

Requirements Engineering, Part 1

Developed and presented by
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for INCOSE



Brief Bio

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Dick Fairley is a long-time member of INCOSE. He is an author of the Guide to the Systems Engineering Body of Knowledge (SEBoK V 1.0), an editor of the present SEBoK V 1.9.1, an INCOSE commissioner for ABET accreditation of systems engineering degree programs, and INCOSE liaison to the IEEE Systems Council.

He is principal associate of Systems and Software Engineering Associates (S2EA), a consulting and training company. Dick is a former professor and associate dean of the Oregon Graduate Institute and past Chair of the IEEE Computer Society Systems and Software Engineering Committee. He was co-editor of the Software Engineering Body of Knowledge (SWEBOk V 1.3) and leader of the teams that developed the Software Engineering Competency Model (SWECOM) and the Software Extension to the PMI Guide to the Project Management Body of Knowledge (SWX).

His Bachelors and Masters degrees are in electrical engineering and his PhD is in computer science and applied math. He worked in industry as an electrical and systems engineer before returning to school to obtain his PhD from UCLA.

Dick and his wife Mary Jane live in the Colorado mountains northwest of Colorado Springs. He enjoys listening to jazz, hiking, and skiing. They enjoy motorcycling together.

Five training webinars

1. Stakeholders' requirements

November 8, 2018

2. System requirements

November 15, 2018

3. System architecture

January 3, 2019

4. System design

January 10, 2019

5. System implementation

- January 17, 2019

All 5 webinars are being presented at noon EST and recorded for later viewing

Primary references for this training webinar #1 (1)

Clauses 6.4.1 and 6.4.2 of ISO/EIC/IEEE Standards 15288:2015 and 12207:2017

- **15288:** Systems and Software Engineering - - System life cycle processes
 - <https://www.iso.org/standard/63711.html>
 - <https://standards.ieee.org/standard/15288-2015.html>
- **12207:** Systems and Software Engineering - Software Life Cycle Processes

15288 <https://www.iso.org/standard/63712.html>
12207 <https://standards.ieee.org/standard/12207-2017.html>

Primary references for this training webinar #1 (2)

Systems Engineering for Software-enabled Physical Systems
e.g., embedded, IoT, cyber-physical, C2 systems, and others

To be published by Wiley in early 2019

Author: Dick Fairley

References for this webinar:

Section 5.2: Capabilities-based system development

Chapter 6: The I³ system definition phase

Other reference materials

1. INCOSE Systems Engineering Handbook
2. INCOSE Systems Engineering Competency Framework
3. INCOSE Guide for Writing Requirements
<https://connect.incose.org/Pages/Store.aspx>
3. The Guide to the Systems Engineering Body of Knowledge
<https://sebokwiki.org>
4. ISO/IEC/IEEE 29148:2011 Systems and software engineering
Life cycle processes -- Requirements engineering
<https://www.iso.org/standard/45171.html>
<https://standards.ieee.org/standard/29148-2011.html>

Agenda for this training webinar #1

- Some terminology
- Business or mission analysis
- Stakeholder needs and requirements definition
- Brief intro to capabilities-based RE

Some terminology

The following roles to be played in requirements engineering are defined in Annex 1 to these slides:

Acquirer

Specialist engineer

Supplier

System architect

Primary stakeholder

System designer

Secondary stakeholder

System implementer

Customer

System verifier

Project manager

System validator

Systems engineer

System operator

Disciplinary engineer

System maintainer

Users and uses of requirements

- Systems engineers*:
 - Define the system requirements
 - Preparing plans for the technical work to be done.
 - Conducting risk analysis for the technical work.
 - Aid project manager by preparing estimates and plans for needed technologies and technical disciplinarians (kinds and numbers).

*Systems engineers use stakeholders' requirements;
They may or may not prepare the stakeholders' requirements

Requirements Engineering

Part 1 agenda

- Some terminology
- **Business or mission analysis**
- Stakeholder needs and requirements definition
- Brief intro to capabilities-based RE

The role of Business or Mission Analysis

- According to Section 6.4.1 of the 15288 standard, the purpose of the Business or Mission Analysis process is:
“to define the business problem or mission need or the opportunity,
characterize the solution space, and
determine potential solution class(es) that could address a problem or take advantage of an opportunity.”

Business or Mission Analysis

Input	A business problem, mission need, or opportunity to be studied.
Process	Define the business problem, mission need, or opportunity. Then describe the solution space and Determine one or more solution classes in the solution space.
Output	A documented definition of a business problem, a mission need, or an opportunity plus a description of the solution space and one or more solution classes. And a go, no-go, no-bid, or further-study decision.

A small example

- An opportunity:
 - To develop, license, and sell a variety of realistic driving system simulators for land based vehicles having four or more wheels.
- The solution space:
 - The solution space ranges from a simple laptop and touch pad application; to a steering wheel and a display screen; to full-scale vehicles instrumented with sensors, actuators, controls, and displays.
- A solution class
 - Flight training simulators used to train and certify commercial and military pilots provide a solution class for realistic driving system simulators.

The role of systems engineers in business or mission analysis

Systems engineers should participate in:

- Defining the business problem, mission need, or opportunity
- Documenting the business problem, mission need, or opportunity
- Describing the solution space
- Defining one or more solution classes
- Determining how to proceed
 - go, no-go, no-bid, further study

Systems engineers may not be directly involved in business or mission analysis, but should be

The role of systems engineers in business or mission analysis (2)

- The list of activities on the previous chart can be used as a review checklist when systems engineers are not directly involved in business or mission analysis:
- Is the business problem, mission need, or opportunity adequately defined?
- Is the business problem, mission need, or opportunity adequately documented?
- Is the solution space adequately described?
- Is one or more solution classes adequately defined?
- Is the next step appropriate?
 - go, no-go, no-bid, further study

Adequately: is there a sufficient basis for defining the stakeholder's requirements?

Documenting business or mission analysis

A Business or Mission Analysis statement should contain the following information:

- A statement of the business problem, mission need, or opportunity;
- Conformance with the organization's mission and vision statements;
- A characterization of the operational context;
- A characterization of the solution space;
- Analysis of some alternative solution classes and solution strategies;
- Current and potential stakeholders;
- Primary operational concepts;
- Upper bounds on acceptable cost and schedule;
- Analysis of technical, financial, social, environmental, political, and regulatory constraints;
- Security threats and safety hazards that need to be understood and accounted for;
- Enabling systems, services, and/or infrastructure needed; and
- A recommendation to proceed or to not proceed.

Requirements Engineering Part 1

agenda

- Some terminology
- Business or mission analysis
- **Stakeholder needs and requirements definition**
- Intro to capabilities-based RE

Stakeholders' Needs and Requirements Definition

Input	A documented statement of a business problem, a mission need, or an opportunity. And a decision to proceed.
Process	Identify stakeholders and characterize the operational environment. Elicit, categorize, and prioritize operational requirements. Identify needed system capabilities, constraints, and risk factors. Conduct a feasibility study. Develop a documented agreement between the acquiring organization and the supplying organization.
Outputs	Assuming a decision to proceed based on the feasibility study and a risk analysis: Stakeholders' requirements definition, system capabilities, constraints, and identified risk factors. A Statement of Work or Memo of Understanding. A Concept of Operations that includes operational scenarios.

SOW,MOU, and ConOps

- Descriptions of, and formats for, SOWs, MOUs and a ConOps are presented in Annex 2 of these slides

The role of systems engineers in stakeholders' requirements definition

- Identify system stakeholders
- Elicit stakeholders' needs, wants, and desires
- Prioritize and categorize stakeholders' need, wants, and desires
- Document the stakeholders' requirements definition
- Analyze technical feasibility
- Manage the stakeholders' requirements definition

Systems engineers may not be directly involved in defining stakeholders' requirements, but should be

The role of systems engineers in stakeholders' requirements definition (2)

- The list of activities on the previous chart should be used as a review and revise checklist when systems engineers are not directly involved in stakeholders requirements definition:
 - Are the system stakeholders adequately identified?
 - Are stakeholders' needs, wants, and desires adequately elicited?
 - Are the stakeholders' need, wants, and desires adequately prioritized and categorized?
 - Is the stakeholders' requirements definition adequately documented?
 - Is technical feasibility adequately analyzed?
 - Are plans for managing the stakeholders adequate?

Adequate: is there a sufficient basis for defining the system requirements?

Stakeholder Needs and Requirements Definition

The system engineering activities of stakeholder needs and requirements definition include:

1. Identifying the stakeholders
2. Eliciting stakeholders' requirements
3. Categorizing and prioritizing stakeholders' requirement
4. Determining technical feasibility
5. Verifying and validating stakeholders' requirements
6. Managing stakeholders' requirements

Identifying stakeholders

- Start with those who initiated the business or mission inquiry
 - To clarify the business problem, mission need, or opportunity
 - Ask them for other contacts and contact them
- Identify and interview subject matter experts
 - To determine their views and other contacts
- Write a narrative statement of the business problem, mission need, or opportunity and
 - Develop a wordcloud from the narrative statement

A wordcloud



<https://worditout.com/word-cloud/create>

Other considerations

- Use the wordcloud and other considerations to identify primary stakeholders
- Other stakeholders' concerns may be:
 - Managerial, contextual, social, political, or regulatory
- Continue to be on the lookout for system stakeholders

Caution: a wordcloud is no better than the narrative on which it is based

Stakeholder Needs and Requirements Definition

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Techniques for eliciting stakeholders' requirements

- Elicitation techniques include:
 - Brainstorming;
 - Questionnaires;
 - Surveys;
 - Observations;
 - Structured interviews;
 - Prototyping;
 - Focus groups; and
 - Structured workshops.

Elicitation is the process of discovering the real stakeholders' needs, wants, and desires

Stakeholder Needs and Requirements Definition

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Categorizing the stakeholders' requirements definition

- The stakeholders' requirements definition can be categorized as:
 - System features;
 - Quality attributes;
 - Design constraints;
 - Will nots; and
 - Must nots.

System features

- System features include externally observable functions and behaviors
- Observable system functions are input/output relationships
- Observable behaviors are sequences of executed functional inputs and outputs across time
 - Also, monitoring of continuous analog performance indicators

Some behaviors may execute functions concurrently

Some quality attributes

Externally observable	Internally observable
Safety	Testability
Security	Modifiability
Reliability	Reusability
Availability	Configurability
Performance	Serviceability
Ease of use	Installability

Externally observable quality attributes must be prioritized

Stakeholders' design constraints

- Stakeholders' design constraints are “must-bes” and may include:
 1. Inclusion of legacy elements

Q: Are the elements suitable choices for inclusion?
 2. Performance parameters, and displays and reports to be generated

Q: Are they subjective? Are they realistic? Are they necessary?
 3. Requests for use of unproven technologies

Q: Are there acceptable proven technologies?

Always examine stakeholders' design constraints and propose alternatives, if necessary

Categorizing the stakeholders' requirements definition

- The stakeholders' requirements definition should include:
 - System features;
 - Quality attributes;
 - Design constraints;
 - Will nots; and
 - Must nots.

Will nots: to control stakeholder expectations

Must nots: to satisfy safety, security, policies, rules, regulations, and other constraints

Prioritizing stakeholders' requirement

Stakeholders' requirements can be prioritized as:

- Essential: minimal must-be requirements
 - To be included in the initial version of a system (V1.0)
- Desirable: should-be requirements
 - To be included in V1.0 if possible, or in later versions
- Optional: could be requirements
 - A placeholder for future versions when time, resources, technology, and/or stakeholder demand justifies including them

Prioritization criteria for features, quality attributes, and design constraints

- Essential priorities
 - Those implemented first will be tested most as others are added
 - Some will provide a platform for developing others
- Desirable priorities
 - Some will be more desirable than others for inclusion in V1.0 if time and resources permit inclusion
 - Some will be candidates for first inclusion in V2.0
- Optional priorities
 - Some will be first candidates based on the business problem, mission need, or opportunity
 - Some will be first candidate based on evolution of needed technologies

Driving system simulator requirements

- Essential requirements:
 - Those needed to simulate realistic driving conditions on dry, smooth roads
- Desirable requirements:
 - Those needed to additionally simulate driving conditions on wet, slick roads
- Optional requirements:
 - Those needed to simulate Level 5 self-driving automobiles

Requirements should be prioritized within the E, D, and O categories

Stakeholder Needs and Requirements Definition

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Determining technical feasibility

- Technical feasibility can be determined by examining:
 - Available expertise (domain and disciplinary)
 - Local experience with similar projects
 - Analogies from other systems and organizations
 - Historical precedents for similar systems
 - Maturity of the needed technologies
- The outcome may be:
 - Proceed
 - Proceed if the stakeholders' requirements are significantly revised
 - Delay for more study
 - Defer until later
 - A no-bid or no-go decision

Some outcomes may not be as recommended by systems engineers

Stakeholder Needs and Requirements Definition

The activities of stakeholder needs and requirements definition include:

1. Identifying the stakeholders
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Verifying stakeholders' requirements

- Verification: *determining the degree to which* stakeholders' requirements, when implemented, will
 - Provide a solution to the business problem, mission need, or opportunity
 - And, satisfy the stakeholders' needs

Verification techniques

- Verification techniques for stakeholders' requirements include:
 - Storyboarding
 - Persona modeling
 - Use case analysis
 - Operational scenarios
 - Prototyping
 - Simulating
 - Traceability to keywords in the business problem, mission need, or opportunity narrative

Validating stakeholders' requirements

- Validation: *determining the degree to which* the documented stakeholders' requirements will serve the needs of those who will use the requirements to:
 - Define the system capabilities and system requirements
 - Define the operational context for the proposed system
 - Conduct managerial and technical feasibility studies
 - Analyze infrastructure requirements
 - Prepare a ConOps and a SOW or an MOU

Determining the degree to which:
V&V outcomes are not binary

Stakeholder Needs and Requirements Definition

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Manage stakeholders' requirements

- Stakeholders' requirements should be placed under change control
 - All appropriate stakeholders should be consulted about proposed changes and all stakeholders should be notified when changes are made
- Change notices should include:
 - Date change(s) were made
 - Who made the change(s)
 - What was changed
 - Rationale: Why the change(s) were made
 - Impact of a change on other requirements and other work products

Requirements Engineering

Part 1 agenda

- Some terminology
- Business or mission analysis
- Stakeholder needs and requirements definition
- Brief intro to capabilities-based RE

Defining and analyzing stakeholder needs and requirements

Stakeholder needs and requirements definition*

“The purpose of the Stakeholder Needs and Requirements Definition process is to define the stakeholder requirements for a system that can provide the *capabilities* needed by users and other stakeholders in a defined environment.”

* ISO/IEC/IEEE Standard 15288, clause 6.4.2.1

System capabilities

- A system capability is the ability of a system to execute a ~~specified~~ course of action or to exhibit ~~specified~~ a state of being
 - Specified or perhaps unwanted;
 - ✓ unwanted: emergent and non-deterministic behaviors
- Capabilities can be derived from stakeholders' requirements
 - And can provide the bridge from stakeholders' requirements to system requirements

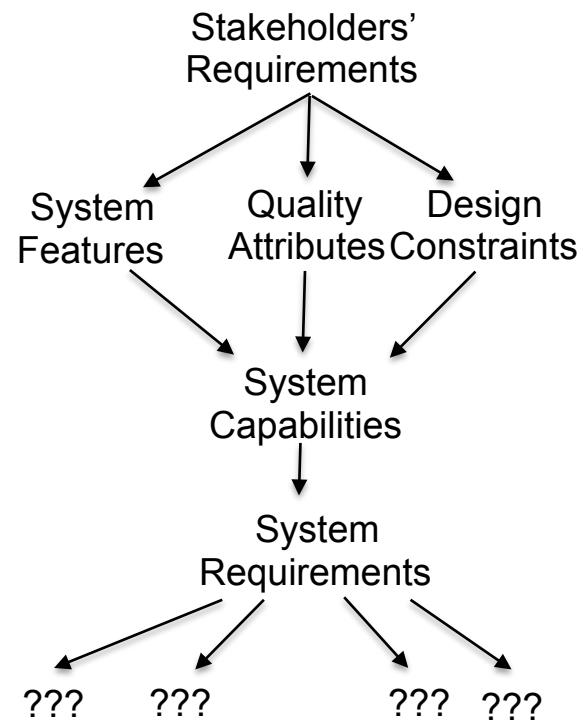
System requirements are generated for each system capability and conflicts among the requirements are reconciled

The capabilities-based approach for an ATM

	Hardware, Software, and Interfaces							
Capabilities	Card Reader	Display Screen	Keypad	Cash Safe	Cash Dispenser	Funds Depository	Printer	
Customer authentication	X	X	X					
Session termination		X	X				X	
Balance query		X	X					
Cash withdrawal		X	X	X	X			
Funds deposit		X	X			X		
Funds transfer		X	X					

Each system capability is realized by concurrently developing hardware, software, and interfaces

A requirements taxonomy



Stay tuned for Part 2 of requirements engineering
To be presented and recorded on Nov. 15, 2018

Question? Comments?

Note: Annexes 1 and 2 follow
Annex 1: terminology
Annex 2: SOW, MOU, ConOps

Annex 1: Terminology

The following roles to be played in requirements engineering are defined this Annex 1:

Acquirer

Specialist engineer

Supplier

System architect

Primary stakeholder

System designer

Secondary stakeholder

System implementer

Customer

System verifier

Project manager

System validator

Systems engineer

System operator

Disciplinary engineer

System maintainer

Some terminology: Acquirer and Supplier

- An *acquirer* is an organization or an individual that enters into an agreement with a *supplier* to obtain a product or service enablers.
 - An acquirer may, in addition, be a customer, a system user, and/or other system stakeholder; or a distinct entity
- A *supplier* is an organization or an individual that enters into an agreement with an *acquirer* to provide a product or enable a service.
 - The agreement may be formal (e.g., a contract & SOW) or informal (e.g., an informal MOU).

Some terminology: Stakeholders

- *Primary Stakeholders* are hands-on system users
 - Those who will use a new or modified system to perform their job functions or pursue their leisure activities
 - System operators and system maintainers
- *Secondary stakeholders* are those others who will affect or be affected by development, deployment, and/or operation of the system Some may provide system inputs
 - Some may use the outputs
 - Some may be responsible for preparing the system infrastructure
 - Some may have social or political concerns

Some terminology: Customer

- A *customer* is an organization or an individual that:
 - provides the stakeholders' requirements and/or provides access to stakeholders;
 - reviews work products and provides guidance during system development; and
 - accepts the delivered product or service enablers on behalf of the stakeholders
- A customer may also provide financial resources and legacy elements to be incorporated into the envisioned system
- The customer may also be the acquirer

Users and uses of requirements

- Acquirer:
 - Assess the validity of the requirements and prepare a facilities plan.
- Customer:
 - Validate the degree to which the requirements included needed features, quality attributes, and design constraints.
- Project manager: Prepare estimates and plans; conduct risk analysis.

Users and uses of requirements (2)

- Systems engineers*:
 - Define the system requirements
 - Preparing plans for the technical work to be done.
 - Conducting risk analysis for the technical work.
 - Aid project manager by preparing estimates and plans for needed technologies and technical disciplinarians (kinds and numbers).
- Engineering specialists:
 - For safety, security, reliability, availability, and other quality requirements

*Systems engineers use stakeholders' requirements;
They may or may not prepare the stakeholders' requirements

Users and uses of requirements (3)

- System architects and designers:
 - Use the system requirements as a basis for architecture and design
 - Establish and analyze traceability links
- System implementers:
 - determine the implementation requirements that must be satisfied.
- System verifiers and validators:
 - Determine the needed V&V facilities
 - Develop initial test plans, test scenarios, and test cases
 - Maintain and analyze traceability links

Users and uses of requirements (4)

- System operators and maintainers: Assess the degree to which operational and maintenance requirements are adequately addressed.
- All stakeholders:
 - Analyze the degree to which the desired and necessary system attributes *of interest to them* are included in the stakeholders requirements
 - Iterate, Iterate, iterate

Multiple representations and views of stakeholders' requirements are needed to serve all interests

Annex 2: SOW,MOU, and ConOps

- Descriptions of, and formats for, SOWs, MOUs and ConOps are presented in this Annex

The SOW or MOU

- A Statement Of Work (SOW) is a formal agreement between a supplier and an external acquirer and may be part of a formal contract
- A Memo Of Understanding is an informal agreement between a supplier and an acquirer and may be for an internal or external acquirer

Elements of a SOW or MOU

Elements of SOWs and MOUs include:

- Technical goals to be achieved;
- Scope of work to be accomplished;
- Identification of acquirer, customers, and key stakeholders;
- Supplier key personnel, availability, and responsibilities;
- Cost, schedule, resource, and technology constraints;
- Policies, guidelines, regulations, and standards to be observed;
- Shared responsibilities and dependencies between the acquirer and supplier; and
- Other goals, objectives, and constraints that will affect system development, deployment, and sustainment.

The Concept of Operations

- IEEE Standard 1362-1998 documents the format and contents of a ConOps.
- It is available for purchase from IEEE
- The contents of 1362 have been absorbed in the ISO/EAC/IEEE standard 29148:2011 for requirements engineering
 - And the ConOps material is less visible

Various forms of ConOps can be found by Web search

The Concept of Operations (ConOps)

Key elements of a ConOps include:

- the business problem, mission need, or opportunity
- deficiencies of the current system or situation
- the envisioned system
- key stakeholders
- prioritized features, quality attributes, and design constraints
- envisioned modes of operation
- operational scenarios
- operational policies and constraints
- functions and behaviors the envisioned system will not provide
- limitations and restrictions on what the envisioned system must not do
- managerial and technical risk factors
- impacts during development and operation of the envisioned system

Operational scenarios

- Operational scenarios can be often documented in Use Cases using one or more of:
 - Itemized sequences of interactions
 - Sequence diagrams
 - Activity diagrams
 - State diagrams
 - Use case diagrams

See <http://www.omg.org>