Systems engineering exercises and teaching materials

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1.5	2013-02-21	New contact person; new logo	Stefan Hallerstede

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Introduction

This booklet has been prepared to as part of the Systems Engineering course at Aarhus University School of Engineering (ASE). The booklet is a result of a collection of exercises and training materials with the purpose of aiding the learning process of the course.

Since 2010 systems engineering has been a mandatory graduate course for the students of the information and communications technology (ICT) program. The course is based on current methods, best practices and standards in systems engineering as defined by the The International Council on Systems Engineering (INCOSE) organization [1].

Learning objectives

Upon the completion of the course the students should be able to:

- Analyze the overall concepts which are characteristic of a systems approach to engineering and to organize concepts into a generic systems engineering framework.
- Analyze the overall process elements, and their relationships, which collectively constitute the methodology of systems engineering.
- Explain the different roles involved in product life-cycle stages and discuss the roles of the customer, acquirers (internal and external) and suppliers (internal and external) within this framework.
- Analyze and discuss customers and users' needs and requirements.
- Perform the basics of important techniques of system requirements analysis, evaluation of solution alternatives and system design iteration including their subsequent validation and verification.
- Sketch plans for development of systems.
- Implement principles and techniques of engineering management in a development project context.
- Explain and present proposed engineering solutions and methods in a clear and concise way.

Learning philosophy

The course intends to align with the practices and learning philosophy of the Seraswati project as outlined by Kasser *et al.* [2]. While it still uses a lecture-centric format, the course aims to gradually transform into an activity based learning format. As such, the focus of the course is on 'practice by doing' in the form of team exercises, and 'teaching others' in the presentations made by the students.

The purpose of the practical aspects of the course can be summarized as follows (from [2]):

- to practice systems engineering, and problem solving,
- to understand the scope of multidisciplinary and interdisciplinary engineering,
- to enable the student to grow intellectually and deal with ambiguity and complexity,
- to learn about systems engineering by doing systems engineering, and
- to understand the need for the various competences, skills and knowledge and to develop them.

Organization of the booklet

This booklet is organized into three main parts. The first part is a collection of exercises divided into the main course topics. The second part contains descriptions of the case work. Finally, the third part is a collection of document templates that may be useful for the practical aspects of the course.

Acknowledgment

Sincere thanks are given to the contributors of the case work and exercises. In particular, I would like thank Tommy Vestergaard, Mikkel Vestergaard Hansen and Morten Høyer from Terma for their help to kick-start the course and for the development of one of the first case studies. I would like to thank Mikkel Michelsen from Systematic for his inspiration to the exercise on user interaction design and to Anders Jacob Truelsen, also from Systematic, for support with the Systematic case. Furthermore, I would like to thank my colleague Finn Overgaard Hansen for his contribution to exercises and material related to SysML and the healthcare application domain.

Part I

Exercises

Chapter 1

Concept and project definition

Exercise 1.1 Screw-nut-and-washer system

The screw-nut-and-washer systems is a common sub-system in many constructional, mechanical, household systems etc. Figure 1.1 shows a picture of a screw-nut-washer system consisting of three parts.

Figure 1.1: Hexagon screw-nut-and-washer set.

a) What are the requirements of the systems?

Use cases can play a role when analyzing the functional requirements of a system and a use cases can be considered as a refinement of functional requirements. Standards can be found throughout our daily lives. Standards provide the foundation for many of the engineering systems.

b) Describe the impact of standards on your list of requirements for the screw-nut-and-washer system?

c) Decompose the system and present it in a logical structure. Provide project-unique identifiers for its parts.

Exercise 1.2 The body area network

The aging population in many countries and the rising costs of healthcare services have triggered the introduction of novel technology-driven enhancements to current healthcare services. Recent advances in electronics have enabled the development of tiny and intelligent medical sensors which can be worn on or implanted in the human body. These sensors need to send data to an external medical server where it can be stored and analyzed by professionals. Wireless communication can beneficially be used for this communication.

Figure 1.2a illustrates a wireless body area network (WBAN) for medical applications. One such application is the patient monitoring. Figure 1.2b shows how the WBAN connects to the medical servers via the Internet. The wearable sensors communicate

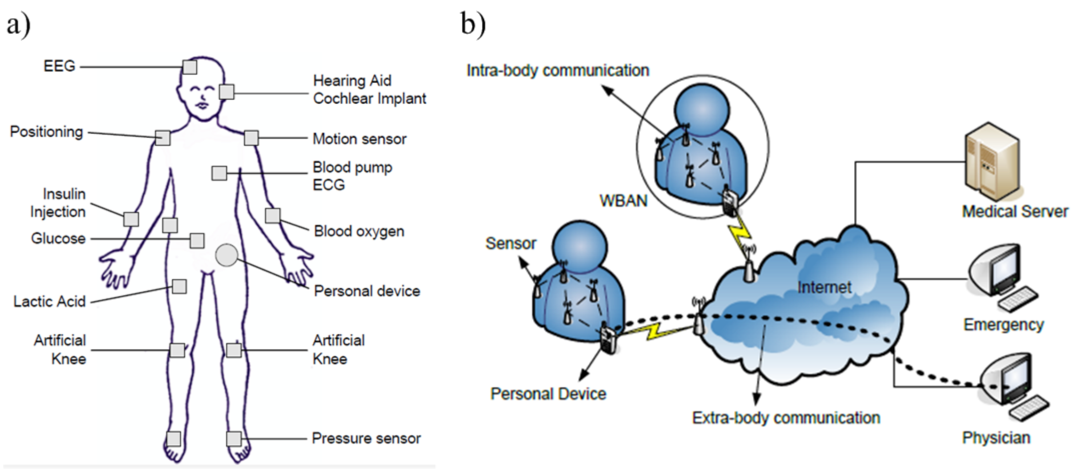

Figure 1.2: Body area network for home healthcare applications.

with the personal device. The personal device aggregates data and communicates with the external medical server or directly with the work stations of the relevant professional e.g., the physician.

Our system-of-interest is the WBAN which is a part of a larger healthcare service system of systems.

a) Describe the healthcare service system-of-system, e.g., by using a diagram or similar, and show how the WBAN is one of a multitude of perceivable systems in such healthcare service system of systems.

b) What are the stakeholders of the WBAN? Explain why and how they could influence on the system design.

A number of factors constrain the BAN. Individual devices use small form factor, have limited battery power and must run energy-efficiently for long-lasting operation. All devices are equally important. There is a significant attenuation of radio waves in a lossy medium such as the human body. Data in the network must be delivered with a high degree of reliability. Stringent security and privacy mechanisms must be applied to ensure confidentiality. Furthermore, the BAN must be simple to operate.

c) Invent and describe one or more use cases for the system.

d) What are the requirements for the WBAN system? (Give examples for textural requirements).

Exercise 1.3 Super high speed train

The INCOSE handbook describes a case of the superhigh speed Train in China (pp. 49-51) [1]. The transportation system is based on magnetic levitation. The train levitates above a steel rail while electromagnets, attached to the train.

Instead of wheels the train, the so-called maglev train, uses electromagnetism to lift and control the movement of the train. The movement of the train is controlled by the frequency, intensity, and direction of the electrical current in the track called the guideway (see Figure 1.3).

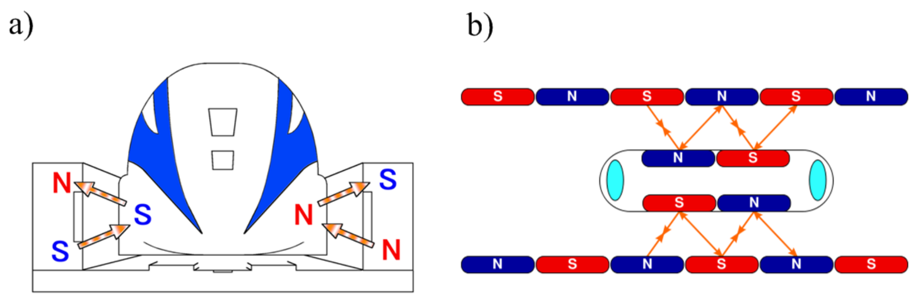

Figure 1.3: Principle of magnetic propulsion for maglev train.

Suppose that you have been asked to run a project for the development of the embedded control software used in the build-in electric motor that makes the an electromagnetic field that pulls the train along the track.

a) Give an estimate of the cost distribution in percentages of the following parts of the project:

1. Project definition
2. System and detailed design
3. Implementation
4. Integration
5. Test and verification
6. Support

and explain your answers.

b) Give some examples of different types of requirements.

c) Give some examples of different types of verification methods.

A contract contains a requirement specification with several hundred items. Beside your own company you need several sub-suppliers to build the system.

d) Describe how you make sure all requirements are fulfilled.

e) List the most essential competencies needed in the project.

Environmental impact analyze is briefly introduced in Section 9.4 of the INCOSE handbook [1].

f) What are the potential harmful effects of a maglev train system development, construction, use, and disposal?

Exercise 1.4 Requirement management database

INCOSE handbook (p. 63) describes the Requirement Database tool for managing requirements of systems.

a) List the relevant data elements of a requirement management database taking into consideration process of systems engineering.

b) Suppose we will construct such relational database with requirements sketch how should this database be designed?

Suppose we want to source in a database from a tool vendor.

c) Give examples of requirements on the database tool that we should ask the tool vendor to respond to?

Exercise 1.5 Systems engineering planning

Your company has asked you to join a newly started project with the objective of creating a large, complex system. One of your first assignments in the systems engineering team is to draft the Systems Engineering Plan (SEMP).

a) What is the purpose of the SEMP? When in the life-cycle should it be developed? How does it relate to each of following: *i*) the project plan, *ii*) the configuration management strategy, *iii*) the verification strategy, and *iv*) the supplier strategy.

The planning and control of large-scale projects may be accomplished by using an *activity network diagram* as the planning and control medium (cf. Ref. [6], Sec. 11.5). Such network portray the interrelationships among the *activities* and *events* and it is used in connection with the program/project preparations. An event is represented by a circle. It

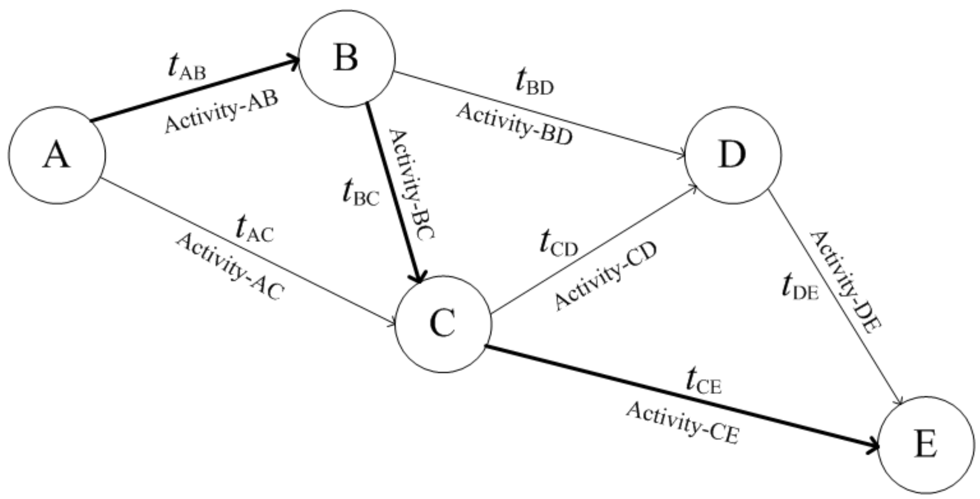

Figure 1.4: Example of an activity network diagram with 5 activities and 6 tasks. The critical path in the network is indicated by thick solid arrows.

indicates the completion of an activity. Activities are represented by arrows (or vectors) that interconnect events. Arrows symbolize the effort required to complete an event, i.e., the length of the arrow. Effort is measured in units of time e.g., days, weeks, or months. The direction of an arrow denote the sequence of activities, i.e., the interdependencies between activities.

b) Assume that you have been assigned to develop a SEMP for a system of your choice. Describe briefly the purpose of the system? Identify and describe the functions/tasks that need to be accomplished in the program.

A *critical path* is the sequence of project network activities which add up to the longest overall duration.

c) Identify the critical path for the activity network diagram constructed in b). What is the relationship between the parameters t_{NM}, where $\{N, M\} \in \{\mathrm{A, B, C, D, E}\}$ for the critical path shown in Figure 1.4? How would the answer be influenced if activity AC was not needed and hence cancelled?

d) For the network in b), develop a cost projection that relates the cost to each scheduled activity. For each cost element, estimate a optimistic t_a, a most likely t_b, and a pessimistic t_c of the cost parameters.

e) In the evaluation of program status in b), you discover that an activity along the critical path in your diagram that is behind schedule. What steps would you take to correct the situation?

Assume that we can define the time varible t as a random variable with a log-normal distribution (cf. Table 1.1) and approximate the mean value t_e and variance σ^2 by:

$$t_e = \frac{t_a + 4t_b + t_c}{6} \qquad \text{and} \qquad \sigma^2 = \left(\frac{t_c - t_a}{6}\right)^2 \tag{1.1}$$

Support	$x \in [0; \infty]$
Probability density function	$\frac{1}{x\sqrt{2\pi\sigma^2}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$
Cumlative distribution function	$\frac{1}{2} + \frac{1}{2}\mathrm{erf}\left(\frac{\ln x - \mu}{\sqrt{2\sigma^2}}\right)$
Mean (or expected)	$e^{\mu + \sigma^2/2}$
Variance	$(e^{\sigma^2} - 1)e^{2\mu + \sigma^2}$

Table 1.1: Mathematical formulas for the log-normal distribution. erf is the Error function.

f) Based on you activity network diagram in b) and your estimations in d) how long duration can you with 90% probability say that you project will take?

Exercise 1.6 Building a SE capability

Assume that you have just been promoted to be manager of a new systems engineering capability in your company.

a) Construct a hypothetical organizational chart for the company from the highest level down to the organizational elements responsible for the accomplishment of systems engineering tasks.

b) Describe the interface relationships between the systems engineering organization and other critical organizational groups.

c) You are responsible for the staffing of the systems engineering organization. What type of individual would you hire? Describe background and experience expectations, personal characteristics, and specific desired skills of suitable systems engineer candidates.

In accomplishing your required functions, you will be dealing with a large number of external organizations located both nationally and internationally.

d) Describe some of the requirements that you would implement in the organization to ensure the successful accomplishment of your objectives.

Exercise 1.7 IT system for unemployment fund

An unemployment insurance funds (arbejdsløshedskasse) is responsible for the administration of unemployment benefits. Unemployment benefits are payments made by authorized bodies to unemployed people. Unemployment benefits are generally given only to those registering as unemployed and often on conditions ensuring that they seek work and do not currently have a job. Furthermore, the unemployment funds are active in CV and job consulting and play an active role in dissemination of jobs.

Denmark, as well as most other Nordic countries, uses the Ghent system, under which unemployment insurance is voluntary and where a significant proportion of unemployment benefits are distributed by independent insurance funds with strong relationships with the unions.

Assignment

The Swedish Company *SAIT Systems*, who specializes in administrative IT systems, considers to enter the Danish IT market for unemployment insurance funds. The company has a strong competence in similar systems deployed in Sweden and is now looking for expanding its business outside Sweden. Due to the different laws and regulations between Sweden and Denmark the current system need to go through a significant redesign and new development. However, a high degree of efficiency and digitalization in SAIT System's current product have made the product superior compared to other products on the market. The system has the potential of significantly reducing the time for working the client cases at an unemployment insurance fund.

SAIT Systems has estimated the cost of new development for the system in order to be ready for the Danish market to be 20 million kr. A possible development project will be financed with a loan with an interest rate of 8,0%.

An investigation into the market has given the figures listed in Table 1.2 (from [7]). During the recent financial crisis the member decline has stopped. From 2000 to 2008 the cost of administration has dropped with more that 24% (in fixed prices). This trend is attributed to the increased competition between unemployment insurance funds. This trend is expected to continue in the future. The unemployment insurance funds use almost 0,5 billion kr. on IT (2008). In fixed prices this is a drop of 12,3% compared to 2005. The rate of inflation in the period from 2000 to 2010 have been 2,1% p.a. in average.

There are two dominant competitors on the market with similar systems: Modulus system from Tieto and the Winnie system from Organisator. These systems together accounts for 70% of the market share. The remaining systems are proprietary and will in the near future be replaced by one of the IT systems available on the market.

a) Estimate the potential market for adminstrative IT systems to Danish unimployment insurance funds (in kr.). What are your underlying assumptions about the market, clients and the competitors?

b) Suppose SAIT Systems manage to increase its market share linearily over a 5-year period: Assuming a gross profit margin[1] of 20% how large a market share is needed to have break even after 5 years?

Figure 1.5 shows the logical structure of an IT system for managing unemployment benefits. The core of the system handles the membership and the payout administration. It draws on modules for handling of documents and for administration of cases (sagsbehandling) as well as a system for archiving. The system interface a web module that contains a self-service portal for its members (net unemployment fund). Finally, it interfaces to other administrative IT systems such as systems at e.g., SKAT, NemID etc. As

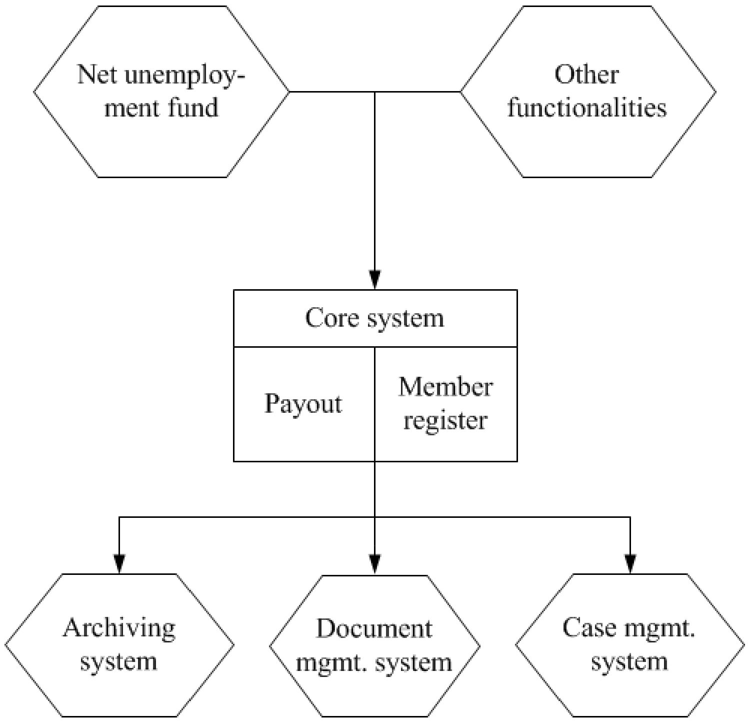

Figure 1.5: Structure of IT system for unemployment insurance fund.

an example for dimensioning of the IT system a unemployment fund with around 100.000 members, such as e.g., the unemployment fund for engineers (IAK), can run a quad-core CPU server systems and by using a total of 10 TB of storage for files, databases, achieves etc. The interconnection between remote system elements can be based on 100 Mbps data connections.

c) Design the IT system based on standard COTS component. Make a accompanying bill of material for the system?

d) Search the Internet (or other sources) to find prices for all the items on bill of material (if you cannot find a price make a "educated guess")?

e) At what price shall SAIT Systems offer its IT system for handling unemployment benefits?

f) How is the price impacted if the system in question c) is a high availability system, i.e., a fully redundant solution with all servers, storage and connections are replicated? (if your system is already is fully redundant the question is how much can be saved by a non-redundant system?)

[1]Gross Profit = Sales minus 'Cost of Sales'. Gross Profit margin = Gross profit / Sales

SAIT Systems can also offer to operate the system as a hosted and managed solution from its data centers in the Nordic countries. In this case SAIT will charge the customer a monthly fee of 15 kr./member/month based on the number of members of the particular unemployment insurance fund.

g) Calculate the internal rate of return for the operating business case assuming that a SAIT Systems will initially have get a market share of 20% for the hosted and managed system business.

h) What service level guarantee such as e.g. availability, can SAIT Systems offer for the solution design in question c)?

The CEO of SAIT is a cautious individual. She wants to hear you opinion on the opportunity of entering the Danish market.

i) What do you say to her?

Number of unemployement insurance funds in Denmark:	29
Number of members :	2,2 million kr.
Fraction of workforce being ensured:	74%
Typical membership fee	4500-4900 kr./year (full time insured)
Total payout by UIF:	34,7 billion kr. in 2008 and 43,5 billion kr. in 2009 (expected).
Cost of administration	4,0 billion kr. in 2000 3,0 billion kr. in 2008
Cost of IT systems	0,5 billion kr. in 2008
Division between central systems, office systems and services	30% (servers), 30% (office), and 40% (services)

Table 1.2: Selected data for Danish unemployment insurance funds.

Chapter 2

System design

Exercise 2.1 Pill dispenser

Are you taking many medications? Are you beginning to forget if you took your medications? What pills do I take with food or without food? These are some of the questions that patients on prescription medication are facing every day. By using ICT there is a way never to miss or double dose again!

Healthcare at Home (tier 2):

ASE has been running a research project called SIH (Healthcare at Home) with the purpose of supporting people to live longer and to be more independent in their own home. To accomplish this, functions to support monitoring of vital healthcare signals or systems to help people in remembering to take their medicine has been designed. A healthcare at home system under consideration incorporate the following components in the home:

- An ADSL connection and modem,
- a router,
- a healthcare computer (running the healthcare applications),
- an automatic pill dispenser wirelessly connected to the healthcare computer,
- a blood pressure meter,
- an ECG-sensor (Electrocardiogram) mounted on the person, and
- a fluid balance sensor (mounted on a person).
- a fall detector (mounted on the person).

The healthcare computer comprises a touch screen and a computer hardware with Bluetooth and TCP/IP communication interfaces. All healthcare devices such as the blood pressure meter, the ECG-sensor, the fall detector, the fluid balance sensor, and the pill dispser are connected wirelessly (Bluetooth) to the healthcare computer.

National healthcare System (tier 1):

In a larger system context the home of the patient can be regarded as a block called HealthCareAtHome. Other entities at this higher abstraction level could be Hospitals, Local Care Centres, Local Doctors and Monitoring Facilities (like SOS/Falck-Securitas).

a) Draw a SysML Block Definition Diagram (bdd) for tier 1

Automatic pill dispenser (tier 3):

The purpose of the pill dispenser system is to assist people in taking their medicine in form of pills at the right doses and at the right time of the day. A prototype of a pill dispenser developed at ASE is pictured in Figure 2.1.

Figure 2.1: IHA pill dispenser prototype.

The system shall support two different pill dispenser mechanical mechanisms. The first mechanism is based on pill boxes. The local nurse will refill the machine with pill boxes every 14 days based on the prescription information from a health care system. The use of pill boxes is very convenient when the medicine could be changed during the 14 days period. The second mechanical mechanism is based on doses packages received from the local pharmacy. Pills for a given time in a day are collected in a bag which should be dispensed or ejected from the machine. These bag packages are also typically delivered for a 14 days period and are very convenient when a person has a stable condition.

It is a requirement that it should be very easy to change the dispensing mechanism and the system shall consist of the same user interface and control mechanism (software/hardware). The pill dispenser shall be connected to the healthcare computer with a wireless Bluetooth connection. The system shall be based on RFID identification of the person using the system. Only a person with the right RFID-tag can release the pills from the system. The system shall have a display showing the next time interval for dispensing. If this interval is exceeded a local alarm shall be given and after a certain time interval an alarm message is sent to the local care center or some other registered persons.

For the pill box variant the time intervals for dispensing are loaded from the Health-Care computer. For the doses package version the time intervals shall be read automatically from the bags which contains readable information about the dose and the schedule for intake.

b) Draw a SysML Block Definition Diagram (bdd) for either the tier 2 or the tier 3 system (choose one of them)

c) Draw a SysML Internal Block Diagram (ibd) for the selected system in step b).

Exercise 2.2 Interaction design

In this exercise we will look into a survailence system deployed in the Great Belt tunnel. The tunnel connects the Danish islands of Zealand and Funen.

The tunnel consists of a southern and a northern tubes at a length of 8024 m, which are built of prefabricated concrete panels mounted in rings with 7 elements in each. Rings outer diameter is 8,5 m. The inside diameter is 7,7 m. There are 25 m between the centers of the two tubes. The tunnel main pipe is lined with 8,846 concrete rings, consisting of a total of 61.922 prefabricated units of 40×165 cm. In addition, approximately 18.000 base elements and approximately 20.000 sidewalk elements. The total construction quantities amount 205.000 m^3 of concrete reinforced with 19.000 tons of reinforcing steel. There are 31 cross tunnels, including 29 in the drilled section, connects the 2 main tunnels every 250 m, and serve as escape routes in an emergency. The cross tunnel inner diameter is 4,5 m. Transverse tunnels are lined with a total of 11.160 cast iron elements. Most transverse tunnels consists of 22 rings assembled from 18 individual items in each 60 m in width. The tunnel's largest trace depth is 75 m below sea level.

In this exercise you will make an interaction design for a touch screen for one person surveillance and monitoring the tunnel below Great Belt.

a) What sensors systems are used for monitoring?

Make a sketch of the user interface.

b) How does these systems appear and how does the user interact with them?

You may what to consider how status on each sensor/system is shown. How is an alarm shown and how does the user interact with the system and the alarms? Consider the states, touchability, number of displays etc.

Exercise 2.3 Wireless sensor design

Figure 2.2 shows the ASE-BAN wireless sensor device [16]. It is built from an a stacking of PCBs that allows the customization of the device in accordance with the required functionality.

The base PCB equips an integrated ambient temperature sensor, and an accelerometer and has connectors to other PCB layers, a micro USB connector as well as connectors for power intake (battery or energy harvesting module). The Radio PCB equip a micro-controller unit (MSP430), a radio transceiver (CC2420), and an integrated antenna. In the example in the top of figure a fluid balance sensor is attach. The fluid balance sensor contains a high precision impedance converter system.

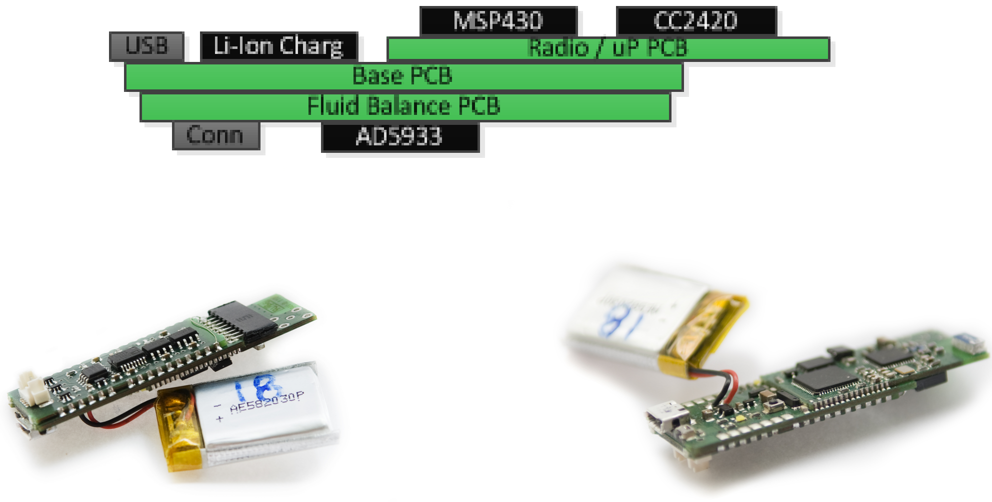

Figure 2.2: ASE-BAN sensor node. The top shows the stacking of PCB in a modular structure. The lower part shows pictures of the actual sensor node with sensor side (left) and energy side (right) respectively. On the top figure a fluid balance sensor is shown. This sensor is not included in the pictures below.

a) Draw system architecture (logical, block).

b) Describe the interfaces.

c) Identify each CI PUID and sketch a design specification tree.

Exercise 2.4 Configuration Management and issue handling

You are working as systems engineer in a project developing a complex system for a customer. The system is largely finished and field testing of the first several prototypes is in progress when the end-user requests a change of requirements. The change may involve significant re-engineering. Furthermore, the change may affect a sub-system developed and delivered by a sub-supplier. Low Rate Initial Production (LRIP) has been initiated.

a) What actions do you initiate to reach a decision whether the change should be executed?

b) It has been decided to execute the change. Make a plan of activities and an overview of documents that may need to be changed.

c) How do you handle the change with your sub-supplier?

Chapter 3

Verification, validation, and certification

Exercise 3.1 CE marking

The CE marking is a mandatory conformance mark for many products placed on the single market in the European Economic Area (EEA). The CE marking certifies that a product has met EU consumer safety, health or environmental requirements. Originally "CE" stood for ("Communauté Européenne") "European Community". According to the European Commission today the CE logo has become a symbol for free marketability of industrial goods within the EEA and without any literal meaning. By affixing the CE marking to a product, the manufacturer – on his sole responsibility – declares that it meets EU safety, health and environmental requirements.

CE marking apply to products such as toys, construction products, telecommunications, medical devices, machinery, personal protective equipment, measuring instruments, marine equipment, electrical products etc. The manufacturer of a product affixes the CE mark to the product himself, but has to carry out a *conformity assessment*, set up a technical file and sign an EC declaration of conformity. The CE mark for a product may be obtained by self-certify methods or by making use of an third party certification body.

There are four directives which are quite inclusive and most likely to apply. In addition, when more than one directive applies to a product, the product must comply with all applicable directives

- The *Machinery directive*[1] became effective in 1995 and covers new and used machinery with moving parts (except manually operated machines).
- The *Medical Device directive*[2] was effective in 1998. This directive requires an Authorized Representative be located in Europe.
- The Electromagnetic Compatibility directive[3] was effective in 1996. This directive applies to most electronic equipment and deals with electromagnetic emissions and immunity.
- The *Low Voltage directive*[4] has been in place since 1973 and was amended in 1997.

[1] http://ec.europa.eu/enterprise/sectors/mechanical/documents/legislation/machinery/index_en.htm

[2] http://ec.europa.eu/consumers/sectors/medical-devices/regulatory-framework/index_en.htm

[3] http://ec.europa.eu/enterprise/sectors/electrical/documents/emc/legislation/

[4] http://ec.europa.eu/enterprise/sectors/electrical/documents/lvd/legislation/index_en.htm

This directive applies to all electrical equipment designed for use with a voltage rating between 50 and 1000 V AC and between 75 and 1500 V DC.

Assignment

A USA based company, MedicalElectronicsNow (MEN), wishes to export its advanced wearable electrocardiogram (ECG) monitoring system to Europe. Our ECG monitoring system can be functionally divided into four subsystems [9]: 1) ECG sensors, 2) data sampling, 3) wireless transmission, and 4) host interface. The ECG sensor is a compact ECG sensor that does not require skin preparation, gels, or adhesives. Its output signal range is adjustable from differential ($-4,5\,\mathrm{V}$ to 4,5 V) to single-ended (0 V to 4,5 V). The ECG wireless sensor node is a compact and low power wireless sensor node. It consumes less than 10 mA in transmission mode (0 dBm) and 22 mA in receiving mode. Its maximum data rate and radio transmission range are 1 Mbps and 10 m, respectively. The transmission output power is also software configurable for four different levels: -20 dBm, -10 dBm, -5 dBm, and 0 dBm. The wearable devices are battery powered with custom 40 mAh rechargeable lithium polymer battery. Three types of base station is available for the product: USB, Fast Ethernet, and Wi-Fi.

You are an independent CE consultant. MEN has turned to you to seek consulting on how to obtain the CE mark for their product.

a) Which directives apply to which part of the product/system and to what extend does these directives apply?

b) Outline the conformity assessment procedure and make a plan for its completion?

c) What are the applicable product standards and test methods for your product?

The declaration of conformity contains information adequate for tracing the product back to the manufacturer or the authorized representative in the EU.

d) Prepare a declaration of conformity that includes a list of the directives and standards that your product conforms to; its product identification, the manufacturer's name, address and signature.

Then the finally step is to affix the CE mark to your product.

e) What would be the main differences in answers to a)-d) be if your product would be a 1) personal protective equipment or 2) radio telecommunication equipment?

Chapter 4

Production and operations

Exercise 4.1 Issue handling

You have been working as systems engineer in a development project for a complex system consisting of several subsystems. One day a customer calls you to tell that they have experienced that a safety interlock switch does not correctly disable the system in one of their 100 installations. The safety interlock is used to ensure the system is disabled and safe e.g., during maintenance. Due to person safety concerns the customer has taken the affected system out of active operation and has initiated his own fault finding. Furthermore, the customer is concerned that his other installations may be affected too. The customer is losing money every day the system is not working and is in dire need of a solution.

a) What do you tell the customer?

b) Make a plan for what actions may be necessary to handle the issue.

Exercise 4.2 Configuration Management

Your company has been producing a safety interlock switch for ten years. The switch is installed in some variants of several hundreds of systems sold to at least ten different customers. At some point in time during production, the purchasers have changed supplier on a custom made mechanical component in order to save cost. Unfortunately, they have missed to initiate a new First Article Inspection (FAI) and the new component is not compliant with the Part Drawing resulting in occasional failure of the switch unit.

a) What data would be relevant to ensure confident identification of affected units, installed systems and end-customers?

b) What corrective actions should be initiated?

c) How do you and your customer identify and differentiate potentially affected units and known-good units?

Part II

Case work

Chapter 5

Case work

5.1 Way of working with the case

The case work descriptions included in this chapter are based on realistic challenges from a companies. They represent past projects and business evaluations.

The case descriptions are presented in the format of a Statement of Work (SOW). The SOW explains its purpose, the scope of the work, location of work, period of performance, delivery schedule, applicable standards, acceptance criteria and any special requirements and the type of contract/payment schedule. Note, that SOWs may purposely be incomplete and ambiguous.

The way of working with the cases is perhaps best described as a role play game. Put yourself in the position of a systems engineer working in the company described in the case. Image that this company has an ongoing discussion with a customer on an engineering contract. Identify and carry out the relevant systems engineering work processes in order to pursue the challenge of the company. Deliver the requested information (system documentation) in the cases. Work in accordance with the mantra: Rather complete a work process than to work out all the details in limited parts of a process.

5.1.1 The SE-case process

For large, complex systems the work with the systems engineering process can run for several months and even years. For the purpose of training the practice of systems engineering we will tailor a systems engineering process scope and duration to be suitable for the course. The tailored *SE-case* process, described below, is a tailored process based on the systems engineering framework from INCOSE [1]. The process is the same for a subsystem.

Concept and project definition phase

Prepare the System requirements based on the input from a stakeholder requirement definition phase. Requirements must be verifiable.

Typical document outputs from this phase are the Concept documents, System Requirement Specification, initial Requirement Traceability Matrix, project steering documents including a project plan.

System design phase

The overall design of the system is decided. Subsystems are identified. Major interfaces between subsystems are defined. System verification and qualification of the project are

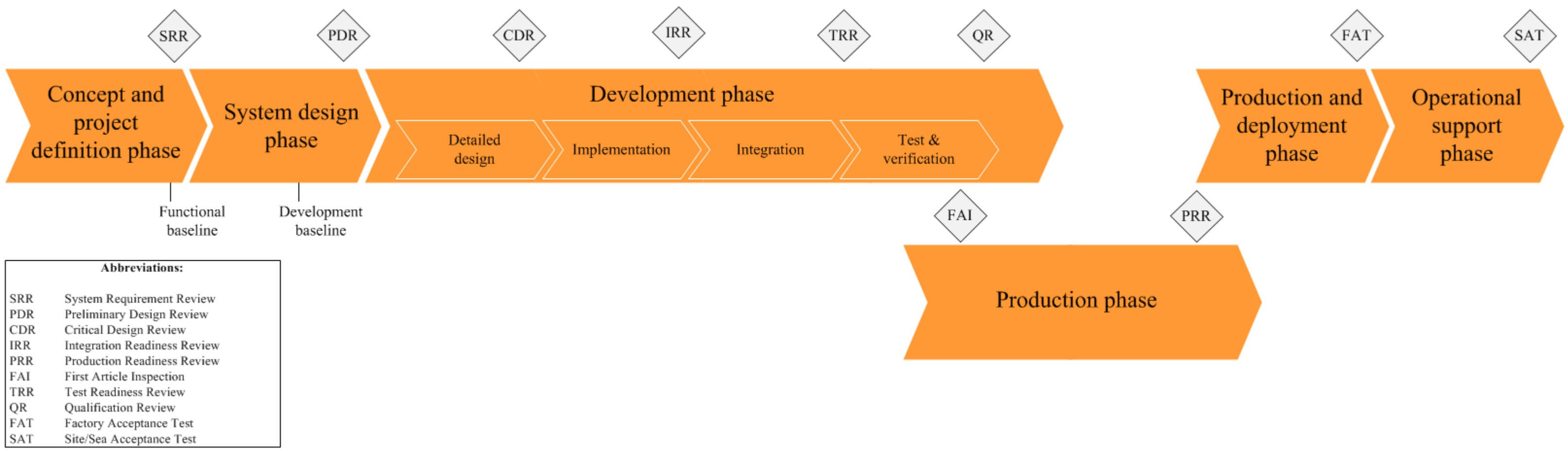

Figure 5.1: SE-case process

planned. Processes for production are selected. Possible new subcontractors are approved and negations of contracts are started. Requirements and changes to requirements are properly handled.

Typical document outputs from this phase are preliminary and detailed design documentation, system test specification etc.

Development phase

Subsystems and units are designed and documented. Prototypes of the critical subsystems are produced in order to verify the principles, functionality and performance. Implementation and verification of subsystems in accordance with requirements. Individual subsystems are integrated successively into a complete system. Compliance to all the requirements of the System Requirement Specification is verified.

Typical document outputs from this phase are design documentation and test reports.

Production phase

Production (or manufacturing) is the use of machines, tools and labor to produce the systems and the services supporting the system. The main tasks in the phase is production planning and the first unit serial production. This phase typically involves low rate initial production (LRIP).

Production and deployment phase

In this phase systems are installed at the customer premises and training of personnel is undertaken. A change from LRIP to mass production takes place.

Operational support phase

In this phase the organization is supporting the systems in use at customer premises.

5.1.2 Case organization

The case work is carried out in small systems engineering and integration teams (SEITs). Each team has 3-5 team members and acts as a prime contractor for a case. The SEITs receives a statement of work and has a fixed deadline for the delivery of an offer/product for the system-of-interest. Secondly, each SEIT is requested to use a subcontractor for parts of the system. In the case exercise this is simulated by letting another team become the subcontracter to a prime contracter.

Figure 5.2 illustrates this setup with six interacting SEITs and two cases: Case I and Case II. From the figure the following can be concluded:

- Company A is *prime contractor* to customer in Case I and *subcontractor* to Company B.
- Company B is *prime contractor* to customer in Case II and *subcontractor* to Company C.
- Company C is *prime contractor* to customer in Case I and *subcontractor* to Company D.
- Company D is *prime contractor* to customer in Case II and *subcontractor* to Company E.

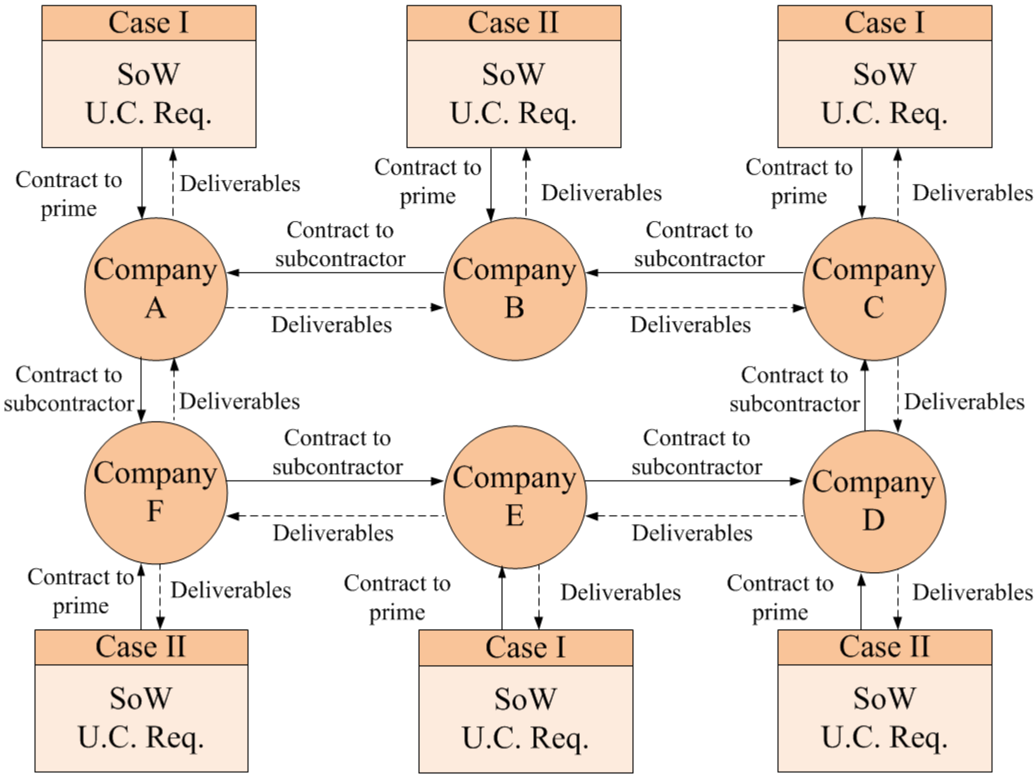

Figure 5.2: Context flow diagram for the case work. The typical input for describing the case is a Statement of Work (SoW) and/or use case requirements (U.C. Req.). The term "use case requirement" is used for the output of a use case-based requirement analysis process.

- Company E is *prime contractor* to customer in Case I and *subcontractor* to Company F.
- Company F is *prime contractor* to customer in Case II and *subcontractor* to Company A.

Appendix B shows a similar setup but with eight groups. This is used for classes with more than 30 students.

Process schedule

The intention is that the case work process runs over a period of 6-7 weeks and hence can be adapted to the quarter structure used by ASE. See the lecture plan for the dates of the review meetings.

Milestone reviews and deliverables

The milestone reviews (MSRs) and the required deliverables that are relevant for the case work are given in Table 5.1. Some of the review meetings are held internally (marked "(internal)") and does not require participation of the customer. The SSR, CDR, TRR, SAT review involve the customer. Reviews will be conducted in accordance with the practices outlined in Appendix N of the NASA Systems Engineering Handbook [10]. The three type roles will be assigned to SEIT members. For the case review the following roles shall be assigned to individuals:

Milestone review	Mandatory deliverables	Optional deliverables
SRR (customer)	Time plan. System Requirement Specification.	System engineering plan. Verification matrix. List of system objects. Request for Proposal
PDR (internal)	Preliminary Design Description.	Preliminary Interface Control Document.
CDR (customer)	Detailed Design Description	Interface control document Preliminary verification plan
TRR (customer)	System Test Description (including verification plan, procedure and verification matrix)	
SAT (customer)	Customer presentation of project/product/offer Document baseline	

Table 5.1: Milestone reviews and deliverables in case-SE process.

- Author(s)
- Moderator
- Inspectors

The roles and responsibilities are described in [10]. The customer will assume the role of an inspector.

Note, that document templates for (some of) the deliverables can be found in Chapter 6. You may choose to apply these templates for the case work and adapt it to the needs of your case project.

Responsibilities of the SEIT

The following responsibility apply for the prime contractors MSR with the customer:

§1 All documents for the MSR shall be delivered to the customer no less that 72 hours in advance.

§2 Delivery information: Reports must be delivered in Campusnet.

§3 All documents shall be in portable document format (PDF) format and written in English.

§4 All documents shall be revision controlled and a project-unique document identification must be clearly visible on the first page.

§5 The MSR shall be conducted at a time agreed with the customer. It is the prime contractor's responsibility that the MSR time is not conflicting with other meetings.

The following responsibility apply for the subcontractor's MSR with the prime-contractor:

§6 The requirements for the documentation is the same as for the prime-contractor's MSR with the customer.

§7 Minutes of meeting (MoM) from the MSR shall be produced and sent to the customer by the prime contractor no less that 48 hours after the MSR meeting

§8 Minutes of meeting shall be in PDF format containing a maximum of 1000 words.

5.2 Terma case

5.2.1 About Terma

Terma A/S (www.terma.com) develops and markets high-tech solutions, systems, and products for defense and non-defense applications. The products are designed for use in extreme mission-critical environments and situations, where human lives and valuable material assets are at stake. The business areas of Terma cover:

- Aerostructures: Development and production of advanced structures for defense and non-defense aircraft and helicopters.
- Integrated Defense Systems: Network and tactical systems; self-protection equipment for aircrafts, helicopters, and ships; and electronics manufacturing and services within the defense industry.
- Radar Systems: Advanced radar systems for coastal surveillance, naval surveillance, vessel traffic surveillance, perimeter surveillance, and surface movement surveillance at airports.
- Space: Mission-critical products, software, and services for space applications.

Terma A/S was established in 1949. For many years, Terma has worked closely with the public authorities in Denmark and international organizations around the world. Through these relationships, Terma has gained in-depth knowledge of and insight into its customers' working environment and an equally deep understanding of their situations and needs.

Terma is an international organization with headquarter in Lystrup near Aarhus in Denmark, and with other Danish facilities at Grenaa, Copenhagen (Herlev), and Skive. International subsidiaries and facilities in The Netherlands, Germany, USA, and Singapore.

5.2.2 Electronic warfare systems

The electromagnetic spectrum has been used for commercial and military applications for over a century. Electronic warfare [8] is defined as the military action involving the use of electromagnetic and directed energy to control the electromagnetic spectrum or to attack or impede enemy assaults via the spectrum. The purpose of electronic warfare is to deny the opponent the advantage of, and ensure friendly unimpeded access to, the electromagnetic spectrum. Electronic warfare capabilities are applied from the air, land, sea, and space by manned, unmanned, attended, or unattended systems.

In conflict situations, commanders attempt to dominate the electromagnetic spectrum. They do this by locating, targeting, exploiting, disrupting, degrading, deceiving, denying, or destroying the enemy's electronic systems that support military operations or deny the spectrum's use by friendly forces.

The increasing portability and affordability of sophisticated electronic equipment guarantees that the electromagnetic environment in which forces operate will become even more complex. To ensure unimpeded access to and use of the electromagnetic spectrum, commanders plan, prepare, execute, and assess electronic warfare operations against a broad set of targets within the electromagnetic spectrum.

Customers typically require a combination of subsystems that is specific for the role and mission of the particular aircraft. Terma tailors customizes electronic warefare. Over the years more than 1,600 self-protection suites have been integrated in fighters, transport aircraft, and helicopters. In addition, Terma offers an electronic warefare management system that integrates any combination of electronic warfare subsystems on any type of military aircraft. The system is operational in a large number of fighters, transport aircraft, and helicopters, and is well-proven from conflicts in Kosovo, Iraq, and Afghanistan. The system operates in a manual, semi-automatic, or automatic mode, providing the pilot with very low workload or, if in the automatic mode, no workload at all. The system incorporates an advanced threat display and 3-D Audio Warning, which reduces pilot reaction time and increases situational awareness. The system is night vision compatible and it is fully compatible with helmet mounted displays.

5.2.3 Statement of work

The Royal Danish Air Force has requested your company to deliver a self-protection suite for the F-16 combat aircraft (Figure 5.3. The required solution incorporates a pod[1]

Figure 5.3: F-16 combat aircraft.

and an intelligent cockpit control unit for controlling the electronic warfare suite. The pod will be dispensing payloads (chaffs[2] and flares) and hosting the Missile Warning System (MWS). The solution shall provide warning upon detection of missile threats and be able to automatically dispense payloads in response. The MWS will be provided

[1]The pod is a detachable compartment on an aircraft for carrying instrumentation.

[2]Chaffs are strips of metal, foil, or glass fiber with a metal content, that are used to reflect electromagnetic energy as a radar countermeasure. Chaffs are cut into various lengths and having varying frequency responses.

as Government Furnished Equipment (GFE) and will be physically installed by your company.

Requirements

Functional requirements

- The pod shall include a minimum of eight standard magazines (UR-1).
- The pod shall be able to dispense forwards, downwards and sideways (UR-2).
- Introduction of the system may not compromise the operation of the current weapon systems (UR-3).
- Threats shall be transmitted to the aircraft mission computer in body frame format (relative to aircraft) for displaying purposes (UR-5).
- The system shall provide the aircraft mission computer with status information and built-in test results (UR-6).
- The system shall interface the aircraft intercom system to provide audio cues and warnings (UR-7).
- The system shall include a hardware implemented safety interlock to prevent dispensing on ground (UR-8).
- The system shall be able to erase sensitive data upon input from a discrete zeroize signal from aircraft (UR-9).
- The system status on individual LRU level shall be provided by cockpit unit (UR-10).
- The cockpit unit shall be able to control power of dispensing system and MWS (UR-11).
- The system shall comprise at least three modes, manual, semi-automatic and automatic (UR-12).
- Manual mode shall dispense the program selected by the pilot (UR-13).
- Semi automatic shall initiate an intelligent threat response upon consent from the pilot (UR-14).
- Automatic mode shall initiate an intelligent threat response without pilot interaction (UR-15).
- The system shall provide a method of loading software to MWS (UR-16).

Performance requirements

- The system shall be able to dispense a minimum of two payloads simultaneously (UR-20).
- The system shall be able to dispense an intelligent pattern of payloads programmable by the customer (UR-21).
- The system shall provide the optimal coverage against missile threats (UR-22).

Environmental requirements

- The pod structure shall remain intact when exposed to steady state acceleration levels of 5g fore 2.5g aft, 25g up, 11g down (UR-30).
- The total weight of pod cannot exceed 270 kg (UR-31).
- The pod shall be operational at temperatures of 95 degree Celcius on outer skin and 102 degree Celcius on leading edge for 25 minutes (UR-32).
- The pod shall be operational at temperatures of 134 degree Celcius on outer skin and 151 degree Celcius on leading edge for 3 minutes (UR-33).

Interface requirements

- The cockpit unit shall communicate with the MWS via a MIL-STD-1553-B data bus (UR-40).
- The cockpit unit shall communicate with the mission computer via a MIL-STD-1553-B data bus (UR-41).
- The pod shall be mounted on the aircraft wing with standard T-hooks spaced by 13 inches (UR-42).
- The power consumption of the pod shall not exceed 700 W (UR-43).
- The pod shall be mounted on the left-hand wing (UR-4).

Preconditions

Power conversion

Your company has access to a qualified Power Conversion Unit (PCU), converting 115 VAC 400 Hz to 28 VDC. The PCU can output a maximum of 250 W. The PCU weights 25 kg.

Missile Warning System

- The MWS consists of six sensor units and one Electronics Control Unit (ECU).
- The ECU will provide threat information in inertial format. Direction of the threat is relative to north.
- The MWS must receive navigation data from the aircraft mission computer with a minimum latency. Navigation data includes aircraft attitude, heading, altitude and GPS data.
- The MWS is qualified to the following steady state acceleration levels 4g fore 2.5 aft, 22g up, 10g down.
- The MWS requires a maximum of 85 W from 28 VDC and a maximum of 100 W from 115 VAC 400 Hz.
- The MWS including ECU and six sensors weighs 18,2 kg.
- The MWS operating maximum temperature is 70 degree Celcius.

Production cost	Weight [kg]	Cost [kr.]
MWS complete	18,2	0
PCU	25	30.000
DSS	5	50.000
Dispenser assembly	3	5.000
Pod harness	20	100.000
Pod structure	175	2.000.000
Cockpit unit	4	112.000

Table 5.2: Production cost

Development cost		Amount [kr.]
Development costs	NA	4.000.000

Table 5.3: Development cost

Provided interfaces

- The cockpit unit is provided with sufficient 28 VDC power.
- Various aircraft discrete signals can be routed to the cockpit unit, to be discussed.
- Wiring in wing available to pod: 6 discrete wires, shielded wires suitable for data bus, 115 V AC, 400 Hz power.

Pod

The pod structure, and if necessary, additional climate control must be purchased from a sub-supplier.

Dispensing

The power required to ignite a payload is up to 126 W for a period of up to 20 ms. The Digital Sequencer Switches (DSS) run on 28 VDC and each consumes 3 W for operating power plus the power required to ignite the payloads. Each DSS can control 2 magazines.

Pricing

Tabel 5.2 and 5.3 list the production cost and the cost of development, respectively. Units from own company can be redesigned to better suit the actual need. In general, a redesign will add a non-recurring development cost of 15 times the production cost. For each percentage point the weight is reduced the cost is increased with two percent. For items ordered at sub supplier no development costs will be added by changing requirements. They are included in the offer made by a subcontractor.

The contract sum is 8.000.000 Danish kroner. Your company's management expects a profit of no less than 15% and aims for 20%.

5.3 Systematic case

5.3.1 About Systematic

Systematic was established in 1985. The company specializes in software and system development. It has headquarter in Aarhus and affiliated offices in Tampere, London and

Washington.

The customer base spans 35 countries. The company is highly recommended by its customers and more that 97% of the existing customers will recommend Systematic to other customers.

Systematic has approximately 500 employees of which more that 70 % hold a master or a Ph.D. degree in software development. Systematic is CMMI certified on level 5.

Systematic is organized into four business areas: defence, healthcare, integration services, intelligence and national security. In the defence area Systmatic develops and maintain two distinct product lines and a number of stand-alone products.

- SitaWare suite product line is aimed to create situational awareness and efficient communication in a military operation scenario.

- IRIS suite product line is an electronic communication system for sharing electronic information between different nations, systems and equipment. IRIS suite that ensures full, consistent compliance with the constantly evolving NATO and US message text format (MTF) standards.

5.3.2 SitaWare product line

Accurate, up-to-date situational awareness is essential for virtually all high-risk operations, military and civilian. The SitaWare suite provides a fully scalable command and control solution that fulfills all core requirements right off the shelf. This means it is easy to procure and rapidly deployable. The SitaWare suite consists of a number of systems:

- *SitaWare Portal* is an off-the-shelf C2 platform[3] that provides divisional-level headquarters with an easy-to-deploy synchronized workspace for effective command and control collaboration, information sharing and data transparency.

- *SitaWare Track Server* is a high-performance common operations picture (COP) service with a small footprint and a big impact on decision-making. It is used for quickly and effectively aggregating large quantities of information to generate a COP for land, maritime, air and joint-forces operations.

- *SitaWare C2 Server* is a rapidly deployable, off-the-shelf enabler for building C2 applications. It provides an open platform based on the principles of service-oriented architecture (SOA). By using SitaWare C2 Server Web Services, users can develop custom C2 applications specific to their needs and requirements, for instance to build and display a single unified COP.

- *SitaWare Headquarters* software is the C2 system of choice for brigade, battalion and company command posts, providing a framework of situational awareness capabilities focused on planning or current operations.

- *SitaWare Battle Management* software is normally used in hardware fitted inside military vehicles of all kinds, integrated with radio-based networks and with in-vehicle sensors and weapons. Its specifically designed for use in environments where an easy-to-use touch screen is the only viable user interface. SitaWare Battle Management is designed for dealing with situational awareness and the communication of both orders and reports within mobile operating environments usually based on hardware mounted in vehicles.

[3]Command and Control, or C2, is the exercise of a military authority and direction by a designated commanding officer over assigned and attached forces in the accomplishment of the mission.

- *SitaWare Dismouted* software provides the dismounted soldier with the same situational awareness and interoperability capabilities as other levels in the chain of command. SitaWare Dismounted features the key functionalities available in the vehicle-mounted SitaWare Battle Management system, specially configured to meet the practical needs of the individual soldier.

- *SitaWare Maritime boarding* is a uniquely capable backpack-based system, designed to provide maximum tactical awareness for both the boarding party and the command vessel. You get a fully integrated C2, communications and video set-up, pre-configured for "big-pipe" wireless IP (or tactical radio) links to support vessels and other units.

- *SitaWare MIP Replication* software is designed to support the information exchange requirements of modern military organisations – not least in the multinational operating scenarios now common.

5.3.3 Statement of work

In a military battlefield we have the capability to establish situational awareness, what in other settings may be referred to as a common operations picture (COP). We want to extend the possibilities offered by Systematic SitaWare to cover civilian scenarios where actors from police, armed forces, hospitals and emergency management work together to control a crisis situation. We envision a scenario where the commanders from a mobile headquarter can evaluate incoming information, act upon it and possibly dispatch orders or information to relevant actors to respond to.

Requirements

Provide a Common Operations Picture (COP) to the commanders in charge of the operation. The COP must provide both static and dynamic information. Static information may be:

- demographic data,
- fresh water supplies,
- hazardous matters, and
- construction work.

Dynamic information must at least be:

- location of the actors deployed in the area,
- observations made by actors in the arena, and
- weather information.

It must be possible to focus on various sources and types of information in the COP.

It must be possible to review the history of one or more events shown in the COP.

It must be possible to register events using the platforms currently employed by the various actors.

It must be possible to send information to the platforms currently employed by the various actors.

It must be possible to control the distribution of messages based on at least the following set of criteria:

- geography,
- role,
- group, and
- identity.

Finally, we want a proposal for a future Dismounted COP, i.e., the combined hardware and software. This solution must be hand-held and shall provide a condensed COP which enables the commanders to act independently of the mobile HQ. The solution may require commercially available terminals, middleware and protocols not currently employed. The development of the dismounted solution proposal shall be sourced from a subcontractor.

Warranty

In contrast to many software acquisitions, which are typically delivered "as is" and without warranty of any kind, the customer specifically request that software shall be covered by warranty. Warranty period shall be at least 10 years. In particular, the customer requires the following paragraphs (see Figure 5.4) to be part of the warranty statement[4].

Price[5]

From a statistical point of view an average developer can code a software class (block) in 14 days (mean value with a log-normal distribution and with 3 days of standard deviation). The internal cost of using software developers is 4000 kr./day. Furthermore, the following rule of thumbs for the total project can be applied [4]:

- 1/3 of effort is planning and project management
- 1/6 of the total effort is coding
- 1/4 of the total effort is component test and early system test
- 1/4 of the total effort is system test (all components)

Based on the above the customer shall be quoted a price for the project including all non-invoiceable obligations such as warranty service. In addition, the price of a maintenance contract shall be quoted. Finally, a risk assessment related to the business aspect of the development shall be prepared for the management at the company.

[4]Adapted from HP's Global Limited Warranty Statement.

[5]It should be noted that numbers related to the economic aspects of this case are not from Systematic, but merely based on imaginary figures.

Software Warranty Service consists of:

Defect Reporting. For Critical Defects, the Customer will have 24x7 access to the Service Centre by e-mail or phone to request defect repair, as described below. “Critical Defect means that the application is down or is at high risk, business functions cannot be conducted, or the Customer is experiencing continual failures or data corruption as a result of the defect. To report non-critical defects, the Customer will have e-mail or phone access to the Service Centre during the Principal Period of Maintenance (”PPM”), which is 8:00 a.m. to 5:00 p.m., local time, Monday through Friday, excluding local holidays.

Defect Repair. Defect repair includes verification of the existence of a defect, determination of the severity or impact of the defect, and determination of the conditions under which the defect may recur. The Company will, at its option:

- For a Critical Defect, commence action within a 2-shift hour response window using commercially reasonable efforts to provide an immediate fix or temporary solution of, or workaround to, the defect.
- For a non-critical defect, commence action within an 8-shift hour response window to provide either the action described for a Critical Defect or a statement that the defect will be corrected in a software product revision or a future software release.
- Provide a statement that the Software operates as described in then-current user documentation or that the defect arises when such Software is used other than in a manner for which it was designed. For Software added to an installed System, warranty service must be upgraded to the same software support plan, if any, as that of the Software already installed on that System. Customer will pay the difference between standard warranty and upgraded warranty service.

Figure 5.4: Software Warranty Service statement.

Part III

Additional course material

Chapter 6

Document templates

This section includes document templates relevant for the case work. The list of templates are:

- Concept of Operations (CONOPS)
- System requirement specification (SRS)
- Requirement traceability matrix (RTM)
- Detailed design document (DDD)
- Interface Control Document (ICD)
- System Test Description (STD)
- Request for Proposal (RFP)

6.1 Concept of operation

The Concept of Operations (CONOPS) documents the ways of working with need analysis in the project..

---

1. Introduction

1.1 **Purpose**

1.2 **Output**

1.3 **Executive summary**

1.4 **Revision summary**

2. Capability Need

2.1 **Business Need(s)**

2.2 **Business Need Capability Gap**

2.3 **Current situation**

3. Operations and Support Description

3.1 **Missions (Primary/Secondary)**

3.2 **Users and Other Stakeholders**

3.3 **Policies, Assumptions and Constraints** — Policy, Assumption, Constraint

3.4 **Operation Description** — Operating Concept (OpCon), Employment Modes, Scheduling and Operations Planning, Operating Environment, Geographic Area(s), Environmental Conditions, Interoperability with Other Elements,

3.5 **Product Support Description**

3.6 **Potential Impacts**

3.7 **Scenarios** — Support Name, Functional Capabilities Needed

4. Functional Capabilities

4.1 **Operations**

4.2 **Support**

5. CONOPS Development Team

List the office codes and names of personnel who made meaningful contributions to the document. This provides the reader with points of contact to follow-up when questions arise.

A. Additional Information

Attach any additional information that supplements this plan.

A.1 Analysis reports

4.2 Glossary and Terms

4.3 Acronyms and Abbreviations

4.4 References

6.2 System requirement specification (SRS)

The purpose of the SRS is to document the functional as well as the non-functional requirements derived from the Requirement Analysis phase. The SRS clearly identifies the requirements and contains detail information about it. This template is adapted from [11].

---

1. Scope

1.1 **Identification**. This section includes a full identification of the system-of-interest to which this document applies.

1.2 **System overview**. A brief statement of the purpose of the system of interest.

1.3 **Document overview**. Summarize the purpose and the content of the document. Security and privacy considerations associated with the use of this document might be added.

2. Referenced documents

Provide a list of the document references in this specification. The documents shall be uniquely identifiable.

3. Requirements

The section on system requirement can be organized into a number of subsections. Both functional and non-functional requirements shall be included. Each requirement shall be assigned a project-unique identifier to support testing and traceability.

3.1 **Required states and modes**. If the system is required to operate in multiple states or modes, these states and modes shall be defined.

3.2 **System capability requirements**. This paragraph specifies requirements on the behavior of the system and shall include applicable relevant parameters. It shall be divided further into subparagraphs depending on the system capability in question.

3.3 **System external interface requirements**. This paragraphs shall be divided into subparagraphs to specify the requirements, if any, for the system's external interfaces. Interfaces shall be assigned a project-unique identifier. One or more interface diagrams shall be provided.

3.4 **System internal interface requirements**. This paragraph shall be divided into subparagraphs to specify the requirements, if any, for the system's internal interfaces. It shall state if there are internal interfaces left to the design or to system requirement specifications for components. Furthermore, the description in item 3.3 also applies to internal interfaces.

3.5 **System internal data requirements**. Requirements on data internal to the system such as databases, data files etc. shall be stated. If there are internal interfaces left to the design or to system requirement specifications for components these shall be identified.

3.6 **Adaptation requirements**. Requirements on installation-dependent data and operational parameters that the system requires.

3.7 **Safety requirements**. System requirements concerning minimizing unintended hazards to personnel, property and the physical environment.

3.8 **Security and privacy requirements**. This paragraph shall specify the system requirements, if any, concerned with the maintaining security and privacy.

3.9 **System environment requirements**. This paragraph shall specify the system requirements, if any, regarding the environment in which the system must operate.

3.10 **Computer resource requirements**. This paragraph specifies resource utilization requirements. It can be further divided into hardware, software, communications etc.

3.11 **System quality factors**. This paragraph specifies quantitative requirements concerning system functionality, reliability, maintainability, availability, flexibility, portability (software), reusability, testability, usability an other attributes.

3.12 **Design and construction constraints**. This paragraph specifies the requirements, if any, that constrain the design and construction of the system.

3.13 **Personnel-related requirements**. This paragraphs specifies the requirements, if any, included to accommodate the number, skill levels, duty cycles, training needs, or other information about the personnel who will use or support the system.

3.14 **Training-related requirements**. System requirements pertaining to training.

3.15 **Logistics-related requirements**. This paragraphs specifies the requirements, if any, concerned with logistics considerations.

3.16 **Packaging requirements**. This paragraphs specifies the requirements, if any, for packaging, labling and handling the systems and its components for delivery.

3.17 **Other requirements**. Examples include requirements for system documentation not covered in other contractural documents.

4. Quality provisions

A set of qualification methods shall be defined for each requirement. These are the methods to ensure that the requirements have been met. Qualification methods may include but are not limited to: a) demonstration, b) test, c) analysis, d) inspection, or other special methods.

5. Requirements traceability

Based on the information in the section is shall be possible to trace system requirements to user needs. An RTM may be included (see Figure 6.1). If this is a subsystem-level specification this paragraph shall contain the traceability from each subsystem requirement to the system requirement that it addresses (backwards) as well as from each system requirement that has been allocated to the subsystem. All system requirements allocated to the subsystem shall be accounted for.

6. Other

General information that aids in understanding this document e.g,. background information, glossary etc. may be included here.

Project name:		Business Area:	
Project manager:		Business Analysts lead:	
QA lead:		Target implementation date:	

Req. id.	Category or functional activity	Requirement description	Use case reference	Design document reference	Code or module reference	Test case reference	User acceptance validation	Comments

Table 6.1: Requirement traceability matrix template

6.3 Detailed design document (DDD)

The DDD documents how the system or subsystem will be structured to satisfy the system requirements. It is the primary reference for subsequent implementation and it must contain all the information needed by developers to construct the system. The DDD is based on a preliminary design in which the overall system architecture and data architecture are defined; but it is more detailed. This template is adapted from [12].

---

1. Scope

1.1 **Identification**. This section includes a full identification of the system-of-interest to which this document applies.

1.2 **System overview**. A brief statement of the purpose of the system of interest.

1.3 **Document overview**. Summarize the purpose and the content of the document. Security and privacy considerations associated with the use of this document might be added.

2. Referenced documents

Provide a list of the document references in this specification. The documents shall be uniquely identifiable.

3. System-wide design decisions

This section shall be divided into paragraphs as needed to present decisions about the systems behavioral design and other decisions affecting the selection and design of system components. This includes also design decisions that are explicit in the requirements or that are deferred to the design of the system components. Examples of system-wide design decisions are the following:

a) Design decisions regarding inputs the system will accept and outputs it will produce.

b) Design decisions on system behavior in response to each input or condition, including actions the system will perform, response times and other performance characteristics.

c) Design decisions on how system databases/data files will appear to the user.

d) Selected approach to meet safety, security, and privacy requirements.

e) Design and construction choices for hardware or hardware-software systems, such as physical size, color, shape, weight, materials, and markings.

f) Other system-wide design decisions made in response to requirements, such as selected approach to providing required flexibility, availability, and maintainability.

4. System architectural design

This section shall be divided into multiple paragraphs to describe the system architectural design. If part or all of the design depends upon system states or modes, this dependency shall be indicated.

4.1 **System components**. Identify the components of the system (configuration items and manual operations). Each component shall be assigned a project-unique identifier. Show the static relationship(s) of the components. State the purpose of each component and identify the system requirements and system-wide design decisions allocated to it. Identify each component's development status/type, if known. Provide characteristics for resources identified for use in the system such as e.g., processors, memory, input/output devices, and communications/network equipment for computer systems.

4.2 **Concept of execution**. This paragraph shall describe the concept of execution among the system components. It shall include diagrams and descriptions showing the dynamic relationship of the components, that is, how they will interact during system operation.

4.3 **Interface design**. This paragraph shall be divided into subparagraphs to describe the interface characteristics of the system components. It shall include both internal and external interfaces. If part or all of this information is contained in Interface Control Descriptions (ICDs) or elsewhere, these sources may be referenced.

4.3.1 Interface identification and diagrams. Project-unique identifier shall be assigned to each interface.

4.3.x (Project-unique identifier of interface). This paragraph shall briefly identify the interfacing entities, and shall describe the interface characteristics of one or both of the interfacing entities. The description shall include the following, as applicable:

1. Type of interface (such as real-time data transfer, storage-and-retrieval of data, etc.) to be implemented.
2. Characteristics of data elements that the interfacing entity(ies) will provide.
3. Characteristics of data element assemblies (records, messages, files, arrays, displays, reports, etc.) that the interfacing entity(ies) will provide, store, send, access, receive, etc.
4. Characteristics of communication methods that the interfacing entity(ies) will use for the interface.
5. Characteristics of protocols the interfacing entity(ies) will use for the interface.
6. Other characteristics, such as physical compatibility of the interfacing entity(ies) e.g., dimensions, tolerances, loads, voltages, plug compatibility, etc.

...

5. Requirements traceability

The traceability from each system component to the system requirements allocated and the traceability from each system requirement to the system components to which it is allocated is described here. An RTM may be included (see Figure 6.1).

6. Other

This section shall contain any general information that aids in understanding this document e.g., background information, glossary, rationale.

6.4 Interface control document (ICD)

The ICD describes the interface characteristics of one or more systems, subsystems, configuration items, manual operations, or other system components. An ICD may describe any number of interfaces and can be used to supplement the Detailed Design Description (DDD). This template is adapted from [13].

---

1. Scope

1.1 **Identification**. This section includes a full identification of the system-of-interest to which this document applies.

1.2 **System overview**. A brief statement of the purpose of the system of interest.

1.3 **Document overview**. Summarize the purpose and the content of the document. Security and privacy considerations associated with the use of this document might be added.

2. Referenced documents

Provide a list of the document references in this specification. The documents shall be uniquely identifiable.

3. Interface design

This section shall be divided into paragraphs to describe the interface characteristics of one or more systems, subsystems, configuration items, manual operations, or other system components.

3.1 **Interface identification and diagrams**. For each interface this paragraph shall state the project-unique identifier assigned to the interface and shall identify the interfacing entities (systems, configuration items, users, etc.) by name, number, version, and documentation references, as applicable.

The identification shall state which entities have fixed interface characteristics and which interfaces are being developed or modified. One or more interface diagrams shall be provided, as appropriate, to depict the interfaces.

3.x **(Project-unique identifier of interface)**. This paragraph shall briefly identify the interfacing entities, and shall be divided into subparagraphs as needed to describe the interface characteristics of one or both of the interfacing entities.

The design description shall include the following, as applicable,

1. Type of interface (such as real-time data transfer, storage-and-retrieval of data, etc.) to be implemented.
2. Characteristics of individual data elements that the interfacing entity(ies) will provide, store, send, access, receive, etc.
3. Characteristics of data element assemblies (records, messages, files, arrays, displays, reports, etc.) that the interfacing entity(ies) will provide, store, send, access, receive, etc.

4. Characteristics of communication methods that the interfacing entity(ies) will use for the interface.
5. Characteristics of protocols the interfacing entity(ies) will use for the interface.
6. Other characteristics, such as physical compatibility of the interfacing entity(ies) (dimensions, tolerances, loads, voltages, plug compatibility, etc.)

. . .

4. Requirements traceability

The traceability from each system component to the system requirements allocated and the traceability from each system requirement to the system components to which it is allocated is described here. An RTM may be included (see Figure 6.1).

5. Other

This section shall contain any general information that aids in understanding this document e.g., background information, glossary, rationale.

6.5 System test description (STD)

The STD describes the test preparations, test cases and test procedures to be used to perform qualification testing of the system or subsystem. The STD enables the aquirer to assess the adequacy of the qualification testing performed. This template is adapted from [14].

---

1. Scope

1.1 **Identification**. This section includes a full identification of the system-of-interest to which this document applies.

1.2 **System overview**. A brief statement of the purpose of the system of interest.

1.3 **Document overview**. Summarize the purpose and the content of the document. Security and privacy considerations associated with the use of this document might be added.

2. Referenced documents

Provide a list of the document references in this specification.

3. Test preparations

3.x (Project-unique identifier of a test). This section identifies a test and provides a brief description of the test. The section shall include description for the hardware and software preparations needed as well as other preparations needed to carry out the test. Diagrams and step-by-step instructions shall be provided as applicable.

...

4. Test descriptions

This section shall identify and describe the test cases. The test cases are mapped to requirements and preconditions must be established prior to performing the test. The following considerations shall be discussed:

1. Hardware and software configuration.
2. Control paramenters or initial data to be set/reset prior to the start of the test.
3. Preset system conditions or states of relevant subsystems necessary to run the test case.
4. Initial conditions to be used in making timing measurements.
5. Conditioning of the simulated environment.
6. Other special conditions peculiar to the test case.

Test input and expected output shall be specified as well as the critera for evaluating the results. The section also define the test procedure for the test cases. Any assumptions made and constraints or limitations imposed in the description of the test case, due to system or test conditions, shall be mentioned.

5. Requirements traceability

Tracebility from any test case to the system requirement (or any other relevant requirement) is addressed here. An RTM may be included (see Figure 6.1).

6. Other

General information that aids in understanding this document e.g., background information, glossary etc. can be included here.

6.6 Request for proposal

While the RFP may differ depending on the context and the engineering domain the template below constitute a common set of sections found in most RFPs. Before sending the RFP, consider the need for all bidders to sign a non-disclosure agreement to keep the entire RFP process confidential.

---

1. Statement of purpose

Describe the general scope, nature, specifications, and purpose of goods, products, and services to be acquired in a manner that will enable providers to early decide to submit either an offer or a no-proposal letter.

2. Background information

Present a brief overview of your organization and its operations. Use statistics, customer demographics and psychographics. State strengths and weaknesses of your company. Do not forget to include comprehensive information on the people who will handle future correspondence.

3. RFP process and scope of work

Describe the steps potential bidders must follow to complete the RFP process. Specify the different project phases broken down into tasks, detailing their objectives, timeline, and provisions in competitive procurement. Share the schedule for the various events that will ultimately lead to the selection of a supplier. Enumerate future tasks, obligations, and responsibilities for the soliciting organization, the contractor, and subcontractors, if any, in regards to the performance of the contract.

4. Outcome and performance standards

Specify the expected outcome, minimal performance standards expected from the contractor, and methods for monitoring performance and process for implementing corrective actions.

5. Evaluation criteria and award process

Outline the general procedures, criteria, and priorities used to evaluate and rank proposals, and to make the final selection decision. The evaluation criteria can be elaborated here based on the parameters that you have decided such as price, duration, quality, flexibility, reliability, innovation etc.

6. Deliverables and proposal response format

Provide a list of all products, reports, and plans that will be delivered to your organization and propose a delivery schedule. To facilitate the analysis of responses to the RFP, you can ask vendors to prepare the proposals in a specific format which can be outlined in this section.

7. Payments, incentives, and penalties

Specify the preffered procurement or compensation model. List all the terms of payment for adequate performance. Highlight the basis for incentives for superior performance and penalties for inadequate performance or lack of compliance.

8. Contractual terms and conditions

Specify length, start-date and end-date of the contract, as well as specific clauses for governing law, performance and default, termination and renewal, protest procedures, cost for proposal preparation, confidentiality, intellectual property, subcontracting, advertising of the contract award, compliance with laws and regulations, insurance, and indemnity.

9. Requirements for proposal preparation

A consistent structure in terms of content, information, and documents types simplifies things for the people evaluating the proposals. Describe the requirements in simple language avoiding jargons.

10. Process Schedule

Clearly and concisely present the timeline for the steps leading to the final decision, such as the dates and deadlines for submitting the letter of intent, sending questions and extension requests, attending the pre-proposal conference, withdrawing and submitting the proposal, filing a protest, etc.

12. Contacts

Include a complete list of people to contact for information on the RFP, or with any other questions. Incorporate their name, title, responsibilities, and the various ways of contacting them into this list.

6.7 Trade study report

The trade study report documents the analysis and conclusion of a trade study. This template is adapted from [1].

---

1. Scope

2. Trade study team members

Names and specialties of the contributors to the trade study.

3. Referenced documents

Provide a list of the document references in this specification. The documents shall be uniquely identifiable.

4. Functional and performance and design requirements

A.

B.

C.

5. Design approaches

Describes the design approaches considered and their significant characteristics.

Alternative 1

Alternative 2

Alternative 3

...

6. Comparison matrix

Feature or design requirement	Alternative 1	Alternative 2	Alternative 3
Requirement 1			
Requirement 1			
Requirement 1			
...			

7. Design approach recommended

A.

B.

C.

6.8 Systems engineering plan

*The Systems engineering plan (SEMP) documents the ways of working with systems engineering in the project. This template is adapted from [**?**].*

---

1. Scope

2. Referenced documents

3. Systems engineering process

3.1 **Systems engineering planning** — decision database (deliverables), process inputs, technical objectives, work breakdown structure, training, standards and procedures, resource allocation, constraints, work authorization, verification planning.

3.2 **Requirements analysis** — reliability and availability; maintainability, supportability, and integrated logistics support (ILS); survivability; electromagnetic compatibility; human engineering and human systems integration; safety, health hazards, and environmental impact; system security; producibility; test and evaluation; testability and integrated diagnostics; computer resources;M transportability; infrastructure support; other engineering specialties.

3.3 **Functional analysis** — Scope, approach, method, procedures tools (system-level functional block diagram).

3.4 **Synthesis** — approach, methods to transform the functional architecture into a physical architecture, to define alternative system concepts, to define physical interfaces, and to select preferred product and process solutions.

3.5 **System analysis and control** — trade studies, system/cost effectiveness analysis, risk management, configuration management, interface management, data management, system engineering master schedule (SEMS), technical performance measurement (TPM), technical reviews (design reviews), supplier control, requirements traceability.

4. Transitioning critical technologies

Activities, risks, criteria for selecting technologies and for transitioning these technologies.

5. Integration of the system engineering effort

Team organization, technology verification, process proofing, manufacturing of engineering test articles, development test and evaluation, implementation of software designs for system end items, sustaining engineering and problem solution support, other systems engineering implementation tasks.

6. Additional system engineering activities

Long-lead items, engineering tools, design to cost/cost as an independent variable, value engineering, system integration plan, compatibility with supporting activities, other plans and controls.

7. Systems engineering schedule

Systems engineering master schedule (SEMS), systems engineering detailed schedule (SEDS).

8. Systems engineering process metrics

Cost and schedule performance measurement, other process control technique (control charts).

9. Systems engineering process metrics

Cost and schedule performance measurement, other process control technique (control charts).

10. Other

General information that aids in understanding this document e.g., background information, glossary etc. can be included here.

Bibliography

[1] INCOSE Systems Engineering Handbook v. 3.2, INCOSE-TP-2003-002-03.2, January 2010.

[2] Joseph Kasser, Phil John, and Yeoh Lean Weng, Systems engineering a 21st century introductory course on systems engineering: the Seraswati project, APCOSE 2008.

[3] NASA Systems Engineering Handbook, SP-610S, June 1995.

[4] Frederick P. Brooks, Jr. The Mythical Man-month; Essays on software engineering, Addison-Wesley, 1995.

[5] http://standards.ieee.org/findstds/standard/830-1998.html

[6] Benjamin S. Blanchard and Wolter J. Fabrycky, Systems Engineering and Analysis, 5th ed., Persons Education, Inc., 2011.

[7] Arbejdsdirektoratet, Benchmarking af arbejdsløshedskasserne 2009, Report, November 2009.

[8] Electronic warfare in operations, Report (public), Department of the Army, Washington, DC, February 2009.

[9] Chulsung Park and Pai H. Chou, Ying Bai, Robert Matthews, and Andrew Hibbs, An Ultra-Wearable, Wireless, Low Power ECG Monitoring System, IEEE Biomedical Circuits and Systems Conference, 2006. BioCAS 2006.

[10] Appendix N: Guidance on Technical Peer Reviews/Inspections, NASA Systems Engineering Handbook, SP-610S, June 1995.

[11] System/Subsystem Specification (SSS), DI-IPSC-81431, 1994.

[12] System/Subsystem Design Description (SSDD), DI-IPSC-81432, 1994.

[13] Interface Design Description (IDD), DI-IPSC-81436, 1994.

[14] Software Test Description (STD), DI-IPSC-81439, 1994.

[15] Systems Engineering with SysML/UML, Modeling, Analysis, Design. OML Press, Morgan Kaufmann, 2008.

[16] Rune Hylsberg Jacobsen *et al.*, A Modular Platform for Wireless Body Area Network Research and Real-life Experiments, Int. Journal On Advances in Networks and Services, Vol. 2, No. 3&4, February 2012.

Appendix A

Glossary

This glossary lists the specific terms and abbreviation used in the exercises and in the case work.

ASE	Aarhus University School of Engineering
BAN	Body Area Network
Bill of material	A bill of materials (sometimes bill of material or BOM) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities of each needed to manufacture an end product.
C2	Command and Control
CDR	Critical Design Review
CMMI	Capacity Maturity Model Integration
COP	Common Operations Picture
COTS	Commercially available Off-The-Shelf (COTS) is a term defining a non-developmental item (NDI) of supply that is both commercial and sold in substantial quantities in the commercial marketplace, so it can be procured and utilized under a supplier contract.
ECG	Electro Cardio Gram
EW	Electronic Warfare
FAI	First Article Inspection is one of the primary methods for the inspection and testing of vendor components. The testing of a pre-production sample is considered essential in the process of approving an order or contract. The FAI should determine if the product meets acceptance requirements and quality control requirements.
GFE	Government Furnished Equipment
ICT	Information Communication Technology
IHA	Ingeniørhøjskolen i Aarhus — Engineering College of Aarhus
INCOSE	The International Council on Systems Engineering
LRIP	Low rate initial production (LRIP) is a term commonly used in military weapon projects/programs to designate the phase of initial, small-quantity production of a systems.
LRU	Line Replaceble Unit
MIP	Multi-lateral Interoperability Programme
MSR	MileStone Review
MWS	Missile Warninig System
PDR	Preliminary Design Review

PUID	The Project uniques identifier (PUID) is a tag to uniquely identify a delivery item of a project such as e.g., a document.
QA	Quality Assurance
QR	Qualification Review
RFID	Radio frequency identification (RFID) is the use of a wireless non-contact radio system to transfer data from a tag attached to an object, for the purposes of autoRatic identification and tracking.
RFP	Request for Proposal
SAT	Site Acceptance Test
SEIT	Systems Engineering and Integration Team
SOW	A statement of work (SOW) is a formal document that captures and defines the work activities, deliverables and timeline a vendor will execute against in performance of specified work for a client.
SRR	System Requirement Review
SysML	System Modeling Language
TRR	Test Readiness Review
U.C. Req.	Use Case Requirement

Appendix B

Context flow diagram

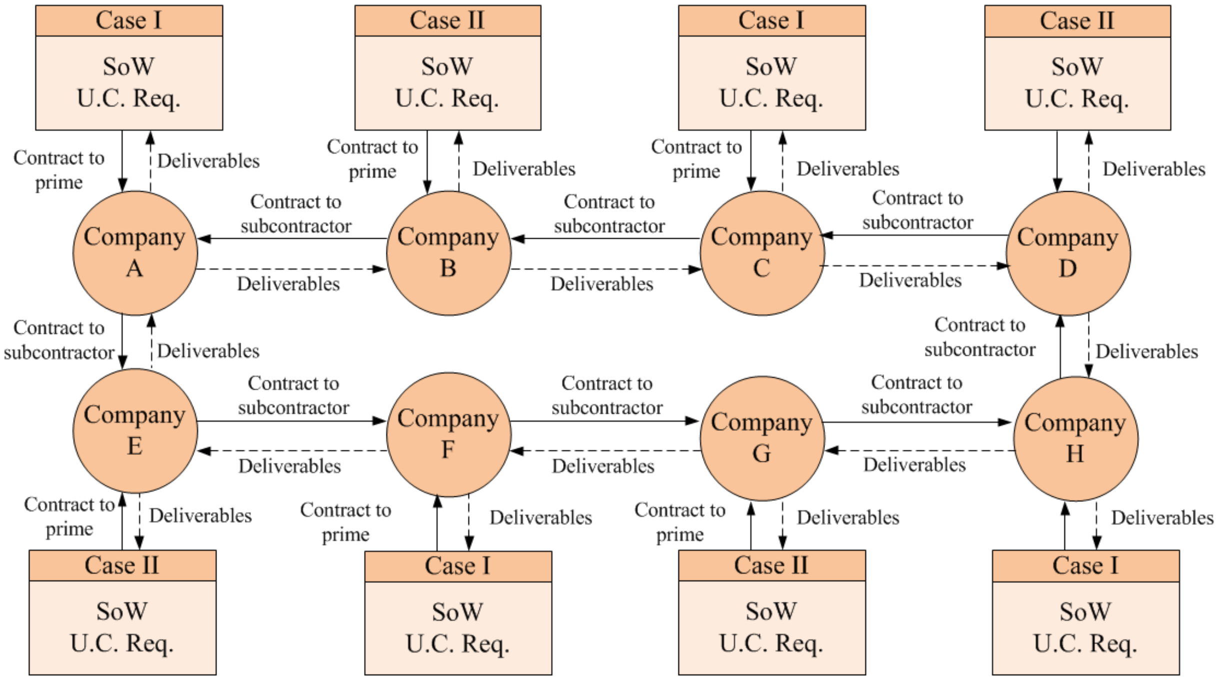

Figure B.1: Context flow diagram for the case work. The typical input for describing the case is a Statement of Work (SoW) and/or use case requirements (U.C. Req.). The term “use case requirement” is used for the output of a use case-based requirement analysis process.