At the dawn of a systems engineering process

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ABSTRACT

This is an era which the ELT telescopes define 'the new science' for astronomy. Thus, to make optimal contribution (i.e. valuable scientific output in an efficient, sustainable manner), a mid class telescope such as DAG 4m, must have a carefully designed Systems Architecture, which, in our opinion, could only be possible by means of a proper Systems Engineering (SE) process. From a Platonic perspective, the SE work must be started well before (at least conceptually), even the ‘idea’ of erecting an observatory. As can be seen from the experiences, this, however, never happens, and also it did not happen in our case. Regarding the facts given above, a SE process for DAG observatory has been initiated soon. As a bunch of constraints had already been formed, the work primarily focuses on the scientific instrumentation. This paper demonstrates various phases of the SE process carried until now. We will also discuss the methodologies/techniques that are planned to be used in the future.

Keywords: Systems Engineering, MBSE, SysML, Brownfield, Greenfield

BRIEF HISTORY OF THE DAG PROJECT

The DAG project is essentially erecting a full observatory facility which includes a 4 meter class telescope, two buildings (a service building and a telescope building, actually latter only includes a concrete pier for the telescope and the pier/basement for the rotating enclosure), the rotating enclosure and the other necessary infrastructure such as communication and power infrastructure. Due to the funding issues, the Project was initiated in two separate lifecycles, so called Telescope Project and Focal Plane Instruments (FPI) Project. Initially, it was foreseen the FPI project was going to start after one or two years ahead of the start of the Telescope Project, and it had happened so. The initial motive for erecting the Observatory is to provide a so-called ‘general purpose’ telescope to the national scientific community. However a major paradigm shift decision has been made by the board, such as putting the intent and emphasis on topics like international collaboration and world-widely used observatory. Apparently, this shift is highly effective both on the Project life-cycle and the prospective scientific outcomes that could be made.

WHY DO WE WANT TO DO THE SYSTEMS ENGINEERING? SE RATIONALE

First, who are we? : A small but ‘colorful’ group of people having some experience in various fields such as astronomy, engineering and software systems working at the DAG Project Office. A subgroup of the group’s initial responsibility domain was defined as organizing (and participating in) the production of the Observatory Control System (OCS). The OCS, which is a critical subsystem of the whole observatory, is the orchestrating software for the observatory subsystems in which various levels of actors involved to perform the operations. To do the job, we started the routine process of ‘need ← requirement analysis ← design” for the OCS software. Through the process, the amount of domain specific knowledge collected by the team (i.e. for the various physical/logical subsystems) reached to some certain level at which the necessity for a formal approach of SE highly recognized. Regarding the paradigm shift, we have believed that in order to bring a “major league” player to the international astronomical community, every remaining step of the erection process must carefully be planned, applied and verified. Finally, conveying this perception to the DAG Board and reaching an agreement with them, resulted in the SE initiative of
CURRENT SITUATION AKA BRIEF DESCRIPTION OF EXISTING SYSTEMS.

First it is better to give a definition for the phrase ‘existing system’: Hereafter, an existing system means either implemented/manufactured/produced or being implemented/manufactured/produced or designed-with-well-defined-and-frozen-interfaces system.

As of now, our existing systems are (aside from the infrastructures):

- The Telescope with active optics system (aO): A 2-mirror RC Telescope with a f/14 effective f-ratio having a 4 mt primary with active optics system capable of applying figurative corrections on the primary,
- The Alt-Az Mount providing two Nasymth platforms for the foci
- One field derotator system responsible of the compensation of the rotation of the field due to the Alt-Az mount. It is embedded inside one of the altitude bearings of the mount,
- The Rotating Enclosure which is responsible of providing suitable observation conditions in addition to off-observation protection
- The respective control hardware and software

To be more specific, currently, the manufacture of the Telescope with aO and the Rotating Enclosure is almost complete. i.e. Factory Acceptance Tests of the Telescope will be carried out in a couple of months and the installation of the Rotating Enclosure on site has just started. SE initiative mandates an answer to a critical question: “Problem Statement”, which implies a clear need for a definition for the System boundary that the SE process applies. As described above, the DAG Project had started in two phases. The first phase defined a main system boundary as “Telescope only” with a foreseen use of a separate Adaptive Optics (AO) system. At that time the needs and requirements for a particular AO system were not completely given. The second phase is the FPI (which is an abbreviation in plural form, i.e. should be read as FPIs). Regarding the remaining complementary parts for a fully functional observatory, it is trivial to see that the new System boundary is the Observatory itself.

IS IT MEANINGFUL TO START A SE WORK FOR AT THIS STAGE? ARE WE LATE?

“System engineering focuses on defining needs and functions early in the development cycle. It entails documenting all requirements at the start, ...”[1]

First, the question needs to be reduced down to identification of our case, if it is a so-called “Greenfield” or “Brownfield” or something-else? Greenfield systems engineering is the term generally used for doing a “top-down” SE for unprecedented systems or thinking a system ‘clear-sheet’. It is obvious that this doesn’t reflect our reality as we have a telescope already manufactured. Considering the almost complete first phase and the upcoming second phase (FPI) of the Project, one might want to take our case as upgrading an existing system (usually called ‘Brownfield’[2]). However, it is apparent that instead of doing an upgrade to an already working system, we are going to complete a partially existing system by taking the first phase outputs as constraints (which are available to us as interfaces). So, we feel brave (and stupid at the same time) to use a technical term for our case -without giving a formal reference- as a completion process.

The next question about the timing can better be understood by looking at some of the expected outcomes of the planned SE work, are we late? or is it a last exit before the bridge? (All the below items are stated considering a
MBSE approach which is described in the following section):

- First and maybe foremost, obtaining a full operational view covering the aspects with a certain level of detail is planned to be obtained: Definitions of Concept of Operations and regarding this information, Operational Concepts for various scenarios. This will also include detailed definitions of maintenance and safety procedures for the systems' components. The importance of operational view is obviously not a matter of debate for such a big investment as the operational readiness time and efficiency within that time, constitute two key parameters of the observatory.

- Analysis of the Observatory from different perspectives. Especially performance viewpoint: The performance requirements for some of the existing systems were given at the Requirements Specification Document for the Telescope[3]. However, the “full” system performance requirements within error budgets are apparently needed. For example, to specify the Image Quality at a particular FPI, we can state much accurately from our current standpoint as we now know the existing systems' limits practically.

- Better understanding of the system as a whole, capturing the missed points and derivation of requirements for them. Instead of trying to capture every detail from the existing documents and try to figure out the relevant part of the picture in the mind, a live model is highly desirable.

- Identification of the potential upgrades to existing systems as early as it can be (i.e before the first light) otherwise which may end up with disaster during integration. For example: The hard real time control interfaces provided by the Telescope Control System (TCS) and Mount Control System (MCS) would need to be upgraded depending on a particular choice of FPI. As another real-life example: We have realized a need for hard-real time communication between the derotator and the TCS a year ago where it needs to be a minor upgrade to the TCS interface.

- Opportunity to test and assign metrics for the evaluation of the alternative designs.

**SYSTEMS ENGINEERING PLAN**

Apparently, nowadays a “general purpose” 4 meter telescope could not be considered as a frontier in technology development for astronomical instrumentation domain. Observatories having this size of telescopes with the aforementioned “general purpose” intentions are willing to be designed and manufactured upon COTS/MOTS\(^1\) technologies. This makes our job relatively easy while thinking the functionality of the subsystems and the necessary allocations by forming the functional domains is straightforward. Here is an incomplete list of functional domains for our system: A SCAO AO system, independent Derotator unit, SLODAR telescope (working as an auxiliary system, mainly providing statistical data), meteorological systems, acquisition systems for wave front sensors for aO, etc.

Additionally, for some parts of the existing systems, document based SE process (apparently for their own system boundary) have already been applied by the manufacturer companies/contractors. Once again this somehow eases our job especially in terms of integration.

**WHAT IS A CASysE\(^2\) MODEL?**

Referencing the reasons and experiences of some big astronomical projects such as LSST[4], TMT[5], and considering the general views like[6], the smartest way to go for the SE work is a CA SysE, or better, MBSE approach. A computer aided model is generally conceived by the outsiders as a bunch of different kind of

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1 Modified / Modifiable off-the-shelf.
2 Intentionally distorted by the author. The original term is CASE for Computer Aided Software Engineering
diagrams that describes the structural and behavioral aspects of a system from different perspectives. Although being true, this perception is very limited in the sense of reflecting the full picture. Apart from the traditional holistic (system level) models that can be formed even without using computers (i.e. with pen and paper), a computer aided model is made by using a modeling language (which implies having a full syntax and deep semantics) and a tool (as well as auxiliary tools) with application of proper methodology. So it is not wrong to take a model created on a computer as programming (modeling) the physical world (domain being modeled) by considering the real world entities (events and triggered executions)[7].

As all the creation of the artifacts of MBSE process occurs in a computer, the first requirement of the process itself is choosing a tool (an application). Following the fact, it is easy to see that a proper tool selection is highly dependent on the modeling language to be used for the model. As best practices show, almost all the time going with standards is a time-saving approach. By this reasoning, we chose SysML as our language. It is a UML metamodel profile created out by the extension mechanism of UML and although UML was not designed thinking software-only systems, it’s design is highly Object Oriented (a decades old programming/design/architecture paradigm for Software Systems) and SysML inherits this property from it’s parent.

The proper selection of the tool is mainly dependent on the capabilities provided by the tool and the experience of the users. Concerning the budget issues, we have decided to go on a free software platform for a trial kickstart and the Eclipse [8] ID Environment with architectural modeling extensions framework, particularly Papyrus turned out to be our choice. The last remaining part of the process is the approach (and a methodology) to go for MBSE. The general approach for MBSE is defined as Use-Case driven, architecture centric and incremental-iterative. These three concepts represent well enough the way of thinking while modeling. However, as it is prescribed in [6], a set of guidelines and a methodology (like OOSEM or SySMOD) turns out to be crucial after some period of struggle even when a modeler tries to model a very well known component of a subsystem. This is the issue we are currently making research and experiments on.

CONCLUSIONS

Since the beginning of the DAG Project, we have gathered and processed serious amount of information related with various sized observatories. The accumulated knowledge for various design choices used in other observatories have been investigated by the team and have been addressed by the relevant parties of the project. But all the work done until now existed as informal diagrams and documents. In order to convert them into concrete deliverables which can provide a solid information base for future operations and upgrades of the system, a computer generated model is decided to be made. This model will hopefully convey all the information that can be obtained from the traditional SE processes. Besides, depending on the transformation capacity (as documents, as software codes) it carries, the DAG Project team as a whole (not only the OCS team) could find it very useful if not inevitable.
Figure 1: Block Definition Diagram of the SE Initiative [9],[10],[11]
REFERENCES

[4] C. F. Claver et.al., Systems Engineering in the Large Synoptic Survey Telescope project: an application of model based systems engineering,