Software Engineering (COMP 401)
Chapter 6- System Engineering

Rabindra Bista, PhD
DoCSE, SOE, KU
Spring 2021

Topics covered

- Sociotechnical systems
- Conceptual design
- Systems procurement
- System development
- System operation and evolution

Systems

- Software engineering is not an isolated activity but is part of a broader systems engineering process.
- Software systems are therefore not isolated systems but are essential components of broader systems that have a human, social or organizational purpose.
- Example
  - Wilderness weather system is part of broader weather recording and forecasting systems
  - These include hardware and software, forecasting processes, system users, the organizations that depend on weather forecasts, etc.

Types of system

- Technical computer-based systems
  - Include hardware and software but not humans or organizational processes.
  - Off the shelf applications, control systems, etc.
- Sociotechnical systems
  - Include technical systems plus people who use and manage these systems and the organizations that own the systems and set policies for their use.
  - Business systems, command and control systems, etc.

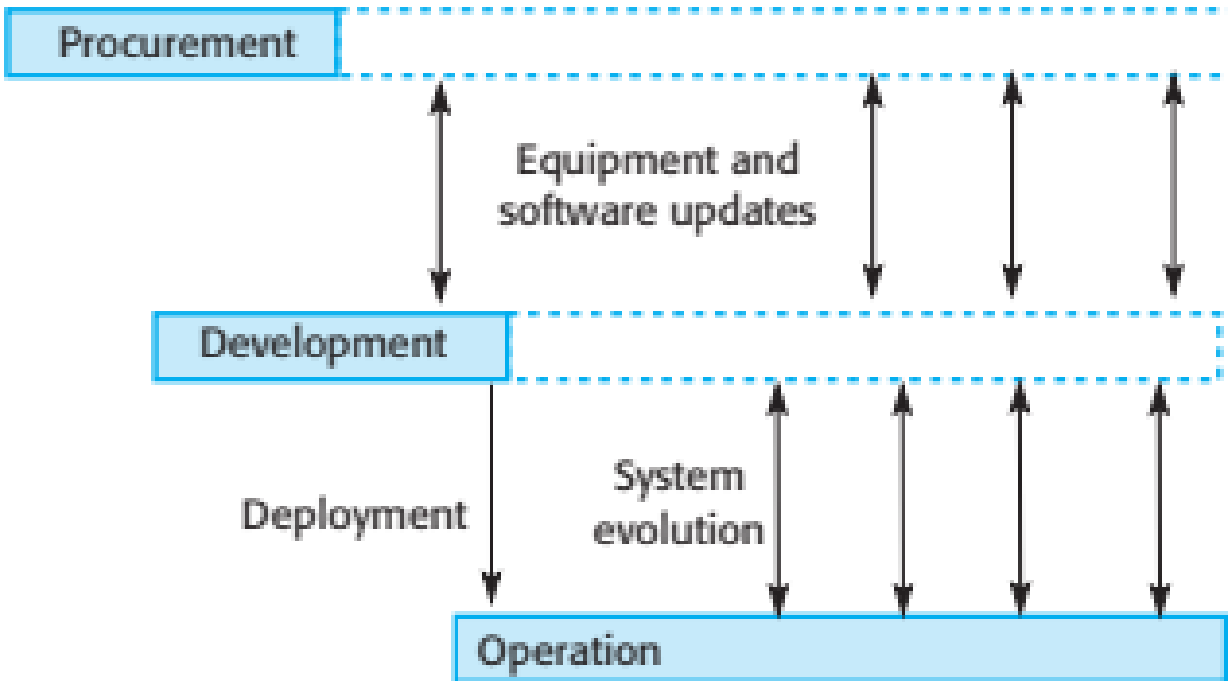
Systems engineering

- Procuring, specifying, designing, implementing, validating, deploying and maintaining sociotechnical systems.
- Concerned with the services provided by the system, constraints on its construction and operation and the ways in which it is used to fulfil its purpose or purposes.

Systems and software engineering

- Software is now the dominant element in all enterprise systems. Software engineers have to play a more active part in high-level systems decision making if the system software is to be dependable and developed on time and to budget.
- As a software engineer, it helps if you have a broader awareness of how software interacts with other hardware and software systems, and the human, social and organizational factors that affect the ways in which software is used.

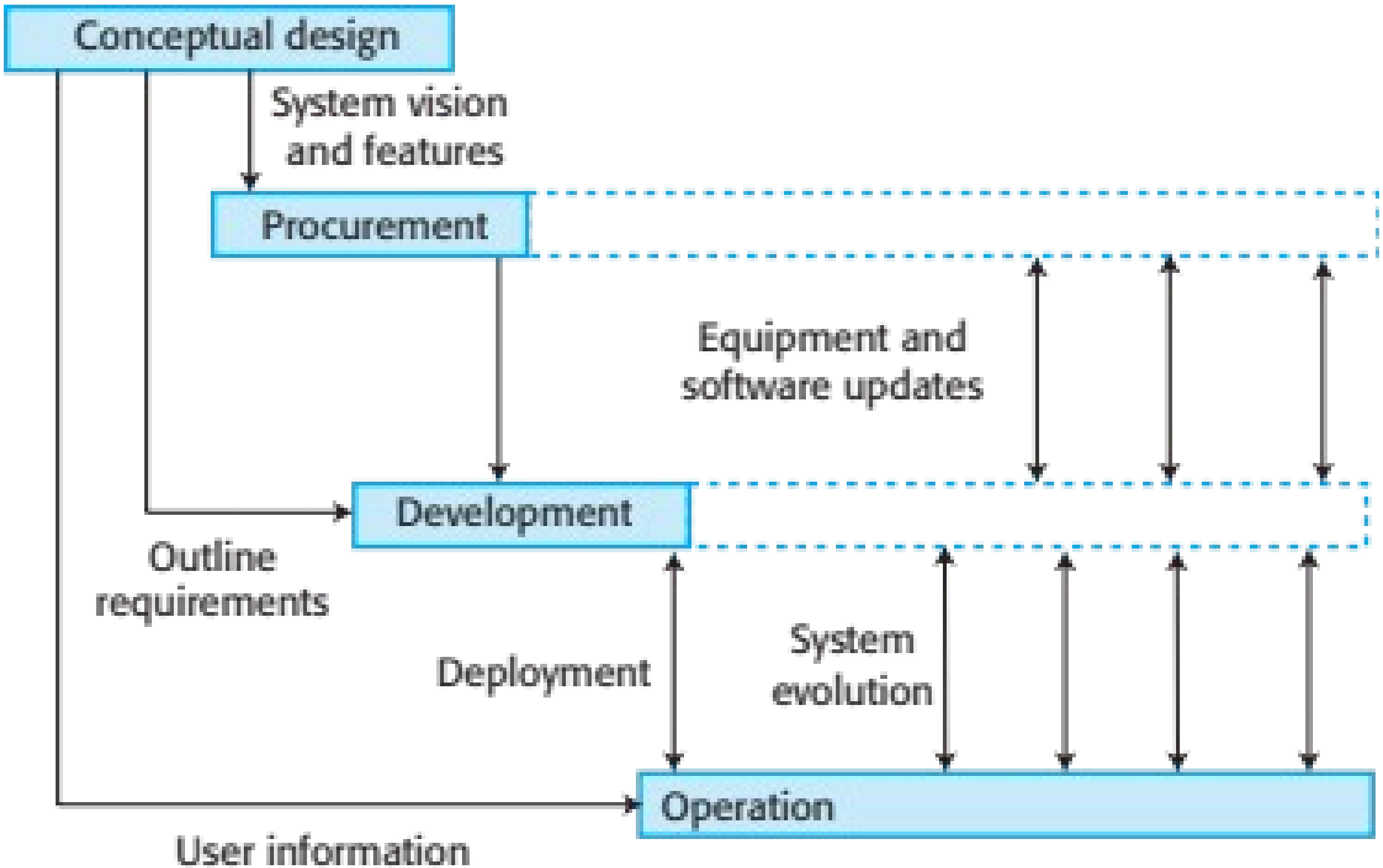
Stages of systems engineering



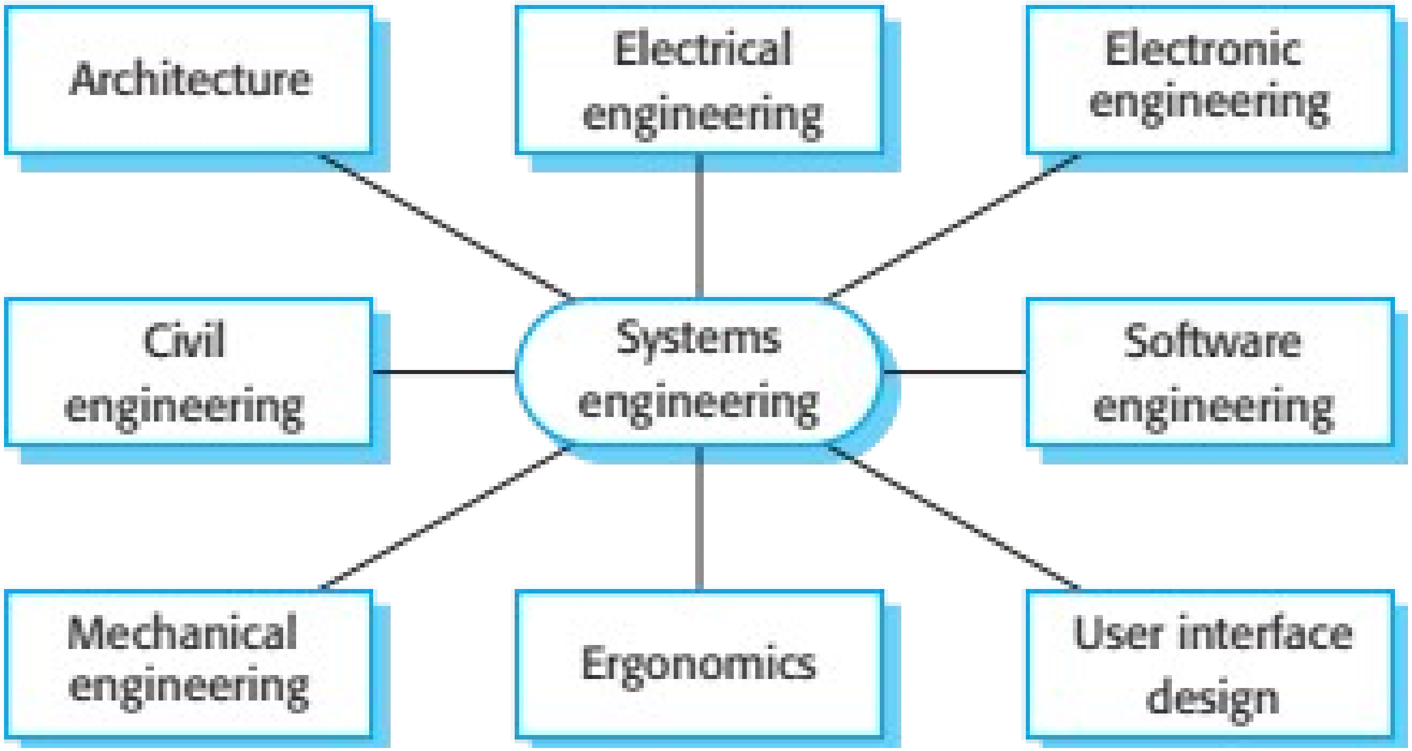
Systems engineering stages

- Conceptual design
  - Sets out the purpose of the system, why it is needed and the high-level features that users might expect to see in the system
- Procurement or acquisition
  - The conceptual design is developed so that decisions about the contract for the system development can be made.
- Development
  - Hardware and software is engineered and operational processes defined.
- Operation
  - The system is deployed and used for its intended purpose.

Stages of systems engineering



Professional disciplines involved



Inter-disciplinary working

- Communication difficulties
  - Different disciplines use the same terminology to mean different things. This can lead to misunderstandings about what will be implemented.
- Differing assumptions
  - Each discipline makes assumptions about what can and can't be done by other disciplines.
- Professional boundaries
  - Each discipline tries to protect their professional boundaries and expertise and this affects their judgments on the system.

Sociotechnical systems

Sociotechnical systems

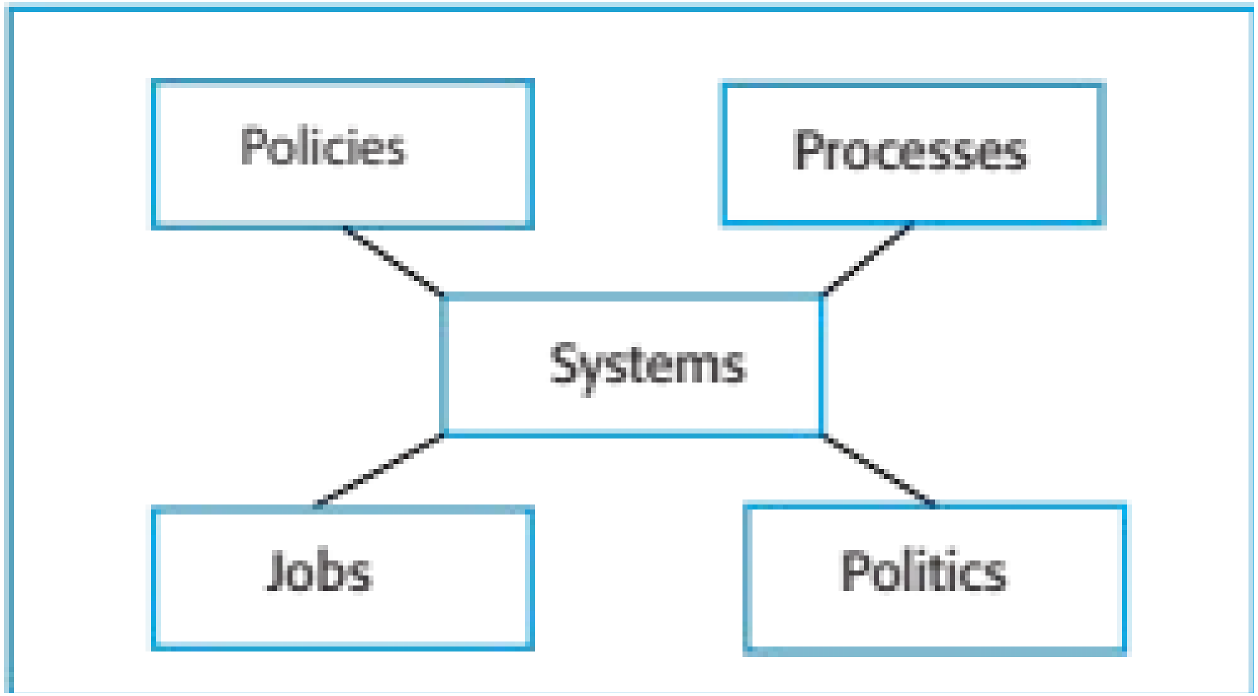
- Large-scale systems that do not just include software and hardware but also people, processes and organizational policies.
- Sociotechnical systems are often ‘systems of systems’ i.e. are made up of a number of independent systems.
  - Systems of systems are covered in Chapter 20
- The boundaries of sociotechnical system are subjective rather than objective
  - Different people see the system in different ways

Layered structure of sociotechnical systems

Systems and organizations

- Sociotechnical systems are used within organizations and are therefore profoundly affected by the organizational environment in which they are used.
- Failure to take this environment into account when designing the system is likely to lead to user dissatisfaction and system rejection.

Organizational elements



Organizational affects

- Process changes
  - Systems may require changes to business processes so training may be required. Significant changes may be resisted by users.
- Job changes
  - Systems may de-skill users or cause changes to the way they work. The status of individuals may be affected by a new system.
- Organizational policies
  - The proposed system may not be consistent with current organizational policies.
- Organizational politics
  - Systems may change the political power structure in an organization. Those that control the system have more power.

Complex systems

- A system may include software, mechanical, electrical and electronic hardware and be operated by people.
- System components are dependent on other system components.
- The properties and behaviour of system components are inextricably inter-mingled. This leads to complexity.
- Complexity is the reason why sociotechnical systems have emergent properties, are non-deterministic and have subjective success criteria.

Socio-technical system characteristics

- Emergent properties
  - Properties of the system of a whole that depend on the system components and their relationships.
- Non-deterministic
  - They do not always produce the same output when presented with the same input because the systems's behaviour is partially dependent on human operators.
- Complex relationships with organisational objectives
  - The extent to which the system supports organisational objectives does not just depend on the system itself.

Emergent properties

- Properties of the system as a whole rather than properties that can be derived from the properties of components of a system
- Emergent properties are a consequence of the relationships between system components
- They can therefore only be assessed and measured once the components have been integrated into a system

Examples of emergent properties

Property	Description
Reliability	System reliability depends on component reliability but unexpected interactions can cause new types of failures and therefore affect the reliability of the system.
Repairability	This property reflects how easy it is to fix a problem with the system once it has been discovered. It depends on being able to diagnose the problem, access the components that are faulty, and modify or replace these components.
Security	The security of the system (its ability to resist attack) is a complex property that cannot be easily measured. Attacks may be devised that were not anticipated by the system designers and so may defeat built-in safeguards.
Usability	This property reflects how easy it is to use the system. It depends on the technical system components, its operators, and its operating environment.
Volume	The volume of a system (the total space occupied) varies depending on how the component assemblies are arranged and connected.

Types of emergent property

- Functional properties
  - These appear when all the parts of a system work together to achieve some objective. For example, a bicycle has the functional property of being a transportation device once it has been assembled from its components.
- Non-functional emergent properties
  - Examples are reliability, performance, safety, and security. These relate to the behaviour of the system in its operational environment. They are often critical for computer-based systems as failure to achieve some minimal defined level in these properties may make the system unusable.

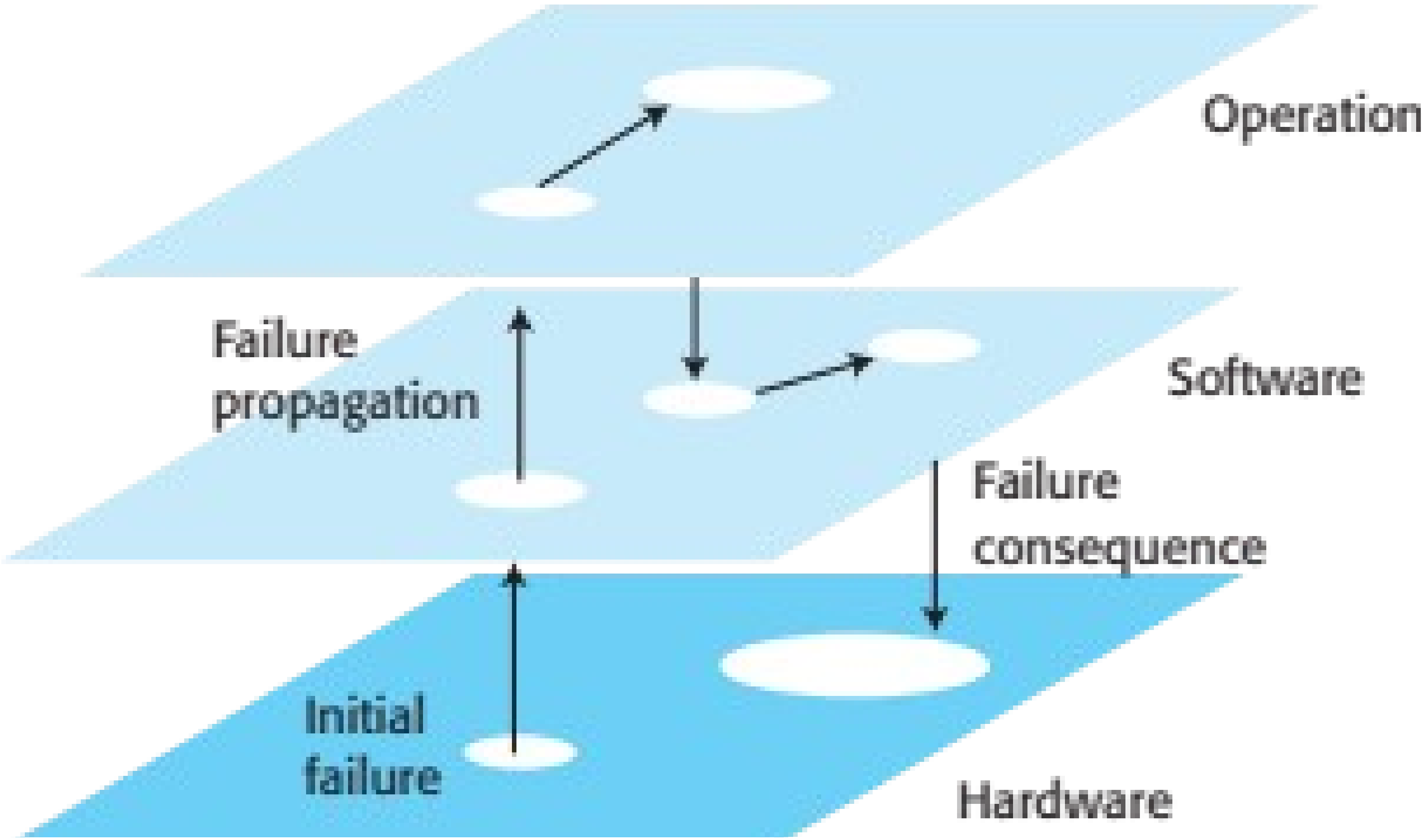
Reliability as an emergent property

- Because of component inter-dependencies, faults can be propagated through the system.
- System failures often occur because of unforeseen inter-relationships between components.
- It is practically impossible to anticipate all possible component relationships.
- Software reliability measures may give a false picture of the overall system reliability.

Influences on reliability

- *Hardware reliability*
  - What is the probability of a hardware component failing and how long does it take to repair that component?
- *Software reliability*
  - How likely is it that a software component will produce an incorrect output. Software failure is usually distinct from hardware failure in that software does not wear out.
- *Operator reliability*
  - How likely is it that the operator of a system will make an error?
- Failures are not independent and they propagate from one level to another.

Failure propagation



Reliability and system context

- System reliability depends on the context where the system is used.
- A system that is reliable in one environment may be less reliable in a different environment because the physical conditions (e.g. the temperature) and the mode of operation is different.

Non-determinism

- A deterministic system is one where a given sequence of inputs will always produce the same sequence of outputs.
- Software systems are deterministic; systems that include humans are non-deterministic
  - A socio-technical system will not always produce the same sequence of outputs from the same input sequence
  - Human elements
    - People do not always behave in the same way
  - System changes
    - System behaviour is unpredictable because of frequent changes to hardware, software and data.

Success criteria

- Complex systems are developed to address 'wicked problems' – problems where there cannot be a complete specification.
- Different stakeholders see the problem in different ways and each has a partial understanding of the issues affecting the system.
- Consequently, different stakeholders have their own views about whether or not a system is 'successful'
  - Success is a judgment and cannot be objectively measured.
  - Success is judged using the effectiveness of the system when deployed rather than judged against the original reasons for procurement.

Conflicting views of success

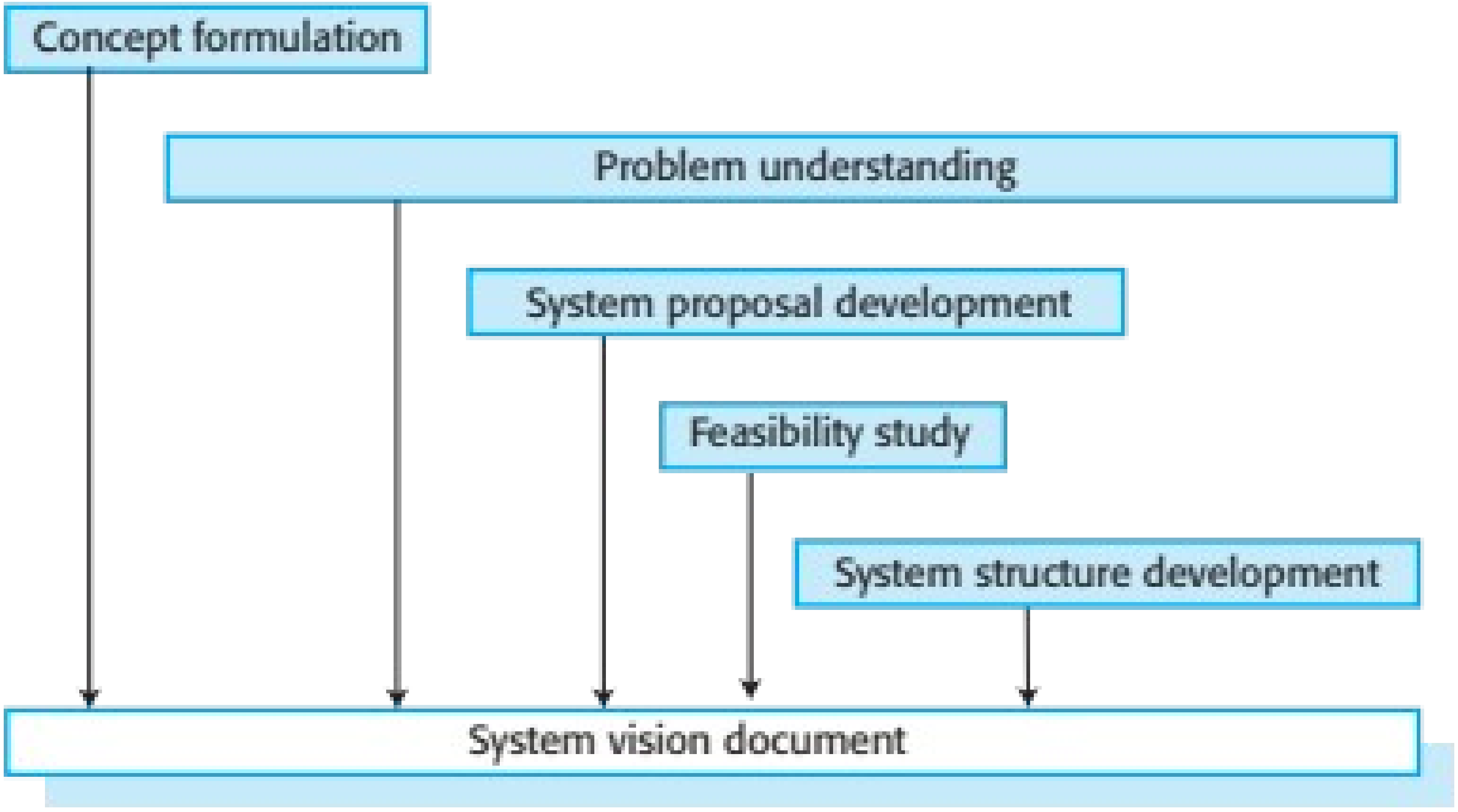
- The Mentcare system is designed to support multiple, conflicting goals
  - Improve quality of care.
  - Provide better information and care costs and so increase revenue.
- Fundamental conflict
  - Doctors and nurses had to provide additional information over and above that required for clinical purposes.
  - They had less time to interact with patients, so quality of care reduced. System was not a success.
- However, managers had better reports
  - System was a success from a managerial perspective.

Conceptual design

Conceptual design

- Investigate the feasibility of an idea and develop that idea to create an overall vision of a system.
- Conceptual design precedes and overlaps with requirements engineering
  - May involve discussions with users and other stakeholders and the identification of critical requirements
- The aim of conceptual design is to create a high-level system description that communicates the system purpose to non-technical decision makers.

Conceptual design activities



- Concept formulation
  - Refine an initial statement of needs and work out what type of system is most likely to meet the needs of system stakeholders
- Problem understanding
  - Discuss with stakeholders how they do their work, what is and isn’t important to them, what they like and don’t like about existing systems
- System proposal development
  - Set out ideas for possible systems (maybe more than one)

- Feasibility study
  - Look at comparable systems that have been developed elsewhere (if any) and assess whether or not the proposed system could be implemented using current hardware and software technologies
- System structure development
  - Develop an outline architecture for the system, identifying (where appropriate) other systems that may be reused
- System vision document
  - Document the results of the conceptual design in a readable, non-technical way. Should include a short summary and more detailed appendices.

User stories for presentation of system vision

Digital art

Jill is an S2 pupil at a secondary school in Dundee. She has a smart phone of her own and the family has a shared Samsung tablet and a Dell laptop computer. At school, Jill signs on to the school computer and is presented with a personalized Glow+ environment, which includes a range of services, some chosen by her teachers and some she has chosen herself from the Glow app library.

She is working on a Celtic art project and she uses Google to research a range of art sites. She sketches out some designs on paper then uses the camera on her phone to photograph what she has done and uploads this using the school wifi to her personal Glow+ space. Her homework is to complete the design and write a short commentary on her ideas.

User stories (2)

At home, she uses the family tablet to sign on to Glow+ and she then uses an artwork ‘app’ to process her photograph and to extend the work, add colour, etc.

She finishes this and to complete the work she moves to her home laptop to type up her commentary. She uploads the finished work to Glow+ and sends a message to her art teacher that it is available for review. Her teacher looks at this in a free period before Jill’s next art class using a school tablet and, in class, discusses the work with Jill.

After the discussion, the teacher and Jill decide that the work should be shared and they publish it to the school web pages that show examples of students’ work. In addition, the work is included in Jill’s e-portfolio – her record of schoolwork from age 3 to 18.

System procurement

System procurement

- Acquiring a system (or systems) to meet some identified organizational need.
- Before procurement, decisions are made on:
  - Scope of the system
  - System budgets and timescales
  - High-level system requirements
- Based on this information, decisions are made on whether to procure a system, the type of system and the potential system suppliers.

Decision drivers

- The state of other organizational systems and whether or not they need to be replaced
- The need to comply with external regulations
- External competition
- Business re-organization
- Available budget

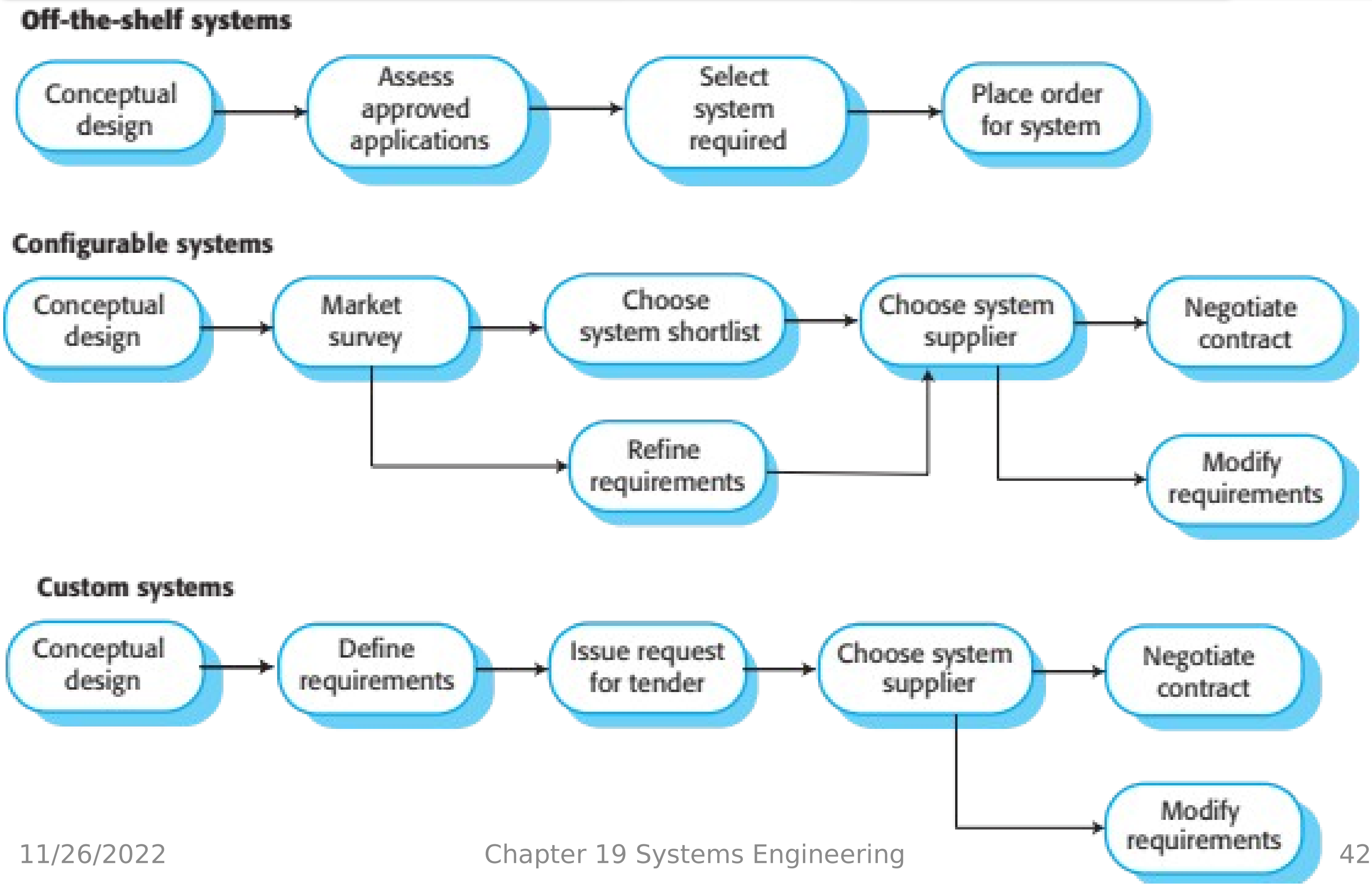
Procurement and development

- It is usually necessary to develop a conceptual design document and high-level requirements before procurement
  - You need a specification to let a contract for system development
  - The specification may allow you to buy a commercial off-the-shelf (COTS) system. Almost always cheaper than developing a system from scratch
- Large complex systems usually consist of a mix of off the shelf and specially designed components. The procurement processes for these different types of component are usually different.

Types of system

- Off-the-shelf applications that may be used without change and which need only minimal configuration for use.
- Configurable application or ERP systems that have to be modified or adapted for use either by modifying the code or by using inbuilt configuration features, such as process definitions and rules.
- Custom systems that have to be designed and implemented specially for use.

System procurement processes



Procurement issues

- Organizations often have an approved and recommended set of application software that has been checked by the IT department.
  - It is usually possible to buy or acquire open source software from this set directly without the need for detailed justification.
  - There are no detailed requirements and the users adapt to the features of the chosen application.
- Off-the-shelf components do not usually match requirements exactly.
  - Choosing a system means that you have to find the closest match between the system requirements and the facilities offered by off-the-shelf systems.

Procurement issues (2)

- When a system is to be built specially, the specification of requirements is part of the contract for the system being acquired.
  - It is therefore a legal as well as a technical document.
  - The requirements document is critical and procurement processes of this type usually take a considerable amount of time.
- For public sector systems especially, there are detailed rules and regulations that affect the procurement of systems.
  - These force the development of detailed requirements and make agile development difficult

Procurement issues (3)

- For application systems that require change or for custom systems there is usually a contract negotiation period where the customer and supplier negotiate the terms and conditions for the development of the system.
  - During this process, requirements changes may be agreed to reduce the overall costs and avoid some development problems.

Procurement decisions

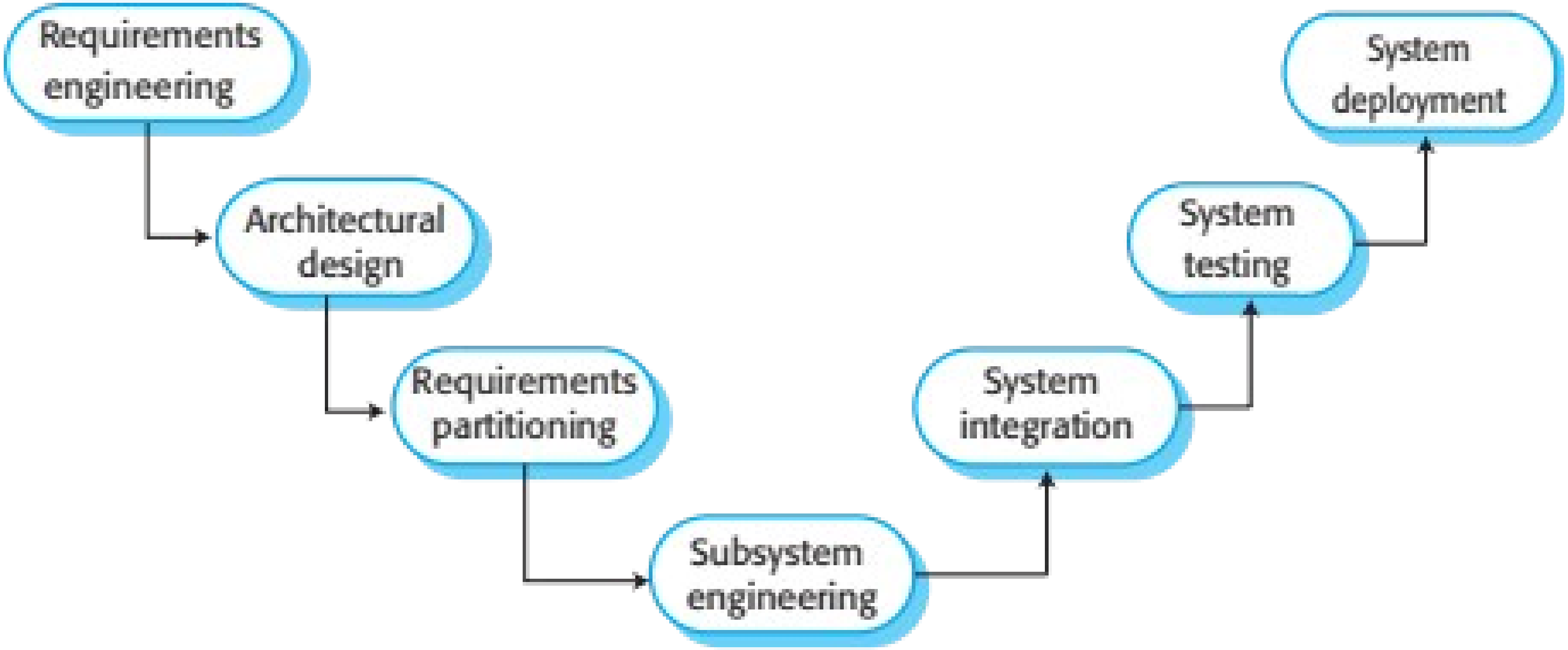
- Decisions made at the procurement stage of the systems engineering process are critical for later stages in that process.
  - Poor procurement decisions often lead to problems such as late delivery of a system and the development of systems that are unsuited to their operational environment.
  - If the wrong system or the wrong supplier is chosen then the technical processes of system and software engineering become more complex.

System development

System development

- Usually follows a plan-driven approach because of the need for parallel development of different parts of the system
  - Little scope for iteration between phases because hardware changes are very expensive. Software may have to compensate for hardware problems.
- Inevitably involves engineers from different disciplines who must work together
  - Much scope for misunderstanding here.
  - As explained, different disciplines use a different vocabulary and much negotiation is required. Engineers may have personal agendas to fulfil.

Systems development



The system development process

- Requirements engineering
  - The process of refining, analysing and documenting the high-level and business requirements identified in the conceptual design
- Architectural design
  - Establishing the overall architecture of the system, identifying components and their relationships
- Requirements partitioning
  - Deciding which subsystems (identified in the system architecture) are responsible for implementing the system requirements

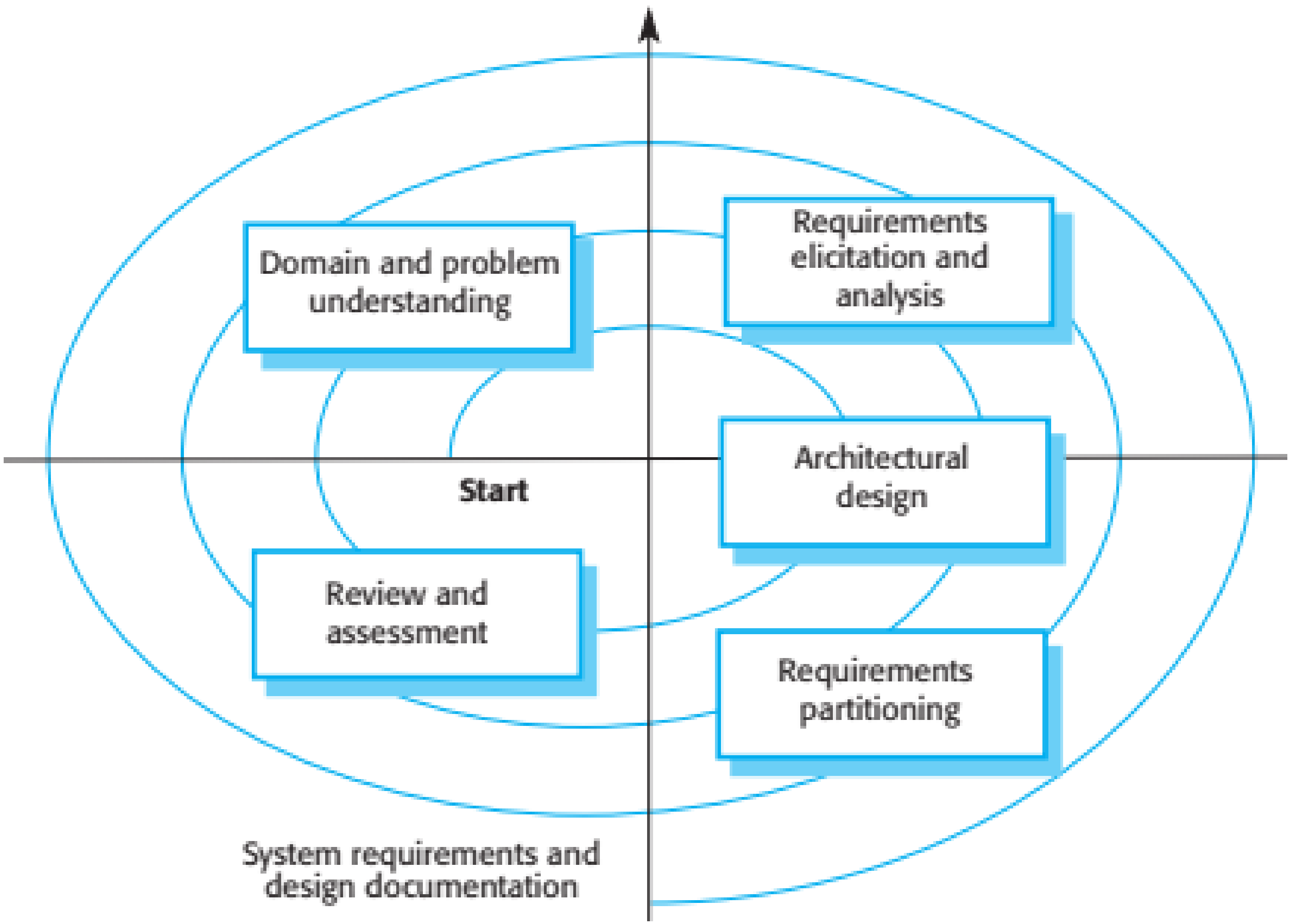
The system development process (2)

- Subsystem engineering
  - Developing the software components of the system, configuring off-the-shelf hardware and software, defining the operational processes for the system and re-designing business processes
- System integration
  - Putting together system elements to create a new system
- System testing
  - The whole system is tested to discover problems
- System deployment
  - the process of making the system available to its users, transferring data from existing systems and establishing communications with other systems in the environment

Requirements and design

- Requirements engineering and system design are inextricably linked.
- Constraints posed by the system’s environment and other systems limit design choices so the actual design to be used may be a requirement.
- Initial design may be necessary to structure the requirements.
- As you do design, you learn more about the requirements.

Requirements and design spiral



Subsystem engineering

- Typically parallel projects developing the hardware, software and communications.
- May involve some application systems procurement.
- Lack of communication across implementation teams can cause problems.
- There may be a bureaucratic and slow mechanism for proposing system changes, which means that the development schedule may be extended because of the need for rework.

System integration

- The process of putting hardware, software and people together to make a system.
- Should ideally be tackled incrementally so that sub-systems are integrated one at a time.
- The system is tested as it is integrated.
- Interface problems between sub-systems are usually found at this stage.
- May be problems with uncoordinated deliveries of system components.

System delivery and deployment

- After completion, the system has to be installed in the customer's environment
  - Environmental assumptions may be incorrect;
  - May be human resistance to the introduction of a new system;
  - System may have to coexist with alternative systems for some time;
  - May be physical installation problems (e.g. cabling problems);
  - Data cleanup may be required;
  - Operator training has to be identified.

System operation and evolution

System operation

- Operational processes are the processes involved in using the system for its defined purpose.
- For new systems, these processes may have to be designed and tested and operators trained in the use of the system.
- Operational processes should be flexible to allow operators to cope with problems and periods of fluctuating workload.

Problems with operation automation

- It is likely to increase the technical complexity of the system because it has to be designed to cope with all anticipated failure modes. This increases the costs and time required to build the system.
- Automated systems are inflexible. People are adaptable and can cope with problems and unexpected situations. This means that you do not have to anticipate everything that could possibly go wrong when you are specifying and designing the system

System evolution

- Large systems have a long lifetime. They must evolve to meet changing requirements.
- Evolution is inherently costly
  - Changes must be analysed from a technical and business perspective;
  - Sub-systems interact so unanticipated problems can arise;
  - There is rarely a rationale for original design decisions;
  - System structure is corrupted as changes are made to it.
- Existing systems which must be maintained are sometimes called legacy systems.

Factors that affect system lifetimes

Factor	Rationale
Investment cost	The costs of a systems engineering project may be tens or even hundreds of millions of dollars. These costs can only be justified if the system can deliver value to an organization for many years.
Loss of expertise	As businesses change and restructure to focus on their core activities, they often lose engineering expertise. This may mean that they lack the ability to specify the requirements for a new system.
Replacement cost	The cost of replacing a large system is very high. Replacing an existing system can only be justified if this leads to significant cost savings over the existing system.

Factors that affect system lifetimes

Factor	Rationale
Return on investment	If a fixed budget is available for systems engineering, spending this on new systems in some other area of the business may lead to a higher return on investment than replacing an existing system.
Risks of change	Systems are an inherent part of business operations and the risks of replacing existing systems with new systems cannot be justified. The danger with a new system is that things can go wrong in the hardware, software and operational processes. The potential costs of these problems for the business may be so high that they cannot take the risk of system replacement.
System dependencies	Other systems may depend on a system and making changes to these other systems to accommodate a replacement system may be impractical.

Cost factors in system evolution

- Proposed changes have to be analyzed very carefully from a business and a technical perspective.
- Subsystems are never completely independent so changes to a subsystem may have side-effects that adversely affect other subsystems.
- Reasons for original design decisions are often unrecorded. Those responsible for the system evolution have to work out why these decisions were made.
- As systems age, their structure becomes corrupted by change so the costs of making further changes increases.

Key points

- Systems engineering is concerned with all aspects of specifying, buying, designing and testing complex sociotechnical systems.
- Sociotechnical systems include computer hardware, software and people, and are situated within an organization. They are designed to support organizational or business goals and objectives.
- The emergent properties of a system are characteristics of the system as a whole rather than of its component parts. They include properties such as performance, reliability, usability, safety and security.

Key points

- The fundamental systems engineering processes are conceptual systems design, system procurement, system development and system operation.
- Conceptual systems design is a key activity where high level system requirements and a vision of the operational system is developed.
- System procurement covers all of the activities involved in deciding what system to buy and who should supply that system. Different procurement processes are used for off-the-shelf application systems, configurable COTS systems and custom systems.

Key points

- System development processes include requirements specification, design, construction, integration and testing.
- When a system is put into use, the operational processes and the system itself inevitably change to reflect changes to the business requirements and the system’s environment.