GEMMA
Time Domain Astronomy Project Execution Plan

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A - TDA - 004

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List of Acronyms

Acronym	Definition
AEON	Astronomical Event Observatory Network
ANTARES	Arizona-NOAO Temporal Analysis and Response to Events System
ALeRCE	Automatic Learning for the Rapid Classification of Events
AURA	Association of Universities for Research in Astronomy
CDR	Critical Design Review
CP	Cerro Pachón (the site of the Gemini South telescope)
CSA	Cooperative Support Agreement
DR	Data Reduction
ELT	Extremely Large Telescope
EM	Electromagnetic
ESO	European Southern Observatory
FoV	Field of View
FTE	Full-Time Equivalent
FWHM	Full-Width Half Maximum
GHOST	Gemini High-resolution Optical SpecTrograph
GMOS	Gemini Multi-Object Spectrograph (-S located at Gemini South, -N at Gemini North)
GMT	Giant Magellan Telescope
GN	Gemini North
GNIRS	Gemini Near InfraRed Spectrograph
GW	Gravitational-wave
GS	Gemini South
IRAF	Image Reduction and Analysis Facility
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
ICD	Interface Control Document
IQ	Image Quality
IR	InfraRed
KPP	Key Performance Parameter
KSR	Key Science Requirement
LCO	Las Cumbres Observatory
LIGO	Laser Interferometer Gravitational-Wave Observatory
LSST	Large Synoptic Survey Telescope
MMA	Multi-messenger Astrophysics
NASA	National Aeronautics and Space Administration
NCOA	National Center for Optical-Infrared Astronomy
NIFS	Near-Infrared Integral Field Spectrometer
NOAO	National Optical Astronomy Observatory
NIR	Near InfraRed
NSF	National Science Foundation
O&M	Operations and Maintenance
OCS	Observing Control System (Gemini operations software)

OIR	Optical and Infrared
PI	Principal Investigator
PM	Project Manager
PMO	Portfolio Management Office
QAP	Quality Assurance Pipeline
rToO	Rapid Target of Opportunity
SOAR	Southern Astrophysical Research Telescope
TDA	Time Domain Astronomy
TMT	Thirty Meter Telescope
TOM	Target Observation Manager (a standard software agent used by many LC science programs)
ToO	Target of Opportunity
TFT	Transient follow-up system
VIS	Visible wavelength region
WBS	Work Breakdown Structure
ZTF	Zwicky Transient Facility

1 Introduction

1.1 Scientific Objectives

On August 17, 2017 the Advanced LIGO and Virgo detectors observed a gravitational wave signal consistent with a neutron star - neutron star merger. The Fermi gamma-ray observatory then detected a gamma-ray burst in the same part of the sky 1.7 seconds later. This led to a massive observing campaign by electromagnetic (gamma rays to radio, including Gemini) and neutrino telescopes. Although no neutrinos were observed, the electromagnetic campaign detected the remains of a "kilonova" explosion that resulted from the merger[1].

One month later, on September 22, 2017 a muon produced by a collision with a 290 TeV neutrino was detected by the IceCube Neutrino Observatory. The neutrino's origin was apparently coincident with a known gamma-ray blazar[2]. Electromagnetic follow-up observations from gamma-ray to radio frequencies were then carried out in response to the IceCube alert. These observations showed that the blazar was in a "flaring" state and showed that blazars can be a source of high-energy neutrinos.

These examples show that we are entering the era of multi-messenger astrophysics (MMA). A "messenger" is any independent form by which we can receive information from astronomical sources. Our current messengers are gravitational waves, neutrinos, high-energy particles (muons, cosmic rays, etc), and electromagnetic radiation. As in the two examples above, combining information from different messengers allows us to understand the nature of the sources and the physical processes involved. In science new technologies and capabilities always lead to new discoveries, so the current era has the potential to be very exciting if the resources can be used to their full potential.

The Large Synoptic Survey Telescope (LSST) is currently under construction on Cerro Pachón near La Serena, Chile, and will take MMA and time-domain astronomy (TDA) to the next level. LSST will image the entire visible sky every few nights for ten years in order to identify variable and transient objects and make very deep stacked images[3]. LSST will produce thousands of new alerts every few minutes from variable stars, AGN, solar system bodies, and all varieties of cosmic explosions. It will not be possible to understand the nature of many of these detections from LSST photometry alone, so observations at other electromagnetic wavelengths and, and in some cases also from neutrinos and gravitational waves, will be required.

The TDA project will allow Gemini to take a leadership role in this era of MMA and transients. Being among the largest of the optical-infrared (OIR) telescopes, Gemini has an important role to play in the study of fainter transients. Gemini currently observes many transients under its Target-of-Opportunity (ToO) observing mode, but the process is somewhat manual and inefficient. Gemini provides data reduction software for its facility instruments, but some of the steps require manual interaction and will not run in real time. The overall objectives of the TDA project are to:

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[1] LIGO and Virgo collaborations, et al. 2017, ApJ, 848, L12 (https://doi.org/10.3847/2041-8213/aa91c9)
[2] IceCube Collaboration et al., Science 361, eaat1378 (2018). DOI: 10.1126/ science.aat1378
[3] Ivezić, et al. 2008, arXiv:0805.2366

- Allow Gemini to cope with the expected massive increase in follow-up ToO requests, interrupts and the resulting rescheduling,
- Satisfy user demand for transient follow-up while preserving our ability to support non-transient observational programs
- Ensure that the observatory is efficiently utilized in a wider network of telescopes for transient science in the MMA era

In short, this project will build on and augment the OCS upgrades program and existing developments in data reduction so that Gemini can operate efficiently and provide the most useful data possible. For clarity, TDA does not:

- Provide all of the infrastructure needed by the Gemini observatory control system (OCS) including databases, observation and target models, graphical user interfaces, etc.
- Create an entire follow-up system (see Figure 1 below).
- Create the routines and algorithms needed to reduce the data from Gemini facility instruments.

1.2 Scientific Requirements

The following requirements will achieve the overall objectives listed above and allow Gemini to work within the time domain follow-up system described in Section 1.3. The requirements are based in part on initial user stories developed for the OCS Upgrades Program (see Section 1.3.3) and discussions with AEON participants.

Description of Scope	Threshold Key Science Requirements	Objective Key Science Requirements
Gemini to automatically accept up to N% of its observing time in the form of unplanned alerts	N=20%	N <= 100%, not limited by the system implementation.
Reduce manual scheduling to simple oversight and occasional human intervention	Manual scheduling time <= 1 person-hour / day / site	Manual scheduling time = 10 min / day
Optimization of a metric	The automatic scheduling system shall create observing plans by maximizing a metric for selecting observations. The metric to be developed includes scientific ranking, matches to conditions, timing constraints, and other considerations consistent with and based on current planning practices.	

Scheduling frequency	The automatic scheduler shall be able to deliver a new schedule to the telescopes on a timescale shorter than 15 minutes, typical of weather changes.	The scheduler shall be able to deliver a new schedule to the telescopes on a timescale shorter than 5 minutes, typical of weather changes on unstable nights.
Scheduling multiple telescopes together	The scheduler shall be able to generate plans for Gemini North and South at the same time and coordinate observations between the two.	The scheduler shall be able to coordinate observations with facilities outside of Gemini
Available components	On a given night the scheduler shall only schedule observations that can be done with available instruments in their current configurations (eg. filters, masks, gratings).	
Weather conditions	At a given moment the scheduler shall only schedule observations that can be executed under the current conditions. The conditions may come from weather sensors, data reduction pipeline measurements, or operator entry.	
Calibrations	The automated scheduler shall schedule the required calibration observations along with the science observations so that the data can be fully reduced within one day.	Whenever possible and appropriate the automatic scheduler shall schedule the required calibration observations before the science observations so that the data reduction pipeline uses the best calibrations and the pipeline/PI does not have to reprocess the data once better calibrations become available.
Forward-look schedules	The scheduler shall be able to project a plan at least 7 days into the future while accounting for weather forecasts and telescope, instrument, and staff calendars.	The scheduler shall be able to project a plan at most 6 months into the future while accounting for weather forecasts and telescope, instrument, and staff calendars, to allow Gemini to simulate an entire semester. It would be desirable for the scheduler to make suggestions about when to install instrument components such as gratings and MOS masks.

Alternative scenarios	The scheduler shall allow an operator to create plans for different scenarios in the future including variations in weather (eg. forecast uncertainties), and changes in instrument configurations.	The scheduler shall allow an operator to create plans for different scenarios in the future including variations in weather (eg. forecast uncertainties), and changes in instrument configurations.
Manually adjustable observation weight	It shall be possible for a human operator to manually adjust the weight of an observation.	
Interrupting Target of Opportunity Triggers	It shall be possible for urgent or interrupting ToOs to automatically interrupt an ongoing observation by applying a set of rules (e.g. an algorithm for determining whether to abort or read out).	
Non-interruptable observations	It shall be possible to set observations with a time-critical or coordinated status that gives very high priority and prevents interrupts.	
Manual control of scheduler	It shall be possible for a human operator to turn off reception of the automated plans so that manual operation can be performed.	
Target of Opportunity Requests	It shall be possible for external users to request ToO (targets not defined in the proposal) observations using either a user interface (UI) or application programming interface (API)	It shall be possible to request ToO (targets not defined in the proposal) observations using either a user interface (UI) or application programming interface (API) that are common to all AEON members.
Telescope status API	It shall be possible for external users to request telescope open status, weather conditions, ToO status (accepting?), and instrument configurations for Gemini using an API.	It shall be possible to request telescope open status, weather conditions, ToO status (accepting?), and instrument configurations from Gemini, SOAR, and other AEON members via a common API.
Scheduler/Telescope API	There shall be APIs to receive status information (e.g. open/closed, weather conditions, execution status) and for the scheduler to send the schedule to each telescope node (e.g. Gemini sequence executors) .	The APIs shall be common to AEON in order to support multiple telescopes.

Real-time spectroscopic pipeline	There shall be a real-time longslit spectroscopic reduction pipeline for at least one of Gemini's legacy spectrographs (e.g. existing, pre-GHOST, instruments such as GMOS and GNIRS, the priority is GMOS) that will produce an extracted, wavelength calibrated spectrum within 30 minutes of the end of readout for 10 raw frames.	There shall be a real-time spectroscopic reduction pipeline for **all** of Gemini's legacy spectrographs that will produce an extracted, wavelength calibrated spectrum within 5 minutes of the end of readout for 10 raw frames.
Real-time imaging pipeline	There shall be a real-time imaging reduction pipeline for at least one of Gemini's legacy imagers that will produce a flat-fielded, stacked image and a photometry catalog within 1 hour of the end of readout for 50 raw frames.	There shall be a real-time imaging reduction pipeline for **all** of Gemini's legacy imagers that will produce a flat-fielded, stacked image and a photometry catalog within 1 hour of the end of readout for 50 raw frames.
Reduced data in the Gemini Observatory Archive	It shall be possible for external users to download raw and reduced data from the Gemini Observatory Archive using an API within 5 minutes of the end of readout (raw) or the completion of the reduction (processed).	
Target Observation Manager Plugin	Gemini shall provide a plugin for the TOM Toolkit to make it easier for external users to use the Gemini/AEON APIs to request observations, check status, and download reduced data products from the Gemini Observatory Archive.	The TOM toolkit plugin shall include a way to connect to a service that can push data and data products to the user.

High Level Requirements

Parameter	Baseline Value
Application Program Interface	It shall be possible to send observation requests, receive status, and retrieve data via an application or script, and without the need for a manually driven interface.
Automated scheduling	An algorithm running in an application must be able to automatically generate telescope schedules that maximize a quality metric in less than 15 minutes.
Real-time data reduction	Data for at least one legacy imager and one legacy longslit spectrograph must be reduced automatically on the night in which it is taken.

1.3 Facility/Infrastructure

1.3.1 Overview

As noted above, our response to the challenge of time-domain astronomy in the LSST era is to incorporate Gemini into a wider network of telescopes (the Astronomical Event Observatory Network, or AEON), covering multiple apertures and capabilities. Figure 1 gives a schematic of the working model for the complete follow-up system, based on and around the current Las Cumbres Observatory (LCO)).

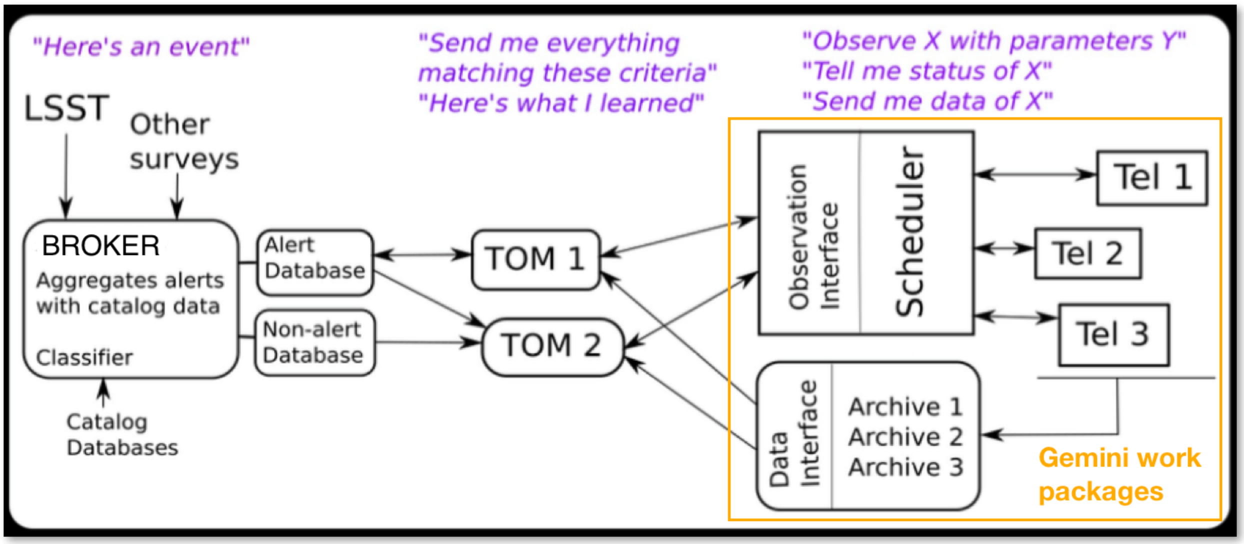


Figure 1 - Concept for the broad transient follow-up system (credit: Rachel Street, LCO). The yellow box (AEON) provides scheduling and data reduction for NCOA and LCO telescopes. The TDA work packages involve the components in this box and the interface to the TOMs (user software agents).

The main components of the overall system are:

1. **Alert Broker**: This accepts transient event alerts from one or more facilities (eg. LIGO, IceCube) or surveys (e.g. ZTF, LSST) and classifies the objects based on position, color, and light curve information and associations with existing catalogs. Research teams can configure filters in order to extract objects of interest. There are ongoing broker projects at NOAO (ANTARES[4]), in Chile (ALeRCE[5]), and in the UK (Lasair[6]). The AEON network will take alert streams from ANTARES.
2. **Target Observation Manager** (TOM): These are observation management tools for specific research projects. They collect alerts from surveys or brokers and allow the teams to review data, make decisions, and submit observations to the observatories on which the teams have observing time[7]. Las Cumbres Observatory has initiated a community TOM development effort and has produced a TOM development kit[8].
3. **Scheduler(s)**: This is an algorithm that schedules observations on the telescopes on the

[4] https://www.noao.edu/ANTARES/
[5] http://alerce.science/
[6] https://github.com/lsst-uk/lasair
[7] https://www.noao.edu/meetings/lsst-tds/agenda.php
[8] https://tomtoolkit.github.io

network. There can be a single network scheduler, or individual telescopes can have their own schedulers. The schedulers must be responsive in order to react to new events and changes in site conditions.
4. **Telescopes**: These are the individual nodes of the network. They must be able to broadcast their current observing status (closed, open, current target), receive the observation plans from a scheduler, execute the observations.
5. **Data reduction pipelines**: These reduce the data immediately after they are taken. Both raw and processed data are transferred to an archive.
6. **Data archives**: These are databases for raw and reduced data. Authenticated users (often using TOMs) can download the data as soon as it is available.

The current plan for the AEON project is to develop interfaces and scripting capabilities to execute time-domain observations from the LCO scheduler on the Southern Astrophysical Research (SOAR) telescope during dedicated nights by the end of 2019. The TDA project will incorporate Gemini into the network by 2021, in time for LSST commissioning and early operations.

The following three subsections detail current Gemini infrastructure and software, and the ways in which they will develop to enable integration into AEON.

1.3.2 Telescopes and Instrumentation

Gemini operates twin 8-m telescopes on Cerro Pachón in Chile and Maunakea in Hawaii, providing coverage of the entire sky. Thus, while Gemini is ideally suited to observe targets detected by LSST, it is also capable of reaching any LIGO or IceCube target with an identified electromagnetic counterpart and supporting space missions like Chandra and JWST. The telescopes were designed for queue observing, so switching between facility instruments happens in less than a minute. Complementary optical and NIR instrumentation is available at both sites. The longitude difference between Gemini South and North will be increasingly useful in the era of LSST Operations, allowing 8-m followup to continue after targets have set in Chile. Thus, the geography, hardware, and software already make Gemini an ideal platform for MMA and transient follow-up. The most significant development supporting TDA will be the building of a new broad-wavelength imaging spectrograph, SCORPIO, specifically as a follow-up workhorse instrument. This will be delivered to Gemini South, and thus colocated with LSST, in time for the start of LSST survey operations.

1.3.3 Evolving the Gemini Observatory Control System

Gemini's current observation preparation and execution software (known as the Observatory Control System, OCS) has been under continuous development since about 2000. However the fundamental design has not changed greatly and has also made it very difficult to include the constraints needed for proper automated scheduling. Therefore, static nightly observing plans are still created manually, and it is cumbersome and inefficient for observers to update plans as new rapid target-of-opportunity (rToO) observations arrive or to switch plans as conditions change. A substantial increase in the rate of rToOs, as we expect, will lead to more inefficiencies.

For these reasons, Gemini has embarked on a project to modernise the entire OCS suite, and this upgraded OCS will by design support the MMA and time domain follow-up network. Currently the ability to trigger ToO observations at Gemini programmatically is rudimentary, using scripts via a very basic Application Program Interface (API). A defining concept of the new system is that all the fundamental services should be accessible both through manual user interfaces, and through APIs that define how programs interact with the systems. The OCS Upgrades Program will provide the infrastructure such as the databases and the observation and target models that will support the constraints needed by the scheduler.

The TDA project will build upon these developments to meet the science goals laid out in Section 2.1. Specifically, we will

- Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
- Provide new application programming interfaces (APIs) that comply with a set of standards that will be generally applicable across a wider network of follow-up facilities. These will allow observations to be requested, provide the required feedback, and allow automated data access as described in a later section.
- Provide software to help Gemini users work with the new APIs

The performance and success of the system will be evaluated by tracking time use and completion statistics in a manner similar to what we do now. Some policies, such as the charging for interrupting ToOs, will be evaluated and updated if we start to notice problems or impacts on other programs. In order to make the system understandable and transparent, we will publish the quality metric (weighting algorithm) and present both the schedule history and future plans with a much detail as permitted by the privacy restrictions of the programs (e.g. don't publically publish target information).

We will also be discussing new time allocation modes for AEON with partner observatories. We have proposed a common AEON TAC to allocate time on multiple facilities in order to reduce multiple jeapardy in the proposal process and help make the decision-making process more uniform. While outside the scope of this project, it may help promote the use of the followup network.

Finally, we will be participating in community discussions about MMA procedures, especially the coordination of observations between very different facilities (e.g. Gemini, the VLA, space observatories, IceCube, LIGO, etc).

1.3.4 Evolving Gemini Data Reduction

Gemini currently provides data reduction software for all of its facility instruments. The purpose is to make the data amenable to scientific analysis by removing instrument, telescope, and atmospheric signatures (including sky/telluric features). For all but one instrument, this takes the form of a package of Image Reduction and Analysis Facility (IRAF) scripts or command line tools. IRAF is growing obsolete, especially its compatibility with modern operating systems and file structures. Therefore, we have begun a project to replace Gemini IRAF with a Python-based platform using and aligned with AstroPy. The first release to support all facility imagers will take place in early 2019. The next step will be GMOS long-slit spectroscopy (our most commonly used instrumental mode). This is a major undertaking that will lead to the foundation of our Python spectroscopy software suite, the bulk of which will be reusable for other spectroscopic instruments. However, neither the IRAF reduction package nor its Python-based replacement run automatically or unattended.

Gemini currently distributes raw data using the Gemini Observatory Archive[9] that runs on Amazon Web Services. PIs who receive notification of completion of observations on their science program are able to login to the archive and download the raw, proprietary data for processing using the data reduction package referred to above. The archive supports reduced data only in a rudimentary fashion.

The TDA project will enhance these data reduction and archiving efforts to close the data loop with the science teams. Specifically we will:

- Automate the data reduction for selected modes (e.g. GMOS long-slit) of at least one legacy (pre-GHOST) instrument working within the new infrastructure to provide reduced products in almost real-time at night, so that these products may be fed back immediately to the requesting PI or software agent (TOM). New instruments such as GHOST and SCORPIO will be delivered with Gemini-compliant data reduction pipelines.
- Improve the ingestion of reduced data products and provide for communication to and from the TOMs to enable automatic download of products.

1.4 Scientific & Broader Societal impacts

Multi-messenger astrophysics is one of NSF's Ten Big Ideas. As described above, it combines the results from some of the NSF's major astrophysics facilities in order to elucidate the nature of new and rare events. In response to the NSF-sponsored report by the National Research Council on *Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System*[10] and the NOAO/LSST report on *Maximizing Science in the Era of LSST*[11], NOAO initiated a project to establish a transient follow-up network based on the Las Cumbres Observatory design and incorporating multiple facilities that will be under the forthcoming umbrella of NSF's National Center for Optical-Infrared Astronomy (NCOA). As noted above, the TDA project will make both Gemini telescopes active and crucial participants in that network. The particular impact of incorporating Gemini into this network is that Gemini will provide by far the largest apertures in the initial network, thus enabling spectroscopy of the most distant transient events.

Gemini Observatory is aligning itself with NSF priorities and is preparing to be a leader in exploring and discovering the nature of transient and time-variable sources. The Gemini Board's guidelines state that "Gemini will strive to be the best observatory in the world for the execution of flexible, innovative, and efficient science programs." Between physical location and hardware and software changes, Gemini will be well positioned in this new environment.

[9] https://archive.gemini.edu/

[10] https://www.nap.edu/catalog/21722/optimizing-the-us-ground-based-optical-and-infrared-astronomy-system

[11] https://www.noao.edu/meetings/lsst-oir-study/

2 Organization

2.1 Internal Governance & Organization and Communication

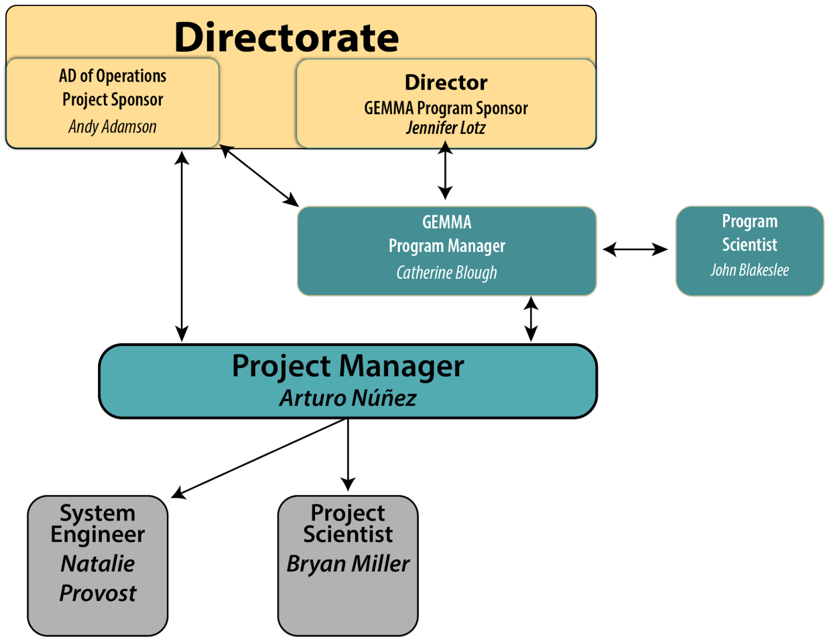


Figure 2 - Internal organization of key project staff

Project Manager: Reports to the Project Sponsor and the Program Manager. The Project manager is accountable to the Project Sponsor for the management of the project and is accountable to the Program Manager for adherence to the program goals. Within the tolerances agreed upon with the Project Sponsor/Program Manager the Project Manager has the authority to make decisions on all aspects of the project. Decisions outside the tolerances must be approved by the Project Sponsor/Program Manager.

Project Sponsor: Reports to the Gemini Directorate. The Project Sponsor is responsible for supporting the Project Manager and ensuring that the Project Manager performs the assigned tasks. The Project Sponsor functions as a link between the Gemini Directorate and the Project Manager and manages the escalation process outside of the purview of the Project Manager. The Project Sponsor works with the Program Manager to make decisions outside of the Project Manager's tolerances.

Program Manager: Reports to the Gemini Directorate. The Program Manager is responsible for setting program and project goals and ensuring that these goals are met. The Program Manager works with the Project Sponsor to make decisions outside of the Project Manager's tolerances. The Program Manager communicates directly with funding organizations, the Gemini Board and Science and Technology Advisory Committee (STAC).

Systems Engineer: Reports to the Project Manager. Responsible for the system engineering activities pertaining to the project as detailed in the TDA Systems Engineering Plan (SEMP).

To lead this effort, we have a core team which will remain the same throughout the project's lifespan:

- Andy Adamson, Associate Director of Operations, as Project Sponsor for TDA.
- Arturo Nunez, Software Department Manager, as Project Manager for TDA.
- Natalie Provost, System Engineer, as Lead System Engineer for TDA.
- Bryan Miller, Tenured Astronomer GS, as Project Scientist for TDA.
- Andrea Blank as Project Coordinator for TDA.

In parallel with this, we will proceed with the four hirings described elsewhere in this document.

Please refer to the TDA Internal Communication Plan listed in Appendix A.

2.2 External Organization and Communication

Please refer to the Program Execution Plan for External Organization and Communication.

2.3 Partnerships

There are two significant external partners in this project to date:

1. **Las Cumbres Observatory** - already operating a network of follow-up telescopes of the 1-2 m aperture class, and currently working with the SOAR telescope to enable coordinated work for TDA observations.

2. **NOAO** - Responsible for the ANTARES event broker which will feed the TDA network, and for the project currently incorporating SOAR into LCO.

2.4 Roles and Responsibilities

Please refer to the Program Execution Plan for external organization roles and responsibilites.

2.5 Community Relations and Outreach

We anticipate taking two main approaches to acquiring adequate community input. Firstly, the community, including National Gemini Offices, is already being consulted on issues and capabilities of the new OCS, both via formal communications and at conferences and science meetings. Secondly, in consultation with the STAC we are assembling a TDA working group whose terms of reference are to advise the Observatory on its plans for the time-domain network. This working group will include members who have a direct interest in TDA, and some who undertake non-transient astronomy. The latter inclusion is consistent with the science requirement to control the impact of TDA on other Gemini science, and is a specific recommendation of the STAC.

3 Design and Development

3.1 Project Development Plan

In order to satisfy the scientific objectives and requirements for this project, we have identified five major products that need to be developed:

- Gemini TDA APIs: A new set of application programming interfaces (APIs) that will allow observations to be requested, provide the required feedback, and allow automated data access.
- Gemini Plugins for Target and Observation Managers (TOMs): Provide software to help Gemini users work with these new APIs
- Scheduler: Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
- Real Time Pipelines: Provide a mechanism to automatically reduce imaging and long slit spectroscopic data in real-time for rapid characterization of transient sources and more responsive decision-making during night operations.
- Product Distribution Manager: Updates the Gemini Observatory Archive to be able to deliver reduced data to users.

These TDA software products are built on top of existing software infrastructure that support telescope operations as shown in the next figure:

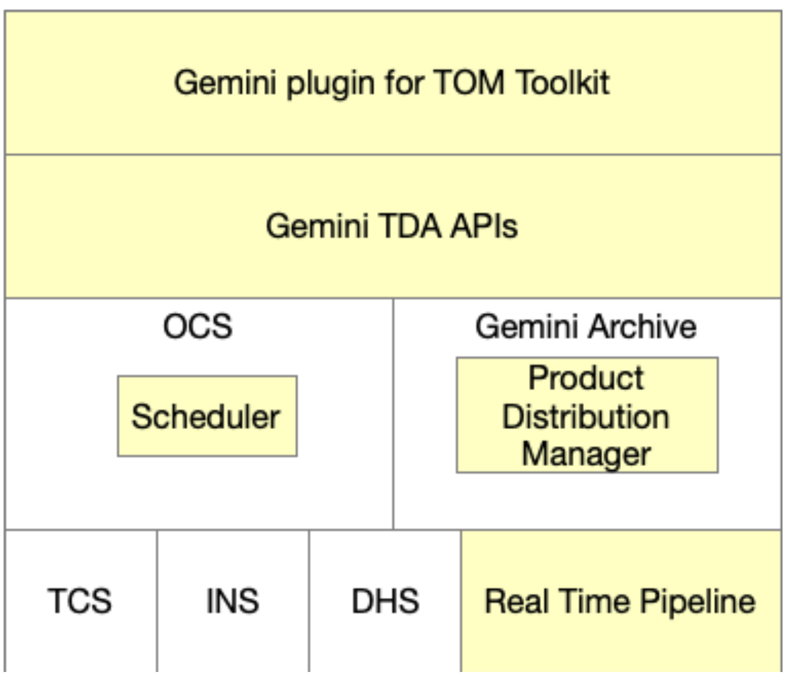


Figure 4 - (Yellow) the work on GEMMA-TDA as it fits into other systems.

Descriptions of each of these five product plans and milestones follow:

Scheduler. In order to implement the Gemini Scheduler in support of TDA, the following are the main activities and milestones we plan to follow:

- Requirements and initial prototype: August 2019

- Final Architecture definition: November 2019
- OCS Support infrastructure completed: September 2020
- Implementation completed: July 2020
- Verification and Testing: January 2021

Gemini TDA APIs. In order to implement the Gemini TDA APIs, the following are the main activities and milestones we plan to follow:

- Operational requirements baselined: May 2019
- TOM Interface implementation: August 2019
- Scheduler Interfaces implementation: December 2019
- API testing and verification: February 2020

Gemini Plugin for TOM Toolkit. With both operational requirements of the Gemini TDA APIs and Scheduler, the work on the Gemini Plugin for the TOM toolkit can begin. The following are the main milestones in that work package:

- TOM plugin and User Interface implementation: July 2020
- TOM testing and verification: September 2020

Product Distribution Manager. In order to implement the Product Distribution Manager in the Gemini Archive, the following are the main activities and milestones we plan to follow:

- Gemini Archive requirements baselined: March 2020
- Archive Implementation and testing: December 2020

Real Time Pipelines. In order to implement the Real Time Pipelines, the following are the main activities and milestones we plan to follow:

- Pipeline requirements baselined: May 2019
- GMOS Long Slit Spectroscopy Automation: December 2020
- (GOAL) NIR (e.g. F2 or GNIRS) Long Slit Spectroscopy Automation: November 2021

For additional details, please refer to the TDA Project Plan listed in Appendix A.

3.2 Development Budget and Funding Sources

Please refer to the TDA Project Plan listed in Appendix A.

3.3 Development Schedule

Please refer to the TDA Project Plan listed in Appendix A.

4 Construction Project Definition

4.1 Summary of Total Project Definition

This project will develop the following products:

1. TDA APIs: A new set of application programming interfaces (APIs) that comply with a set of standards that will be generally applicable across a wider network of follow-up facilities. These will allow observations to be requested, provide the required feedback, and allow automated data access.

2. Gemini Plugins for Target Observation Managers (TOMs): Provide software to help Gemini users work with these new APIs.
3. Scheduler: Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
4. Real Time Pipelines: Provide a mechanism to automatically reduce imaging and longslit spectroscopic data in real-time for rapid characterization of transient sources and more responsive decision-making during night operations.
5. Product Distribution Manager: Updates the Gemini Observatory Archive to be able to deliver reduced data to users.

The estimated total labor cost of this project is 14.3 FTE. Non labor costs are estimated at $120,000. The baseline schedule of the project is Q1-2019 to Q4-2021. Details are discussed in section 4.9.

4.2 Work Breakdown Structure (WBS)

WBS #	WBS Title	Deliverable	Responsible Organization
1.4.1	Operational Concept Definition	Concept of Operation for TDA Software	Gemini Observatory
1.4.2	Scheduler	Automated Queue Scheduler	Gemini Observatory
1.4.3	TDA APIs	TDA APIs	Gemini Observatory
1.4.4	Gemini Plugin for TOM Toolkit	Gemini Plugin for TOM Toolkit	Gemini Observatory
1.4.5	Real Time Pipelines	Automation of GMOS and NIR Long Slit Spectroscopy	Gemini Observatory
1.4.6	Product Distribution Manager	Improvements to Data Archive to support distribution of reduced data	Gemini Observatory
1.4.7	Integration and Commissioning	Verification, Validation, Integration, and Commissioning Tests Complete	Gemini Observatory
1.4.8	Documentation, training and Handover to operations	Handover of TDA products to operations	Gemini Observatory

4.3 WBS Dictionary

WBS #	WBS Title	WBS Description
1.4.2	**Scheduler**	
1.4.2.1	Requirements and initial prototype	Defines the Key Science Requirements and Key Performance Parameters of adaptive queue scheduling for Gemini in the context of the anticipated TDA network of telescopes, and generates software for testing of concepts (not anticipated to be the same architecture as the final version). Also, defines Interface Control Documents to other software systems.
1.4.2.2	Inital Prototype and Architecture definition	Final software architecture defined, and prototype software created based on that
1.4.2.3	Implementation	Scheduler moved from prototype to facility and integrated with the OCS / Observing database
1.4.2.4	OCS Support infrastructure	Database infrastructure in support of the automated scheduler, in particular AND and OR logic
1.4.2.5	Scheduler Testing	Testing the scheduler against KSRs defined in 1.4.2.1, including its ability to match (or better) existing queue planning methods.
1.4.3	**TDA APIs**	
1.4.3.1	Operational Requirements	Generate requirements on the APIs to satisfy the KSRs, and user stories in the Concept of Operations.
1.4.3.2	TOM APIs Implementation	Coding of APIs in AGILE “Sprints”, with close interaction with project scientist and other relevant staff.
1.4.3.3	Scheduler Interfaces implementation	Coding of interfaces involved in automated scheduling. Limited to interfaces with elements of the OCS.
1.4.3.4	API testing	Testing the APIs against KSRs defined in 1.4.3.1.
1.4.4	**Gemini Plugin for TOM Toolkit**	

1.4.4.1	TOM Plugin UI and Implementation	Provides users with the ability to interact with the Gemini observing system, database and archive directly from their TOMs.
1.4.4.2	TOM Testing	End-to-end testing of the interaction between users' TOMs and the Gemini observing system, database and archive. Verification that all User Stories and Key Science Requirements have been met.
1.4.5	**Real Time Pipelines**	**Automation of the pipeline reduction for Gemini long-slit spectrometers in advance of the delivery of SCORPIO**
1.4.5.1	Pipeline Requirements	Define key scientific and performance requirements to allow for almost real-time data reduction upon completion of observation sequence.
1.4.5.2	GMOS Long Slit Spectroscopy Automation	Automate all steps for GMOS Long Slit Spectroscopy reduction. Includes documentation and testing.
1.4.5.3	NIR Long Slit Spectroscopy Automation	Automate as many steps as possible for NIR Long Slit Spectroscopy. Includes documentation and testing for steps completed.
1.4.6	**Data Products Management**	**Required changes to the Gemini Observatory Archive and its interfaces to enable ingestion and automatic distribution of reduced data products from the Pipeline**
1.4.6.1	Archive Requirements	Define new requirements on the Gemini Observatory Archive specifically to support the ingestion of reduced data products from the automated pipeline and to provide them to external users or software agents (TOMs).
1.4.6.2	Archive Improvements Implementation	Add functionality to track data provenance and data reduction software version, including the necessary API changes.
1.4.7	**Integration and commissioning**	**Producing a working overall system from the products of the previous five work breakdown items**
1.4.8	**Documentation and Training**	**Documentation and Training necessary to hand over TDA software products to**

		operations
1.4.9	**Project Management and Administration**	**Overall project management effort in support of this project**

4.4 Scope Management Plan and Scope Contingency

Please refer to the TDA Scope Management Plan listed in Appendix A.

4.5 Cost Estimating Plan, Cost Reports and Baseline Budget

This is covered in section 4.5 of the Program Execution Plan.

4.6 Complexity Factor

This is covered in section 4.5 of the Program Execution Plan.

4.7 Cost Book, Cost Model Data Set and Basis of Estimate

Not Applicable
Since this is not a large facility project. The TDA project is an addition to existing observatory operations, this section is not applicable.

4.8 Baseline Funding Profile

Baseline Funding profile per WBS - Labor (US$)					
WBS #	**WBS Title**	**2019**	**2020**	**2021**	**TOTALS**
1.4.1	Operational Concept Definition	$12,933	$0	$0	**$12,933**
1.4.2	Scheduler	$191,240	$235,300	$3,276	**$429,816**
1.4.3	TDA APIs	$201,156	$13,192	$0	**$214,348**
1.4.4	Gemini Plugin for TOM Toolkit	$0	$106,915	$0	**$106,915**
1.4.5	Real Time Pipelines	$204,173	$297,293	$165,977	**$667,444**
1.4.6	Product Distribution Manager	$28	$100,017	$6	**$100,052**
1.4.7	Integration and Commissioning	$0	$0	$165,546	**$165,546**
1.4.8	Documentation, training and Handover to operations	$0	$34,489	$34,489	**$68,978**
1.4.9	Project Management and Admin	$15,520	$15,520	$15,520	**$46,560**
	Contingency	$0	$28	$292,292	
	TOTALS	**$625,051**	**$802,753**	**$677,107**	**$2,104,911**

Baseline Funding Profile per WBS - Non-Labor (US$)					
WBS #	**WBS Title**	**2019**	**2020**	**2021**	**TOTALS**
1.4.1	Operational Concept Definition				**$0 f**
1.4.2	Scheduler	$10,000	$10,000		**$20,000**
1.4.3	TDA APIs	$10,000			**$10,000**
1.4.4	Gemini Plugin for TOM Toolkit	$10,000	$10,000		**$20,000**
1.4.5	Real Time Pipelines	$3,000		$3,000	**$6,000**
1.4.6	Product Distribution Manager				**$0**
1.4.7	Integration and Commissioning			$20,000	**$20,000**
1.4.8	Documentation, training and Handover to operations		$13,000	$10,000	**$23,000**
1.4.9	Project Management and Admin				**$0**
	Contingency	$7,000	$7,000	$7,000	
	TOTAL	**$40,000**	**$40,000**	**$40,000**	**$120,000**

4.9 Baseline Schedule Estimating Plan and Integrated Schedule

The Baseline Schedule is shown below:

WBS	Description	Begin	End
1.4	Time Domain Astronomy Software	Nov 19, 2018	Dec 31, 2021
1.4.1	Operational Concept Definition	Nov 26, 2018	Feb 15, 2019
1.4.2	Scheduler	Feb 18, 2019	Jan 15, 2021
1.4.3	TDA APIs	Apr 17, 2019	Feb 5, 2020
1.4.4	Gemini Plugin for TOM Toolkit	Feb 5, 2020	Sep 5, 2020
1.4.5	Real Time Pipelines	Feb 18, 2019	Nov 19, 2021
1.4.6	Product Distribution Manager	Jan 20, 2020	Dec 18, 2020
1.4.7	Integration and Commissioning	Jan 18, 2021	July 30, 2021
1.4.8	Documentation, Training and Operations Handover	Sep 7, 2020	Dec 17, 2021

The integrated schedule is shown in the next figure:

WBS Code	Title	Expected Start	Expected End
1.4.	▼ **Time Domain Software Plan**	**Nov 19, 2018**	**Dec 31, 2021**
1.4.1	▷ Operational Concept Definition	Nov 26, 2018	Feb 15, 2019
1.4.2	▼ **Scheduler**	**Feb 18, 2019**	**Jan 15, 2021**
1.4.2.1	▶ **Requirements and initial prototype**	**Feb 18, 2019**	**Aug 2, 2019**
1.4.2.2	▷ Inital Prototype and Architecture definition	Aug 5, 2019	Nov 22, 2019
1.4.2.3	▷ Implementation	Nov 25, 2019	July 31, 2020
1.4.2.4	▶ **OCS Support Infrastructure**	**Aug 5, 2019**	**Sep 25, 2020**
1.4.2.5	▷ Scheduler Testing	Aug 3, 2020	Jan 15, 2021
1.4.3	▼ **TDA APIs**	**Apr 17, 2019**	**Feb 5, 2020**
1.4.3.1	▷ Operational Requirements	Apr 17, 2019	May 1, 2019
1.4.3.2	▷ TOM APIs Implementation	May 1, 2019	Aug 21, 2019
1.4.3.3	▷ Scheduler Interfaces Implementation	Aug 21, 2019	Dec 11, 2019
1.4.3.4	▷ API testing	Dec 11, 2019	Feb 5, 2020
1.4.4	▼ **Gemini Plugin for TOM Toolkit**	**Feb 5, 2020**	**Sep 4, 2020**
1.4.4.1	▷ TOM Plugin and UI Implementation	Feb 5, 2020	July 10, 2020
1.4.4.2	▷ TOM Testing	July 13, 2020	Sep 4, 2020
1.4.5	▼ **Real Time Pipelines**	**Feb 18, 2019**	**Nov 19, 2021**
1.4.5.1	▷ Pipeline Requirements	Feb 18, 2019	May 10, 2019
1.4.5.2	▷ GMOS Long Slit Spectroscopy Automation	May 13, 2019	Dec 18, 2020
1.4.5.3	▷ NIR Long Slit Spectroscopy Automation	Dec 21, 2020	Nov 19, 2021
1.4.6	▼ **Product Distribution Manager**	**Jan 20, 2020**	**Dec 18, 2020**
1.4.6.1	▷ Archive Requirements	Jan 20, 2020	Mar 13, 2020
1.4.6.2	▷ Archive Improvements Implementation	Mar 16, 2020	Dec 18, 2020
1.4.7	▷ Integration and commissioning	Jan 18, 2021	July 30, 2021
1.4.8	▶ **Documentation, Training and Ops Handover**	**Sep 7, 2020**	**Dec 17, 2021**
1.4.9	▷ Project Management and Administration	Nov 19, 2018	Nov 12, 2021

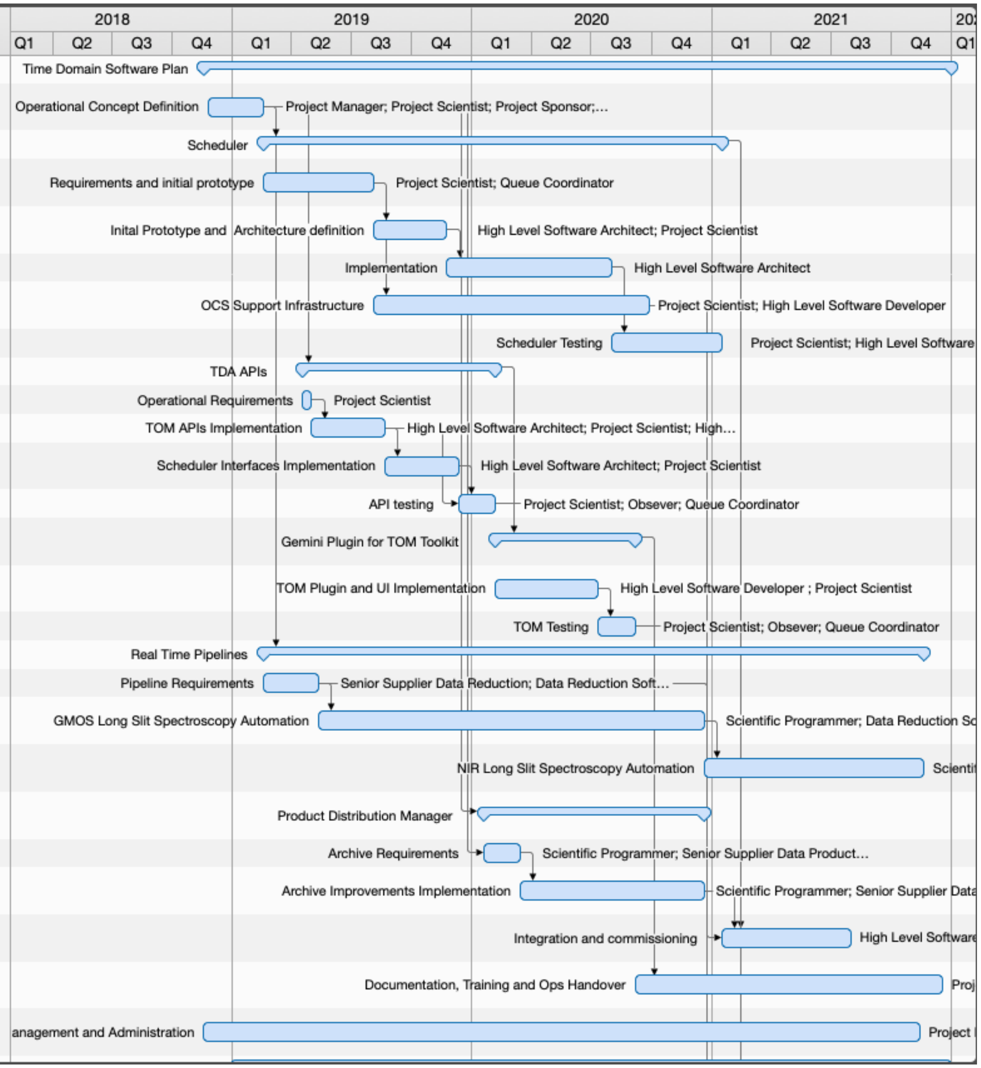


Figure 5 - baseline project Gantt chart

4.10 Schedule Contingency

This schedule in this project is fixed and therefore contingency will be managed via scope adjustments. Initial scope is described in the TDA Scope Managemen Plan document listed in Appendix A.

5 Staffing

5.1 Staffing Plan

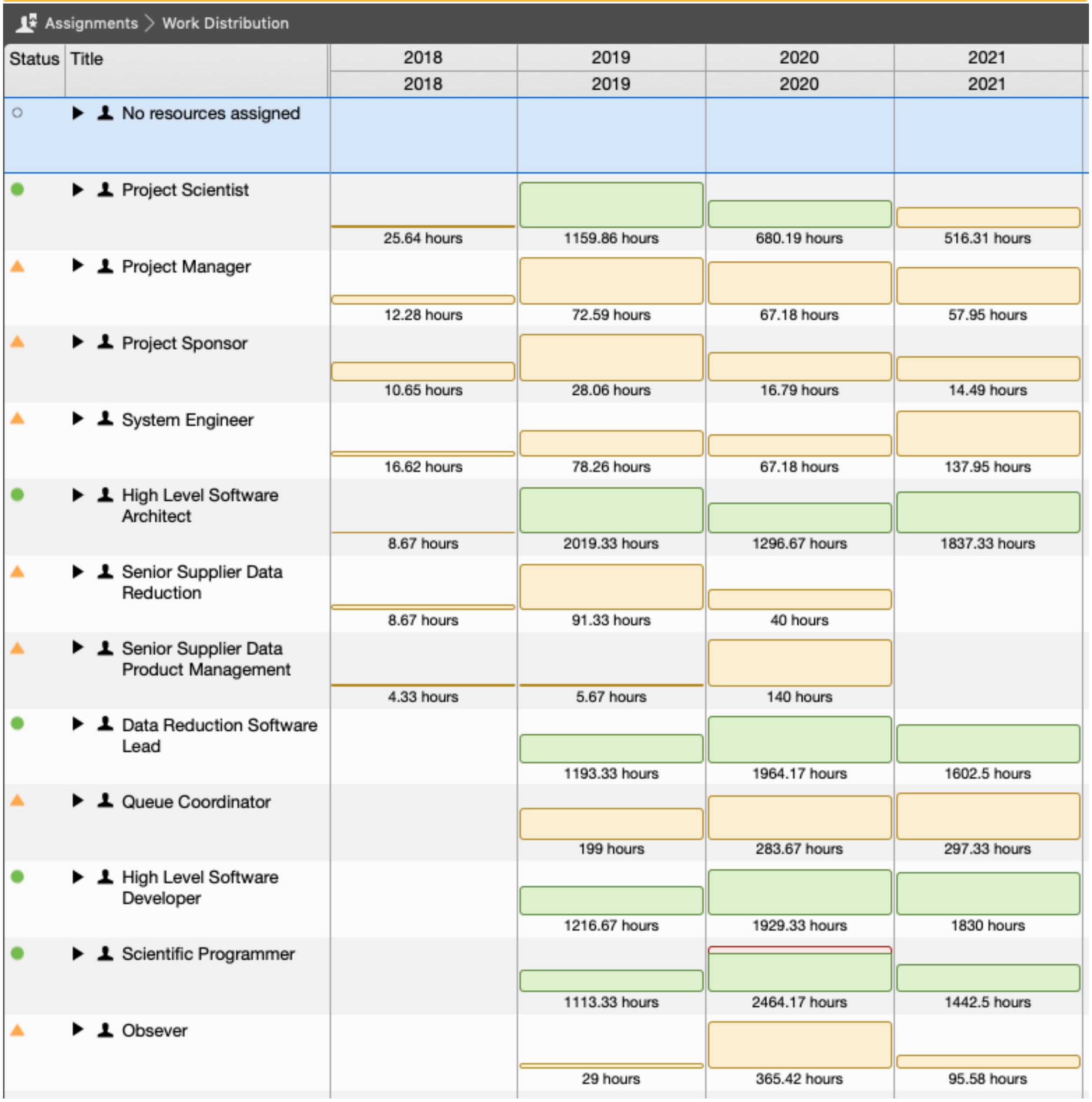
The following resources are required to complete this project during the period of performance:

Core management team
- Project Sponsor: 0.05 FTE
- Project Manager: 0.1 FTE
- Project Scientists: 1.4 FTE
- Systems Engineer: 0.2 FTE

Software Engineering effort
- High Level Software Engineers: 6 FTE
- Scientific Programmers: 6 FTE

Science effort
- Observers: 0.2 FTE
- Queue Coordinators: 0.3 FTE

.
The initial staffing plan for this project is shown in the following diagram. Final balancing of effort is pending



Assignments > Work Distribution

Status	Title	2018	2019	2020	2021
○	No resources assigned				
●	Project Scientist	25.64 hours	1159.86 hours	680.19 hours	516.31 hours
▲	Project Manager	12.28 hours	72.59 hours	67.18 hours	57.95 hours
▲	Project Sponsor	10.65 hours	28.06 hours	16.79 hours	14.49 hours
▲	System Engineer	16.62 hours	78.26 hours	67.18 hours	137.95 hours
●	High Level Software Architect	8.67 hours	2019.33 hours	1296.67 hours	1837.33 hours
▲	Senior Supplier Data Reduction	8.67 hours	91.33 hours	40 hours	
▲	Senior Supplier Data Product Management	4.33 hours	5.67 hours	140 hours	
●	Data Reduction Software Lead		1193.33 hours	1964.17 hours	1602.5 hours
▲	Queue Coordinator		199 hours	283.67 hours	297.33 hours
●	High Level Software Developer		1216.67 hours	1929.33 hours	1830 hours
●	Scientific Programmer		1113.33 hours	2464.17 hours	1442.5 hours
▲	Obsever		29 hours	365.42 hours	95.58 hours

Figure 6 - Staff-effort profile over the lifetime of the project

5.2 Hiring and Staff Transition Plan

The effort in this project is heavily focused on software development. We need approximately 12 software FTE for the duration of this project (3 years) covered by 4 positions, indicated as High-Level Software Architect, High Level Software Engineer, Data Reduction Software Lead and Scientific Programmer in Figure 6. These positions will be covered by new hires and existing Gemini staff, as follows:

- High Level Software Architect: Covered by existing Gemini Staff
- High Level Software Engineer: New Hire, expected to be in place by April-June 2019

- Data Reduction Software Lead: 50% Covered by existing Gemini Staff and 50% by new hire to be in place by April-June 2019
- Scientific Programmer: Covered by existing Gemini Staff.

6 Risk and Opportunity Management

6.1 Risk Management Plan

Please refer to the TDA Risk Management Plan listed in Appendix A. This plan covers:

- Project Risk Process
- Other Roles and Responsibilities
- Budgeting
- Timing
- Risk Register Scoring and Interpretation, with Impact and Likelihood scoring
- Reporting Formats
- Tracking

6.2 Risk Register

Please refer to the TDA Risk Register listed in Appendix A. This register includes:

Part I - Risk Identification
1. Categorization & Description
2. Impact, Likelihood & Total risk scores

Part II - Existing controls, per risk
1. Effectiveness
2. Residual risk score

Part III - Risk Response, per mitigation strategy
1. Effectiveness
2. Residual risk score
3. Contingency Plan
    a. Cost
    b. Owner
    c. Review schedule
    d. Status

6.3 Contingency Management Plan

Please refer to the Part III columns in the Risk Register for Contingency Management information. The risk Register is listed in Appendix A.

7 Systems Engineering

An initial revision of the TDA Systems Engineering Management Plan (SEMP) has been developed to document the role of systems engineering throughout the TDA life cycle. We will refine this plan early in the Conceptual Design Phase to reflect systems engineering process and programmatic details as the system definition matures.

The primary systems engineering roles are to perform and/or lead the following activities:

- Technical management through all phases
- Concept of Operations Management
- Requirements Management
- System Design
- Interface Management
- System Integration
- Verification and Validation
- Quality Control Management

Please refer to the TDA Systems Engineering Management Plan listed in Appendix A.

7.1 Systems Engineering Requirement

Please refer to the TDA Systems Engineering Management Plan listed in Appendix A. This plan has the following structure:

- System Design Process
- Logical Decomposition and Requirements Definition
- Requirements
- Decomposition Methodology
- System Design
- Conceptual Design
- Preliminary Design
- Critical Design
- System Development
- Documentation Plan
- Validation & Verification

7.2 Interface Management Plan

The objective of the interface management is to achieve functional and physical compatibility among all interrelated system elements. Early in the design phase, we will define external, internal, functional, and physical interfaces. In this project, most of these interfaces are software interfaces that will be specified through Application Programming Interface (API) documentation. We plan to use software standards APIs to document these, like the Open API Specification (OAS) - (https://github.com/OAI/OpenAPI-Specification).

Please refer to the TDA Systems Engineering Management Plan listed in Appendix A for more details.

7.3 Quality Assurance and Quality Control Plan

Quality Assurance (QA) provides an independent assessment to the project manager and systems engineer of the items produced and processes used during the project life cycle. The project manager and systems engineer will manage quality risks and enforce adherence to procedures and specifications throughout the system development and system integration.

Please refer to the TDA Systems Engineering Management Plan listed in Appendix A.

7.4 Concept of Operations Plan

The Concept of Operations (ConOps) is an important component in capturing stakeholder expectations, driving system requirements, and driving the architecture of a project. It will serve as the basis for subsequent definition documents such as the operations plan and operations handbook and provides the foundation for the long-range operational planning activities such as operational facilities and staffing. We will generate a Concept of Operations as a first step in the Conceptual Design Phase, and will use it as a basis for requirements and interface definition.

Please refer to the TDA Systems Engineering Management Plan listed in Appendix A.

7.5 Facility Divestment Plan

Not Applicable
Since this is not a large facility project and implementation is an addition to an existing observatory, this section is not applicable.

8 Configuration Control

8.1 Configuration Control Plan

This is covered in section 9.1 of the Program Execution Plan.

8.2 Change Control Plan

This is covered in section 9.2 of the Program Execution Plan.

8.3 Documentation Control Plan

This is covered in section 9.3 of the Program Execution Plan.

9 Acquisitions

9.1 Acquisition Plans

Acquisition Plans will be developed as decisions are made regarding the proposed procurements during the project lifecycle. Currently, there are no planned acquisitions / procurements planned in this project.

9.2 Acquisition Approval Process

Gemini follows the AURA CAS procurement policies that can be found here.

10 Project Management Controls

10.1 Project Management Control Plan

The project management team has defined a detailed WBS with associated cost, scope and schedule, and this will be used as a roadmap to plan detailed software development effort. The software development will be done using Agile software methodologies, ensuring frequent communication across all stakeholders and regular reporting and monitoring, on a week by week basis. These techniques have been used successfully in the past by Gemini in similar software intensive projects.

In addition, formal monthly updates and monitoring using Gemini's project management processes will assist the PM in closely controlling this project.

Gemini has a Portfolio Management Office which provides guidance to the project management process by providing:

- Methodology for the Project Life Cycle
- Project Management and Systems Engineering Templates in the Portfolio Management Toolkit.
- Reporting and resource allocation tools
- Training

Please refer to the Project Methodology documents listed under the Program Execution Plan Reference Documents. This methodology and the applicable templates are used throughout this project.

10.2 Earned Value Management System (EVMS)

This is covered in section 10.2 of the GEMMA Program Execution Plan.

10.3 Financial and Business Controls

This is covered in section 10.3 of the GEMMA Program Execution Plan.

11 Site and Environment

11.1 Site Selection

Not Applicable
The projects under the GEMMA program are funded by the NSF through a Cooperative Support Agreement (CSA) added to an existing observatory management and operations CSA. They are not the construction of a large or new facility.

11.2 Environmental Aspects

Not Applicable
The projects under the GEMMA program are funded by the NSF through a CSA added to an existing observatory management and operations CSA. They are not the construction of a large or new facility.

12 Cyber Infrastructure

12.1 Cyber-Security Plan

This is covered in section 12.1 of the GEMMA Program Execution Plan.

12.2 Code Development Plan

12.3 This is covered in section 12.2 of the GEMMA Program Execution Plan.

12.4 Data Management Plan

Please refer to the GEMMA Program Execution Plan.

13 Environmental Safety and Health

13.1 Environmental Safety and Health Plans

Not Applicable
This project consists of software additions to an existing software system in the observatory, this section is not applicable.

14 Review and Reporting

14.1 Reporting Requirements

Gemini is required by the CSA to provide quarterly financial reports and an annual report in September. The reports are to coincide with other observatory reports required for the governance committees and Board.

14.2 Audits and Reviews

Expected reviews for this project: CoDR, PDR, CDR.

15 Integration and Commissioning

15.1 Integration and Commissioning Plan

When the project nears the final product delivery an Integration and Commissioning plan will be developed. The following items will be addressed as applicable:

- Integration
- Verification and Validation
- Installation plan
- Manuals
- Commissioning plan

For software the V&V step needs to include:

- Developing test cases to confirm that interfaces (e.g. APIs) are receiving and transmitting the correct data
- Running performance tests to confirm that performance and reliability specs are met

15.2 Acceptance / Operational Readiness Plan

Please refer to the TDA Acceptance Test Plan listed in Appendix A. This plan has the following structure:

- Verification Methods Matrix
- Optical Requirements
- Mechanical Requirements
- Detector Requirements
- Control System Requirements
- External Interfaces
- Environmental Requirements
- Other Requirements
- Post-Delivery Test
- Inspection for Transport Damage
- Acceptance Test Repeated After Delivery
- Summary of Test Equipment and Test Software

Relevant sections of this plan will be developed for this project.

16 Project Close-out

16.1 Project Close-out Plan

- When the project nears the final product delivery a Project Close-out plan will be developed. Please refer to the Project Methodology documents listed under the Program Execution Plan Reference Documents.

16.2 Transition to Operations Plan

Once the project passes its Integration and Commissioning plans, we will use Gemini standard Change Request processes to deploy the system in regular operations.

17 Appendix A: Support Documents

1. Project Plan
2. Risk Management Plan
3. Risk Register
4. Scope Management Plan
5. Systems Engineering Plan

18 Reference Documents

(PMO templates not included in the PEP submission)

1. Acceptance Test Plan
2. Acquisition Plan
3. Change Request
4. Closure Report (Programs)
5. Risk Management Plan (Programs)
6. Staffing Plan
7. Stage Plan

GEMMA
Time Domain Astronomy
Project Plan

December 25, 2018

A - TDA - 004

Issued By:	Arturo Núñez
Sponsored By:	Andy Adamson
Approved By:	Catherine Blough

Table of Contents

1 Plan Description

This is the Project Plan for the Time Domain Astronomy (TDA) Software, part of the GEMMA Program. This project will allow Gemini to take a leadership role in the era of MMA and transients. The main specific products to be delivered are:

- Gemini TDA APIs: A new set of application programming interfaces (APIs) that will allow observations to be requested, provide the required feedback, and allow automated data access.
- Gemini Plugins for Target Observation Managers (TOMs): Provide software to help Gemini users work with these new APIs.
- Scheduler: Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
- Real Time Pipelines: Provide a mechanism to automatically reduce imaging and longslit spectroscopic data in real-time for rapid characterization of transient sources and more responsive decision-making during night operations.
- Product Distribution Manager: Updates the Gemini Observatory Archive to be able to deliver reduced data to users.

2 Plan Prerequisites

The TDA software products are built on top of existing software insfrastructure that support telescope operations as shown in Figure 1.

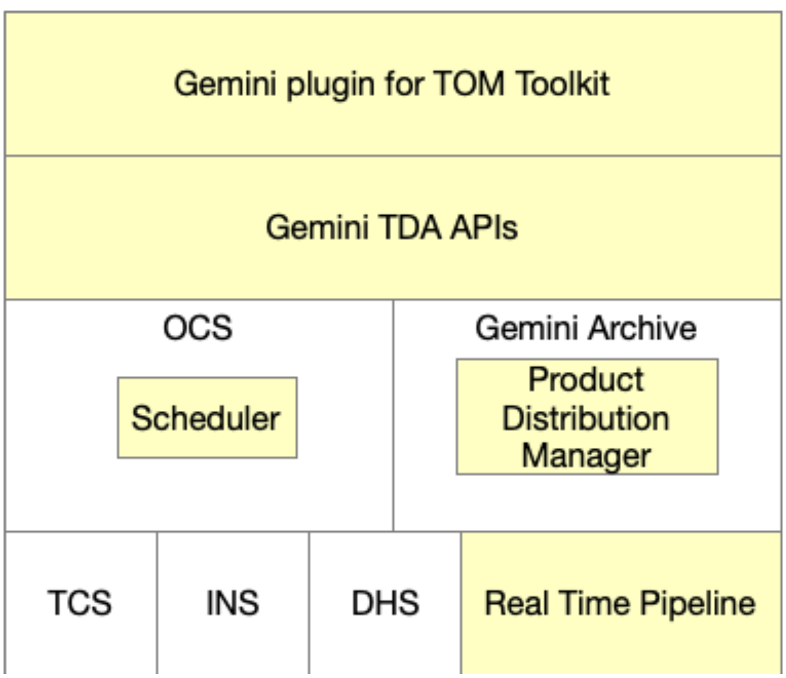


Figure 1 - yellow indicates the work on GEMMA-TDA as it fits into other systems.

The TDA software products, shown in yellow in Figure 1, have interfaces with existing software components of the Gemini Software infrastructure. In particular, the Gemini plugin for the TOM Toolkit uses the Gemini TDA APIs to access the observatory. The Gemini TDA APIs connect to both the Observatory Control System (OCS) and the Gemini Archive. These two systems, in turn, need to be modified and updated to incorporate the Scheduler (in the OCS) and the Product Distribution Manager (in the Archive). OCS will continue using the existing interfaces to the Telescope Control Software (TCS), Instruments (INS) and the Data Handling System (DHS). The Real Time Pipeline produces reduced data from the DHS, and delivers that to the Gemini Archive. These interfaces and dependencies will be documented in corresponding Interface Control Documents.

All the elements depicted in white in Figure 1 must be in place and remain in place for the TDA software plan to be successfully completed.

3 Planning Assumptions & External Dependencies

The Observatory Control System is going through a major upgrade, so that effort must be coordinated with this project. Project management is shared across both projects to ensure this coordination.

It is expected that the work on the APIs and the scheduler will be done in some form of collaboration with Las Cumbres Observatory, NOAO, and SOAR. Project scientists currently meet biweekly to discuss activities. Communication channels between project scientists and project managers and developers must remain in place to avoid unexpected changes in requirements.

Gemini and NOAO will be restructuring into the National Center for Optical/IR Astronomy (NCOA) starting in 2019. It is assumed that the project structure and personnel will be retained during this transition. We assume also that a similar process for resource allocation and portfolio management will continue, so this project will be able to continue without adding significant management overheads.

There are several efforts ongoing in the community to replace core IRAF spectroscopic reduction tasks with python equivalents. Gemini has been in communication with the astropy group, STScI, and SOAR about such efforts. It is assumed that Gemini will be able to take advantage of such efforts and that unexpected changes will not cause additional work on the Gemini reduction tools.

For this plan to be successful, four new fixed-term software engineers will be hired. It is assumed that these positions will be sufficiently attractive, and filled in a timely manner.

The software needs to be ready and in operations by the time LSST starts its operations. It is assumed that that takes place in 2022.

4 Lessons Incorporated

In this project we will be using a similar approach to other Gemini software projects that we have successfully completed in the last years, improving specific aspects based on our experience. In particular:

- We will use the principles of goal-aided design[1] to develop the functional requirements. This is a similar process to that used during the Phase I/II (UX) project. We will conduct interviews of representative people in all the roles that use the tools (e.g. community users, NGO staff, and Gemini staff with different roles). This information will be used to construct “personas” that will be used to define the operations or use concepts and the requirements.
- We will use an Agile software development methodology, in which developers and users will work as a team to deliver the product, in all stages of the development, from definition to deployment using an iterative approach. This was also used in the UX, Queue Visualization, OCS Advanced Features, Laser Clearance House Target Tracking System and Sequence Executor projects at Gemini, successfully from 2011 to 2018.
- The software will be open-source, hosted in GitHub and subject to the peer code review process currently in place for all high-level software at Gemini. This has been useful not only as an effective revision control system but also as a mechanism to increase software quality through continuous peer code reviews. We assume that the Gemini Plugin for the TOM Toolkit - that will be implemented on top of existing software frameworks done by other observatories - can be developed the same way.
- We plan to build the system such that it will support automatic testing and continuous integration/deployment from the outset. This has been extremely useful not only in recent projects like the Sequence Executor, but also for our existing codebase supporting the Observatory Control System.

5 Monitoring & Control

The plan is developed using PMO methodology, with Agile concepts for software development. We will have specific milestones in the project plan that will be used to assess progress and adjust plans. Highlight reports will be submitted monthly to the project sponsor, and necessary escalations will be provided. As a PMO based project, we plan to manage this by exception.

[1] Cooper, A. Reiman, R, Cronin, D., & Noessel, C. 2014, About Face: The Essentials of Interaction Design, John Wiley & Sons, Inc.

6 Budget & Schedule

6.1 Summary

Investment in **non-labor** (K$):	$120,000
Investment in Gemini labor (FTE[2]):	14.2 FTE
Investment in external labor (FTE and K$):	$0
Other Costs in Operations/ Maintenance (K$):	We estimate a total effort of 0.05 FTE/year per product dedicated to ongoing maintenance and support once the system is handed over to operations, for a total of 0.25FTE total. Out of this, 0.1FTE are scientific programmer effort and 0.15FTE are high-level software support.
Project Duration:	Jan 1, 2019 to Dec 31, 2021
Benefits Realization:	Full Benefit realization is expected at project completion.

TDA Budget

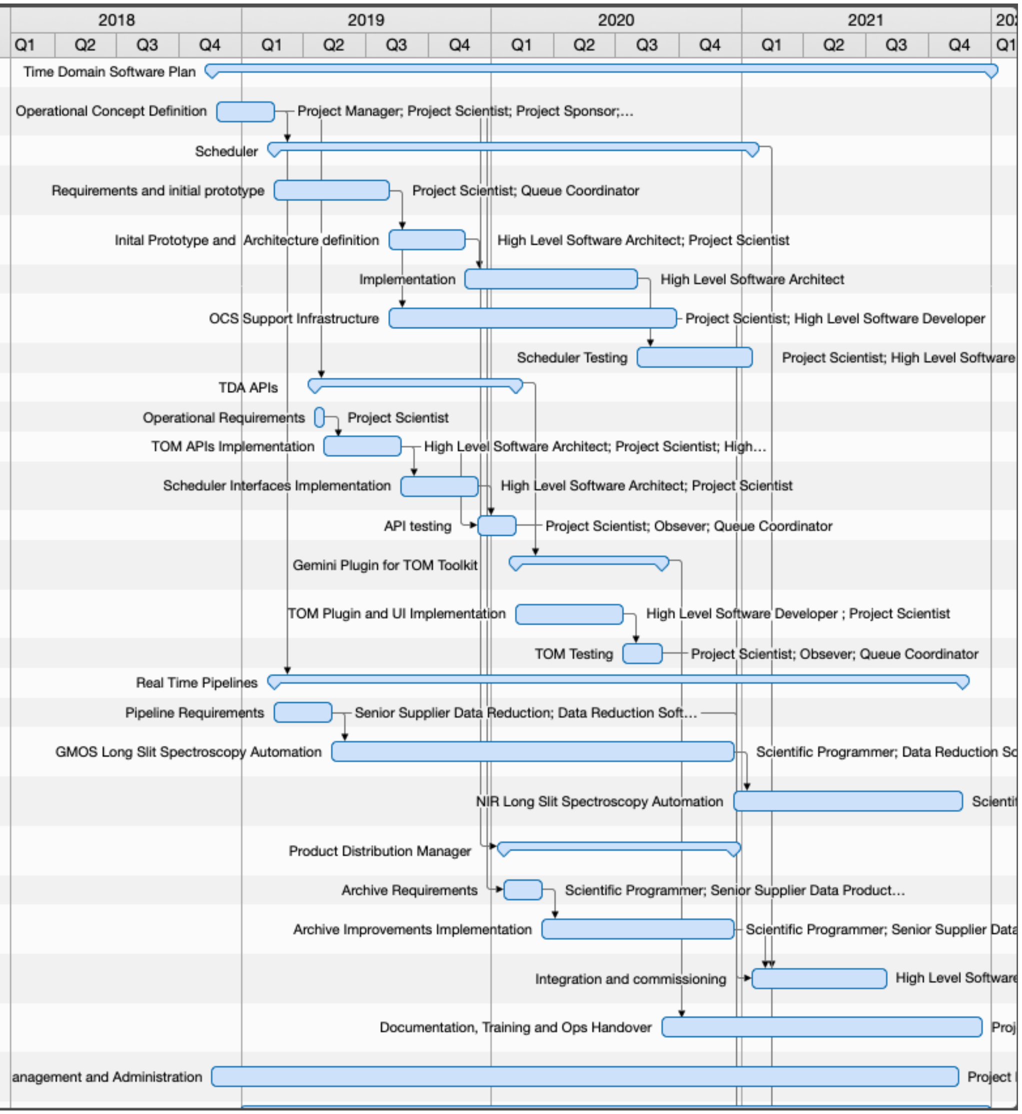
GR2140000 TDA							
	FY 2019	**FY 2020**	**FY 2021**	**FY 2022**	**FY 2023**	**FY 2024**	**-Total Fiscal Years**
010 Salaries Wages - Regular	427,920	443,277	485,118	0	0	0	1,356,315
-TOTAL SALARY & WAGES	427,920	443,277	485,118	0	0	0	1,356,315
0FB Fringe Benefits	133,554	138,347	151,405	0	0	0	423,306
-TOTAL EE BENEFITS	133,554	138,347	151,405	0	0	0	423,306
-TOTAL WAGE & BENEFITS	561,474	581,623	636,524	0	0	0	1,779,620
500 Travel - Domestic - Operations	18,491	18,491	17,392	0	0	0	54,374

[2] Full-Time Equivalent. 1 FTE = 1720 hours

-TOTAL DOMESTIC TRAVEL	18,491	18,491	17,392	0	0	0	54,374
600 Travel - Foreign - Operations	21,915	21,915	21,915	0	0	0	65,745
-TOTAL FOREIGN TRAVEL	21,915	21,915	21,915	0	0	0	65,745
-TOTAL TRAVEL	**40,406**	**40,406**	**39,307**	**0**	**0**	**0**	**120,119**
-TOTAL EXPENSE	601,880	622,029	675,831	0	0	0	1,899,739
-GRAND TOTAL	**601,880**	**622,029**	**675,831**	**0**	**0**	**0**	**1,899,739**

The project schedule is shown in the next figure:

WBS Code	Title	Expected Start	Expected End
1.4.	▼ **Time Domain Software Plan**	**Nov 19, 2018**	**Dec 31, 2021**
1.4.1	▷ Operational Concept Definition	Nov 26, 2018	Feb 15, 2019
1.4.2	▼ **Scheduler**	**Feb 18, 2019**	**Jan 15, 2021**
1.4.2.1	▶ **Requirements and initial prototype**	**Feb 18, 2019**	**Aug 2, 2019**
1.4.2.2	▷ Inital Prototype and Architecture definition	Aug 5, 2019	Nov 22, 2019
1.4.2.3	▷ Implementation	Nov 25, 2019	July 31, 2020
1.4.2.4	▶ **OCS Support Infrastructure**	**Aug 5, 2019**	**Sep 25, 2020**
1.4.2.5	▷ Scheduler Testing	Aug 3, 2020	Jan 15, 2021
1.4.3	▼ **TDA APIs**	**Apr 17, 2019**	**Feb 5, 2020**
1.4.3.1	▷ Operational Requirements	Apr 17, 2019	May 1, 2019
1.4.3.2	▷ TOM APIs Implementation	May 1, 2019	Aug 21, 2019
1.4.3.3	▷ Scheduler Interfaces Implementation	Aug 21, 2019	Dec 11, 2019
1.4.3.4	▷ API testing	Dec 11, 2019	Feb 5, 2020
1.4.4	▼ **Gemini Plugin for TOM Toolkit**	**Feb 5, 2020**	**Sep 4, 2020**
1.4.4.1	▷ TOM Plugin and UI Implementation	Feb 5, 2020	July 10, 2020
1.4.4.2	▷ TOM Testing	July 13, 2020	Sep 4, 2020
1.4.5	▼ **Real Time Pipelines**	**Feb 18, 2019**	**Nov 19, 2021**
1.4.5.1	▷ Pipeline Requirements	Feb 18, 2019	May 10, 2019
1.4.5.2	▷ GMOS Long Slit Spectroscopy Automation	May 13, 2019	Dec 18, 2020
1.4.5.3	▷ NIR Long Slit Spectroscopy Automation	Dec 21, 2020	Nov 19, 2021
1.4.6	▼ **Product Distribution Manager**	**Jan 20, 2020**	**Dec 18, 2020**
1.4.6.1	▷ Archive Requirements	Jan 20, 2020	Mar 13, 2020
1.4.6.2	▷ Archive Improvements Implementation	Mar 16, 2020	Dec 18, 2020
1.4.7	▷ Integration and commissioning	Jan 18, 2021	July 30, 2021
1.4.8	▶ **Documentation, Training and Ops Handover**	**Sep 7, 2020**	**Dec 17, 2021**
1.4.9	▷ Project Management and Administration	Nov 19, 2018	Nov 12, 2021



6.2 Resource Plan

The resources to be used by this project are shown below[1]:

Title	2018 Q4	2019 Q1	2019 Q2	2019 Q3	2019 Q4	2020 Q1	2020 Q2	2020 Q3	2020 Q4	2021 Q1	2021 Q2	2021 Q3	2021 Q4
No resources assigned													
Project Scientist	25.6h	276.5h	226.6h	341.2h	315.5h	194h	43h	374.7h	68.5h	213.3h	152.8h	146.2h	4h
Project Manager	12.3h	22.1h	16.7h	16.9h	16.9h	16.7h	16.7h	16.9h	16.9h	16.4h	16.7h	16.9h	7.9h
Project Sponsor	10.7h	15.4h	4.2h	4.2h	4.2h	4.2h	4.2h	4.2h	4.2h	4.1h	4.2h	4.2h	2h
System Engineer	16.6h	27.7h	16.7h	16.9h	16.9h	16.7h	16.7h	16.9h	16.9h	40h	45.6h	44.5h	7.9h
High Level Software Architect	8.7h	11.3h	306h	803.2h	898.8h	520h	520h	212.7h	44h	586.5h	710.4h	540.4h	
Senior Supplier Data Reduction	8.7h	51.3h	40h			40h							
Senior Supplier Data Product Management	4.3h	5.7h				46h	32.5h	33h	28.5h				
Data Reduction Software Lead		40h	273.3h	440h	440h	485.3h	498.3h	506h	474.5h	448.4h	493.7h	350.4h	310h
Queue Coordinator		170h			29h	51h		188.7h	44h	205.6h	46.9h	44.8h	
High Level Software Developer			462.2h	473.4h	281.1h	662.7h	866.7h	400h		579.2h	710.4h	540.4h	
Scientific Programmer			233.3h	440h	440h	515.3h	660.8h	671h	617h	448.4h	493.7h	350.4h	150h
Obsever					29h	51h		220.9h	93.5h	39.1h	28.9h	27.6h	

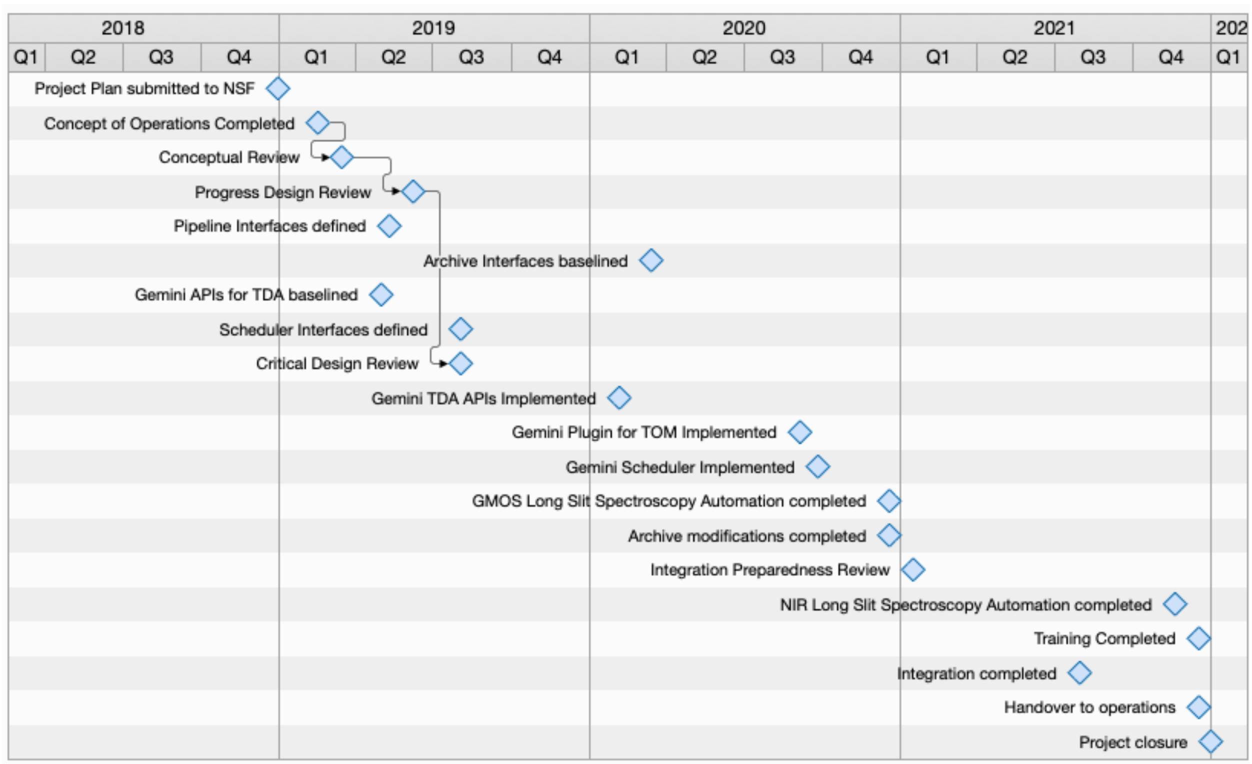
[1] High level software developer and the scientific programmer will be hired and not yet available. Other FTEs are existing staff.

6.3 Acquisition Plan

There are no acquisitions planned in this project. The final schedule for traveling for training and project meetings is still TBD, but we expect a uniform expenditure of those funds per year, i.e, $40K/year (with contingency included).

6.4 Milestone/Product Plan

The following are the top level project milestones in this project (calendar years).



7 Project Tolerances

Project Resource	Baseline value	Proposed Project Tolerance
Software Engineering - High Level	5 FTE	1 FTE
Software Engineering - Scientific Programmers	6 FTE	NIR modes pipelines will be descoped if needed.
Scientist	1 FTE	0.2 FTE
Queue Coordinator	0.3 FTE	0.05 FTE
Observer	0.2 FTE	0.05 FTE
Project Management and Systems Engineering	0.3 FTE	0.1 FTE
Travel and training	$100,000	$20,000
Benefit: ability to automatically accept up to N% of observations in one night from the TDA network	N=20% (minimum)	5% (see PEP main document section 2.2)
Benefit: minimization of staff effort in generating and re-	Manual scheduling time<=1h/day	+120m. At a minimum manual planning

generating schedules as new alerts come in	Experience with using a prototype automated scheduler suggests that manual oversite of the scheduler should be less then one hour a day.	during the day should not take longer, on average, than currently. This effort should decrease with time as the tools are refined.

Whenever the tolerance for one of these baseline values is exceeded (or expected to be exceeded), the Directorate will be alerted of the exception.

8 Applicable Reference Documents - Associated Products

None.

GEMMA
Time Domain Astronomy
Scope Management Plan

December 20, 2018

A – TDA - 004

Issued By:	Arturo Núñez
Sponsored By:	Andy Adamson
Approved By:	Catherine Blough

Table of Contents

1 Introduction

The purpose of this document is to provide an easy to understand summary of the project scope that can be used to help project team members understand why the project is being done, the scope and related boundary conditions of the project, and how they will be managed. The document should focus on the product or service being delivered by the project.

2 Scope Statement

2.1 Project Purpose

The Time Domain Astronomy Software, part of the GEMMA Program, will allow Gemini to take a leadership role in the era of Multi-Messenger and Time-Domain Astronomy. The overall objectives of the GEMMA-TDA project are to:

- Allow Gemini to cope with the expected massive increase in follow-up ToO requests
- Satisfy user demand for transient follow-up while preserving our ability to support non-transient observational programs
- Ensure that the observatory is efficiently utilized in a wider network of telescopes for transient science in the MMA era.

2.2 Product or Service Goals & Objectives

These are the five principal products that will be delivered by TDA Software:

1. Gemini TDA APIs: A new set of application programming interfaces (APIs) that comply with a set of standards that will be generally applicable across a wider network of follow-up facilities. These will allow observations to be requested, provide the required feedback, and allow automated data access.
2. Gemini Plugins for Target Observation Managers (TOMs): Provide software to help Gemini users work with these new APIs.
3. Scheduler: Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
4. Real Time Pipelines: Provide a mechanism to automatically reduce imaging and longslit spectroscopic data in real-time for rapid characterization of transient sources and more responsive decision-making during night operations.
5. Product Distribution Manager: Updates the Gemini Observatory Archive to be able to deliver reduced data to users.

2.3 Scope Summary

Figure 1 below shows the five products - in yellow - that will be provided by TDA software.

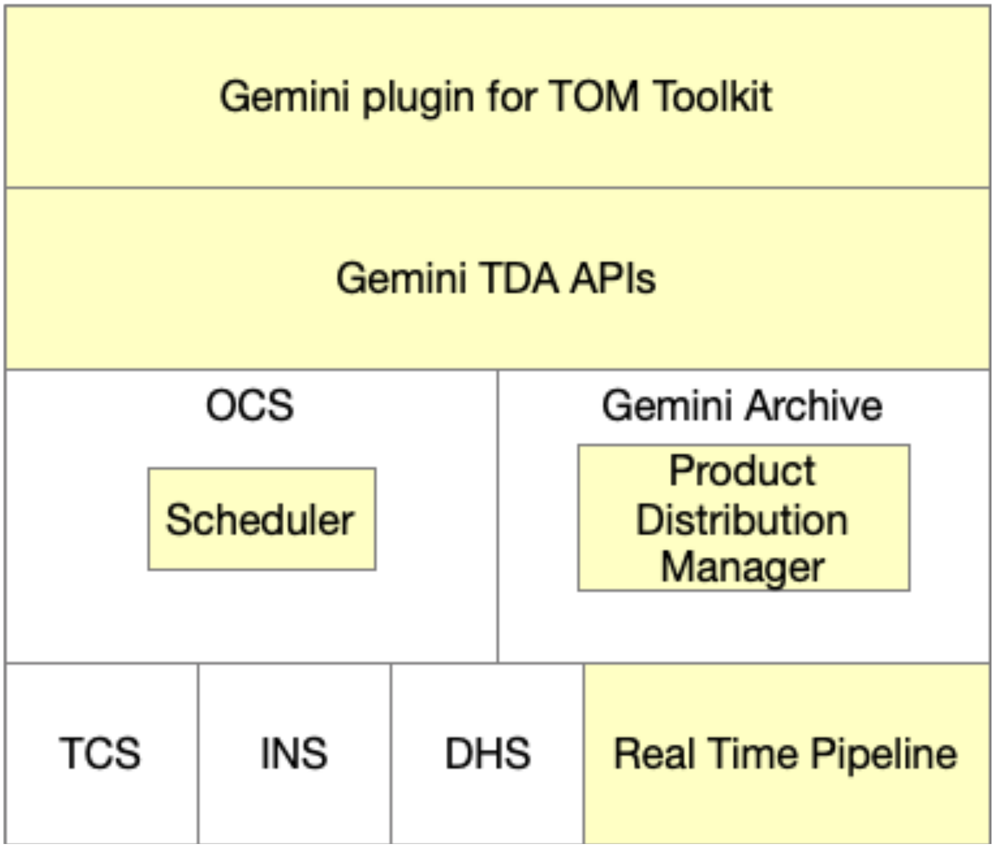


Figure 1 - yellow indicates the work on GEMMA-TDA as it fits into other systems.

2.4 Scope Boundary Conditions

These are the scope boundary conditions for each product in TDA Software:

1. Gemini Plugin for TOM Toolkit: This product will be developed using the TOM Toolkit provided by Las Cumbres Global Telescope Network (LCGTN). This is a Python-based system. This plugin has interfaces to the rest of the LCGTN TOM Toolkit and to the Gemini API Interfaces as shown in Figure 1.
2. Gemini TDA APIs: These APIs will be modeled after similar APIs provided by LCGTN for access to their system, but tailored to Gemini's needs. To facilitate access from TOMs they must be web APIs.
3. Scheduler: The scheduler runs as part of the OCS and is exposed to the outside world only through APIs. As such, its interfaces are internal and the implementation is not constrained.
4. Product Distribution Manager: The Gemini Archive is written in Python, and this product will add the necessary capabilities to the Archive to be able to characterize and retrieve reduced data. The Product Distribution Manager is an internal service in the Archive, and it's used by external products through the Archive API.
5. Real Time Pipelines: This product provides Python data reduction recipes for GMOS Long Slit spectroscopy automation, including documentation and tests. This will also include, as a goal, Near Infrared (F2 and/or GNIRS) Long Slit spectroscopy.

2.5 Scope Details

In Scope
Gemini TDA APIs to support TDA astronomy that will allow observations to be requested, provide the required feedback, and allow automated data access.
Gemini Plugin for TOM Toolkit.
Automatic Scheduler for Gemini. Defines mechanisms and the specification of a merit function to optimize observing schedules.
Updates to the Gemini Archive to improve handling of reduced data including API changes
Data reduction recipes for GMOS Long Slit spectroscopy automation, including documentation and tests

Out of Scope
Any additional APIs that are needed for the Observatory Control Software normal operations. This is assumed to be provided by Gemini Operational software.
Any software to implement the TOM toolkit framework itself. This is assumed to be provided by LCGTN.
Algorithms to optimize the schedule. We will use existing tools that perform this work.
All infrastructure needed by the Gemini observatory control system (OCS) including databases, observation and target models, graphical user interfaces, etc.
Creation of the routines and algorithms needed to reduce the data from Gemini facility instruments.
Creation of an entire follow-up system.
Development of Imaging Pipelines. These are being done outside the scope of this project.

3 Change Management

All changes to the project are requested through a Change Request Form and submitted to the Project Manager. The Project Manager will assess the benefit of the change and the impact on cost, timeline and resources available and decides if the change can be implemented. If the scope of the change is outside of the tolerances for the Project Manager, the Project Sponsor will be asked to approve.

Time Domain Astronomy (TDA) Systems Engineering Plan

December 20, 2018

A – TDA - 004

Issued By:	Natalie Provost
Sponsored By:	Andy Adamson
Approved By:	Arturo Núñez

Table of Contents

1 Plan Description

This is the Systems Engineering Management Plan for the Time Domain Astronomy Software (TDA) part of the GEMMA Program. This project will allow Gemini to take a leadership role in the era of MMA and transients. The main specific products to be delivered are:

- Gemini TDA APIs: A new set of application programming interfaces (APIs) that comply with a set of standards that will be generally applicable across a wider network of follow-up facilities. These will allow observations to be requested, provide the required feedback, and allow automated data access.
- Gemini Plugins for Target Observation Managers (TOMs): Provide software to help Gemini users work with these new APIs
- Scheduler: Provide an efficient, dynamic way to schedule large numbers (order 10-100) of transient observation requests per night.
- Real Time Pipelines: Provide a mechanism to automatically reduce imaging and long-slit spectroscopic data in real-time for rapid characterization of transient sources and more responsive decision-making during night operations.
- Product Distribution Manager: Updates the Gemini Observatory Archive to be able to deliver reduced data to users.

2 Roles & Responsibilities

The TDA project will use a team approach for Systems Engineering (SE). This approach is a recognition that TDA at Gemini requires a complex software system with many internal and external interfaces, which in turn requires specialized knowledge in a number of areas. The team will include experts from areas including astronomy and software engineering. Overall SE team organization is provided by a Lead Systems Engineer, who works closely with the Software Engineers and Project Scientist, and reports to the TDA Project Manager.

The systems engineering team roles are defined and include the following:

- Systems Design and Analysis
  - Design and analysis of systems that cross over functional areas, subsystems or organizations (eg, end-to-end design user interface to science performance).
  - Formation and analysis of trade studies, to inform design choices management of up-scope and de-scope options
- Requirements Management
  - Identification, development, decomposition and linking of project requirements
  - Guide the translation of science cases into software technical requirements, incorporating the operational concepts
  - Flow-down the system requirements to lower-levels (subsystems, then components) until requirements are independently testable
  - Communicate requirements to owners within the development team
- Interface Management
  - Define and document where interfaces exist within the system (internal interfaces).
  - Manage interface control documents (ICD's) with the observatory
- Configuration Management

    - Maintain consistency and visibility of current project documentation and data
    - Manage changes to project documents over the lifecycle of the project
- Quality Management
    - Define a set of policies, procedures, tools and training to ensure that quality is maintained
    - Verify that Quality Assurance procedures are followed during development
    - Verify that the deliverables meet quality standards
- Verification Management
    - Identify verification method for each requirement (design, inspection, analysis, test, etc).
    - Identify at what project stage verification takes place
    - Write or manage the creation of verification test plans and procedures
    - Oversee requirements verification activities, and sign-off on results
    - Track open verification issues and develop a burn-down plan
    - Manage the Acceptance Test Review processes

3 Technical Processes and Systems Engineering Engine

The TDA project team will follow a tailored Systems Engineering "Engine" principle recommended by NASA. There are three sets of common technical processes in the principle: System Design, Product Realization and Technical Management. The processes of the Systems Engineering Engine will be used by the TDA team to develop and realize the end products. There are 18 processes in this context. Processes 1 through 10 indicated in Figure 1 represent the activities in the execution of the project. Processes 11 through 18 are cross cutting tools for carrying out the project, they will be done as part of the Project Management and Software Engineering activities supported by the Systems Engineering.

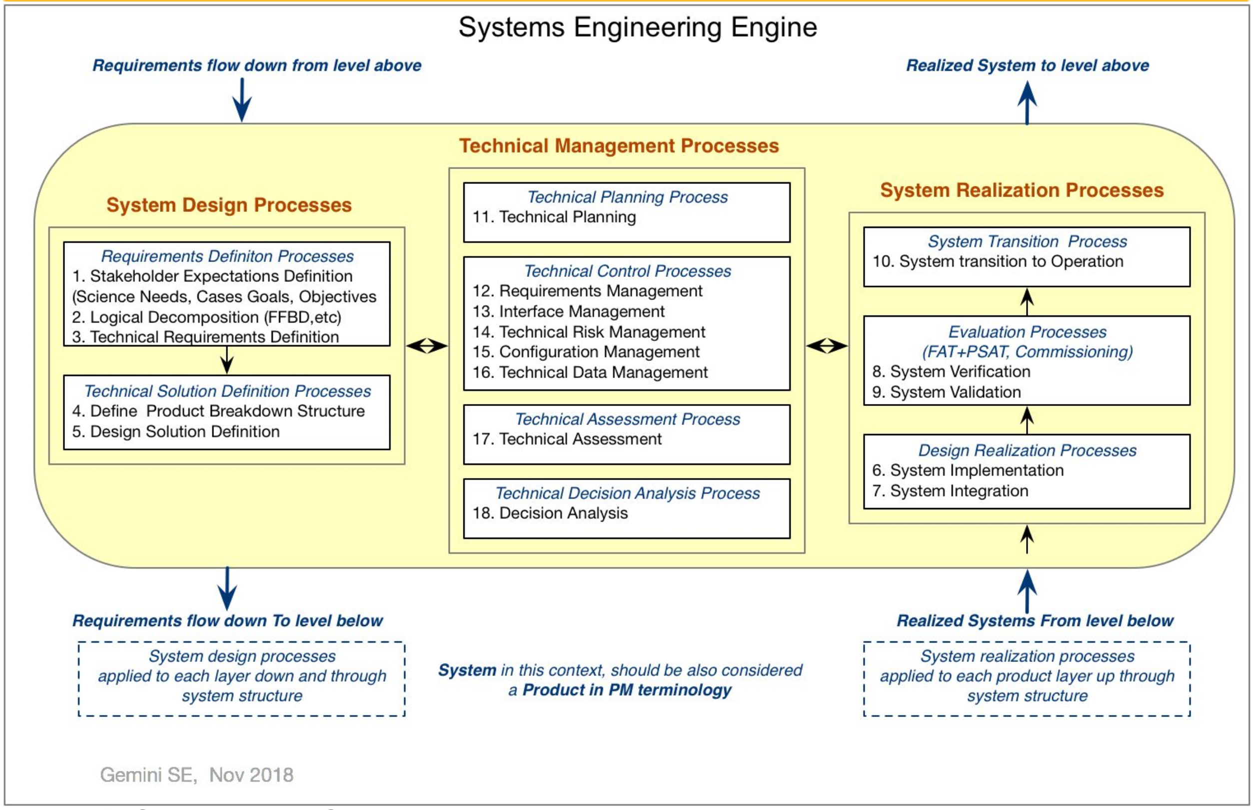


Figure 1. GEMMA-TDA Systems Engineering Engine

3.1 System Design Processes

The five systems design processes shown at the left side of Figure 1 will be used by the TDA systems engineering team to define and baseline stakeholder expectations. This will capture TDA science drivers and objectives, perform initial Logical decomposition, allocate and derive technical requirements, define the functional architecture and generate the product breakdown structure (PBS), to then convert the technical requirements into the design solution that will satisfy the baselined stakeholder expectations.

These processes, when deemed necessary, will be also applied to each subsystem from the top of the TDA structure to the bottom until the lowest elements in the system structure branch are defined to the point where they can be designed, built, bought and/or reused.

The system design processes are interdependent, highly iterative and recursive processes resulting in a validated set of requirements and design solution that satisfies the stakeholder expectations. The relationships among the system design processes are shown in Figure 3 below.

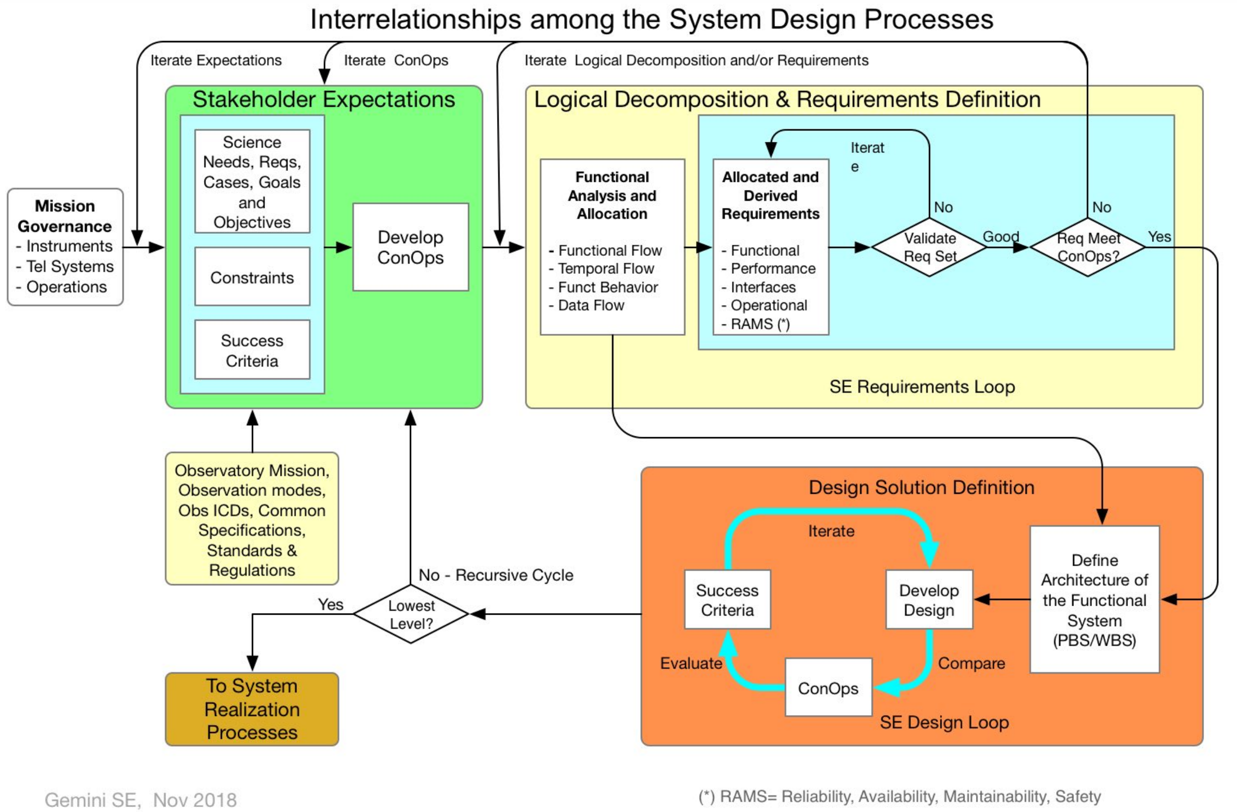


Figure 2. Interrelationship Among Design Processes

TDA systems engineering processes start with the study by the science team defining and clarifying the science objectives and goals of the system. This includes the science cases, the operations modes, the design drivers, the constraints and science requirements to operate TDA at Gemini Observatory, and provide the criteria for defining system success. A team of scientists and astronomers that include collaborators of Gemini Observatory will be formed to review and provide stakeholder feedback on the science cases, high-level science (needs) requirements, and Concept of Operations (ConOps).

This set of stakeholder expectations, plus the high-level science (needs) requirements and the Concept of Operations (ConOps), will be used to drive the iterative design loop. The design loop is developed then by, the functional architecture, the derived/allocated set of technical requirements, supported by the product breakdown structure. These three products will be consistent with each other and will require iteration and design decisions to achieve consistency. The project team, led by the systems and project engineers, will perform consistency analysis with the project team to validate the proposed design against the stakeholder expectations. A simplified validation asks the following questions:

- Will the system work as expected?
- Is the system achievable within budget and schedule constraints?
- Does the system provide the functionality and fulfill the operational needs that drove the project's funding?

If the answer to any of these questions is no, then changes to the design and/or stakeholder expectations will be required, and the process starts again. This process continues until the system architecture, ConOps, and science requirements meets the stakeholder expectations to set the baseline of this process.

3.2 Concept of Operations (ConOps) Management

The ConOps is an important component in capturing stakeholder expectations, driving system requirements, and driving the architecture of a project. It also serves as the basis for subsequent definition documents.

Due to the complex interface and timing requirements for the TDA project, the development of a robust ConOps document is critical. An initial set of science and use cases have already been developed and reviewed by internal working groups as well as with external stakeholder feedback. We will use this as the basis for developing a ConOps document.

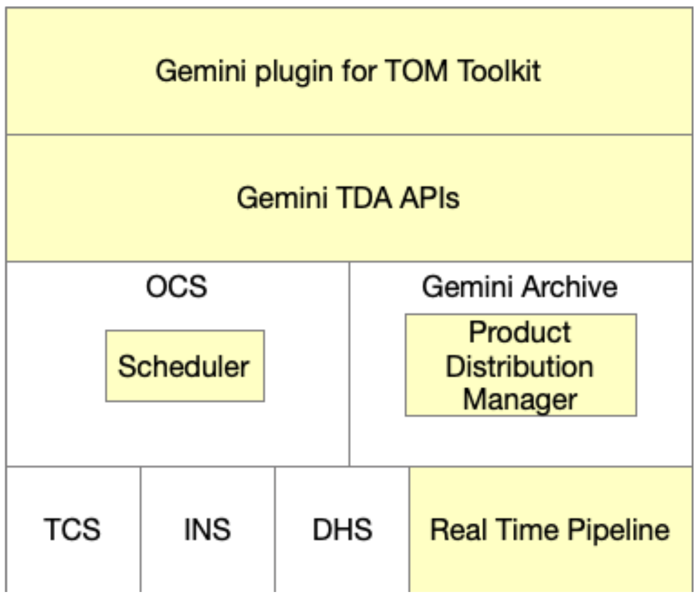


Figure 3. Gemini TDA System Interfaces

The ConOps document will describe the interactions with existing software components of the Gemini Software infrastructure (see Figure 3). The figure depicts in yellow the systems that will be updated or new for TDA. The Gemini plugin for the TOM Toolkit will need to use the Gemini TDA APIs to access the observatory. The Gemini TDA APIs connect to both the Observatory Control System (OCS) and the Gemini Archive. The ConOps will provide an end-to-end command and data flow description, which will inform the design requirements for updates to the OCS and Gemini Archive, and ultimately the Real Time Pipeline.

The ConOps document will reflect this agreed upon implementation, as well as describe operation timelines, operational scenarios, command and data architecture, and operator and external software interfaces. The operational scenarios describe the dynamic view of the systems' operations and include how the system is perceived to function, including interactions with external interfaces.

3.3 Logical Decomposition and Requirements Definition

The top level TDA requirements have been developed and used to determine a high-level conceptual design. We will further develop these requirements based on the outcome of the Concept of Operations. Once the Concept of Operations is developed, technical requirements definition can be further decomposed based on system functions.

Logical decomposition systems engineering process will be utilized to generate the System Functional (parent) requirements. This process and associated activities are depicted in Figure 4. In TDA development, the logical decomposition process will be executed using Function Based Systems Engineering (FBSE). This will help to perform Functional Analysis to create the system functional architecture and decompose detailed functional requirements and interfaces that satisfy the stakeholder expectations and success criteria. This process identifies "what", (not "how well") should be achieved by GEMMA-TDA at each level to enable success.

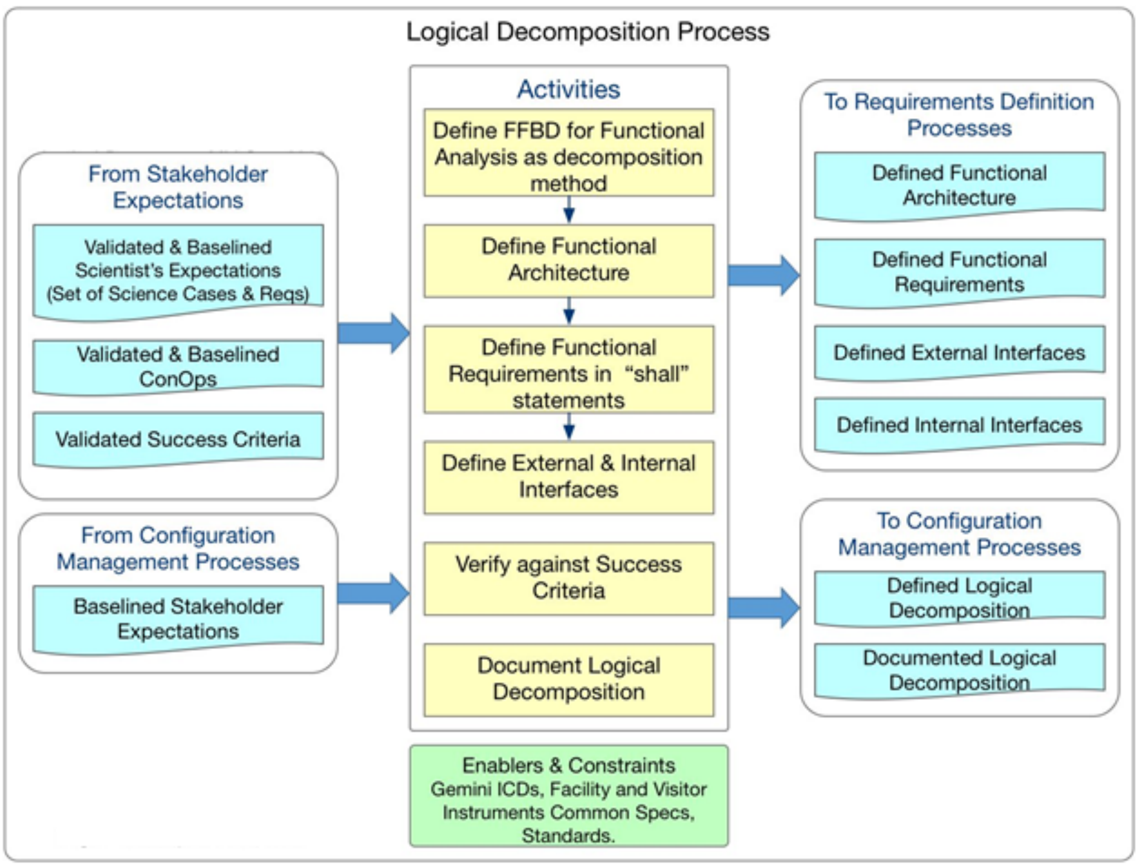


Figure 4. Logical Decomposition Process

The decomposed functional (or parent) requirements are then allocated down to the lowest required level that satisfies the objectives of the design of TDA. The Logical Decomposition, besides assisting to create TDA functional architecture, will also help the team to:

- Improve understanding of the scientists' expectations (TDA functions and performance, science requirements, ConOps, constraints, internal interfaces, Interfaces to the Observatory, etc.)

- Decompose the functional (parent) requirements into a set of logical decomposed functions and the set of derived technical non-functional requirements. Non-functional requirements in this context are: performance, interface, design, operations, and RAMS (reliability, availability, maintainability, safety)
- Develop the set of TDA Technical Requirements and the relationships (traceability) among the requirements (e.g., functional, performance, interface, operational, behavioral, temporal, etc.) for input to the TDA Design Solution Definition process.

4 System Design

To date, we have made considerable strides in developing the conceptual design for time-domain astronomy software at Gemini. Systems Engineering role will be crucial in further defining this conceptual design and fleshing out the interfaces. The successful implementation of good system engineering practices early in the system design process will have implications throughout the system life cycle. Once the conceptual design is complete and successfully passes Critical Design Review (CoDR), the system enters the preliminary design phase. A successful Preliminary Design Review (PDR) will demonstrate that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design. The next milestone, Critical Design Review (CDR), will demonstrate that the maturity of the design is appropriate to continue its software implementation, integration, and test, and that the technical effort is on track to meet system performance requirements within the identified cost and schedule constraints.

4.1 Conceptual Design (CoD) Phase

As mentioned, we have already been working with partners and internal and external stakeholders in determining use cases, internal and external interfaces, and a high level conceptual design. We plan to incorporate Gemini into a wider network of telescopes (the Astronomical Event Observation Network, or AEON), covering multiple apertures and capabilities. Figure 5 gives a schematic of the working model for the complete follow-up system, based on and around the current Las Cumbres Global Telescope Network (LCGTN). The yellow box provides scheduling and data reduction for observatories like LCGTN. The GEMMA-TDA work packages involve implementation of the components in this box for Gemini, which include updates to the scheduler within OCS, updates to the Product Distribution Manager in the Data Archive, updates to the Real-Time Data Pipeline, and a new interface to the TOMs (user software agents).

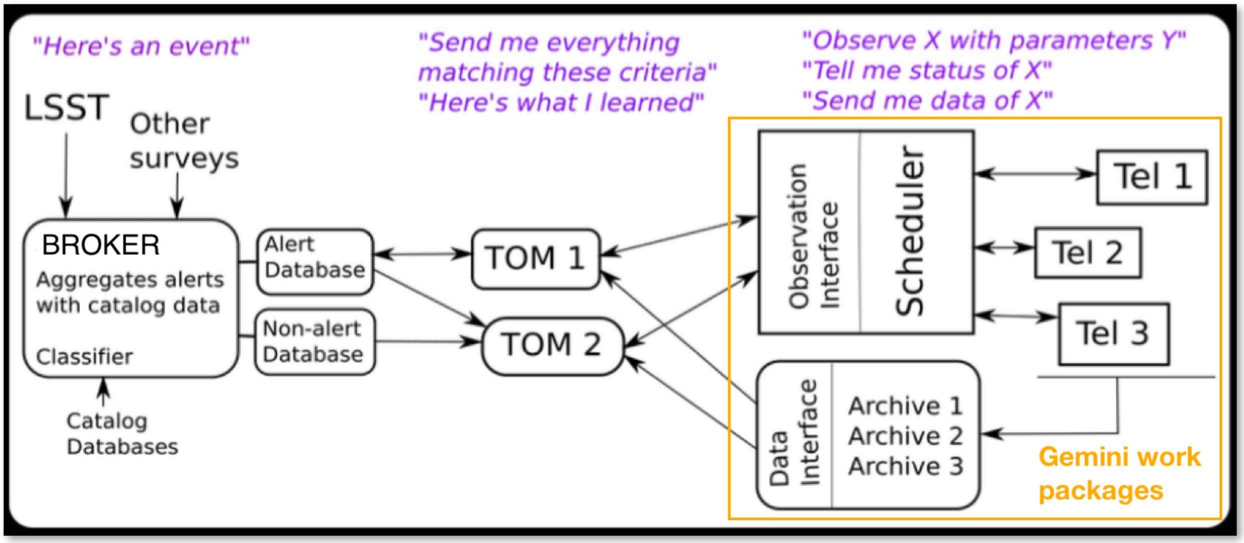


Figure 5 - Concept for the broad transient follow-up system

(credit: Rachel Street, LCGTN)

Once the conceptual design for the system as a whole, the subsystems described above, and the associated interfaces are defined, the project will be ready for the Conceptual Design Review (CoDR). The CoDR entrance and success criteria are listed below.

4.1.1 CoDR Entrance Criteria

- A Project Execution Plan (PEP) has been approved by the NSF.
- Project requirements have been defined that support NSF and AURA requirements on the project.
- Top project risks with significant technical, safety, cost, and schedule impacts and corresponding mitigation strategies have been identified.
- The high-level project requirements have been documented to include performance, safety, and programmatic requirements.
- A project Systems Engineering Management Plan (SEMP) that includes project technical approaches and management plans to implement the allocated project requirements has been produced.
- An approach for verifying compliance with project requirements has been defined.
- Procedures for controlling changes to project requirements have been defined.
- Interfaces are understood and documented.
- Development of technologies that cut across other projects have started.
- Initial cost estimates are derived and a project budget is approved.
- Draft Science Cases.
- Draft Concept of Operations (ConOps).
- A document that describes the TDA conceptual design is available.
- End of Stage Report.
- Preliminary Design (PD) Stage Plan.

4.1.2 CoDR Success Criteria

- With respect to ConOps and science requirements, defined high-level project requirements are complete.
- The project requirements provide for a cost-effective project.
- Major risks are identified with suitable controlling or mitigation strategies.
- Project requirement verification approaches are defined appropriately.
- An appropriate project plan and management approach are complete.
- An appropriate SEMP and technical approach are complete.
- The schedule is adequate and consistent with cost, risk, and operational goals.
- Project cost and uncertainty are within the available budget and tolerance.

4.2 Preliminary Design Phase

Once the CoD is successfully complete, the system enters the preliminary design phase. A Preliminary Design Review (PDR) will occur near the completion of this phase to achieve the following objectives:

- Ensure a thorough review of the products supporting the review.
- Ensure the products meet the entrance criteria and success criteria.
- Ensure issues raised during the review are appropriately documented and a plan for resolution is prepared.
- Approve the design-to baseline
- Authorize the project to proceed into implementation and toward final design.

PDR Entrance and success criteria are listed below.

4.2.1 PDR Entrance criteria

- Successful completion of the CoDR and responses made to all RFAs and RIDs, or a timely closure plan exists for those remaining open.
- A preliminary PDR agenda, success criteria, and charge to the board have been agreed to by the technical team, project manager, and review chair prior to the PDR.
- PDR technical products listed below for software system elements have been made available to the cognizant participants prior to the review:
    - Updated baselined documentation, as required.
    - Preliminary subsystem design specifications for each configuration item (hardware and software), with supporting tradeoff analyses and data, as required.
    - Updated technology development maturity assessment plan.
    - Updated risk assessment and mitigation.
    - Updated cost and schedule data.
    - Applicable technical plans (e.g., technical performance measurement plan, integration plan, reliability program plan, quality assurance plan).
    - Applicable standards.
    - Interface control documents.
    - Verification and validation plan.
    - Plans to respond to regulatory requirements, as required.
    - Technical resource utilization estimates and margins.

4.2.2 PDR Success Criteria

- The top-level requirements—including success criteria, TPMs, and any sponsor-imposed constraints—are agreed upon, finalized, stated clearly, and consistent with the preliminary design.
- The flowdown of verifiable requirements is complete and proper or, if not, an adequate plan exists for timely resolution of open items. Requirements are traceable to science goals and objectives.
- The preliminary design is expected to meet the requirements at an acceptable level of risk.
- Definition of the technical interfaces is consistent with the overall technical maturity and provides an acceptable level of risk.
- Adequate technical interfaces are consistent with the overall technical maturity and provide an acceptable level of risk.
- Adequate technical margins exist with respect to TPMs.
- Any required new technology has been developed to an adequate state of readiness, or backup options exist and are supported to make them a viable alternative.
- The project risks are understood and have been credibly assessed, and plans, a process, and resources exist to effectively manage them.
- The operational concept is technically sound, includes (where appropriate) human factors, and includes the flowdown of requirements for its execution.

4.3 Critical Design Phase

Once the PDR is successfully complete, the system enters the critical design phase. A Critical Design Review (CDR) will occur near the completion of this phase to achieve the following objectives:

- Ensure a thorough review of the products supporting the review.
- Ensure the products meet the entrance criteria and success criteria.
- Ensure issues raised during the review are appropriately documented and a plan for resolution is prepared.
- Approve the build-to baseline, production, and verification plans.
- Authorize system qualification testing and integration.
- Ensure all open issues are resolved with closure actions and schedules.

The CDR entrance and success criteria are listed below:

4.3.1 CDR Entrance Criteria

- Successful completion of the PDR and responses made to all PDR RFAs and RIDs, or a timely closure plan exists for those remaining open.
- A preliminary CDR agenda, success criteria, and charge to the board have been agreed to by the technical team, project manager, and review chair prior to the CDR.
- CDR technical work products listed below for both hardware and software system elements have been made available to the cognizant participants prior to the review:
  - updated baselined documents, as required;
  - product build-to specifications for each hardware and software configuration item, along with supporting tradeoff analyses and data;
  - final API specification;

- acceptance criteria;
- integration and test plans and procedures;
- verification plan (including requirements and specifications);
- updated risk assessment and mitigation;
- update reliability analyses and assessments;
- updated cost and schedule data;
- software design document(s) (including interface design documents);

4.3.2 CDR Success Criteria

- The detailed design is expected to meet the requirements with adequate margins at an acceptable level of risk.
- Interface control documents are appropriately matured to continue implementation, integration, and test, and plans are in place to manage any open items.
- High confidence exists in the product baseline, and adequate documentation exists or will exist in a timely manner to continue implementation, integration, and test.
- The product verification and product validation requirements and plans are complete.
- The testing approach is comprehensive, and the planning for system integration, test, and operations is sufficient to progress into the next phase.
- Adequate technical and programmatic margins and resources exist to complete the development within budget, schedule, and risk constraints.
- Risks to operational success are understood and credibly assessed, and plans and resources exist to effectively manage them.

5 System Development

Once the design is completed, the project enters the development phase. The Systems Engineer and technical team will provide oversight and review throughout the development phase.

Another major systems engineering function during system development is defining and managing interfaces, planning for system integration, and ensuring interface compatibility of the integrated system. Section 3.5 further details the System Interface Management Process.

5.1 Software development

The TDA system has several software interfaces that will need to be tightly coordinated with the OCS upgrade project as well as other observatories. We will define these interfaces early in the Interface Definition Document, and then the interfaces will be maintained in Interface Control Documents. It is critical that software development follow systems engineering processes outlined in this document throughout the project life cycle, which will be outlined in a Software Development Plan.

In this project we will be using a similar approach to other Gemini software projects that we have successfully completed in the last years, improving specific aspects based on our experience. In particular:

- We will use the principles of goal-aided design[1] to develop the functional requirements. This is a similar process to that used during the Phase I/II (UX) project. We will conduct interviews of representative people in all the roles that use the tools (e.g. community users, NGO staff, and Gemini staff with different roles). This information will be used to construct "personas" that will be used to define the operations or use concepts and the requirements.
- We will use an Agile software development methodology, in which developers and users will work as a team to deliver the product, in all stages of the development, from definition to deployment using an iterative approach. This was also used successfully in the UX, Queue Visualization, OCS Advanced Features, Laser Clearance House Target Tracking System and Sequence Executor projects at Gemini, from 2011 to 2018.
- The software will be open-source, hosted in GitHub and subject to the peer code review process currently in place for all high level software at Gemini. This has been useful not only as an effective revision control system but also as a mechanism to increase software quality through continuous peer code reviews. We assume software that will be integrated with other observatories, like Las Cumbres, can be developed the same way.
- We plan to build the system such that it will support automatic testing and continuous integration/deployment from the outset. This has been extremely useful not only in recent projects like the Sequence Executor, but also for our existing codebase supporting the Observatory Control System.

5.2 Documentation Plan

System engineering documentation will be configuration controlled, reviewed, and approved by the GEMMA-TDA technical team throughout the various phases of the project. System Engineering is responsible for initial development of the Concept of Operations, Top level specifications, System Verification and Validation Plans, and the Interface Definition Document.
The following documentation will be required to be delivered at various milestones, at a minimum:

- Concept of Operations
- Requirements and Specifications
- Verification Plan
- Validation Plan
- Software Development Plan
- Interface Definition Document
- Interface Requirements Document
- Interface Control Documents
- Software Description Documents

[1] Cooper, A. Reiman, R, Cronin, D., & Noessel, C. 2014, About Face: The Essentials of Interaction Design, John Wiley & Sons, Inc.

- Software User Manual
- Integration and test plans and procedures
- Failure Modes and Effects Analysis
- Acceptance Test Report
- Operations User's Guide
- Quality Assurance Plan
- Commissioning Plan
- Operations Plan
- Quality Assurance Plan

6 Validation & Verification

Once the system development is complete, verification and validation processes on the realized products and system will be implemented to ensure they meet applicable life-cycle phase success criteria. Realization is the act of verifying, validating, and transitioning the realized product for use at the next level up of the system structure. This verification process will generate evidence necessary to confirm that end products, from the lowest level of the system structure to the highest, conform to the specified requirements (specifications and descriptive documents). For lower level products, this process may be conducted by the software developers.

Planning to conduct the product verification is a key first step that will occur in conjunction with the requirements definition process. From relevant specifications, the type of verification (e.g., analysis, demonstration, inspection, or test) will be established based on the life-cycle phase, cost, schedule, resources, and the position of the end product within the system structure. The verification plan will specify any specific procedures, constraints, and success criteria.

When verification of the end product is conducted, the responsible engineer will ensure that the procedures were followed and performed as planned, and the data were collected and recorded for required verification measures. The Systems Engineer will analyze the verification results and ensure the following:

- End-product variations, anomalies, and out-of-compliance conditions have been identified
- Appropriate re-planning, redefinition of requirements, design and reverification have been accomplished for resolution for anomalies, variations, or out-of-compliance conditions (for problems not caused by poor verification conduct)
- Variances, discrepancies, or waiver conditions have been accepted or dispositioned
- Discrepancy and corrective action reports have been generated as needed
- The verification report is completed.

Once all of the lower level requirements and products are verified, system level verification and validation will be performed. System level verification could include a roll-up of children requirement verification reports or a system level analysis or test. System validation will also be performed to ensure compliance with the Concept of Operations. Validation testing is conducted under realistic conditions (or simulated conditions) on the system to determine the effectiveness and suitability for operations by typical users and to evaluate the results of such tests.

7 Interface Management Plan

The objective of the interface management is to achieve functional and physical compatibility among all interrelated system elements. Early in the design phase, external, internal, functional, and physical TDA interfaces will be defined in an Interface Definition Document that will be maintained throughout development. This document will be the basis for specifying interface requirements which will be documented in an Interface Requirements Document (IRD).

Figure 3 above shows the high-level software interfaces internal to the Gemini system, while Figure 5 depicts some of the external interfaces. These interfaces will be further fleshed out an controlled via Interface Control Documents (ICDs)

Verification of implemented interfaces will be emphasized during system checkout, both prior to assembly and in the assembled configuration. Throughout the product integration process activities, interface baselines are controlled to ensure that changes in the design of system elements have minimal impact on other elements with which they interface. In verifying the interfaces, the systems and software engineers must ensure that the interfaces of each element of the system or subsystem are controlled and known to the developers.

Additionally, when changes to the interfaces are needed, the changes must at least be evaluated for possible impact on other interfacing elements and then communicated to the affected developers. Although all affected developers are part of the group that makes changes, such changes will be captured in a readily accessible place so that the current state of the interfaces can be known to all.

8 Quality Control and Quality Assurance

Quality Assurance (QA) provides an independent assessment to the project manager and systems engineer of the items produced and processes used during the project life cycle. The Project Manager and Systems Engineer will ensure that contractors implement a quality assurance program and ensure visibility into QA processes and risk mitigation. Internally, the project manager and systems engineer will manage quality risks and enforce adherence to procedures and specifications throughout the system development and system integration.

TDA Risk Register A - TDA - 004

Part I. Risk Identification						Part II. Risk Analysis for Existing Controls			Part III. Risk Response							
Name	Project Risk Category	Risk Description (ignoring controls)	Impact 1-5 (ignoring controls)	Likelihood 1-5 (ignoring controls)	Total Risk Score Low = 1 - 8 Med = 9 - 16 High = 17 - 25	What Controls (if any) are currently in place?	Control Effectiveness 1-5	Residual Risk Score Low = 1 - 8 Med = 9 - 16 High = 17 - 25	Control or Risk Mitigation Strategy	Control effectiveness based on mitigation strategy 1-5	Residual Mitigated Risk Low = 1 - 8 Med = 9 - 16 High = 17 - 25	Contingency Plan	Cost of contingency plan	Owner	Review Due Date	Status
Software Resources	Resources	If the software effort is not secured, project will be delayed.	4	5	20	Job Ads submitted to HR to hire 3 new SW engineers.	3	10	Use Internal resources to cover, impacting other software projects.	2	5					
Technology misalignment	Technical	If project team is not aligned on technology stack used for the project, the schedule will be impacted.	3	3	9	Regular technical meetings with team and definiton of technical standards for project development up front.	2	2								
Missed external dependencies	Scope	If a dependency between TDA Software and an external system is not identified, TDA SW Scope will change	4	3	12	Project with sufficient Systems Engineering support to ensure all external interfaces are well understood and identified.	2	3	Regular meetings/communication with Las Cumbres Observatory for work on APIs	3	6					
Key personnel unavailable	Resources	If key personnel aren't available the project will be delayed	4	3	12	Maintain project priority and resource requests visible. Ensure the proper priority is given to project in the observatory	3	6								
Scheduler complexity	Technical	If scheduling Gemini automatically proves to be overly complicated, the project will be delayed.	4	3	12	Investigation of strategies to solve the scheduling problem. Prototying to assess impact of requirements and strategies.	3	6	Consider simplifying requirements and scope.	3	6					
Automation Flexibility	Technical	If automation cannot be made to flexibly handle different GMOS modes, scope will change (only the most common modes will be automated) - note: applies both	3	2	6	Tasks requiring flexibility are prioritized to start first	3	3	Consider simplifying requirements and scope.	3	3					
Scheduler performance	Technical	If the scheduler cannot run fast enough to adapt to changing conditions/events then there may be telescope downtime or missed observing opportunities.	4	2	8	Prototyping to assess performance.	3	4	Early testing at full load to evaluate performance. If not meeting specifications, investigate strategies to improve performance (hardware and	2	2					
Internet connectivity	Technical	If the internet connections between the ODB/scheduler/archive are not reliable then there may be downtime or missed observing	4	3	12	Work with internet providers and other observatories to improve internet connections and make them more reliable.	3	6	Develop contingencies in software to handle some internet distruptions.	3	6					
Changed external dependencies	Technical	If Astropy dependencies change in a way that is incompatible with our data reduction code, project will be delayed	3	3	9	Participate in Astropy coordination and development to avoid such changes	4	7	Fork a previous version that is compatible and maintain it as part of our package going forward	2	2					
OCS3 Dependencies	Scope	TDA presupposes an OCS that is able to ingest, schedule, and execute observstions, but OCS3 remains largely undefined. Lack of definition will delay the project.	5	5	25											
Environmental Monitoring	Technical	TDA presupposes reliable continuous environmental monitoring. Is this in place? Lack of availability will delay deployment.														
Deployment Strategy		TDA requires joint telescope scheduling which requires off-site deployment, but there is no policy about how this is to be done. Lack of guidance or arbitrary constraints will delay the project.														
TAC Changes		TDA may require changes to the TAC process, including changes to scoring methodology in order to allow more accurate scheduling. How will this be negotiated? Lack of defintion (or late decisions) may delay the project.														
Operations Changes		TDA will require changes in nighttime operations. Risk of disruption and loss of time if this is not done carefully.														
Long-Term Scheduling		TDA requires precise short-term scheduling but this must be reconciled with long-term scheduling constraints, which may require simulations or other techniques distinct from the constraint-based scheduler currently under discussion, or SRI-style policy changes. Lack of consideration may delay the project.														