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The Engaporean Air-Defence Upgrade: A Framework for a Case Study development project

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Abstract. Case studies have been shown to be a very effective way of learning, however the few case studies available in the systems engineering literature document the 'what' of the situation and fail to provide the 'why'; the insight into the reason for the decisions. This lack of the 'why' is an undesirable situation because students will potentially be in similar situations in their futures and need to understand the reasons behind the decisions so they can make their own informed decisions. This paper addresses that gap and instead of providing yet another case study, it provides a framework or architecture for a case in which students can perform the activities and develop an understanding of not only the 'what's but the 'why's as well providing a broad overview with plenty of scope for discussion and exercises in each phase of the system development lifecycle (SDLC). The bulk of this paper sets out the timeline for, and provides a high level description of, the Air-Defence system upgrade process in the fictitious nation of Engaporia. The last section of the paper points out some of the extension opportunities currently planned as well as proving a number of discussion points and exercises.

Overview

The first part of this paper provides a quick summary of case studies, the two types of case studies and the holistic thinking perspectives (HTP) (Kasser, 2013) to facilitate understanding their use. The bulk of this paper sets out the timeline for, and provides a high level description of, the Engaporean Air-Defence upgrade process using the HTPs. The last section of the paper points out some of the extension opportunities currently planned as well as providing a number of discussion points and exercises. Table 1 contains a list of acronyms to assist the reader.

Case studies

The purpose of a teaching case study is to establish a framework for discussion and debate among students (Yin, 2009) page 4). Case studies have been shown to be a very effective way of learning (Mauffette-Leenders, et al., 2007). There are two types of case studies:

1. **Documentation:** documenting what happened in a project or situation which allows the students to discuss the events and perhaps what should have been done differently. The students read the material and then analyse and comment on the situation.
2. **Role playing:** in which the student role role-plays the decision maker.

Both types of case studies can be used in classes. For example, classes in:

- **Engineering and project management**: the students role-play managing a project while various events happen that affect cost, schedule and resources.

- **Systems engineering:** the students review seven US Air Force Institute of Technology (AFIT) case studies, pick one of them and write a report analysing and commenting on the differences between the concepts learned in class and the description of what actually happened in the case study.

However, a major problem with the both types of case studies is that students spend more time trying to understand the situation described in the case than actually learning the lessons from the case. This undesirable situation can be remedied by using a cross-class case where different aspects of the case are studied in different classes. For example, the student enrolment and course tracking system (SECTS) Meta-project at University of Maryland University College (UMUC) was a scenario where Hypothetical University (HU) not UMUC was experiencing problems with the SECTS used to enrol students and track their courses (Kasser and Williams, 1999). The focus of each class was as follows:

- System and Software Requirements (CSMN 645) – developed the system and software requirements for the SECTS.
- Software Development and CASE Tools (CSMN 646) - designed the SECTS architecture based on the requirements provided by CSMN 645.
- Software Verification and Validation (CSMN 647) - verified the requirements for the SECTS and developed a Test Plan for validating the design.
- Software Maintenance (CSMN 648) - examined the SECTS from the maintenance and change control perspective.

The use of the same scenario in multiple classes eliminated the scenario learning curve in the subsequent classes.

Table 1 Acronyms

ACM	Active countermeasures
BPR	Business Process Reengineering
C4ISR	Command, control, communications, computers, intelligence, surveillance, and reconnaissance
CDR	Critical Design Review
CONOPS	Concepts of operation
DSTD	Defence Systems and Technology Department
ECDA	Engaporean Capability Development Agency
ECP	Engineering change process
EDF	Engaporean Defence Force
FASE	Federated Aerospace of Engaporia
FCFDS	Feasible conceptual future desired situation
HEADS	Holistic Engaporean Air Defence System
LAMP	Lighter than air missile platforms
MVA	Multi-attribute variable analysis
OCR	Operations Concept Review
OTSC	Off-the-shelf components
PDR	Preliminary Design Review
RAF	Royal Air Force
RAFBADS	RAF Battle of Britain Air Defence System
RFT	Request for Tender
SAM	Surface-to-air missile
SDLC	System development lifecycle
SEP	Systems Engineering Plan
SEMP	Systems Engineering Management Plan
SRD	System Requirements Document
SRR	System Requirements Review
TEMP	Test and Evaluation Master Plan

Documentation case studies

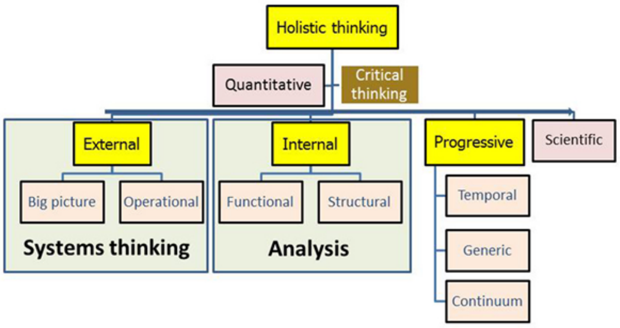

Figure 1 Holistic thinking perspectives (Structural view)

Most of the few systems engineering case studies in the literature including those available from the AFIT web site studies are of the documentation type. These case studies, as written, generally focus on the 'what' and the 'how' and so do not allow students to develop an understanding of 'why' the various decisions were made; the insight into the reason for the decisions. This lack of the 'why' is an undesirable situation because the focus of the case study should be on answering the 'how' and 'why' questions (Yin, 2009) presumably since students will potentially be in similar situations in their futures and need to understand the reasons behind the decisions in the case studies so they can make their own informed decisions. An early attempt to address this deficiency produced the LuZ solar electrical power generating system (SEGS-1) case study (Kasser, 2008) which provided some details of why design decisions were made, yet much of the information was specific to the case and generalizing it to different situations is difficult.

Role-playing case studies

The Engaporean Air-Defence upgrade framework presented herein is a role-playing case study[1]. However, as written, instead of providing a yet another case study, it provides a basis for an expandable case study in which students can perform (role play) the activities and develop an understanding of not only the 'what's but the 'why's as well by providing a broad overview with plenty of scope for discussion and exercises in each phase of the SDLC. As a framework, the reference scenario is that of a successful project. Where things can go wrong provides plenty of scope for the author or other teachers to develop scenarios in the same context to reinforce specific learning points. The Engaporean scenario was first chosen in 2007 to develop an integrated transportation system for the nation of Engaporia (Kasser, et al., 2008)[2]. The scenario was chosen because the bulk of systems engineering is moving away from "top-down" development of brand new systems to the "middle-out" development of systems that have to be interoperable with existing systems (Long and Scott, 2011) page 14).

The Holistic Thinking Perspectives

This section introduces a set of viewpoints on the perspective perimeter called holistic thinking perspectives (HTP) which can be used to provide anchor points for thinking and communicating in a systemic and systematic manner (Kasser, 2013). These viewpoints go beyond combining analysis (internal views) and systems thinking (external views) by adding quantitative and progressive (temporal, generic and continuum) viewpoints. The nine HTP anchor or viewpoints shown in Figure 1 are:

External perspectives: The External perspectives are:

1. ***Big Picture:*** the context for the system.

[1] It is similar to fiction anthologies where multiple authors write stories set in the same conceptual context.

[2] A fictitious setting minimizes the emotional aspects incurrent in discussing real-world scenarios since there is no blame to be allocated and the fictitious sponsoring organization can be at fault.

2. ***Operational:*** what the system does.

Internal perspectives: The Internal perspectives are:

3. ***Functional:*** what the system does and how it does it.
4. ***Structural:*** how it is constructed and organised.

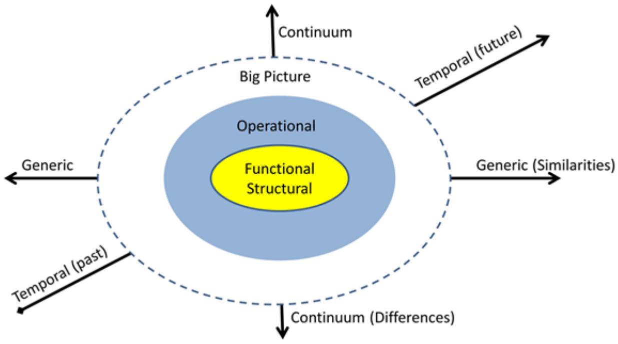

Figure 2 Holistic thinking perspectives

Progressive perspectives: The Functional and Structural perspectives provide internal views, the Big Picture and Operational perspective provide external views. The progressive perspectives are where holistic thinking begins to go beyond analysis and systems thinking and are orthogonal to the internal and external perspectives as shown in Figure 2. The progressive perspectives are:

5. ***Generic***: where the system is perceived as an instance of a class of similar systems.
6. ***Continuum:*** where the system is perceived as but one of many alternatives.
7. ***Temporal:*** which considers the past, present and future of the system.

Other perspectives: The other perspectives are:

8. ***Quantitative:*** the numeric and other quantitative information associated with the system.
9. ***Scientific:*** the hypothesis or guess about the issues

The Engaporean air-defence upgrade

Consider the Engaporean air-defence upgrade project from the HTPs as follows.

Big picture perspective

Once upon a time, in 2003 the (fictitious) nation of Engaporia (Kasser, 2009) discovered a large quantity of off-shore oil reserves and the government at the time felt that its then current air-defence capability might not have had the capability to protect itself from its belligerent northern neighbour. Engaporia is an old British colony, with a stable democratic government, and a small population. It is a non-aligned, mostly ignored member of the UN. It is located between sea and mountains as shown in the map in Figure 3. Other details are:

- A Mediterranean climate; the coastal plain having warm summers and mild winters.
- A mining and farming economy.
- A strategic port location, the Royal Navy used it as a naval base.
- The population is concentrated in Engaporium city.
- The government has recognised that the population is growing to the point where there will be an unemployment problem in near future.
- Impassable mountains to north which are snow covered in winter.
- A disputed border with the northern belligerent neighbour.
- Unnavigable (into the hinterland)

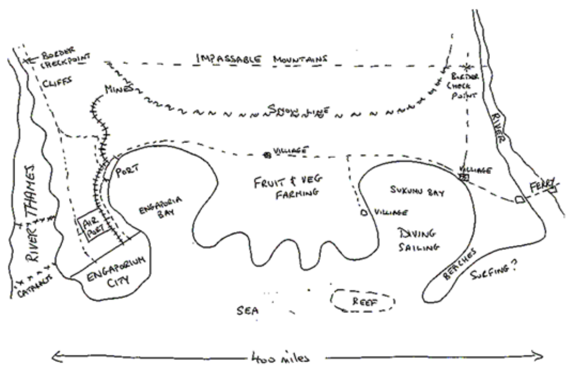

Figure 3 Engaporia

rivers to east and west, although there is a ferry across the western river boundary.
- Friendly borders with eastern and western neighbours.

The government tasked the Engaporean Capability Development Agency (ECDA) to deal with the issue. ECDA manages the state of the entire Engaporean defence system in the context shown in Figure 4.

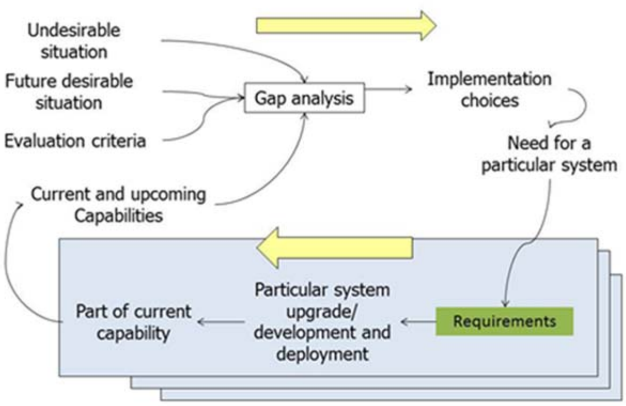

Figure 4 DSTD context loop

Operational perspective

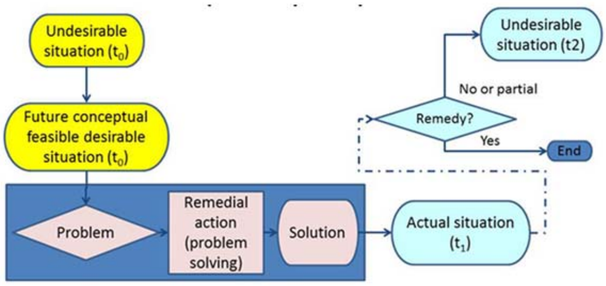

Figure 5 Holistic approach to managing problems and solutions

ECDA employs the Holistic approach to managing problems and solutions shown in Figure 5. Unlike the traditional problem-solving process which begins with a problem and ends with a solution, the holistic approach takes a wider perspective and begins with an undesirable situation which has to be converted to a feasible conceptual future desired situation (FCFDS) (Kasser, 2013). From this perspective, the observer becomes aware of an undesirable situation that is made up of a number of related factors. A project is authorized to do something about the undesirable situation. The systems engineer (problem solver) tries to understand the situation beginning by analysing the operation of the current system and using domain knowledge to identify the deficiencies that make the situation undesirable. The systems engineer then creates a vision of a FCFDS.

The problem then becomes to determine the way to move from the undesirable situation to the FCFDS. Once the problem is identified, the remedial action is taken to create the solution system which will operate in the context of the FCFDS. This remedial action takes the form of an SDLC for the solution system that will be operational in the context of the FCFDS. Once realized, the solution system is tested in operation[3] in the actual situation existing at time t_1 to determine if it remedies the undesirable situation. However, since the remedial action take time, the desirable situation may change from that at t_0 to a new undesirable situation existing at t_2. If the undesirable situation is remedied, then the process ends; if not the process iterates from the undesirable situation at t_2. In summary, in general:

- There is an undesirable or problematic situation.
- A FCFDS is created.
- The problem is how to transition from the undesirable situation to the FCFDS.
- The solution is made up of two parts: (1) the transition process created by process architects and (2) the solution system operating in the context of the FCFDS. Managing the transition process is often known as systems engineering management (which tends to overlap with project management), while the solution system is developed by engineers.

[3] Operational Test and Evaluation.

Functional perspective

The functional perspective provides details of the processes involved in the upgrade[4]. The basic process is represented by the problem-remedial-action-solution box shown in Figure 5 which contains the process for tackling a problem shown in Figure 6 based on (Hitchins, 2007) page 173). The process contains the following major milestones and tasks:

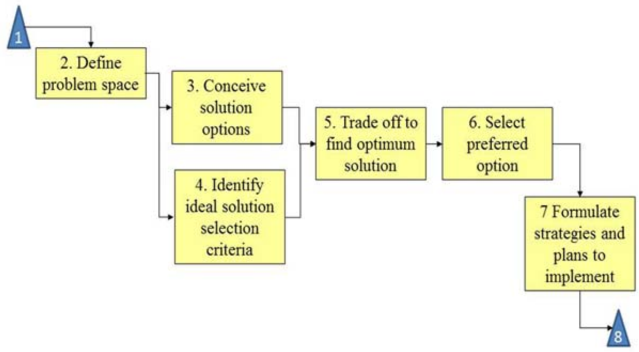

Figure 6 A systems engineering approach to problem solving

1. Milestone to provide authorization to proceed
2. Define the problem.
3. Conceive solution options.
4. Identify ideal solution selection criteria.
5. Perform trade off to find the optimum solution
6. Select the preferred option
7. Formulate strategies and plans to implement the preferred option.
8. Milestone to confirm consensus to proceed with implementation phase.

The process is self-similar mapping into each phase of the Waterfall SDLC since each phase can potentially contain the same sequence of activities.

Temporal perspective

The temporal perspective provides a view of the timeline of the story told in sequence from past to present as described herein. This timeline provides the reference or framework for variations and "what-if" discussions in the classroom.

Early stage systems engineering

ECDA defined their problem as:

1. determining if the then current air-defence system needed upgrading, and if so,
2. initiating a project to perform the upgrade.

ECDA's solution was to assign the task to the Defence Systems and Technology Department (DSTD); the government agency tasked with maintaining national security. DSTD performed a classified feasibility study to determine if the then current air-defence system needed upgrading, and if so, to estimate the scope, costs and development schedule for the upgrade. The feasibility study:

- Summarised the need for defence against the known and estimated threats posed by the unfriendly northern neighbour.
- Identified the then-current operational capability and any additional upcoming capability being acquired or developed.
- Produced a number of scenarios of what threats the upgraded air-defence system would have to counter (Operational perspective).

[4] A functional perspective of HEADS itself would provide a view of the internal functions performed by HEADS. The system under study is the upgrade process; hence the functional view is that of the upgrade process.

- Performed a gap analysis between the capability needed to counter anticipated threats and the then-current operational and upcoming capability taking into account the dates in which the upcoming capability would become operational.
- Showed that:
  1. While parts of the then current system were state-of-the-art, in general, the air-defence system did need upgrading.
  2. There were at least three viable affordable alternative ways to provide the necessary upgrade.
  3. From the generic perspective situation was similar to, and so lessons could be learnt from, the Royal Air Force Battle of Britain Air Defence System (RAFBADS) used in World War II (Bungay, 2000).
- Identified differences between the current situation and the RAFBADS particularly in that while RAFBADS active countermeasures (ACM) were performed by manned fighter aircraft, Engaporia had the option of using surface-to-air-missiles (SAM) as well as aircraft. In addition, the rest of the technology potentially available for use in Engaporia had had 60 years of modernization resulting in greatly expanded functionality.

ECDA reviewed and accepted the results of the study and funded a DSTD project to initiate the SDLC which would develop a new Holistic Engaporean Air Defence System (HEADS) whose mission was defined as detecting and destroying enemy aircraft penetrating Engaporean airspace[5] preferably before they caused any damage to the Engaporean infrastructure. DSTD faced the problem of upgrading the Engaporean air-defence capability from the then current capability to that provided by HEADS without reducing or interfering with the operation of the air-defence system in case a threat occurred before HEADS was fully operational. DSTD performed the early-stage systems engineering following the SDLC A paradigm (Kasser, 2012) beginning with the creation of preliminary concepts of operations (CONOPS) for the following candidate solutions:

1. Lighter than air missile platforms (LAMP).
2. Long range surface to air interception functions (missiles).
3. Manned fighter interceptor functions similar to that used in the RAFBADS.
4. Short range surface to air interception functions (anti-aircraft guns, missiles).
5. A combination of the above.

Each solution was conceptualized as a system containing normal and contingency mission and support functions (Kasser and Hitchins, 2011), where:

- **Mission functions:** two sets; (1) the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) functions to detect enemy aircraft and (2) the ACM functions that would then destroy the enemy aircraft.
- **Support functions:** the necessary functions that would keep HEADS fully operational at all times.

The detection and C4ISR functions performed for all candidate solutions were almost identical. The support functions differed for each candidate due to the nature of the ACM.

Since there was no point in considering a non-feasible candidate, each candidate CONOPS was accompanied by a feasibility study, drilling down into the proposed system to show that there was at least one viable feasible way of physically realizing each candidate. The LAMP option was a conceptual mix of tethered barrage balloons World War II style with

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[5] Engaporia wanted to show that HEADS was purely defensive.

aerial missile platforms supported by Helium filled and hot-air balloons that would remain aloft for long periods of time. However, the accompanying feasibility study determined that while the concept was innovative, it was not feasible at the time, and so the option was dropped.

The solution selection criteria for evaluating the candidates were developed from all of the holistic thinking perspectives after discussions with the stakeholders. The criteria and their importance, on a scale of 0 to 1 where 1 was most important, are shown in Table 2. The DSTD HEADS project team had many separate meetings with the various stakeholders (the Engaporean Defence Force (EDF), the potential realization contractors and local civil government representatives to develop and understand the impact of air attacks on the military and civilian infrastructure). These meetings not only allowed the stakeholders to buy-in on the project but had the added benefit of providing the project team with additional (mostly undocumented and tacit) knowledge in the problem, solution and implementation domains.

Table 2 Section criteria for conceptual options

	Criteria	Importance
1	Technology transfer to domestic industry	1.00
2	Development schedule – preference given to phased implementation	1.00
3	Non-interference with the operational system at any stage in the upgrade process	1.00
4	Local industry involvement	0.95
5	Damage tolerance in action and due to possible pre-attack sabotage	0.95
6	Flexibility for local area defence	0.90
7	Reuse or incorporation of existing capability however obsolescence needed to be taken into account	0.80
8	Interoperable with existing system or subsystems	0.75
9	Lifecycle cost	0.75
10	Self-supportability and maintainability to avoid dependence on foreign contractors once deployed	0.60
11	Complexity – the lower the complexity, the higher the evaluation	0.45

When multi-attribute variable analysis (MVA) was applied, the decision favoured the combination option. It also soon became clear during the numerous discussions with the stakeholders[6] that the realization phase would have to be in four stages and the CONOPS were adjusted accordingly. When this phase of the work was finished the result was presented to the stakeholders in an Operations Concept Review (OCR), in which the following were summarized[7]:

- In the product or system domain
    - The technical, cost and schedule feasibility.
    - Each of the scenarios.
    - The solution selection criteria and their importance.
    - The trade-offs and selection of the optimal solution.
- In the process domain:
    - The acquisition and development strategy.
    - The type of contract (and the reason for the choice) for the realization phases.

At the end of the OCR, the decision to proceed to the acquisition phase was unanimous, so the ECDA authorized the project to proceed.

[6] Who also included potential realization contractors.

[7] The stakeholders were fully cognizant of the facts and the reasons underlying the various choices because of the numerous meetings held before the OCR. Consequently, the purpose of the OCR was to summarize the situation and document the consensus to proceed to the next phase of the project.

The pre-tender phase of the acquisition

The DSTD HEADS project team developed[8]:

- A detailed CONOPS for HEADS covering the normal and anticipated contingency mission and support functions performed by the operational system in the context of its environment (adjacent systems) which became the FCFDS (Operational and Continuum perspectives)[9].
- A summary of the then-current air defence system covering the normal and anticipated contingency mission and support functions based on the inputs to the earlier feasibility study. In the BPR environment this is known as the 'as is' model or view.
- A summary of the gap between the then current situation and the FCFDS ('as is' and 'to be' views).
- A Systems Engineering Plan (SEP) containing a detailed CONOPS expanding the acquisition and development strategy presented at the OCR into a four-stage realization process to implement the strategy to bridge the gap. The problem was to create each of the physical subsystems in such a manner that when all Builds were subsequently integrated, HEADS would perform the mission and support functions according to its specifications without adversely affecting the operation of the air-defence system during the transition period. The contents of the SEP included showing:
    a) what current capability would be integrated into HEADS in each stage,
    b) when that integration would take place,
    c) how HEADS would be realized in a phased manner,
    d) the type of contracts to be used,
    e) where the government-contractor interfaces would be and
    f) what resources would be needed.
- The basic realization strategy which was to use the Cataract Methodology (Kasser, 2002b) summarized in Figure 7 in which:
    - ***Build 0*** would create the HEADS architecture, set up the management and engineering processes and disseminate the detailed transition plan.
    - ***Build 1*** would incorporate some elements of the then-current air-defence system into skeleton HEADS architecture.
    - ***Build 2*** would put flesh into the skeleton with the priority of bridging any gaps.
    - ***Build 3*** would complete the HEADS.

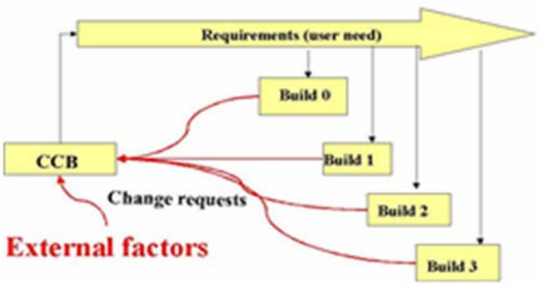

Figure 7 The Cataract Methodology

- More detailed cost and schedule estimates (Quantitative perspective).
- A Request for Tender (RFT) for a local prime contractor multiple-award-task-ordered (MATO) contract, since the strategy was to acquire a system and contribute to building local technological capability to the maximum possible extent.

The documents were studied by the ECDA and approved. The HEADS project then received the go ahead to move to the Tender phase.

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[8] Note that the HEADS project team focused on the transition process as well as the HEADS.

[9] In the Business Process Reengineering (BPR) environment this is known as the 'to be' model or view.

The tender phase of the acquisition

The RFT was issued and four responses were received where each response represented a candidate solution. The responses were evaluated using the same selection criteria as before, namely those shown in Table 2, to select the winning tender. The contract award was made to a consortium led by Federated Aerospace (FA)[10].

SDLC Build 0: Needs and requirements phases

The engineering work in this phase focused on the Big Picture and Operational perspectives of the HEADS. The work was split as follows:

- FA performed the work pertaining to using the Operational perspective to create a matched set of specifications for the functions of the system and the subsystems. The work was performed in two tasks:
  1. FA competed the task of creating a preliminary HEADS architecture based on the CONOPS incorporating appropriate existing EDF physical elements to its subcontractors[11]. Two subcontractors were selected to produce independent architectures.
  2. FA competed the task to identify the solution selection criteria among its subcontractors, precluding the two who were developing the conceptual architectures from tendering for this task. The initial set of solution selection criteria was inherited from those in Table 2.
- The DSTD HEADS project team together with FA and the three subcontractors evaluated the solutions and created an optimal solution by combining aspects from the two independent solutions. The work was performed jointly because the domain knowledge needed for the reuse of existing capability resided in the EDF members of the DSTD project team rather than in FA personnel.
- The DSTD HEADS project team:
  - Performed the feasibility study to ensure that the selected conceptual architectural solution was feasible (affordable and deliverable within the time constraints).
  - Monitored the situation with respect to the unfriendly neighbour in the north to determine if any changes were necessary to the HEADS CONOPS (Big Picture perspective). As it happened, none were necessary.
- FA[12] in consultation with the stakeholders prepared:
  - A feasibility study report.
  - The project plan (PP).
  - A matched set of specifications for the system and its top-level subsystems based on the optimal architectural solution, namely the System Requirements Document (SRD) and the Subsystem Requirements Documents (Operational and Quantitative perspectives).

[10] FA was basically an interface between the government and the consortium. It subcontracted all the work to a consortium of subcontractors both foreign-based and local. Each major task was tendered to the consortium which consisted of both large and small businesses and the local FA division. In addition, FA was known to ECDA and DSTD because they were already developing an integrated transportation system for the nation and their performance had been satisfactory.

[11] The mixture of functional and physical was an imposed real-world constraint.

[12] From this point on, when FA is mentioned, the task was competed and a subcontractor selected to perform the task. Subcontractor selection criteria varied depending on the degree of knowledge to be transferred into Engaporia from the foreign subcontractor.

- The Systems Engineering Management Plan (SEMP).
- The Test and Evaluation Master Plan (TEMP).
- The risk and opportunity management plan identifying process and product risk and opportunities as well as preliminary risk and opportunity management concepts.
- The logistics support plan.
- The rest of the documentation defined in the contract.

The SRR presentations included summaries of these documents. Consensus to proceed was given; the desirable situation was achieved and the ECDA authorized the project to continue to the preliminary design phase.

SDLC Build 0 design phase

The work in this phase focused on the Functional and Structural perspectives of the HEADS. The work was split into preliminary and critical design phases.

Build 0 preliminary design phase

FA created:

- Two independent preliminary functional/physical HEADS architecture designs incorporating appropriate existing EDF physical elements using the Functional and Structural perspectives.
- The selection criteria for selecting the preliminary and detailed designs.
- Updated versions of previously produced documents (i.e. CONOPS, PP, SEMP, TEMP etc.). The detailed PP described how each subsystem would evolve through the Builds and be managed including how its change control board (CCB) would operate. The PP defined a HEADS CCB that would be the strategic CCB for the entire project (Kasser, 2002a) as illustrated in Figure 8. Figure 8 shows a number of subsystems evolving though Builds over time, where changes within a subsystem are controlled by the subsystem CCB while system-wide changes are controlled by the Strategic CCB.

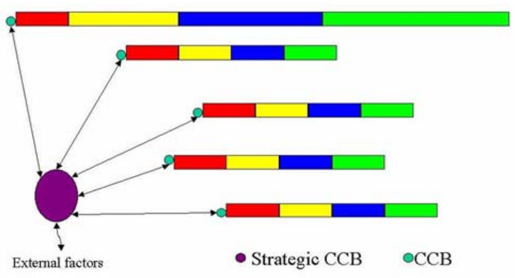

Figure 8 HEADS subsystem evolution and control

The DSTD HEADS project team together with FA used the Structural, Functional, Continuum and Generic perspectives[13] to evaluate the preliminary physical architecture solutions and create an optimal preliminary physical architecture by combining aspects from the two independent solutions.

The DSTD HEADS project team:

- Performed an independent feasibility study on the optimal preliminary physical solution which showed that the optimal preliminary solution was feasible.
- Updated the PP to take into account minor changes in the schedule as a result of findings from the feasibility study.

The work performed during the preliminary design phase was summarized at the Preliminary Design Review (PDR), consensus to proceed was achieved and ECDA authorized the

[13] The Structural perspective provided the architecture. The Generic and Continuum perspectives provided the concepts for evaluating the response of the architecture to failures and other abnormal modes of operation.

project to continue to the detailed design phase.

Build 0 detailed design phase

FA created:

- Updated versions of previously produced documents (i.e. CONOPS, PP, SEMP, TEMP etc.).
- Two independent detailed physical HEADS architecture designs based on variations of the optimal preliminary design (Functional and Structural perspectives). Each architecture design contained a different mixture of SAM, fighter aircraft squadron, and anti-aircraft gun subsystems together with their appropriate supporting subsystems.
- The draft system and subsystem test plans for verifying that each Build of HEADS would be compliant to requirements pertaining to the build.

The DSTD HEADS project team together with FA evaluated the detailed physical architecture solutions and created an optimal detailed physical architecture by combining aspects from the two independent solutions.

The DSTD HEADS project team:

- Performed an independent feasibility study on the optimal preliminary physical solution.
- Updated the PP information to take into account minor changes in the schedule as a result of findings from the feasibility study.
- Monitored the situation with respect to the unfriendly neighbour in the north to determine if any changes were necessary to the HEADS CONOPS (Big Picture and Operational perspectives). As it happened, a few did show up but they were minor and were accommodated within the scope of the proposed system via the engineering change process (ECP).

The work during the detailed design phase was summarized at the Critical Design Review (CDR), consensus to proceed was achieved and ECDA authorized the project to continue to the construction phase.

SDLC Build 0 construction phase

Each physical subsystem became a project in itself, and went through its own SDLC with its own milestone reviews. HEADS systems engineers coordinated with the physical subsystem system engineers to manage unanticipated emergent properties and other factors that impacted the system. The engineering work in the construction phase was split between the DSTD HEADS project team and FA as follows:

- FA performed the work pertaining to constructing the solution system including the building and procurement tasks because some components were to be built and some were to be purchased from local and foreign vendors.
- The DSTD HEADS project team monitored the situation with respect to the unfriendly neighbour in the north to determine if any changes were necessary in the HEADS.

SDLC Build 0 subsystem testing phase

As each subsystem was constructed to the Build 0 specifications, it was validated as a standalone subsystem. Where and when elements of adjacent subsystems were not available they were simulated by documented calibrated test equipment. The documented calibrated test equipment was then incorporated into the system for use later in the SDLC. Once a Build of a subsystem was approved as being validated, it was turned over to the HEADS systems engineers for integration into HEADS at an appropriate time in an appropriate manner so as to not impact the operation of the then-current air-defence system.

SDLC Build 0 systems integration and testing phase

Build 0 provided both product and process capability as follows:

- **Product:** Build 0 laid out the HEADS architecture with enough communications capability to confirm that the concept was feasible.
- **Process:** DSTD and FA used Build 0 to set up and validate the multi-contractor management, engineering and change control processes.

SDLC Build 0 operations phase

Build 0 went into its operations phase when the architecture was validated. As new capability was developed, and integrated, the system was upgraded to the pre-planned Build 1, Build 2 and so on using transition plans evolving from the PP.

SDLC Subsequent Builds

From a theoretical text-book perspective, the SDLC for the subsequent Builds followed the traditional waterfall sequence. The activities in each phase of the SDLC for Build revised the products produced for the previous Build and updated the processes, took into account the intelligence provided on the threat posed by the northern neighbour, and created the appropriate versions for the Build. The change control system was designed to manage change by being able to assess the impact of a proposed change on each subsystem, the adjacent subsystem and HEADS as a whole. In particular:

- The undesirable situation for the Build was the state of HEADS at the time the Build began.
- The FCFDS for the Build was expressed in a CONOPS using the functionality originally allocated to the Build together with all approved changes since that time.
- The solution to achieving the FCFDS was to use one waterfall cataract to realize the build such that:

    1. The requirements phase of the Build focused on the interface requirements between the subsystems and the specifications for the purchase of COTS subsystems.
    2. The realization, unit test and integration phases of the Build focused on the individual subsystems.
    3. The system integration and test phase of the Build integrated the subsystems of the subsystem into the upgraded subsystem.
    4. Once each upgraded subsystem had been validated it was integrated into the HEADS in a manner that minimally impacted the operation of the system.

Variations on a theme: opportunities for class exercises

From a practical perspective, things did not go according to plan. Build 0 had laid out the framework for both the operational HEADS and the realization process using the Cataract Methodology for subsequent Builds. However it soon became apparent that the Builds for the subsystems were stretching out and were in danger of losing synchronization with each other. Design and construction of airfields, missile sites, communications facilities all had different problems; some equipment was ready early, some was ready late. Vendors made changes in COTS that had to be investigated. Requests for change came from internal and external stakeholders. Each change request had to be investigated and accepted or rejected. Accepted change requests were allocated to the appropriate Build depending on the urgency and nature of the impact of the change on the process or the system. After a while, there was no clear distinction between the various Builds, because as time went by, while the communications links of the C4ISR subsystem were generally implemented according to the schedule, civil construction and delivery of equipment from overseas tended to be late. The procurement officers in the subsystems were sometimes able to compensate and even order supplies from alternative vendors who could deliver ahead of schedule. Project managers and senior systems engineers used PERT to keep track of dependencies, identify and compensate for risks and take advantage of opportunities provided by early deliveries.

Somewhere in the middle of the third Build, intelligence reports were received that the unfriendly neighbour was in the process of acquiring a number of surface-to-surface missiles with sufficient range to reach any ground location in Engaporia. The impact of that intelligence was such that a fifth Build had to be added at additional cost to provide the capability needed to deal with that threat.

Discussion and expansion points

This case provides a broad overview with plenty of scope for extension, discussion and exercises in each phase of the SDLC especially using the variations on a theme. Here are some examples to be developed:

1. Discuss the "why's", namely the reasons for the "what's" discussed in this case.
2. Design the conceptual alternatives including the LAMP approach.
3. Reverse engineer the importance of the solution selection criteria shown in Table 2 to identify the contents of the appropriate Engaporean government policies to show the things the government is concerned about and the things it is not? One example is the importance of technology transfer to local industry.
4. Discuss the SDLC described in this case and map it into those discussed in the systems engineering literature.
5. Identify and display the changes from functional to physical, or "what's" and "how's" through the SDLC?
6. Discuss the differences between the SDLC and the "system engineering process"?
7. Develop the CONOPS for the FCFDS?
8. Define the architecture for HEADS.
9. Develop the DODAF for the HEADS.
10. Develop sub-cases based on sensors, C4ISR and other elements of the system.
11. Develop and discuss aspects of survivability and robustness of the HEADS.
12. Develop and discuss aspects of risks and opportunities in the HEADS SDLC.
13. Discuss the impact the fifth Build on the project.
14. Identify the roles of systems engineers and project managers and discuss where and why they overlap.

Typical classroom scenario

As an example of how the HEADS framework could be used in a class on (systems engineering) project management consider the following introduction to a class exercise.

Context

The class exercise is set in the fictitious FA which has won the contract to implement the HEADS. The class exercise is to develop a SEMP for the HEADS in an incremental manner. Each team will perform project management on the same project to allow students to compare their project management with that of other teams. To make the simulation interesting, there will be instructor provided differences between the teams, and a number of different unforeseen events will occur in the second half of the class.

Scope of effort

The scope of effort is determined by the number of people in the team and the number of hours students are expected to invest in the class. Within this constraint, presentations are expected to contain a representative sample of information showing that the knowledge acquired during a session has indeed been applied to the HEADS.

Starting in Session 3[14], student teams will prepare and present sections of a PP for the HEADS in the following session. The weekly presentation will be the section of the PP based on knowledge learnt in the previous session as specified by the exercise in that session together with any upgraded/corrected sections from the previous session. The weekly presentations from Session 3 to Session 7 should be considered practice for the SEMP SRR presentation to be presented in Session 8 in which the SEMP is presented in its entirety[15]. Feedback comments and ideas from other team presentations that would improve your presentation should be incorporated into your presentation.

Space precludes further discussion of this and other exercises. However instructor guides for the use of this case study may be available on request.

Summary

This paper introduced two types of case studies, and then provided a framework, platform or architecture for an expandable role-playing case in which students can perform the activities and develop an understanding of not only the 'what's but the 'why's as well providing a broad overview with plenty of scope for discussion and exercises in each phase of the SDLC. The bulk of this paper set out the timeline for, and provided a high level description of, the Engaporean Air-Defence upgrade process. The last section of the paper pointed out some of the extension opportunities currently planned as well as proving a number of discussion points and exercises.

Biography

Joseph Kasser has been a practicing systems engineer for more than 40 years and an academic for about 16 years. He is a Fellow of the Institution of Engineering and Technology (IET), an INCOSE Fellow, the author of *"Holistic thinking: creating innovative solutions to complex problems"*, *"A Framework for Understanding Systems Engineering*" 2nd edition and "*Applying Total Quality Management to Systems Engineering"*, and many INCOSE symposia papers. He is a recipient of NASA's Manned Space Flight Awareness Award (Silver Snoopy) for quality and technical excellence for performing and directing systems engineering and other awards. He holds a Doctor of Science in Engineering Management from The George Washington University. He is a Certified Manager and holds a Certified Membership of the Association for Learning Technology. He also started and served as the inaugural president of INCOSE Australia and served as a Region VI Representative to the INCOSE Member Board. He has performed and directed systems engineering in the UK, USA, Israel and Australia. He gave up his positions as a Deputy Director and DSTO Associate Research Professor at the Systems Engineering and Evaluation Centre at the University of South Australia

[14] Out of 14 sessions.

[15] Within the time constraints.

in early 2007 to move to the UK to develop the world's first immersion course in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is currently a Visiting Associate Professor at the National University of Singapore.

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