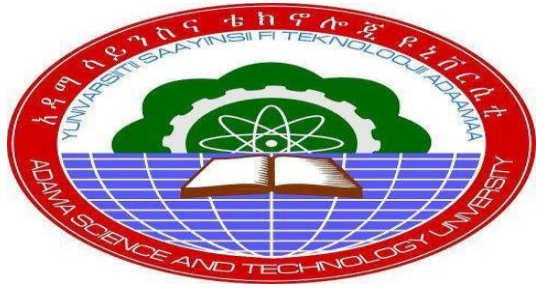

Introduction to Systems Engineering

Chapter 4

Conceptual Design

ASTU, 2025

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Introduction

- **Conceptual Design (System Definition Phase)**
- **Purpose:**
  - To **identify what the system must do** and **explore possible ways** to meet the user's needs before any detailed work begins.
- **Main Activities:**
  - Define **system objectives**, goals, and scope
  - Identify **stakeholder requirements** and constraints
  - Develop **alternative system concepts or architectures**
  - Conduct **feasibility studies** (technical, economic, and operational)
  - Select the **best concept** based on trade-offs
- **Outputs:**
  - **System requirements document (SRD)**
  - **Functional block diagrams** or high-level architecture
  - **Concept of Operations (ConOps)**

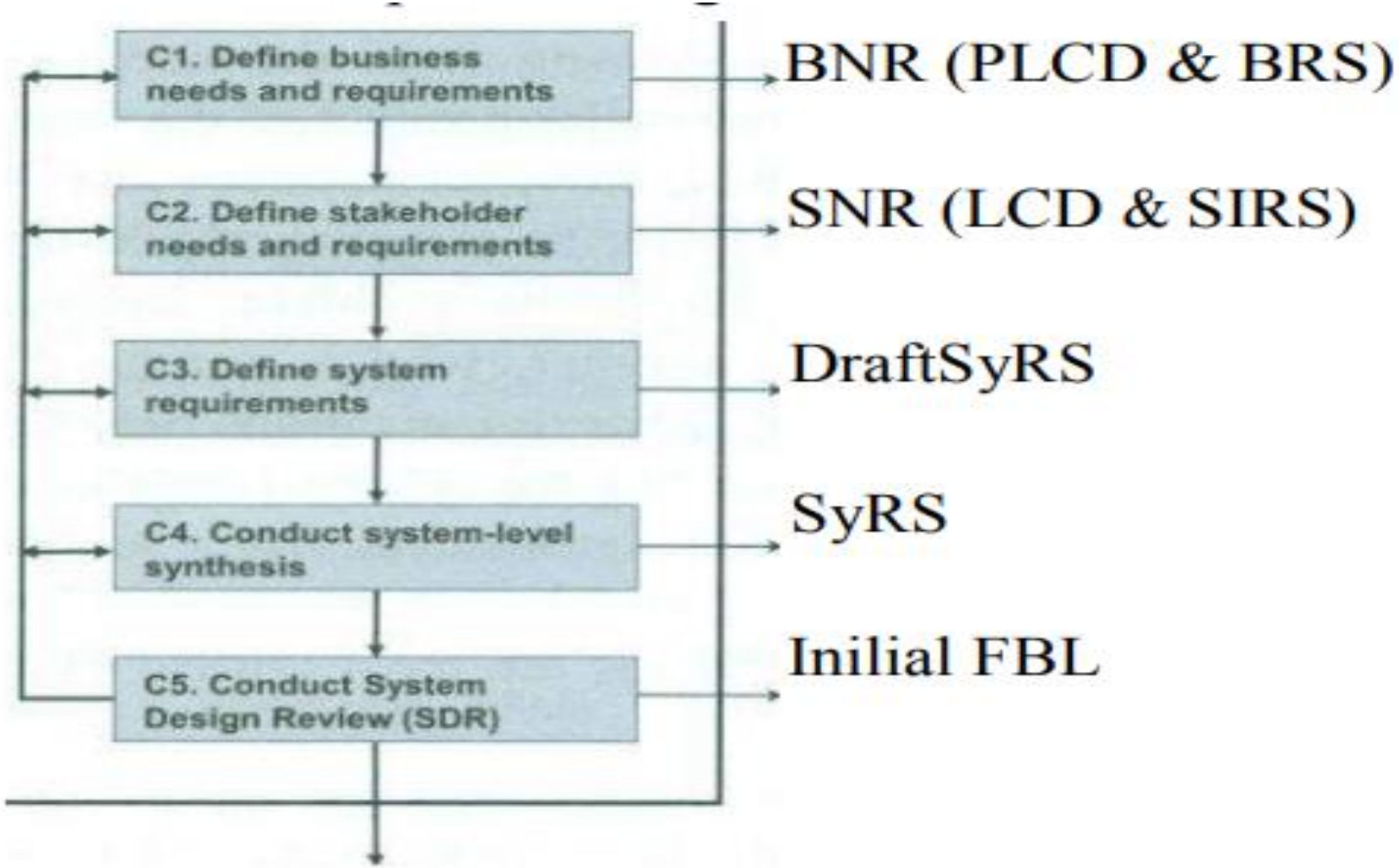
Introduction

- The systems engineering processes begin in earnest with the first activity in the Acquisition Phase: Conceptual Design (or logical design or problem- domain design), which aims to articulate the needs, to analyse and document the system-level requirements flowing from the needs, and to complete a logical design of the system.
- The major product of the Conceptual Design, the Initial Functional Baseline (FBL), provides a system-level logical architecture that is the basis for subsequent lower-level (physical) design.
- The Functional Baseline is a key deliverable in the system engineering process and represents a system-level description of the functions and capabilities that the system should provide.

Introduction …

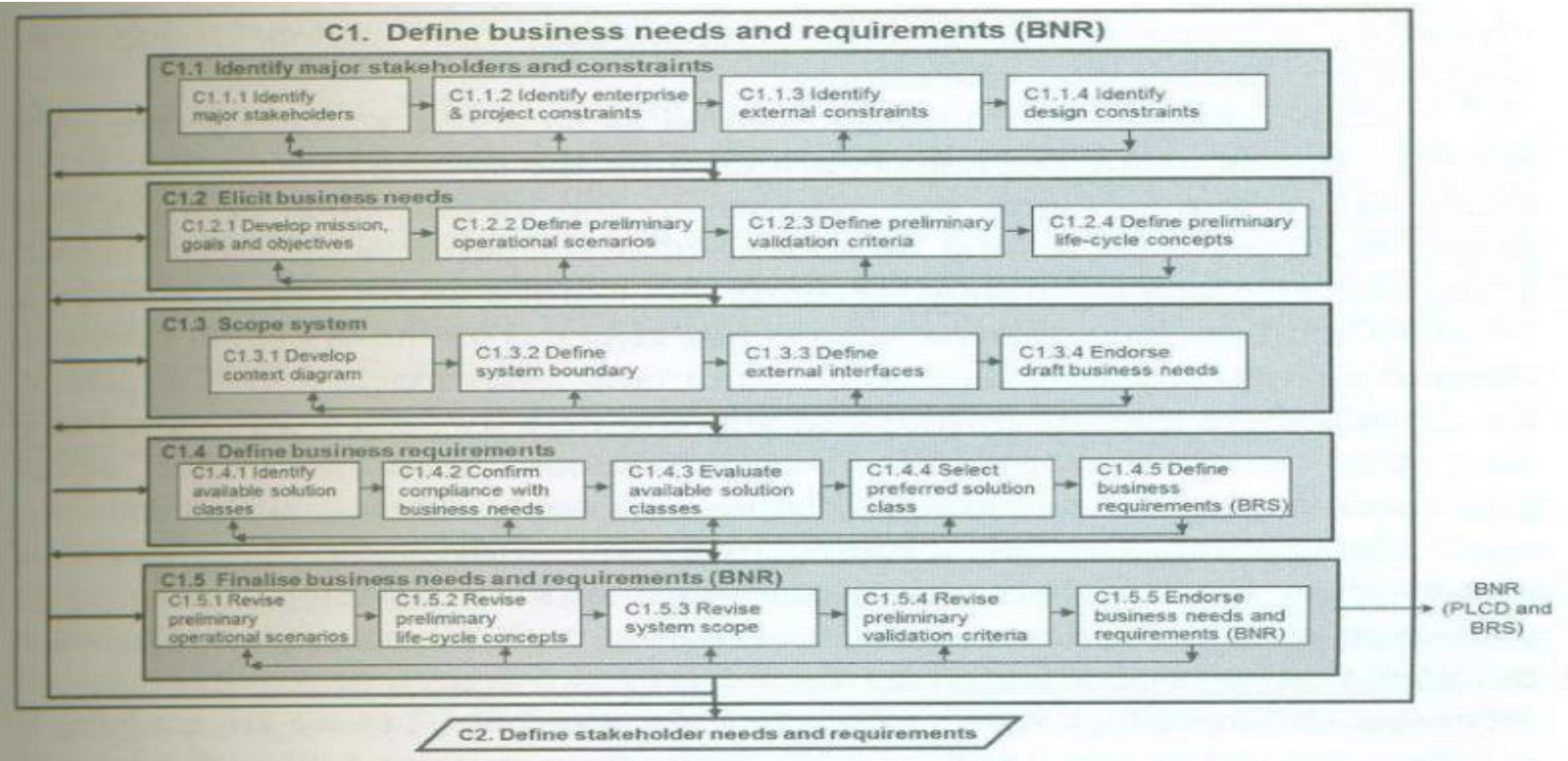
- Conceptual Design is perhaps the most critical of all of the life-cycle activities because:
- Conceptual Design is responsible for the expansion of the system definition from relatively brief business needs into a logical set of system-level requirements that may be hundreds of pages long.
- All subsequent aspects of the system design will be traced back to the FBL that ends this activity-any errors here will flow down to the remainder of the acquisition activities.
- Conceptual Design is concerned with the transition from the problem domain into the solution domain.

Introduction …



- The five major processes performed iteratively during Conceptual Design.

C1–Define Business Needs and Requirements



Cl.l-Identify Major Stakeholders and Constraints

- Business management begin the definition of BNR with the identification of the major stakeholders who are to be engaged to elicit business needs and requirements and to verify design artefacts as the design progresses.
- They also must identify the business, project, external, and design constraints that provide important context within which to consider the system requirements, as well as being the source of many requirements.

C1.1.1-Identify Major Stakeholders

- The first step in developing the BNR requires the identification of the major stakeholders for all aspects of the new system.
- These stakeholders are the individuals and groups that business management identifies as those who will be responsible for writing and agreeing to the BNR prior to their endorsement. These major stakeholders also have a significant role during later activities to assist with the requirements analysis effort-that is, they will most likely lead the development of the SNR.
- A stakeholder is commonly defined as someone who has a stake in the project-that is, someone who is affected by the system in some way, or can affect the system in some way.
- However, the identification of stakeholders cannot involve simply listing those who have, or perceive themselves to have, a stake in the project-in most systems this is not a useful definition since it is often difficult to find someone who is not affected by the system in some way.

C1.1.2-Identify Business and Project Constraints

- Constraints are requirements that are imposed on the system by circumstance, force, or compulsion-they therefore limit absolutely the options open to a designer by imposing immovable boundaries and limits.
- Before focusing on the detail of the desired system, it is therefore essential to identify the business and project constraints that are relevant to the system and its acquisition-a system will fail if it cannot operate under the constraints imposed upon it.
- This analysis provides essential information about the development environment for the system and begins the top-down approach to system development.
- Business constraints include management guidance, organizational policies, procedures, standards, or guidelines that guide system development and procurement. These constraints can include partnering relationships with other companies, use of established life-cycle processes, contracting policies, human resource limitations, budget restrictions, and specific management guidance to the project.

C1.1.2-Identify Business and Project Constraints

- Project constraints include budget and schedule constraints, but also include the resource allocations within the project as well as any external imposed deliverables and acquisition timeframes.
- Many companies have business-wide standards for processes such as quality assurance and system engineering and these methodologies guide the manner in which projects can operate.
- Additionally, projects might be constrained to conform to particles engineering and technical standards; mandated toolsets; metric documentation sets and plan templates; technology use; and control an reporting mechanisms.

C1.1.3-Identify External Constraints

- In addition to enterprise-imposed constraints, there are wider extreme constraints on system development that arise from the requirement for conformance to national and international laws an regulations, compliance with industry-wide standards, as well as ethical an legal considerations.
- Other external constraints include the requirement of interoperability and the capabilities required for interfacing with other: systems.
- Additionally, the capability of competitors, as well as the availability of human resources, specific skill sets, technologies and tools might provide external constraints.
- Again, an important aspect of top-down design is to understand these constraints while considering needs and requirements.

C1.1.4-Identify Design Constraints

- Design constraints include those factors that directly affect the way in which the system design can be conducted.
- Topic; constraints include the state-of-the-art of relevant technologies as well extant methodologies and tools to assist in the design, development construction and production of the system.
- Such issues must be addressed by business management who will address the risk associated with embracing new technologies, the impact of upgrading construction facilities, workfare re-skilling issues, and so on.

C1.2-Elicit Business Needs

C1.2.1-Define Mission, Goals, and Objectives

- It is axiomatic that every project should begin with a concise statement of the mission of the system, elaborated by statements of the upper-level goals and objectives for the system.
- The mission statement should be quite short (stated in a single sentence) and may be expressed in only a few lines, although it must have a word or phrase for every important aspect of the system.
- The following guidelines are used for the format of the system mission statement
  - A single sentence
  - No conjunctions
  - Contain no more than 5-7 concepts
  - Include an 'in order to' clause
  - Avoid physical terms
  - Rely on iteration

C1.2.2-Define Preliminary Operational Scenarios

- Once the mission, goals, and objectives have been articulated, business management in conjunction with stakeholders from business operations identify the range of operational scenarios proposed for the system.
- Scenarios help stakeholders explain how the system will be used.
- These scenarios, often expressed in terms of one or more use cases, provide valuable guidance to the system designers and also form the basis of major validation events in the Acquisition Phase such as testing of the system a it is introduced into service.
- Despite any more detailed technical verification and validation procedures, the system's fitness-for-purpose is fundamentally related to its ability to perform in accordance with the operational scenarios defined at this stage.

C1.2.3-Define Preliminary Validation Criteria

- An important top-level activity is the identification and definition of preliminary validation criteria.
- Broadly, validation criteria encompass any mechanism by which the customer will measure satisfaction with the products of the Acquisition Phase.
- Key criteria include performance in each operational scenario, safety, reliability, supportability, maintainability, ease of use, and time and cost to train.
- There are a number of issues that need to be considered when identifying validation criteria:
  - Measurability
  - Baseline
  - Relevance

C1.2.4-Define Preliminary Life-cycle Concepts

- Early in the Acquisition Phase, business management must give some guidance on the life-cycle concepts related to the acquisition, deployment, operation, support, and retirement of the system.
- While the systems engineering procedures that follow will ensure a life-cycle focus, it is important that there is an early business focus on the major cost drivers that will impact on all aspects of the system throughout its life.
  - Preliminary Operational Concept (OpsCon)
  - Preliminary Acquisition Concept
  - Preliminary Deployment Concept
  - Preliminary Support Concept
  - Preliminary Retirement Concept

C1.3-Scope System

- The next phase in understanding business needs and requirements involves the development an understanding of the scope of the system development effort called scoping. This scoping activity helps to establish a clear understanding of what the system is expected to do by defining the system context, the system boundary, and any external interfaces.
- **C1.3.1-Develop Context Diagram**
- To assist with the scoping process, a tool called a context diagram may be used to illustrate the related systems, relevant regulatory environments, major stakeholders, external systems, external interfaces, and so on.
- The context diagram is a very useful tool because, in this case, a picture is definitely worth a thousand words. In systems engineering there is a common heuristic that, if you can't draw a picture of the system or you can't explain it in five minutes, it is either broken or you don't understand it.

C1.3.2-Define System Boundary

- Definition of the system boundary is essential early in the Acquisition Phase so that it is clear which elements are included in the system and which are outside.
- This activity also identifies which aspects are inside the systems acquisition and which are not, which is also particularly important to the project manager who is principally responsible for defining project scope-that is, what is to be included in the project as well as what is to be excluded.
- **C1.3.3 Define External Interfaces**
- External interfaces are between the system of interest and each of the other existing or future external systems to which it is interconnected.
- The interfaces describe the inputs and the outputs of the system-the interfaces to its external environment. Broadly there are three main steps in interface definition: *Interface Description, Interface Impact Analysis and Interface Control Analysis*.

C1.3.4 Endorse Draft Business Needs

- At this point, business management should pause to review and endorse the draft business needs as articulated in the artefacts produced so far (predominantly in the PLCD).
- Since the next major activities are related to the transformation of those business needs into formal requirements, it is important that the business is satisfied that their stated needs will result in satisfaction of the business case for the system.
- This endorsement is most likely undertaken through a review conducted by the business owner in the presence of business management and the major stakeholders from business operations

C1.4-Define Business Requirements

❖ C1.4.1 to C1.4.4 Feasibility Analysis

- At this stage of Conceptual Design, we have been careful to ensure that business management have stated their needs in logical terms-that is, in terms of the problem domain (the management and operational environment of the business).
- The following steps are completed during feasibility analysis:
  - Step Cl.4.1. Identify the alternative system-level solution classes capable of satisfying the Business Needs.
  - Step Cl.4.2. Confirm compliance of each solution class with the Business Needs and, if not completely compliant, note the likely level of achievement.
  - Step Cl.4.3. Evaluate the alternative solution classes in terms of feasibility, performance, effectiveness, technical and project risk, and other selected measures.
  - Step Cl.4.4. Select the best of the alternative solution classes (ensuring that the options are narrowed down as much as is practicable at this stage).

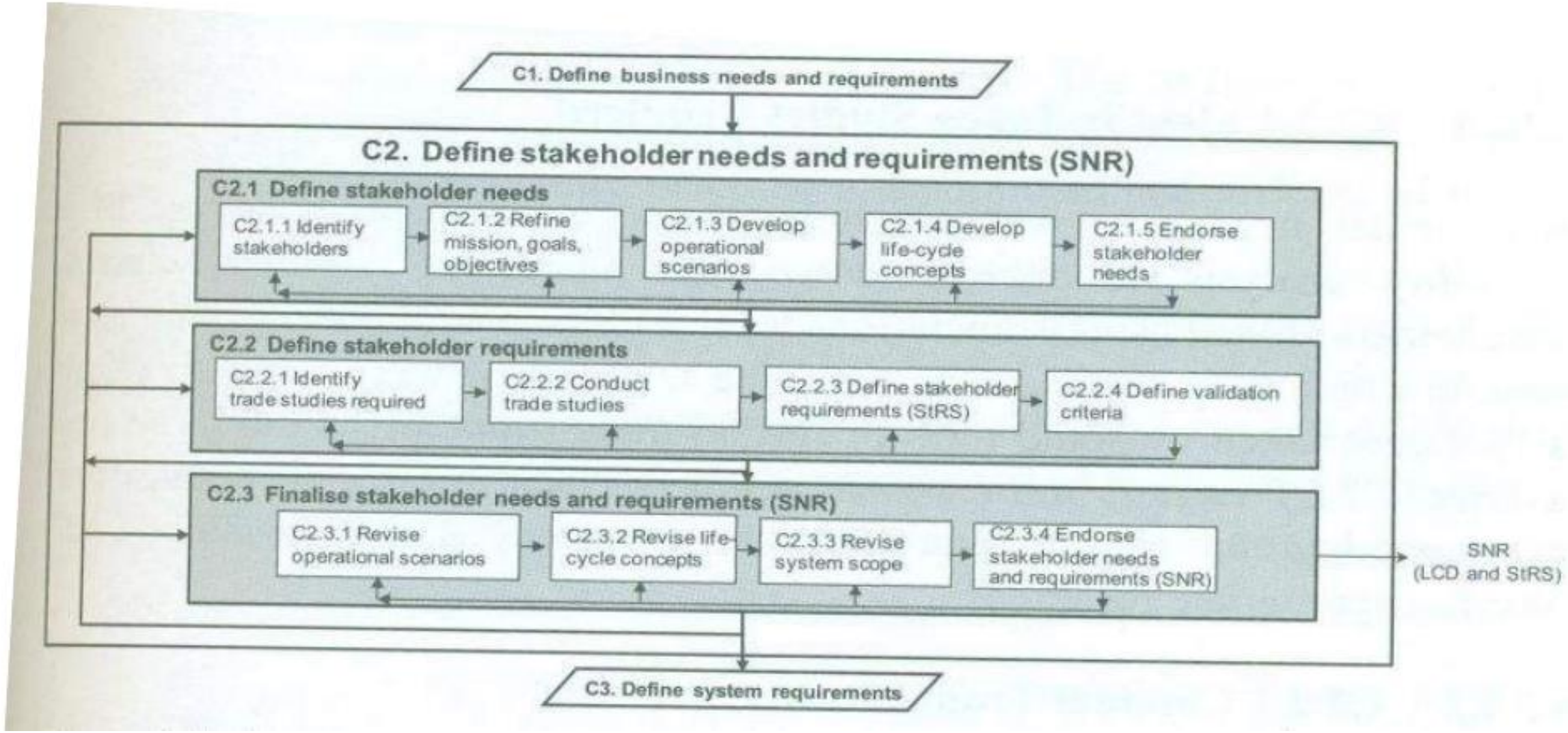
C1.4.5 Define Business Requirements (BRS)

- Development of the business requirements in the BRS can be assisted by a requirements framework around which the logical description of the system can be based.
- Here we call the requirements framework the requirements breakdown structure (RBS).
- The words are deliberately chosen to differentiate this structure from the well-known project management document called the work breakdown structure (WBS)-the RBS is grouped by function, the WBS is structured by physical work packages (including configuration items) and contains other project-related work

C1.5-Finalise Business Needs and Requirements (BNR)

- ✓ At this stage, the business now understands the system much better than it did when it first drafted the mission statement-not only has much more detail been elicited but a solution class has been identified, which provides a much more concrete view of the system and its operation.
- ✓ Consequently, the BNR can be finalized by revisiting earlier artefacts and revising them to incorporate the increased understanding.

C2–Define Stakeholder Needs and Requirements



C2.1-Define Stakeholder Needs

- ✓ C2.1.1 Identify Stakeholders
- ✓ C2.1.2 Refine Mission, Goal, Objectives
- ✓ C2.1.3 Develop Operational Scenarios
- ✓ C2.1.4 Develop Life Cycle Concepts
- ✓ C2.1.5 Endorse Stakeholders Needs

C2.2-Define Stakeholders Requirements

❖ C2.2.1 Identify Trade Studies Required

- ✓ In a similar manner to that which business management made use of a feasibility analysis to narrow down the alternative solution classes, stakeholders at the business operations level will have a number of alternative ways in which their needs can be met.
- ✓ The selection between various options is best undertaken by some form of formal trade (trade-off) study.
- ✓ The first activity, *C2.2.1 Identify trade studies required,* lists those trade studies that are required, groups related trade studies for efficiency, prioritises studies, and allocates appropriate resources.

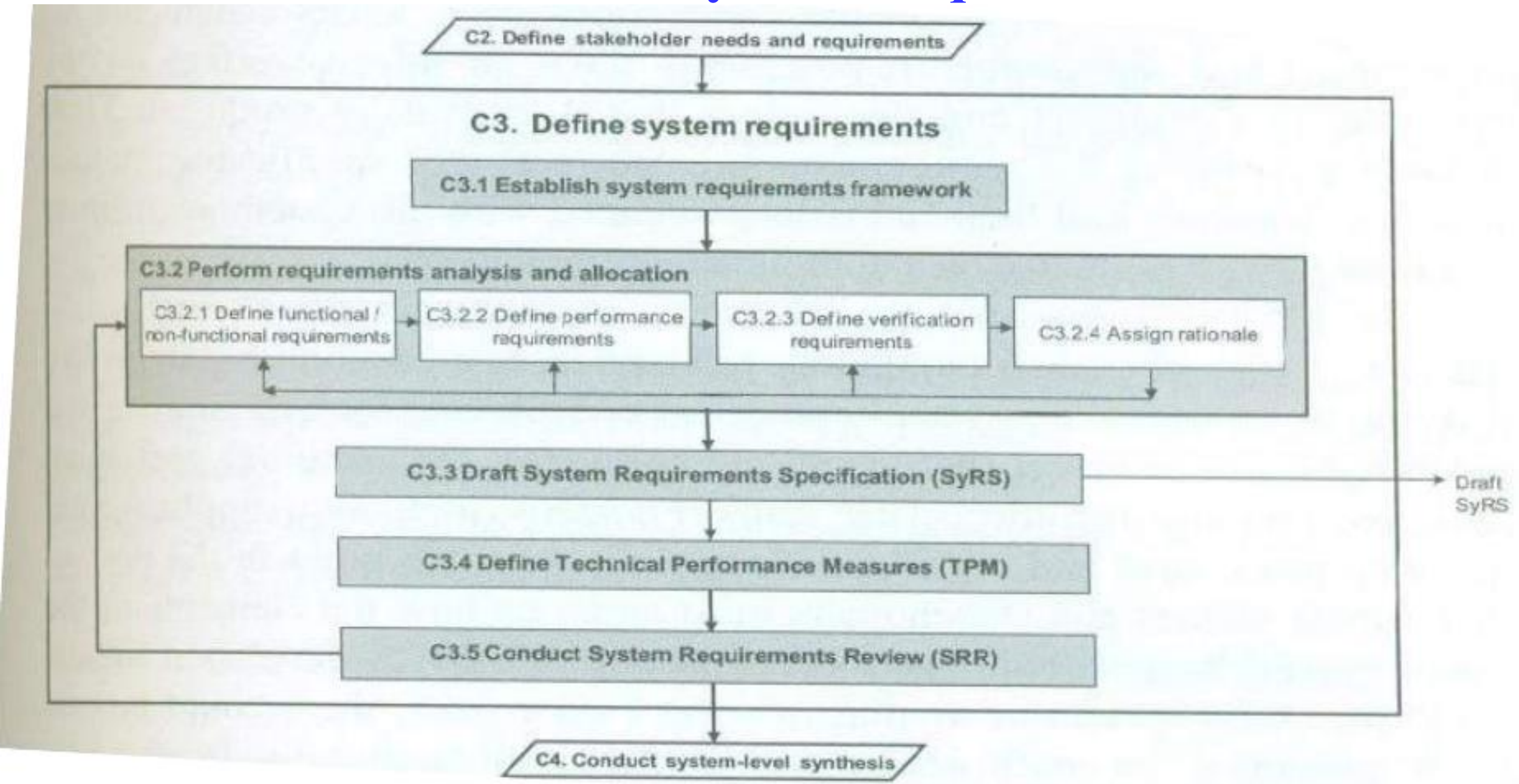
C2.2.2 Conduct Trade Studies

- As noted in the previous section, the conduct of trade studies did not begin here-the feasibility analysis conducted earlier can be considered to be a system-level trade study-and will not end here as trade studies are an important design tool and are used throughout system development and the remainder of the life cycle.
- **C2.2.3 Define Stakeholder Requirements (StRS)**
- The development of the StRS is an essential first step towards a successful system development and is given a number of titles, including simply stakeholder requirements or user requirements.
- **C2.2.4 Define Validation Criteria**

C2.3-Finalise Stakeholder Needs and Requirements (SR)

- C2.3.1 Revise operational scenarios
- C2.3.2 Revise life cycle concepts
- C2.3.3. Revise system scope
- C2.3.4 Endorse stakeholders needs and requirements (SNR)

C3–Define System Requirements



C3.1-Establish Requirements Framework

- The first step in defining system requirements is to establish a requirements framework around which the logical design of the system is to be based.
- As noted earlier, the RBS is a useful framework for refining the StRS into the detail of the SyRS while also assisting in traceability.
- Since we have started with a hierarchical decomposition of mission, goals, and objectives, we can use that information to begin our development of a logical hierarchy, which can be captured in an RBS.

C3.2-Perform Requirements Analysis and Allocation

- C3.2.1-Define Functional/Non-functional Requirements
- C3.2.2-Define Performance Requirements
- C3.2.3-Define Verification Requirements
- C3.2.4-Assign Rationale

C3.3-Draft System Requirement Specification (SyRS)

- The complete and populated RBS forms the framework for the SyRS which, when approved, becomes the centrepiece of the system's FBL.
- At this stage, however, the populated RBS only forms the basis for the draft SyRS because the requirements collected and analysed so far have yet to be synthesized into an architectural solution.

C3.4-Define Technical Performance Measures (TPM)

- IEEE-STD-1220 states that appropriately selected TPMs can be used to: assess conformance to requirements, assess conformance to levels of technical risk, trigger development of recovery plans for identified deficiencies, and examine marginal cost benefits of performance in excess of requirements.
- The first step in identifying TPMs is to identify the quantitative parameters that require tracking throughout the project. Once the parameters have been identified, they should be prioritized in terms of their importance as viewed by the customer.
- A second list of TPMs may be established, prioritized and maintained by the contractor. As is often the case with subjective issues such as risk, a second perspective is always valuable. Both lists will imply priority to potential suppliers of the system during its design and development.

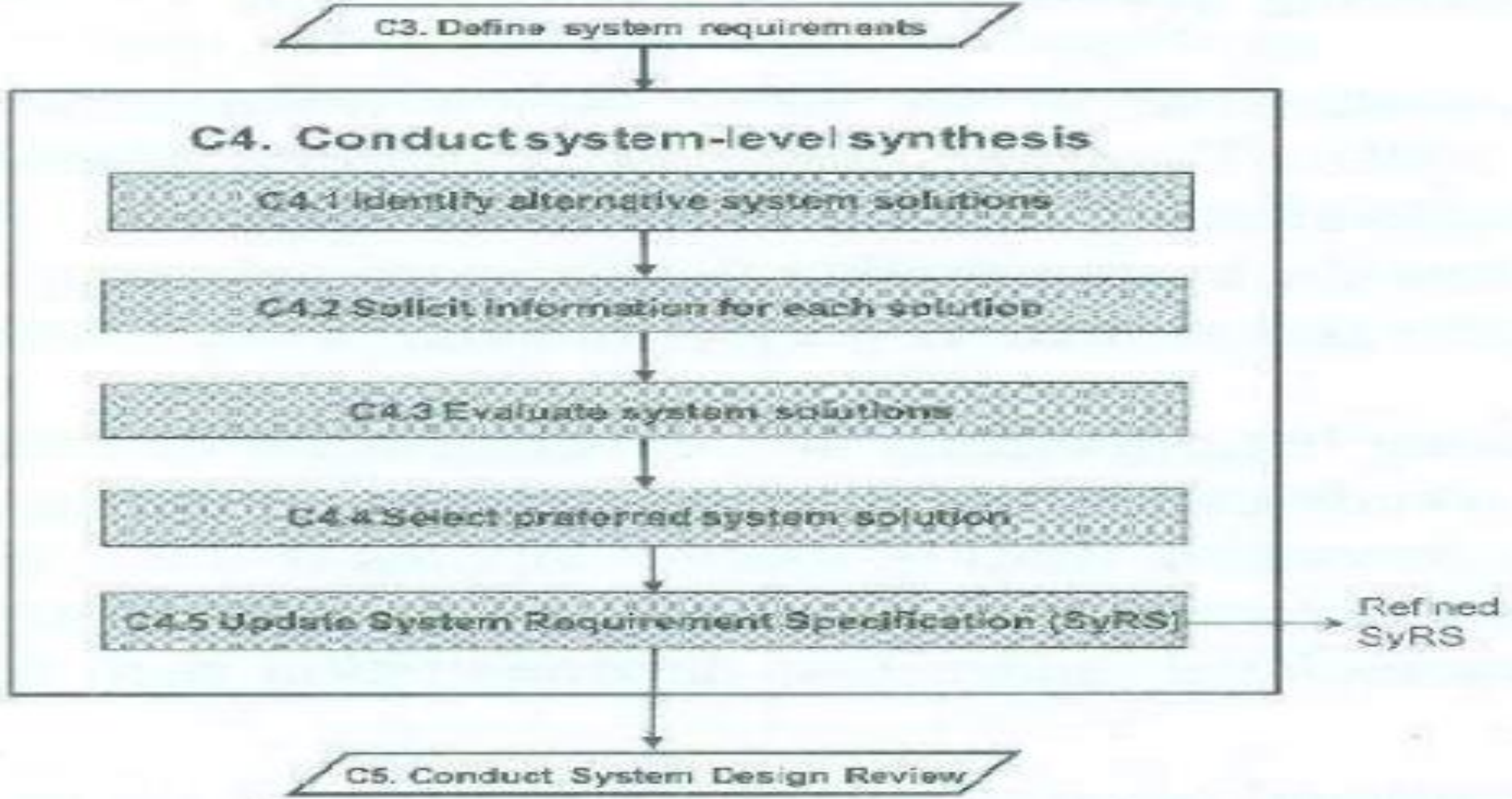
C3.5-Conduct System Requirements Reviews (SRR)

- System Requirements Reviews (SRR) may be conducted periodically throughout Conceptual Design to verify and approve versions of system-level requirements.
- The aim of the SRRs is to monitor and approve progressively the system-level requirements that are developed on the way to the Initial FBL.
- Progressive reviews allow the requirements analysis effort to continue to lower levels in the logical hierarchy in the RBS by providing validation of the higher levels of abstraction, providing a firm start point for the subsequent analysis. SRRs may or may not be considered formal reviews.
- The SRRs may also review other information such as manufacturing plans, design schedules and personnel requirements plans that will assist in fine-tuning the Preliminary Life-cycle Concepts.
- The number of SRRs will depend on size and complexity of the system of interest. Large and complex systems require multiple SRRs during Conceptual Design whereas simple system may require very few.

C4–Conduct System–Level Synthesis

- The system design has now progressed to the stage where some of the system- level design decisions can be made.
- System requirements analysis has identified requirements.
- Synthesis (at the Conceptual Design level) establishes a system configuration that is representative of the final system form.
- The configuration established at this stage is not assumed to be final as the design is very immature and may go through significant changes later in the design process.

C4–Conduct System–Level Synthesis …



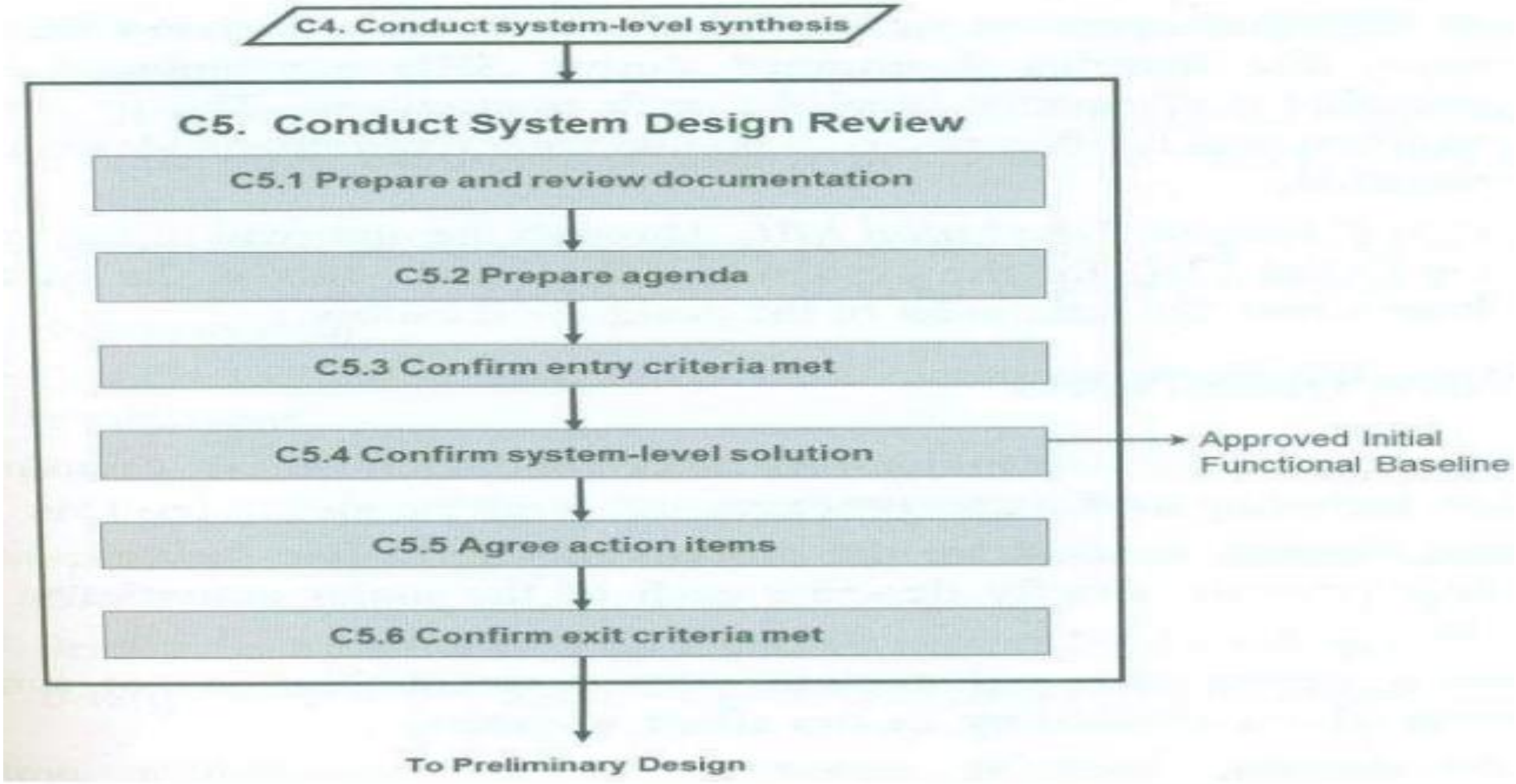
C4–Conduct System–Level Synthesis …

- Based on the results of the requirements engineering and analysis, a range of architectural options is developed (C4.1) that represent potential system solutions.
- The selection of one of these options as the preferred solution requires information to be collected (C4.2) from the systems engineering process, life-cycle costings, quality assurance, test and evaluation, maintenance, integrated logistics support, and so on.
- The potential solutions are then evaluated (C4.3), which requires the development of suitable evaluation criteria as well as an evaluation framework.
- Any discrepancies in the systems engineering products are noted and feedback to previous activities. The preferred solution is then chosen (C4.4).

C5–Conduct System Design Review (SDR)

- At the end of Conceptual Design the System Design Review (SDR) provide the following from a systems engineering perspective:
  - formal confirmation that the logical design meets the business and stakeholder requirements;
  - a formal record of design decisions and acceptance;
  - a formalized communication of the intended design approach to the major players in the design effort;
  - approval of the Systems Engineering Management Plan (SEMP) and supporting plans.
- In addition to review of the systems engineering effort, a number of review activities will most likely be performed at SDR to support project management:
  - confirmation that the system to be procured aligns with the customer's organizational goals;
  - the Project Management Plan (PMP) is refined;
  - cost estimates are refined;
  - the schedule is refined and is confirmed to be consistent with the cost and risk goals for the project; and
  - confirmation that all required project resources are available.

C5–Conduct System Design Review (SDR) …



C5–Conduct System Design Review (SDR)

- Consequently, the review cannot begin until the entry criteria have been met (C5.3).
- Part of that confirmation is to ensure that all of the necessary documentation has been prepared and reviewed (C5.1) in advance of the review, and that all parties have agreed to the agenda for the review (C5.2).
- The principal purpose of the review is to examine each requirement to ensure that it is met by the preliminary system architecture determined during y tern-level synthesis-that is, the review confirms the system-level solution (C5.4).

C5–Conduct System Design Review (SDR)

- Rather than hold up subsequent design, action items are agreed (C5.5) with agreed timelines to account for any outstanding action from the review (providing, of course, that resolution of those issues will not affect the remainder of the design).
- These actions are completed in parallel with the early Preliminary Design activities and are reviewed for completeness in conjunction with a later review or audit. Before the review can be considered to be complete, the exit criteria must be met (C5.6).

Quiz

1. **What is conceptual design**
2. **Explain the stakeholders with examples**
3. **In system engineering there are four life cycles, list them**
4. **What is Business Needs?**
5. **Differentiate functional requirement and non-requirement and give example for each**