

A3 Architecture Overviews for Systems-of-Systems

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Abstract This work describes how the A3 architecture overviews (A3AO) tool, developed by Borches (Borches Juzgado, 2010) for reverse architecting of complex systems, can be used for the description of Systems of Systems (SoS). Where the tool originally focuses on the description of the architecture of a system aspect on an A3, this paper treats how an SoS architecture is described on a single A3AO. This difference emphasizes some of the key features of A3AO's: condensation of architecture knowledge until only the essentials remain and the ability of communicating the descriptions among different disciplines. A case study into the subject is done, describing a complex SoS developed by the Naval Systems department of Thales Nederland B.V. in Hengelo, The Netherlands. In order to initiate the creation of this A3AO, a research methodology consisting of interviews, a questionnaire and testing phases is defined and executed. This research methodology applies a reverse architecting approach as defined in Muller (Muller, 1996) and Borches (Borches Juzgado, 2010). Results from the research are given, and the applicability of the tool for the described purpose is evaluated. Using these results, an approach to the creation of high level A3AO's is defined. Ultimately it is concluded that, with small adaptations, the A3AO tool can be used for the description of SoS.

1 Introduction

Technological progress and tougher requirements lead to increasing complexity in systems. In order to provide additional capabilities surpassing the capabilities of existing systems, Systems-of-Systems (SoS) are developed which combine multiple constituent systems. The SoS overlay integrates different culture, norms and terminology into a system, while simultaneously evolving its capabilities over time (Rebovich Jr., 2008). Examples of SoS are seen often in defense systems such as the Thales TACTICOS system, which integrates subsystems on navy vessels and about which a case study is published in this paper.

At CSER 2012, a panel discussion (Colombi, 2012) resulted in the following point: 'Humans have to fill in for the gaps in SoS'. Means are therefore required that allow for acquiring an overview of the SoS and for detecting the gaps. ISO (ISO/IEC/IEEE, 2011) defines the architecture of a system as being: '*Fundamental concepts or*

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properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution'. Although there are many more definitions (Maier & Rechtin, 2000), this one emphasizes the fact that system architecture is the fundamental organization of a system. In order to acquire an overview of a system, its architecture needs to be understood.

Information about system architecture is consequently relevant for a very wide range of stakeholders and it is important to allow stakeholders to easily access and communicate system architecture information. Communication of architecture information is time consuming and requires the respective expert to be available. Furthermore, implicit information prevents the formation of a common, consistent model which everyone knows and understands. Explicit descriptions of system architecture should therefore be available. As mentioned in (Maier & Rechtin, 2000): *'All successful, unprecedented systems have been explicitly architected'*.

Previous research into the area of system architecture, among others published in (Alvarez Cabrera et al., 2011) and (Bonnema et al., 2010), described promising directions for future research: condensation of information and creation of high level models. These points were also used in the creation of the A3 Architecture Overviews (A3AO) approach, described in (Borches Juzgado, 2010). Until now, this approach has been used to describe system architecture by means of system aspects. The differences between a traditional system and an SoS mean that a different approach to Systems Engineering (SE) needs to be taken. Traditional SE focuses on building the right system, Systems of Systems Engineering (SoSE) focuses on choosing the right systems and their interactions to satisfy the requirements (Ncube, 2011).

The present paper describes difficulties encountered when communicating high level architecture information using architecture descriptions made using available standardized architecture description approaches. Subsequently, an approach is given to the creation of architecture descriptions suited for communication of this high level information, based on the A3 Architecture Overviews (A3AO's) described in (Borches Juzgado, 2010), amplifying the research directions that led to the creation of the original A3AO approach. The approach aims to describe the essentials of an SoS architecture on a single A3AO, in order to allow stakeholders to quickly gain an overview of the architecture. Results from a case study are given supporting the proposed approach.

2 State of Art

Currently, several aids for describing system architecture exist. The earlier mentioned ISO and IEEE standard (ISO/IEC/IEEE, 2011) presents best practices for describing system architecture. The predecessor of this standard – IEEE 1471 – intended to encompass several of the most often used architecture frameworks available today; among others the DoDAF, TOGAF, RM-ODP and the Zachman framework (Hilliard et al., 2007). These best practices do not limit the possibilities available to the description of system architecture. Standard architecture frameworks, however, do. By applying a viewpoint-based approach, the creator of an architecture description is limited to extensive descriptions containing information about only part of the system.

The DoDAF (v2.02), for example, supplies eight main viewpoints consisting of over 40 models. Although this results in complete architecture descriptions, it makes it hard to acquire an overview of the system; the big picture is lost (Bonnema, 2011).

A standard architecture modeling language such as SysML is often used in conjunction with these frameworks. Although SysML aims to provide a universally applicable language for modeling systems, it is not usable by stakeholders without experience in the area of software SE.

As mentioned, the available approaches have several disadvantages which make it ill-suited for the goal of this research. Besides making it hard to acquire an overview of the system by means of these descriptions, there are a number of problems when using them for communication, as they are

- very extensive,
- often aimed at a single discipline and hardly usable by other stakeholders,
- showing only one view of the system, therefore giving only limited information about the system and making them useful in fewer occasions.

(Alvarez Cabrera et al., 2011) mention that a language is required that: ‘*Supports communication independent of stakeholder background; enables relating any domain-specific data to the common model; and facilitates identifying completeness of the information*’. The A3 Architecture Overviews method was created with these points in mind, and does not aim for completeness, but rather for understandability. Yet, the resulting overview should convey the essentials in sufficient detail.

2.1 A3 Architecture Overviews

The A3 Architecture Overviews (A3AO) approach is developed by Daniel Borches (Borches Juzgado, 2010) for effective communication of architecture knowledge. It consists of two main parts;

1. the A3AO tool: a means to display architecture information, and
2. a reverse architecting method: a means for making implicit architecture information explicit.

An A3AO is an A3 sized paper sheet containing system architecture information. One side is composed of textual information regarding a certain system aspect, while the other contains a number of models clarifying that aspect. The summary side is the side one should look at first when starting to work with an A3AO. It is mainly text-based and contains several pre-defined blocks with sizes that may be varied. The other side of the A3AO, the overview side, contains several model-based elements, each with a set position but a very flexible setup. An example of the ‘standard’ A3AO is given in Figure 1. For a full overview of the contents of an A3AO, see (Borches Juzgado, 2010).

The reverse architecting method included in (Borches Juzgado, 2010) and displayed in Figure 2, is an iterative process consisting of three steps. The approach was first introduced by (Muller, 1996). *Information extraction* is the process of finding, capturing and understanding the information. *Abstraction* consists of filtering and grouping the extracted information to obtain a manageable set of relevant information. *Presentation* consists of presenting the information that was acquired

and abstracted. The information presented may be used for gathering additional or better information, completing the iterative cycle.

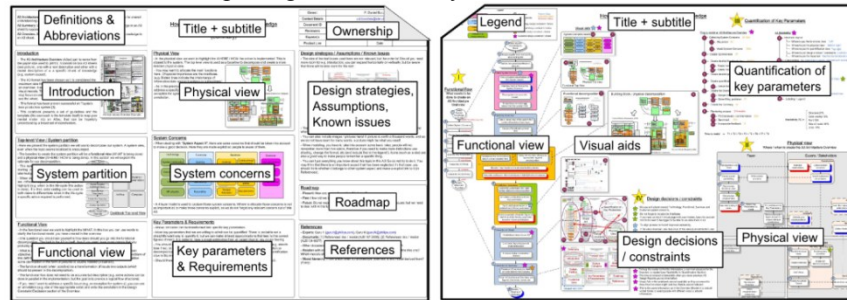


Figure 1. A3AO summary side (left) and overview side (right) as proposed in (Borches Juzgado, 2010)

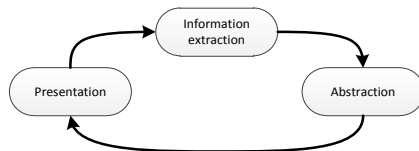


Figure 2. The reverse architecting process, adapted from (Borches Juzgado, 2010)

The main goal of the A3AO approach is to make architecture information easily available to a wide range of stakeholders, while also supporting the evolution of the product. The original A3AO research does not describe the applicability of the tool on SoS level, and remains at the level of aspects of these SoS. This leads to an A3AO repository for a complex system of around 30-100 A3AO's.

3 Research Method

In order to research the applicability of the A3AO tool on SoS level, a case study is done (Section 4), for which a research methodology is developed. The A3AO and the related reverse architecting method introduced in the previous section are applied in an industry-as-laboratory approach (section 3.1). Several reverse architecting iterations are defined (section 3.2) to gather relevant information at each stage.

3.1 The Industry-as-Laboratory Approach

To be able to find out what the requirements of the stakeholders are regarding the overviews, the *industry-as-laboratory* approach will be used. The approach was first mentioned by Colin Potts (Potts, 1993), who defines the method as follows: '*A complementary approach that aims to identify relevant research problems and solutions through close interaction with the industry*'. By participating in a company and observing the use of the newly implemented method, valuable information can be acquired regarding its effects and the required approach.

One of the main problems of using the industry-as-laboratory approach is the lack of exact, provable results. The research phases in which stakeholders are interviewed will therefore be analyzed for trends and opinions instead.

3.2 Iterative A3AO Creation

Jakob Nielsen (Nielsen, 1993) argues that, when talking about the user interface of an application, the only way to achieve a high level of usability is by implementing an iterative process, in which the interface is tested repeatedly. There is a correlation between the usability of user interfaces and the usability of the A3AO's as these can be seen as a user interface for architecture representations.

The 3-step iterative reverse architecting process (Figure 2) has been applied throughout the project to identify the steps of the process and in that way show the position of a certain point within the iterative process. Each of the research phases has its own starting point and goals. The outcome of a single iteration is used as input for the next.

Several main iteration cycles are defined, each with their own approach. This paper draws a clear line between each of the research cycles. In reality, conversations with many stakeholders were held throughout the project. For clarity, the main factors for each part of the research are described. An overview is given in Figure 3.

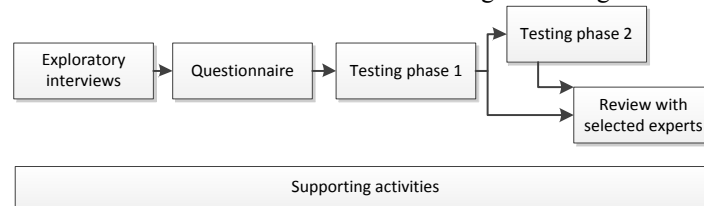


Figure 3. Main research process, chronologically from left to right

To start the research procedure, exploratory interviews are held with 30 employees. Based on (Oppenheim, 2000): *'The purpose of the exploratory interviews is essentially heuristic: to develop ideas and research hypotheses rather than gather facts and statistics'*. The employees selected are expected to be able to significantly contribute to the project: system engineers/ architects, group managers and employees with many years of experience.

A top-level A3AO is created using input from these interviews. Furthermore, Oppenheim mentions: *'Many weeks of planning, reading, design and exploratory pilot work will be needed before any sort of specification for a questionnaire can be determined'*. Using the input of the exploratory interviews and the requirements of the A3AO contents, a questionnaire is developed to acquire more information for the A3AO, and also to acquire information to guide the rest of the project – for example information about the willingness of participants to further participate in the project. After the questionnaire the A3AO is upgraded and many small iterative steps are taken to improve it. To see whether and how the A3AO is actually used, two testing phases are done; one with a wide range of stakeholder types and one with three groups of similar, more precisely defined, stakeholders. These are done to validate the

approach taken and acquire feedback on both the approach and content of the A3AO. The expectation is that testing the A3AO will reveal several requirements which were not mentioned before – ‘latent needs’, defined in (Davis, 2010) as follows: ‘*User needs which the users themselves may not have thought about but which, when met, deliver delight and exceed expectations*’.

During the second testing phase, the A3AO is verified further by having models checked by the specific experts in that field. This is done to improve the overall quality of the information on the overview. After this last check the layout of the overview is polished and the 1.0 version of the overview is released. This overview may be used as a starting point for further implementation activities.

4 Case Study

4.1 Introduction

Thales Nederland B.V. (Thales NL) is the largest defense company in the Netherlands. It is one of the world’s leading suppliers of naval surface systems. Thales NL is the Thales Group’s center of excellence for naval radars and combat management systems (CMS’s).

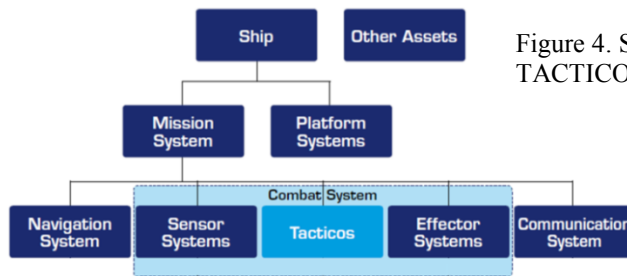


Figure 4. Scope of the TACTICOS CMS (Thales, 2012)

The Combat Management System (CMS) of Thales NL is TACTICOS, which stands for ‘Tactical Information and Command System’. Together with the sensors and actuators, the CMS forms the Combat System (CS). A scope is given in Figure 4. The TACTICOS CMS integrates all parts of the CS to deliver a fully optimized ‘System of Systems’(SoS) that meets all essential requirements for:

- Navigation
- Mission planning and command support
- Threat evaluation and resource allocation
- Coordination of tactical assets (including helicopters and watercraft)
- Tactical information exchange
- Picture compilation and track management
- Onboard training and simulation
- CMS configuration management

The Naval Systems (NS) department of Thales NL, consisting of around 350 employees, is responsible for the development of the TACTICOS CMS. Within this department, the product portfolio management group, consisting of around 10 employees, maintains the TACTICOS system architecture. This group has expressed

interest in the A3AO tool for the description of the system architecture at high level, in order to be able to easily communicate architecture knowledge with a wide range of stakeholders throughout the NS department. The goal of the research is to create a single A3AO containing the essentials of the complete TACTICOS system architecture. Due to the confidential nature of the subject, not all gathered information can be displayed in this paper.

4.2 Resulting A3AO

Figure 5 shows the final A3AO created. The main models of the original A3AO approach, functional, physical and quantification of key parameters are also relevant at high level and have been largely kept. Several operational models are added due to this high level. These include an overview of the capabilities, an overview of naval operations, a high level operational concept graphic (comparable to the DoDAF OV-1) and a model displaying the interface between the operator and the SoS.

The A3AO integrates many aspects on one overview. This leads to the models on the A3AO becoming more generic, and being split up into multiple parts, each describing different aspects. The physical view has been split into a ship view, a network view and a software view. The functional flow has been split into a surveillance and a planning cycle to integrate aspects with a different temporal scope.

The main functional flow is, instead of a linear flow, replaced by a cycle, a so called OODA (Observe-Orient-Decide-Act) loop. This allows for the integration of multiple aspects and is perceived by stakeholders to be more intuitive and closer to the real situation. This may be a result of the prevalence of the OODA loop in defense oriented companies. Due to the amount of information to be described and the addition of some models, 'redundant' information is removed from the A3AO, or merged with others. This includes the top-level views of the functional and physical views, and the visual aids.

4.3 Interview and Test Results

The exploratory interviews led to a large number of opinions, and impressions. The information acquired is mainly about TACTICOS, the information required on the A3AO and the approach to be taken.

The results to the questionnaire confirm many of the expectations resulting from the exploratory interviews. Several impressions are given in Figure 6. From this figure follows that, although over 40% of stakeholders agree that requiring more than one A3AO for the system architecture would lower the usefulness, it is expected that 2-4 A3AO's are required to describe the system essentials. Participants also agree that there should be different A3AO's for internal and external use. Combined with the (not pictured) outcome that the 'Captures & bids' department of Thales NL is one of the four departments that benefits the most from implementation of the method, leads to believe that stakeholders expect the method to be of use in the communication with customers. Four types of models are preferred by stakeholders. Besides the functional and physical views already available on the overview, these are the capability and

operational views, which are added to the overview. The quantification of key parameters presents an approach unknown to stakeholders, but when introduced stakeholder reactions were very positive and the model is kept on the overview.

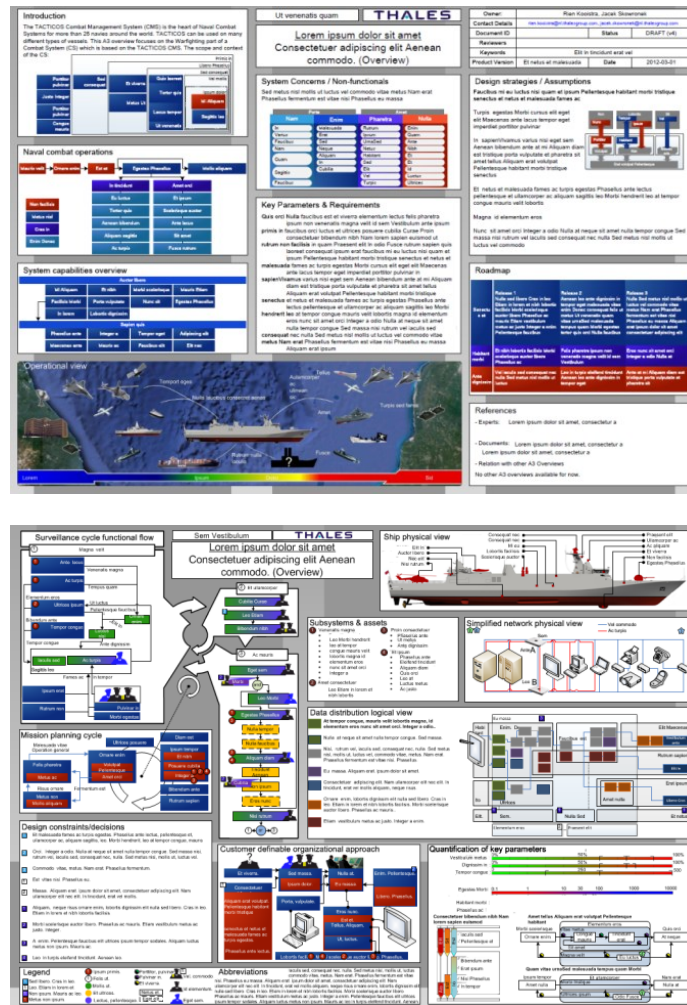


Figure 5. The created A3AO. Top: summary side, bottom: overview side

The most important aspects of the system are selected to be subsystem integration, distributed system, performance, scalability, fire control and the man-machine interface. When asked for their top-three most important aspects of the system, stakeholders give 26 different answers out of a total of 70 (after merging similar answers). When asked for system concerns, stakeholders also give many different concerns for each category. This indicates on the one hand that there is no consensus regarding the most important aspects of the system, but also that there are many different aspects to be integrated on the A3AO.

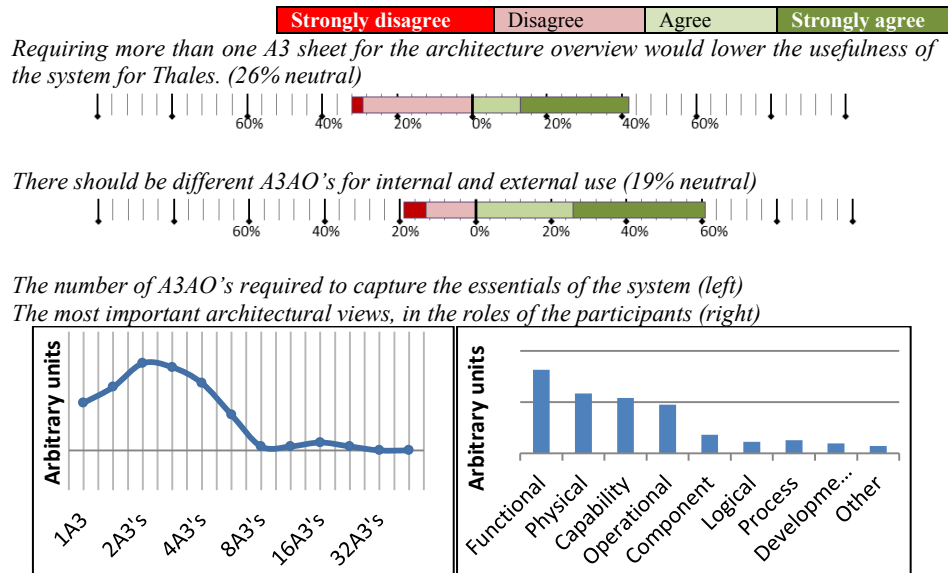


Figure 6. Most important outcomes of the questionnaire

Using the A3AO resulting from the previous phases, the testing phases provide two main inputs; indications on the use of the A3AO in daily work, and feedback on the A3AO contents. The feedback on the content of the A3AO was used to improve its quality. Several reasons for using the A3AO were found, among others: for reference of small but overarching items such as applied terminology and important non-functionals, communication in general conversations or meetings and for introduction of inexperienced stakeholders into the system.

The testing phases provide verification of the layout and type of content, while the expert interviews provided the actual verification of models, data and text. Ultimately the design of the A3AO is evaluated with a graphic designer and version 1.0 is released (pictured in Figure 5).

4.4 Supporting Activities

Project specific supporting activities can be undertaken beside the main research. For Thales NL, producer of defense equipment, the DoDAF (US Department of Defense, 2010) is an important influence for current architecture descriptions. For this reason, a mapping of the created A3AO on the DoDAF framework is made.

This mapping identifies whether information present on a DoDAF description of the TACTICOS CMS is also present on the created A3AO of the TACTICOS CMS. This information is then compared to two sources indicating the importance of DoDAF models: a survey (US Department of Defense, 2008) and a use-case matrix defining the relevance of modes to certain stakeholder groups included in a Thales

internal DoDAF description (Geerink, 2007). Main outcomes of this undertaking are the confirmation that the operational models, the high level operational concept graphic and the naval operations, among others, are relevant. Furthermore, recommendations for additions to the A3AO are made. This led to the inclusion of a short overview of abbreviations used. A few results are shown in Table 1.

Table 1. Selection of notable DoDAF models

Product (v1.5 name)	Short description	Used in [%] of DoDAF descriptions	Relevance to stakeh. groups	Availability in A3AO
OV-1	High level oper. concept graphic	92%	8/10	5/5
AV-1	Overview and Summary Info.	84%	10/10	5/5
AV-2	Integrated Dictionary	79%	10/10	0/5

5 Evaluation

Ultimately, the A3AO resulted as displayed in Figure 5. It turned out to be a great means to introduce the system and its main aspects. The A3AO is also valuable for communication of architecture knowledge between experienced employees and employees with little experience with the system. Employees expect this to be the case in communication with external stakeholders – customers – as well. For the average, more experienced employee, the A3AO was of use as well, as it is used for referencing to things such as terminology. Furthermore, the A3AO helps solving several non-technical challenges associated with SoS: stakeholder groups each have their own objectives and organizational context and stakeholders of individual systems may have little interest in the SoS, may give SoS needs low priority or may resist SoS demands on their systems (Ncube, 2011). The A3AO raises stakeholder awareness by providing overview and defining a clear scope, which was an issue during this case study but also in other available architecture documents. Several stakeholders indicated that the A3AO is also usable for communication between experienced employees. When the release cycle of the A3AO is linked to the release cycle of the system, it may also be used for communication of system changes.

Overall, stakeholder response to the method was very positive. Several employees saw possibilities and started using the created A3AO or even creating A3AO's on their own. The NS department of Thales has therefore decided to implement both the original A3AO and the approach described in this article. The creation of an initial number of 5 A3AO's at SoS level and 55 standard A3AO's is planned. As of now, several have already been created. This collection will serve as a supplement to the current architecture description document, to provide better overview. The present documentation system will be maintained for detailed specifications.

Two main causes for the differences between the created A3AO and the original method are identified: The higher – SoS – level of the created A3AO and the different environment in which the method is implemented. The former is of more importance as these differences will occur for every high level A3AO created.

5.1 Research Methodology Evaluation

The original A3AO creation approach focused on step-by-step filling out the A3AO with a few experts, iteratively improving the A3AO. This approach could not be taken as the requirements of many more stakeholders had to be taken into account, and many experts had to be involved for acquiring the required information. Stakeholder consensus is used to identify the essentials of the system. Documents were used for the creation of the A3AO, but these are not very useful as they often have a different scope, are outdated, and mix system essentials with other information.

The research methodology developed and applied during this project therefore focused on stakeholder interaction and information gathering. The approach displayed (slightly simplified) in Figure 7 turned out to be a great means for acquiring the right kind of knowledge in an environment where it is difficult to acquire high quality data.

Some changes could be made to the research approach taken during the case study;

- using a more mature A3AO for the testing phases,
- extending the testing phases to allow participants to get used to the method,
- having a control group to compare the testing phase results with,
- setting a clearer A3AO scope to prevent confusion among stakeholders.



Figure 7. Proposed main project phases

6 Conclusion

It can be concluded that the description of an SoS by means of A3AO's is certainly possible, and has many benefits within a company. Although several adaptations are made to the A3AO tool, the base of the approach remains the same. The SoS-level A3AO was received very positively during the case study, and led to further implementation of both the system-level and the original A3AO tool within Thales.

The main difference of the high-level A3AO compared to conventional overviews is that there are more stakeholders involved, which requires more user interaction stages for the creation. Other changes following from the research are found in the content of the A3AO. The high level leads to more generic models or to the splitting up of models. Furthermore, operational models describing the interaction of the system with its context are given.

The approach to creation of high-level A3AO's defined in Figure 7 is advised as it allows for input from many different stakeholders to be gathered. Parallel to these activities, system-specific activities can be undertaken to enhance the quality of the A3AO. Future work to be done includes the creation of SoS-level A3AO's at a company outside the defense industry, to further validate the results of this project.

References

- Alvarez Cabrera, A.A. et al., 2011. Modeling and Using Product Development Architectures in Industrial Mechatronic Product Development: Experiments and Observations. In *Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*. Washington DC, USA, 2011. ASME.
- Bonnema, G.M., 2011. Insight, innovation, and the big picture in system design. *Systems Engineering*, 14(3), pp.223-38.
- Bonnema, G.M., Borches, P.D., Kauw-A-Tjoe, R.G. & van Houten, F.J.A.M., 2010. Communication: Key Factor in Multidisciplinary System Design. Hoboken, NJ, 2010. 8th Conference on Systems Engineering Research.
- Borches Juzgado, P.D., 2010. *A3 Architecture Overviews: A Tool for Effective Communication in Product Evolution*. PhD Thesis. Enschede, The Netherlands: Woermann Print Service University of Twente.
- Colombi, J., 2012. (Moderator) Panel discussion: SoS Engineering and Architecture. St. Louis, Missouri, USA: Missouri S&T Conference on Systems Engineering Research 2012.
- Davis, G., 2010. *Design Council - Ergonomics by Gary Davis*. [Online] Available at: www.creative-net.co.uk/About-Design/Design-Techniques/Ergonomics-by-Gary-Davis/Glossary [Accessed 08 March 2012].
- Geerink, B.G.H., 2007. *System architecture description of the TACTICOS Combat Management System based on DoDAF*. Thales Internal Doc. Hengelo: Thales Nederland B.V.
- Hilliard, R., Maier, M. & Emery, D., 2007. *All About IEEE Std 1471*. [Online] Available at: <http://www.iso-architecture.org/ieee-1471/docs/all-about-ieee-1471.pdf> [Accessed April 2012].
- ISO/IEC/IEEE, 2011. *42010:2011 - Systems and software engineering -- Architecture description*. ISO Standard. ISO.
- Maier, M.W. & Rechtin, E., 2000. *The Art of Systems Architecting*. 2nd ed. CRC Press.
- Muller, H.A., 1996. Understanding software systems using reverse engineering technologies research and practice. In *Tutorial 18th ICSE*. Berlin, 1996.
- Ncube, C., 2011. On the Engineering of Systems of Systems: key challenges for the requirements engineering community. In *Requirements Engineering for Systems, Services and Systems-of-Systems (RESS) Workshop*. Trento, Italy, 2011.
- Nielsen, J., 1993. Iterative User Interface Design. *IEEE Computer*, 26(11), pp.32-41.
- Oppenheim, A.N., 2000. *Questionnaire design, interviewing and attitude measurement*. 2nd ed. New York: Continuum International Publishing Group.
- Potts, C., 1993. Software Engineering Research Revisited. *IEEE Software*, 10(5), pp.19-28.
- Rebovich Jr., G., 2008. The Evolution of Systems Engineering. In *SysCon 2008 - IEEE International Systems Conference*. Montreal, Canada, 2008.
- Thales, 2012. *120112 One Page TACTICOS*. Hengelo: Thales Nederland B.V.
- US Department of Defense, 2008. *DoDAF Product Development Questionnaire Analysis Report and New Product Recommendations Report Version 4*. Arlington, Va.
- US Department of Defense, 2010. *DoD Architecture Framework Version 2.02*. [Online] Available at: <http://cio-nii.defense.gov/sites/dodaf20/> [Accessed 8 February 2012].