REQUIREMENTS GENERATION PHASE

This lecture looks at the Requirement Generation phase of the system lifecycle. "Phase A", "Preliminary Analysis or "Concept Exploration" in NASA/ESA speak, "Needs Analysis", "Concept Development" or "System Requirement Analysis" in DoD speak, "Concept" and "Feasibility Study" phases in the Downey Cycle. The buzz phrase for this process is "Requirements’ Capture."

Requirements are statements about what functions the system must have (i.e. what it is required to do) and any constraints on it while doing those functions. In the last lecture we saw this is the equivalent of defining the system boundary and system interfaces.

Another way of looking at the system requirements is a comprehensive statement of what the customer wants (and nothing else!).

Because it contains the customer's perspective, the document defining all these requirements is called the Requirement Specification and it is the most important document in any project - as it is actually the definition of the system. In every subsequent development phase the output of that phase is referred back to the requirement specification.

(Reading: Chapters 2 and 3 of "Systems Engineering Coping with Complexity" by Stevens et al)

WHY REQUIREMENTS ARE IMPORTANT

If you do not know the requirements, you do not have a definition of the system.

Failure to properly evaluate requirements is the main reason projects fail

REASONS PROJECTS FAIL

Incomplete requirements	**13.1%**
Didn’t involve users	**12.4%**
Insufficient resources/schedule	**10.6%**
Unrealistic expectations	**9.9%**
Lack of managerial support	9.3%
Changing requirements	**8.7%**
Poor planning	8.1%
Didn’t need it any longer	**7.4%**

TOTAL DUE TO REQUIREMENTS 82.6%

Standish Group 1995

SYSTEM PURPOSE

The starting point of any system design should be a simple high level definition of the purpose of the system. It should be short, clear and potentially measurable.

e.g. **Land a man on the moon and bring him back safely before the decade is out (**which was the purpose of the Apollo moon landing programme)

Surprisingly this is often not done properly. But it is very important to a successful project and it must be established before the start of the System Requirement Phase. The system's purpose is the input to the System Requirement study and is the start of the TOP DOWN design process.

Really a system should have only one purpose. More than one purpose has the danger of purposes conflicting with no way of resolving the differences. If there is more than one purpose it is worth trying to find a way to combine them in a single higher level purpose. However a look at the example specifications in the lecture notes will show this is not easy.

Although in practice it is not often done I feel it is good practice to formally state the system purpose at the start of the Requirement Specification.

METHODS OF GENERATING SYSTEM PURPOSE

(Revision of some points about the starting point of projects in the last lecture)

Chicken and egg problem? What comes first the customer or the system?

- Does the customer ask for a system that the system engineer then invents

or

- Does the system engineer invent a system that the customer then wants.

In practice a bit of both. Concepts can be generated by:

- Looking at the system currently doing the job - assuming there is one!
- Using mission models
- Exploring technical possibilities. Work bottom up from a technical position to a system. Explore what the system can do and identify viable Purposes. Fine tune the requirements for the identified Purpose. Then work top down in a traditional system engineering manner.
- People being creative

SYSTEM'S PURPOSE, OBJECTIVES AND REQUIREMENTS

We have argued that the purpose should be single short, clear and potentially measurable statement. The keyword here is "potentially" as the measurability may not be actually contained in the purpose statement itself. The next step is to defined measurable "objectives" that if met will ensure the system will fulfil its purpose. That is they unpack the measurability of the purpose.

These Objectives create a definable "success criteria" against which system success can be judged they are also the starting point for the generation of requirements.

So we have a three stage process to reach requirements

The Purpose – the top level expression of what the system is intended to do.

Objectives – The expression of the purpose in terms of a few (no more than 5) measurable objectives – because they are measurable these can be used as success criteria for the system.

Requirements – the list of functions and constraints on the systems that derive from the objectives. These are what the system is actually created to meet.

AN EXAMPLE - UNIVERSAL SPACE INTERFACE STANDARD

Quoting from the Universal Space Interface Standard Requirement specification

"The purpose of the Universal Space Interface Standard is

to be a standard connection that maximises the interconnectivity between independent systems in both the open space (orbital) and celestial body surface environments.

To serve this purpose the USIS shall meet the following objectives:

- to provide a make and breakable connection between space systems in orbit
- to provide an interface for the connection of payloads to transport systems suitable for both ground to space and in orbit launch systems
- to provide a pressurised access path between systems suitable for a universal human presence in space."

REQUIREMENT SPECIFICATION FOR A UNIVERSAL SPACE INTERFACE STANDARD - Issue F - http://www.usisassociation.org/

WHO DETERMINES THE REQUIREMENTS?

The top down design philosophy of systems engineering requires that the process starts with an understanding of the system as defined by its requirements (which is a definition of its boundary). Of course the requirements are ultimately generated the people who use the system - the Customer, users and operators (collectively known as stakeholders).

But who actually formalises the requirements into the Requirement Specification depends on the industry and on its Customer/Supplier relation. There are two basic ways in which it happens:

1 Customer Generated Requirements.

This tends to occur when a system has a single customer. For example, military aircraft are built to specifications produced by the customer air force

Typically the air force will have teams continually reviewing the role and missions the various types of aircraft they use as well as assessing the impact of relevant new technologies. When the procurement cycle comes to purchasing replacements the team will put together a requirement specification that both meets the air force needs and is technically and financially feasible. Sometimes a customer produced specification will be met by a specially built system, sometimes by an off the shelf product which is the result of a supplier generated requirement specification.

2 Supplier Generated Requirements.

This tends to occur when a system is to be sold to many customers. For example civil airliners

Although the supplier is writing the requirement specification typically the suppliers will be in contact with their customers - via market surveys or direct customer involvement. For airlines direct contact with customers will be made; for a product like cars, with many customers, statistical market surveys are normally used.

WHAT IS A REQUIREMENT

Requirement: A function the system must be able to perform or a constraint that is imposed on it in order for it to meet the system objectives.

There are two types of Requirement

Functional – A statement of a function the system must possess.
Function – An emerging property of the system. Something the system does.
Performance – The desired value of a function that can be numerically measured.

Constraint – A statement of restriction limiting the range of acceptable solutions (also called a Non-functional Requirement.)

EXAMPLE- FOR A CAR

The car shall carry 4 passengers.
(Function with performance)

The car shall protect passengers from rain and wind.
(Function)

The car shall have a maximum speed in excess of 110 km/hr.
(Function with performance)

The car shall have maximum dimensions of width 1.9 m, length 4.7 m, and 1.7 height.
(Constraint)

The car shall comply with all UK road vehicle regulations.
(Constraint)

REQUIREMENT SPECIFICATIONS

All the requirements for the system are collected in a document called the **Requirement Specification**

This is the fundamental document for the system engineering process and the key output of the requirement definition phase. The "Requirement Specification" sets out all the things the system must do.

A Requirement Specification should contain:

- The purpose and objectives of the system (although as noted earlier this is often not included.)

- The functions and performance of the system (defined precisely and if possible with numbers)

- The Constraints (a definition of the system interfaces - technical, environmental, legal etc.)

The above is a purest view - in practice some other things are also often included, sometimes with good reason - more often not. These are:

- Some high level element splits within the system. This may be appropriate when there is some question about what the customer expects to be delivered.

- Some definition of the engineering and quality standards to be used. These are additional to any legal obligations outlined above. Generally this is an indication of how much the customer is prepared to pay for risk reduction

- Some constraints on how it should be built. i.e. technical solutions - **Never good practice -** this should be left to Phase B and the design team who will build the system. When it is included it is often just a collection of prejudices of the Phase A team and it greatly restricts innovation and the search for an optimum solution.

REQUIREMENT SPECIFICATION - GOOD PRACTICE

A requirement specification is:

1- The definition of the system: (if it is not clear then the system is undefined.)
2- A legal document: it defines what is to be delivered.

Because of the importance of the requirement specification there has been a growing practice of making them large and complex documents. This is particularly true of customer generated specifications where the customer has a large engineering team who have firm opinions on how the job should be tackled, even though they are not the people who will actually do the job.

This is bad practice. Every line, every word, in a requirement specification costs money. So it should be reduced to the barest minimum. In Stevens et al they suggest the document should not exceed 100 pages but even that is controversially large. It has been proposed that in many cases - even for large systems - the requirement specification can (and therefore should) be written on a single sheet of paper.

> **WARNING – DO NOT TRY THIS AT HOME!** Single sheet requirement specifications are advanced stuff and controversial and only to be attempted by experienced systems engineers who know what they are doing. This definitely does not mean you – YET!

A requirement specification should not include:

- Any direction as to technical approach.
- Any explanation as to why the requirements are set.
- Any negative requirements (i.e. the system shall not...).
- Any conflicting (or potentially conflicting) requirements.

????SAT

Some features of the requirement specification of a certain communications satellite (name withheld to protect the guilty).

The Specification was over 130 pages long. A sure sign of trouble!

It specified on orbit delivery of the satellite i.e. manufacturer is responsible for the launch which is fine this eases the load on the customer and allows more freedom for the contractor to find the best overall system solution. However the specification goes on to undo all the potential benefit of the approach by specifying:

- That the launch system was to be limited to Delta, Proton, Ariane, and Shuttle / PAM-D (with small cover).
- The maximum total launch mass of the satellite although this is implied by the launch system.
- Specified the dry mass of the satellite limiting the contractor on propulsion and orbital strategies that can be employed.

None of the above effected the operational (i.e. communications) functions required of the satellite. It simply restricted potential solutions, excluding some of which may have been better and cheaper.

REQUIREMENT SPECS - ADVICE

TECHNICAL

The contents must be comprehensive - everything that affects the customer must be defined in it. BUT do not include anything that is not a concern of the customer.

Every requirement in the specification must be tracked back to the objectives.

Make sure every requirement is testable (i.e. it can be measured). This means hard numbers and precise definitions. Think how you are going to test a requirement before it goes in the spec.

ENGLISH

The Requirement Specification should be short and concise, but it should also be a proper document with a complete prose style - not just bullet points and notes. The language must be formal and legalistic.

The tense in a Requirement Specification is future i.e. you shall always use "shall".

It is good practice to devote one paragraph to one requirement and every paragraph should be numbered.

Some works make a distinction about “shall”, “will” “may” and “could”. “Shall” and “Will” are almost (but not quite) synonyms in modern English but the legally safe option is “shall.” Using “shall” also makes the work look more professional – it shows you know the code. To me using “may” and “could” is in most cases superfluous, either you want something and are prepared to pay for it, or you don’t. “May” implies it is not essential but a nice to have that you are not prepared to pay for. Which is rarely valuable information in the real professional world.

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USER AND TECHNICAL SPECS.

In industries like aerospace the customer (Military, Space Agency, or Airline) has a body of engineering expertise who fully understand the system and its engineering detail. In these case there is normally only one Req. Spec.

In other areas (especially computer software development) the customer is unlikely to understand the technology involved and would not understand the technicalities in a conventional Req. Spec. And a specification they would understand does not directly contain the information required for subsequent technical work.

To overcome this - a two stage requirement definition process can be used.

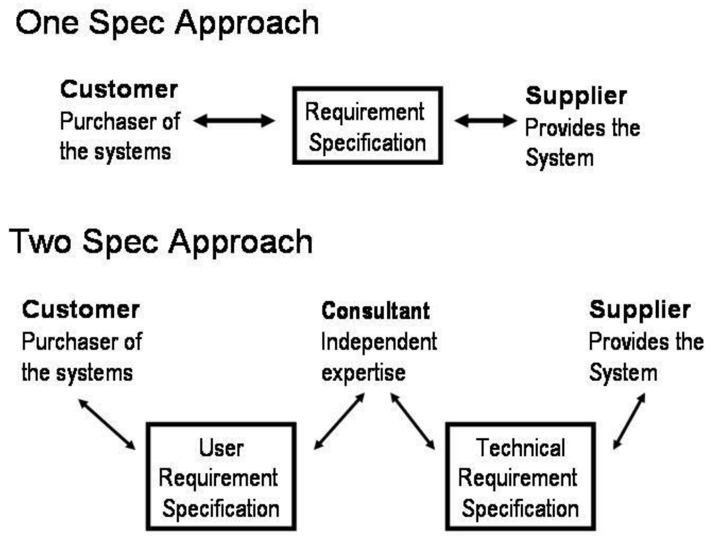
1 - USER REQUIREMENT SPECIFICATION, which is agreed with the customer. It outlines in layman terms what the system is required to do.

2 - SYSTEM REQUIREMENT SPECIFICATION, which "translates" the User Requirement Specification into technical functional and performance requirements.
(Also called TECHNICAL REQUIREMENTS SPECIFICATION)

Silly Example - buying a car

User requirement - *"The car shall go faster than my next door neighbour's car"*

System requirement - *"The car's maximum speed on a straight level tarmac surface shall exceed 75 mph"*



Stevens *et.al*. imply the User requirement specification should always be used (but note the authors' jobs!). In my view User Requirement Specifications have become a bit of a fashion and are used where they are not appropriate. If the customer organisation has the technical expertise the System (or Technical) Requirement specification should be the only formal document – it is less work and less chance of requirement induced problems.

OTHER DOCUMENTATION

The requirement specification is the key document to come out of a requirement generation study. As we have seen this should be short, formal and minimalist in style.

On major projects it is important to have a record of how the requirements were arrived at. This can be just a large number of separate working notes and other reports produced as the requirement studies progresses, but this can prove difficult to track back on later. The best approach is a requirements justification document, which point by point explains why the requirements in the specification are what they are and references supporting documentation.

It should explain what models were used, what assumptions were made, and if guessing or prejudice were the reasons then say so (there are bound to be some requirements that fall into this category so it is better to just admit it).

The requirement justification should be written in parallel with the specification and not left until later. One of its most useful roles is to aid re-evaluation of the requirements in light of the technical and cost feasibility studies during the remainder of the requirement generation phase.

JUSTIFICATION VISIBILITY

A point made above is that the requirement specification should not contain any explanations. This interferes with the legal purpose of the document and can cause confusion. It was also generally thought to be good practice not to show contractors any of the justification documentation - after all there is no need for a contractor to know the reasoning behind the specification.

Some subcontractors may use any explanation of the requirements to justify non-compliance as being “in the spirit of the specification”.

There has been a trend (e.g. Boeing's "Working Together" initiative) to show the contractor the justification for the requirements.

It is addressing the problem summed up by Boeings CEO who when speaking to a contractors meeting to introduce the "Working Together" initiative, said *“the problem is you guys keep giving us what we ask for, not what we want”*

The reasoning behind showing the requirements justification is that if the contractor knows where you are coming from, he can propose alternatives - e.g. existing equipment or new technologies - that, while not strictly meeting the specification, would be better. The contractor might also be able to point out mistakes or issues with the specification that otherwise would cause problems later in the project.

The format Boeing use is after every paragraph (i.e. after each requirement - see advice above) the justification is included in italics as a commentary. This commentary is not legally part of the spec but it provides the reader with the explanation and insight where it is most useful.

E.g. from silly example above

> "2.1.3 The car's maximum speed on a straight level tarmac surface shall exceed 75 mph.
>
> *This requirement derives from the customer's objective to have a car faster than his neighbour. His neighbour drives a Reliant Robin LX with an 848 cc engine. This has a maximum speed of 75 mph in motorway conditions."*

----- And now – (Cue - drum roll and trumpets) -----

THE PROJECT – Stage 1

The objective of this is to get practical experience writing requirement specifications. Requirement Specifications are a key tool in the system engineering, they are also difficult to get right so the logic is to get your first attempt in the safety of this unit.

In Stage 1 you are to write a requirement specification for an everyday object such as cars, TVs, sound systems, washing machines etc. that can be purchased.

Include the system's purpose and measurable objectives as well as the requirements. Also include a commentary explaining why the requirements are there. The project is primarily assessing how well you move from purpose to measurable objectives to workable requirements.

Some advice
1) It does not matter what the system you pick is so do not waste time agonising over your choice
2) Just pick something that could sensibly be categorised as a system and that you know about.
3) Do not make it too complicated, unnecessary requirements score as badly as missing requirements. It is about getting it right!

Due for submission as (MSWord or RTF) before 1st Nov 2019.

(Do not forget to put your name as the author of the requirement specification,)

In Stage 2 your specification will be given to another student to select a real life product that best meets your specification. It means the specification will actually be used - so bear this in mind.