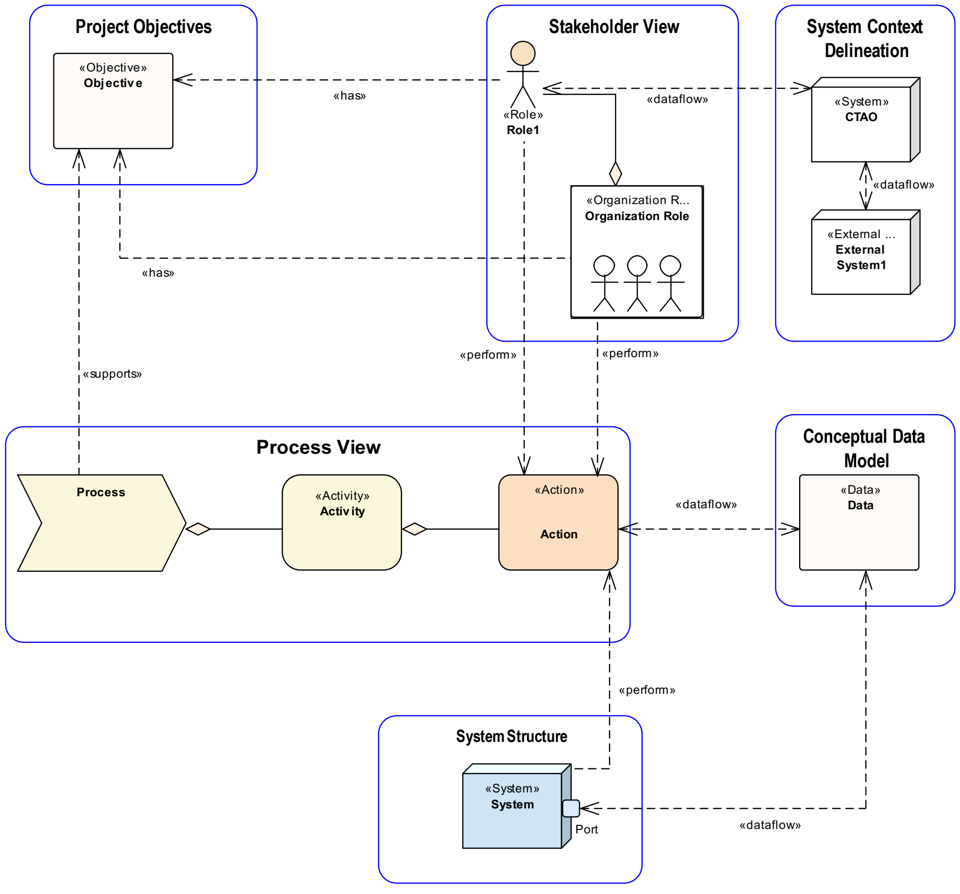


Figure 47: Main modelling elements for system scoping

In the following, an overview on the main views used for system scoping will be given:

Stakeholder View
Stakeholders are human entities that interact in some way with CTAO. Understanding the stakeholders of CTAO is important to understand all the aspects of the observatory, since they are one of the major driving forces behind the whole project. In the stakeholder view, our goal is not to list individual persons, but instead we list roles and organisation roles that people, and organisations have within CTAO. Stakeholders and organisations can be external or internal to CTAO. Only those internal stakeholders and organisations have been captured in the model that appear as actors in the processes. Examples of a role is a tester that performs testing activities or a developer that develops Software. An example of an organisation role is a development team or the project-specific organisation role '*Time Allocation Committee'*.

Project Objectives
Another major architecture driver are the project objectives of CTAO such as '*effective long-term operation*. Modelling the project objectives is not only done for completeness reasons but can also be used to double-check the processes: every objective should have at least one process that supports it and vice versa, for every process, we should identify at least one objective.

System Context Delineation
In the system context delineation, we describe the CTAO as a black box and point out how it interacts with external entities. On one hand, CTAO acquires information from the outside world by means of e.g. the telescopes that detect the Cherenkov light or the atmospheric devices that obtain weather information. On the other hand, CTAO also interacts with external stakeholders, e.g. the science user that submits proposals, and organisations. All these interactions are shown on the system context view.

Process View
The process view is the first view that focuses on the internals of CTAO and is one of the major building blocks of our modelling approach. External stakeholders of CTAO have goals that they want to achieve with the CTAO facilities and how to achieve these goals is modelled in the process view. A process typically starts with an external stakeholder that triggers some internal activities within CTAO. While describing the processes and the internal activities, we identify actions that systems and internal stakeholders perform during the processes as well as data elements that connect them. The actions are used for system scoping, since they describe what a system is supposed to do while the data-exchange between the actions can be used to identify the dataflow to and from systems.
This view is hence the first place where we document interactions between the individual CTAO sub-systems and interactions between CTAO sub-systems and internal and external stakeholders. It can be regarded as a link between the system context, where the process starts and the internal view of the system structure.

System Structure
In the system structure view, we describe the interactions between the major systems of CTAO and between major systems and stakeholders at runtime. It shows the dataflow connections between systems and stakeholders of CTAO. In the process view, already the data-exchange between systems actions have been identified. This dataflow corresponds to a real data-exchange between the systems during runtime. Hence, both views can be checked for consistency and completeness by comparing the dataflow.
It is impossible to show all the data-exchange between the individual sub-systems in one diagram. Hence, the overview diagram of the system structure view shows only the major data

elements that can flow between the individual systems. While our understanding of the CTAO system grows, this view will be enhanced by more diagrams showing the detailed interactions between individual parts of CTAO and will finally lead to the definition of system interfaces. Finally, the system structure view will also contain stakeholders' responsibilities: which organisation develops or operates a system.

Conceptual Data Model

The conceptual data model connects the system context delineation, the process view and the system structure view. Here we describe the data elements of CTAO at a conceptual level, i.e. without going into too many details.

Besides the modelling elements, there are several other views with their modelling elements as shown in Figure 48. Organisations develop or operate systems of CTAO and have organisation roles as described in the stakeholder view. Systems realize requirements and are deployed to geographic locations in the geographic distribution view. Finally, the relevant decisions to address the requirements are identified in the decisions view.

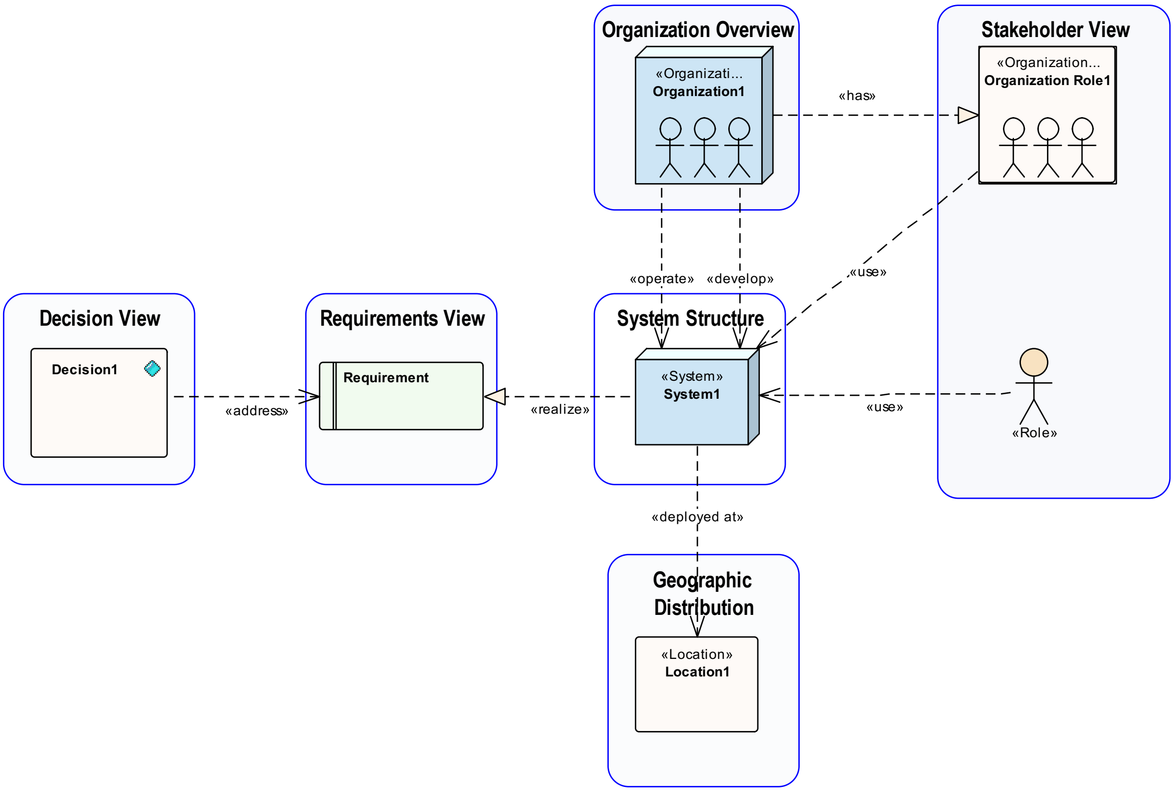


Figure 48: Modelling elements mainly dealing with project organisation and requirements

Requirements View

The requirements view will make the connection between the CTAO top-level architecture and the requirements captured in Jama. Here we link every system of CTAO with its corresponding requirements. It is a hence a mean to double-check both the architecture model as well as the requirements for completeness and consistency.

Decision View

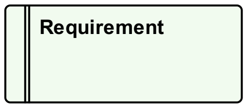
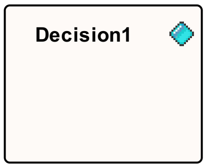
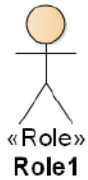
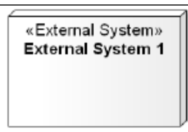
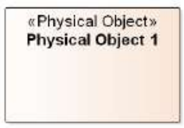
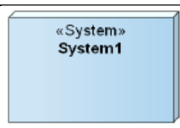
In the decision view, we document the major design decision that shape the CTAO systems. These decisions are typical technical decisions like the question whether there should be a common database for all data, or there should be a distributed database. Explicitly documenting decisions helps to preserve design knowledge, reason about design alternatives and check if assumptions still hold. We do not need to document every decision we make, but the most important ones that are difficult to change and have far-reaching impacts.

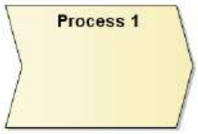
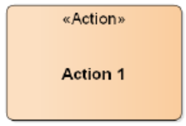
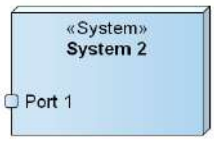
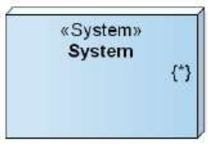
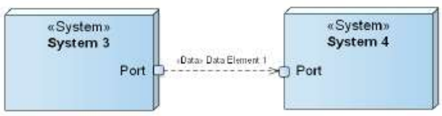
Organisation Overview
In the organisation overview, we show the Overview of the main organisations involved in the project and their dependencies (e.g. an Org-Chart). We moreover show the roles that (real-world) organisations and individuals have within CTAO (i.e. the mapping of stakeholder roles to stakeholders).

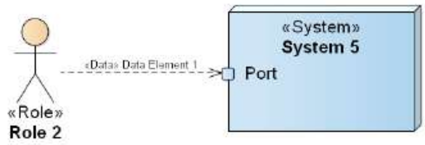
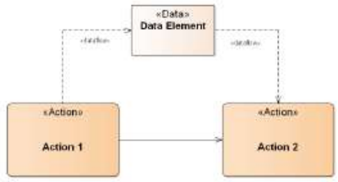
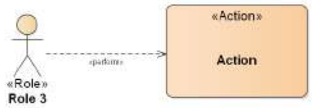
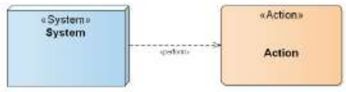
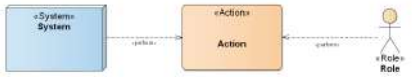
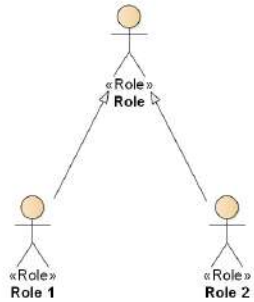
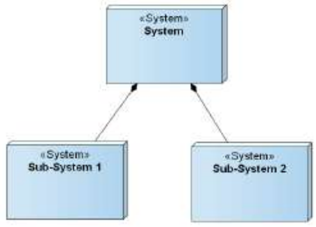
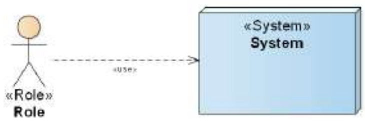
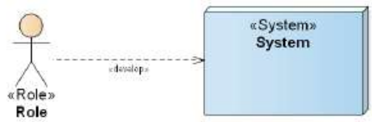
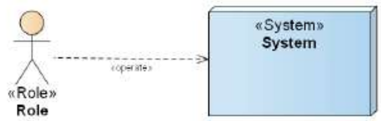
Geographic Distribution
In the geographic distribution view, we show how systems are deployed to the various locations of CTAO, e.g. the observation execution system is deployed to both the Northern site as well as the Southern site.

A glossary of the architectural elements with their graphical representation is given in 6.2.

6.2 Architecture Glossary

Modelling Element	Definition/Explanation	Symbol
Requirement	Requirement that needs to be realized by a system. We distinguish Quality Requirements, Functional Requirements and Constraints.	
Decision	During system design, we make decisions to address the various functional and non-functional requirements in the system. The decision element is the representation of a decision in the model.	
Objective	High-level objective of the CTA Observatory. It is the intended outcome of stakeholder interaction with the CTA Observatory system.	
Stakeholder Role	A stakeholder role is a collection of responsibilities, rights, duties and tasks that can be taken by a real person. Persons with the same role perform the same set of activities within processes. Example of a role is a tester who performs testing activities or a developer who develops software (software developer) or hardware (hardware developer). Individuals, i.e. real-world persons, can have multiple roles within the project.	
Organisation Role	An organisation role is a collection of responsibilities, rights, duties and tasks that can be taken by a real organisation, i.e. an organised body of people such as a university group, a research institute or a dedicated group of people. Similar like (individual) roles, organisation roles perform the same set of activities within processes. Organisations can have multiple organisation roles within the project.	
External System	An external system is a system in the outside of CTAO and that interacts with CTAO, e.g. the Laser Traffic Control system.	
Physical Object	A physical object is an element in the context of CTAO that is observed by CTAO.	
System	A collection of interacting (software and/or hardware) components organised to accomplish a specific function or set of functions within a specific environment. Systems outside CTA are stereotyped “External System”	

Process	A process is a self-contained, ordered sequence of activities initiated by a defined external event that takes one or more kinds of input and creates an output that is of value to an external stakeholder.	
Activity	An activity is a step performed within a process that is initiated by a defined event (e.g. the reception of data by another activity). In contrast to a process, this event is an internal event of CTA. It is either an ordered sequence of actions or (other) activities. It takes one or more kind of inputs and creates an output. In contrast to a process, this output might also be an interim result that is only used by other activities in the process.	
Action	An action is an atomic step within a process that ends in a persistent state. In this context, atomic means that actions are not segmented further in other actions or activities. Each action should contribute a persistent value to the process it belongs to. Persistent means that another action or activity would be necessary for revocation. Each action is either completely executed by exactly one system (without any user involvement), performed by exactly one person (without any system involvement), or performed by a person with a system support. In the last case, exactly one person (acting as exactly one role) can perform an action by interacting with exactly one system.	
Port	A port is an interaction point through which a system communicates with its environment. A port can map to one or more real-world interfaces of various types (e.g. software, electrical).	
System with multiple Instances at one Site	For some systems, it is indicated that several instances exist at one site (e.g. telescopes at one CTA array site, auxiliary instruments at one CTA array site). These are shown with {*}.	
Conceptual Data Element	Elements of data that flow between actions in the processes, between systems and between stakeholders and systems. The data elements are conceptual, thus are independent of their implementation. The data elements are organised with cer	
Information Flow between Systems	Information flow between systems is shown with a dashed line connecting the respective port of the system. The arrow shows the direction of the data exchange and the label names the data element.	

Information Flow between Stakeholder/Organisation and System	Stakeholders and/or organisations can exchange data elements with systems. The information flow is shown with a dashed line connecting the respective port of the system. The arrow shows the direction of the data exchange and the label names the data element.	
Information Flow between Actions	In activity diagrams, data elements can flow between actions, where the data element is produced in one action and consumed in the other.	
User Action	Users can perform actions (manual action).	
Automatic Action	Systems can perform actions (system-automated action).	
System-supported Action	Systems can support users to perform actions (system-supported action).	
Stakeholder Generalisation	Stakeholder roles can be generalised, e.g. the Science User is the generalisation of the Proposer. The generalised stakeholder shares the characteristics of the underlying stakeholders.	
System Composition	Systems can be composed of sub-systems. The aggregation of those sub-systems and their interaction make up the whole of the composed system.	
Stakeholder uses System		
Stakeholder develops System		
Stakeholder operates System		

6.3 Architecture Reading Guide

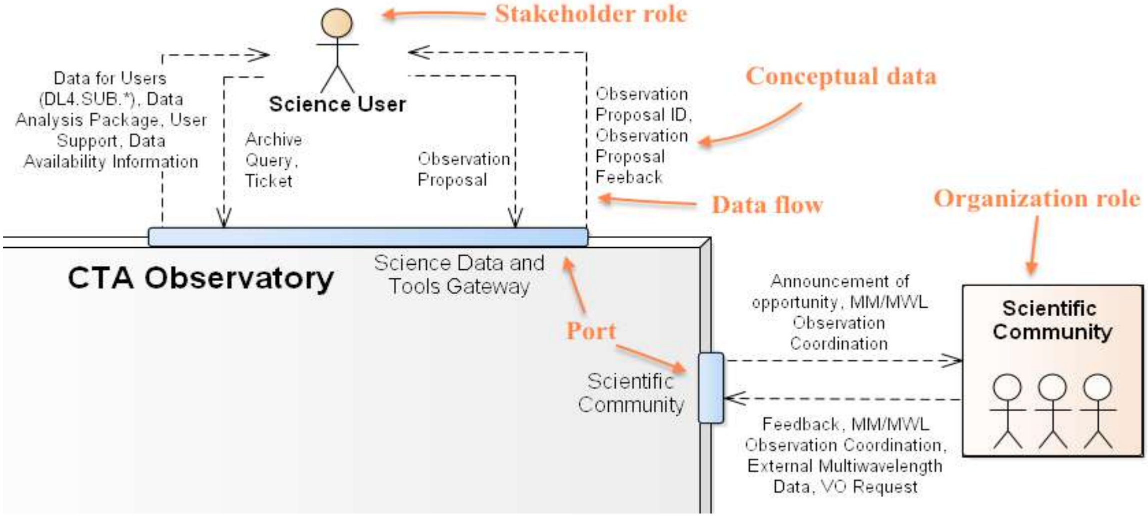


Figure 49: A portion of the system context delineation diagram with annotations indicating the main elements used in the diagram. The dashed lines ending in an arrow marker indicate the information flow and its direction, the text close to it names the data element that is flowing. Multiple data items are separated by comma when present in the same connector. Data flows in and out of the *CTA Observatory* system via ports, indicated as blue rectangles. Individual stick figures indicate individual stakeholder roles, while three stick figures surrounded by a box indicates organisation roles. Data elements and stakeholders are grouped by generalisation relationships (see *Figure 50*) to simplify the visual representation.

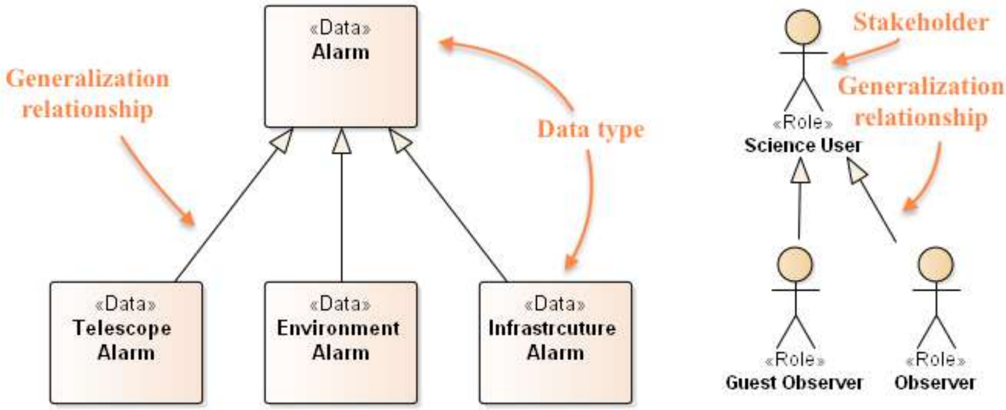


Figure 50: Annotated visual representation of two examples of generalisation relationships. Left: The *Alarm* data type generalizes *Telescope*, *Environment* and *Infrastructure Alarm*. Right: The *Science User* stakeholder role generalizees the *Guest Observer* and *Observer* stakeholder role. Note that the inverse relationship is ‘specialize’, i.e. the *Guest Observer* specializes the *Science User*.

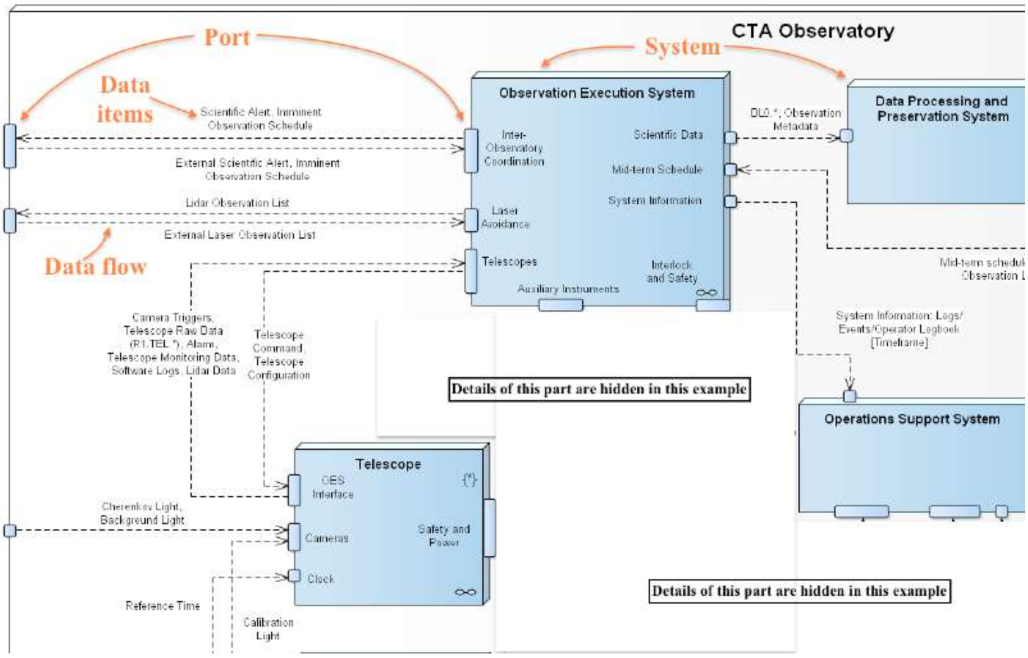


Figure 51: A portion of the system structure view diagram with annotations indicating the main elements used in the diagram. The *CTAO* system is decomposed in a set of systems shown as blue and green boxes. The outer boundary of the *CTAO* system is the same as in the system context delineation diagram (black box, see *Figure 49*), so that the ports of the system context delineation appear here at the outer boundary and are seen from the inside.

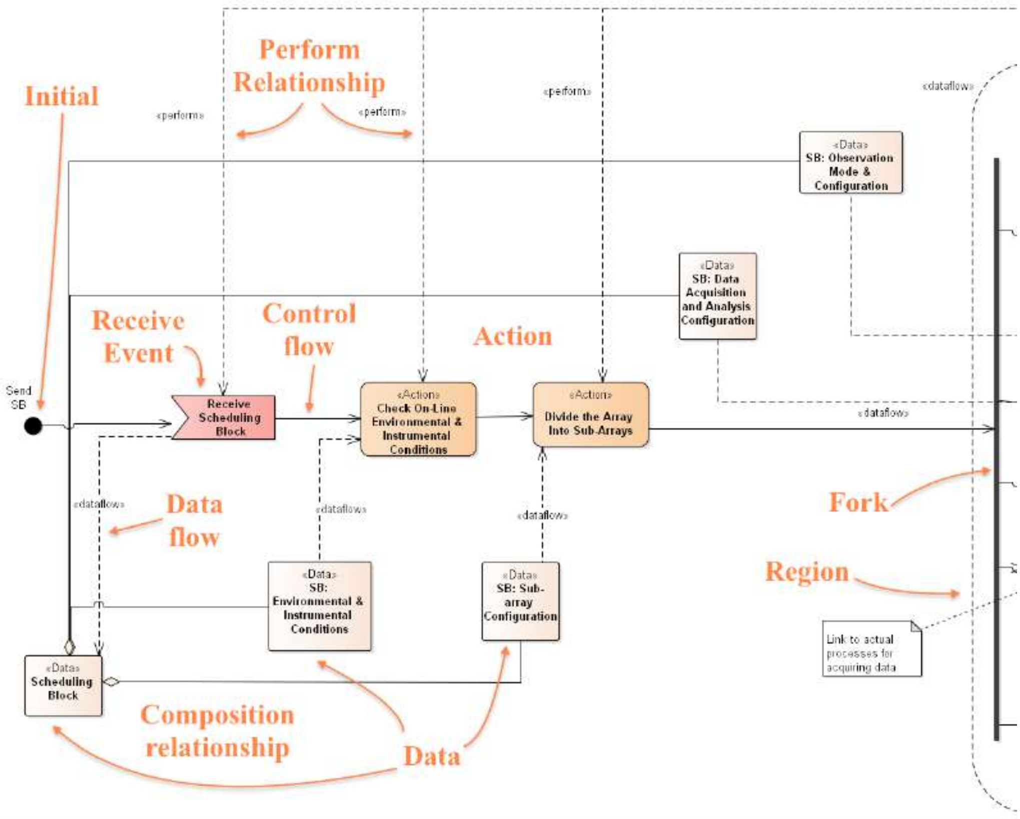


Figure 52: Annotated example of an activity ("*Execute Scheduling Block*", based on the top-level use case UC-CTAO-110 [R14]. This figure only shows the first half of the activity, the second half is shown in *Figure 53*. The *Fork* (vertical solid black line) at the right end of this figure indicates the starting point of parallel actions. A *Region* surrounding it indicates a part of the process with special characteristics (see *Figure 53*). A *Receive Event* (shown as a red flag) is used to define the

acceptance or receipt of a request from another activity in the system. In addition, another relationship of data elements is shown here in the bottom left corner where the *Composition* of the data element *Scheduling Block* of the data elements *Environmental & Instrumental Conditions* and *Sub-array Configuration* is shown.

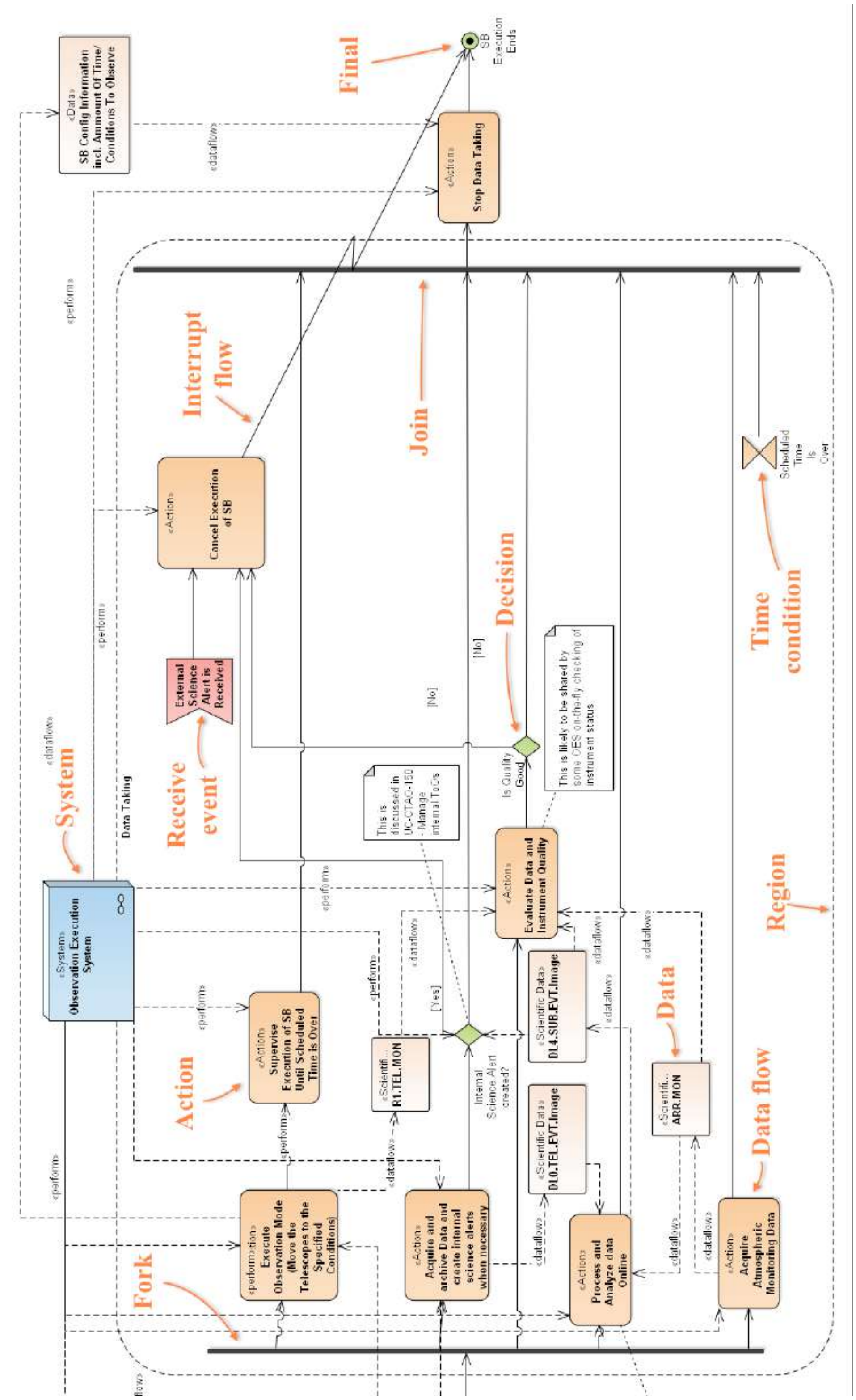


Figure 53: *Second half of the example activity from* Figure 52. *A Join (vertical solid black line at the right) indicates the point when the parallel actions come together (all actions are finalized). A Decision (green diamond) indicates alternative control paths. In this case, the Region indicates a part of the process that can be interrupted. An action can create an interruption, shown via an Interrupt flow (top right).*

7 References

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