Engineering 180
Systems Engineering

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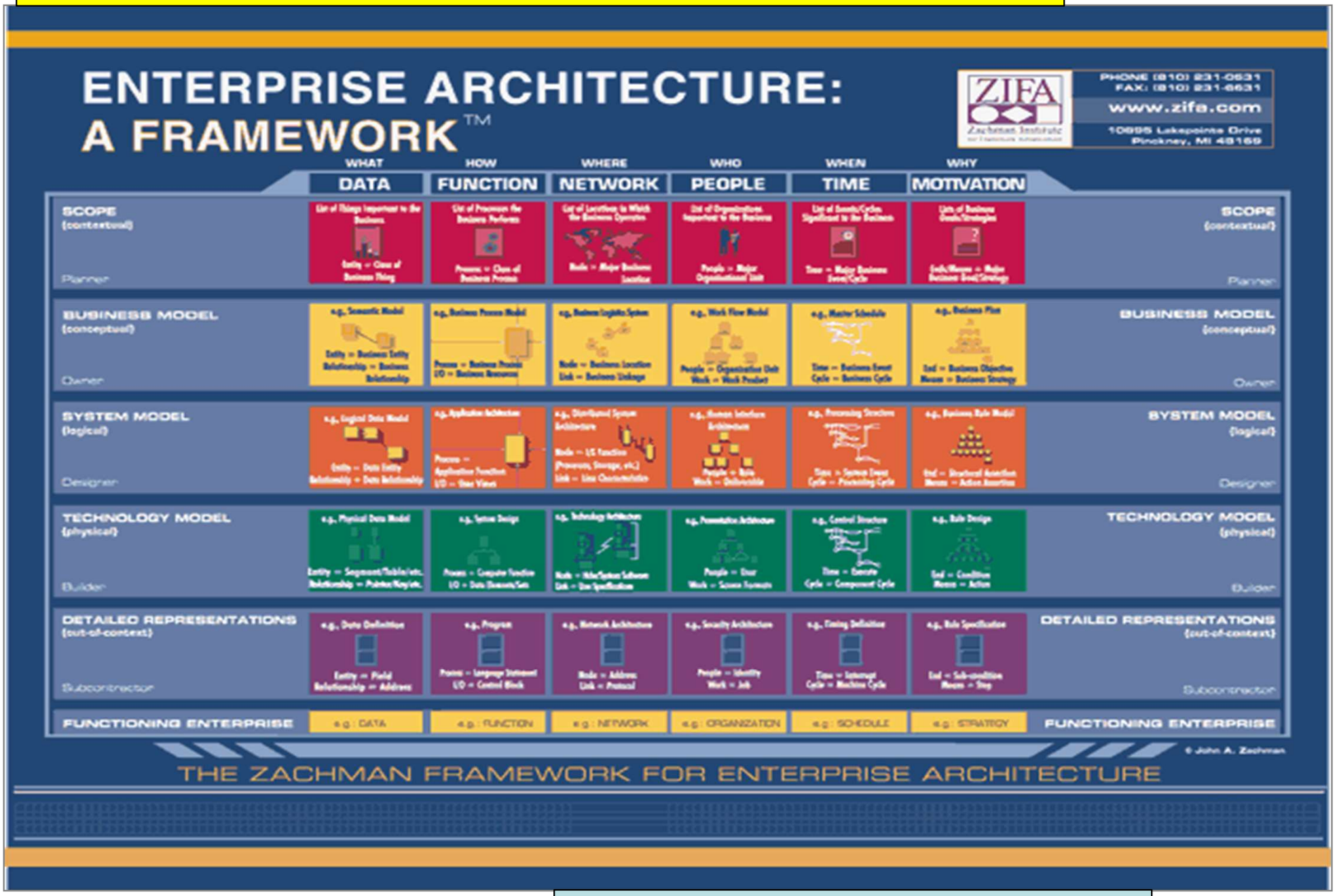
Conceptual Design

Agenda

- Conceptual Design
  - About conceptual design:
    - Goal
    - Who is responsible for conceptual design?
  - Conceptual design process
  - System requirements
  - CONOPS – Concept of operations
  - Requirement analysis
  - Functional baseline, System Specification
  - System-Design Review

Covered in the last lecture

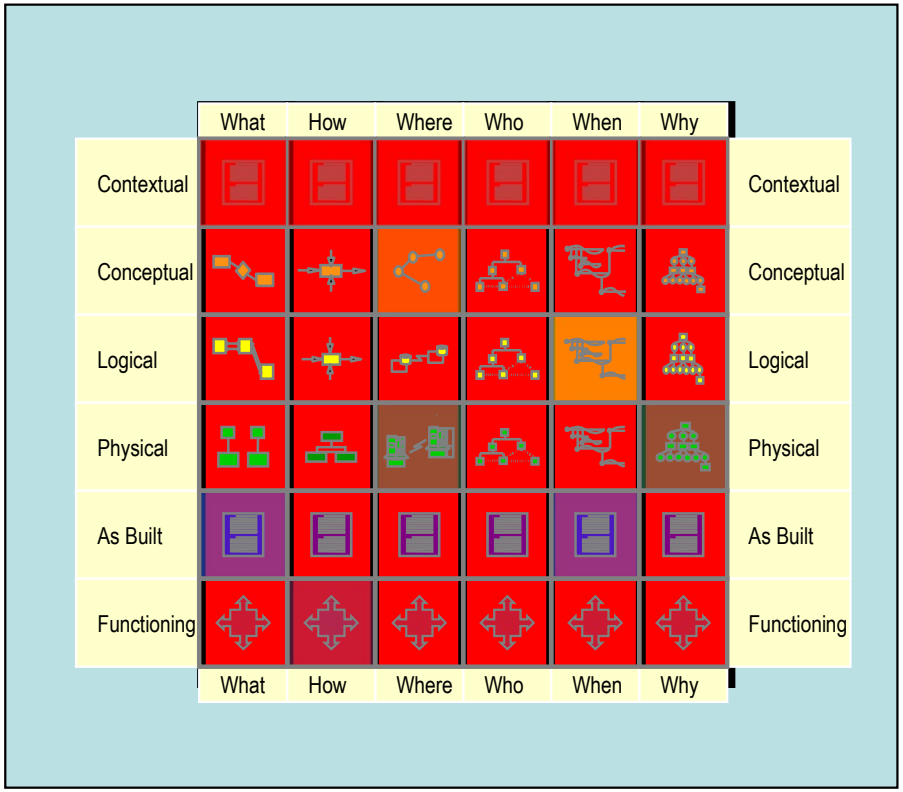


Used with permission

Zachman Framework: Framework Rules*

- The columns have no order
- Each column has a simple, basic model
- The basic model of each column must be unique
- Each row represents a distinct, unique perspective
- Each cell is unique
- The composite or integration of all cell models in one row constitutes a complete model from the perspective of that row
- The logic is recursive

Covered in the last lecture



*John Zachman, J.F. Sowa; *Extending and Formalizing the Framework for Information Systems Architecture*, IBM Systems Journal, Vol. 31, No. 3 (1992); IBM Publication G321-5488

Start with – Why Are We Building This Product or System?

- Row 1, Column 6 – a need
- A large aircraft operator has identified a need for a medium-sized aircraft to
  - Replace the aging platform
  - Over domestic routes and some short international routes
  - Wants an aircraft ideally suited to the role and commercially viable

The Goal of Conceptual Design

- Define the system to be built
  - What the needs are
  - What the system needs to do
  - How well it needs to do it
- Document the findings into two important documents
  - System Requirement Document (SRD): Articulate the need – more descriptive
  - System Specification : The result of system functional design – more technical
    - It is also called the Functional Architecture, Functional Baseline, or Type A spec
    - It is part of the procurement package

System Requirements Document

- Likely applications and missions
- Operational characteristics
- Operational constraints
- External systems and interfaces
- Operational and support environment
- Support concept to be employed

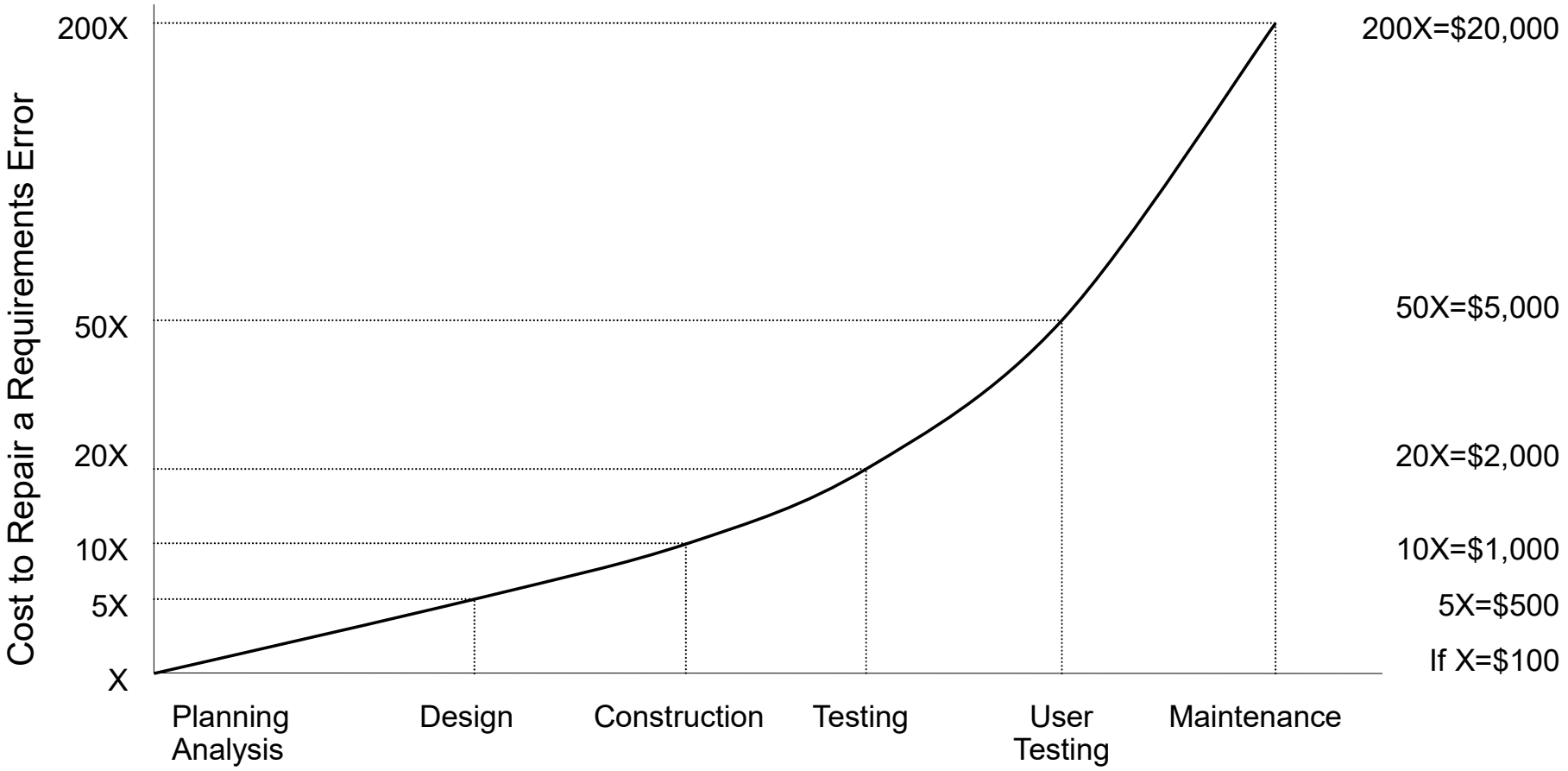
Additional Documents Produced

- Operational Concept Description
  - Use cases
- Verification and Validation Document

Conceptual Design is perhaps the most critical activities in the system life cycle

Cost Risk: Requirements Errors

The cost to repair a requirements error found during *Analysis* is x.
The cost becomes 200x if the error is not found until *Maintenance*.



Development Stage in which error is found and repaired

Source: Davis, Alan. *Software Requirements: Objects, Functions & States*. 1993.

Risks Of An Undisciplined Requirements Process

Factors	% of Responses
Incomplete Requirements	13.1
Lack of User Involvement	12.4
Lack of Resources	10.6
Unrealistic Expectations	9.9
Lack of Executive Support	9.3
Changing Requirements	8.7

Problems related to requirements account for over 60% of project cancellation factors

Source: Standish Group, http://www.standishgroup.com (obtained through Software Productivity Consortium presentation)

Who Is Responsible for the Conceptual Design? (1)

- For custom built systems the conceptual design is the responsibility of the customer procurement agency (e.g. Government program office)
  - The resulting document, System Spec., is part of the procurement specifications.
- Usually all contractors will be asked to participate
  - Procurement agency needs the support from contractors to find optimal solutions – affordable, feasible, practical, …
  - Contractors are eager to learn about customer's preferences and requirements
    - They want to make sure the system specifications are consistent with their design concept, and give them the competitive advantages

Who Is Responsible for the Conceptual Design? (2)

- For most of the commercial products, merchandise are built first then sold in the open market
  - Customer does not exist during the product definition phase
  - Without customer participation
    - Guess who the customers will be
    - What they want from the product
  - The market and product development are usually the responsibility of a senior executive with multidisciplinary team
    - Marketing, engineering, manufacturing, finance, sales, …

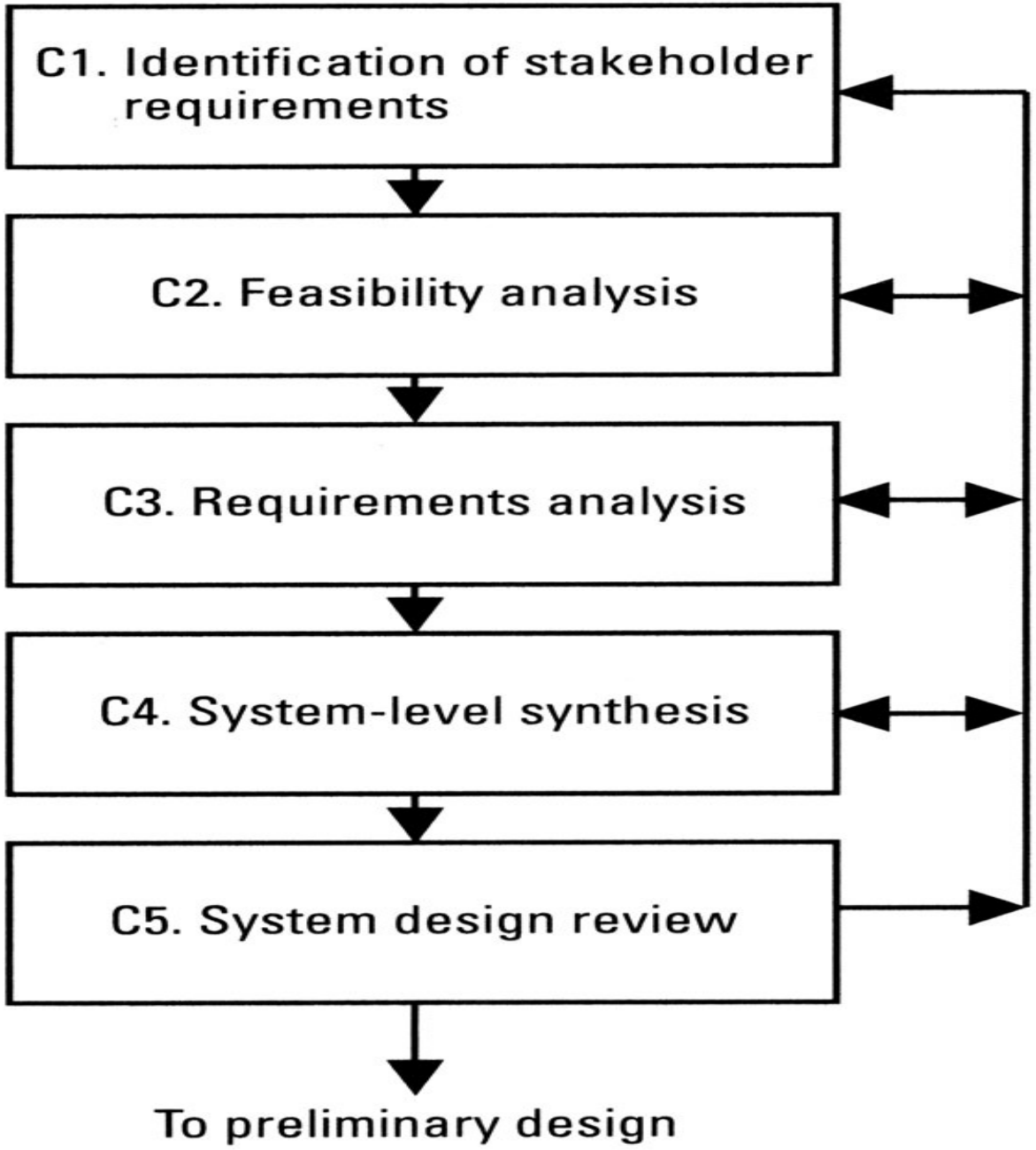
Message

- Conceptual design is when the problem is understood and the solution (the system) is defined
- If mistakes are made, we will be solving the wrong problem and building the wrong system
- It is very expensive and time consuming to correct these mistakes at later date

Recorded Lecture Assignment or In Class Discussion

- Discuss some of the "needs" for your group project system
- If your group has not identified a system
  - Are the products that you are using meet your needs?
    - Examples: Car, dorm room, equipment in this room, computers, cell phone, freeway toll collection system
  - What are missing?
    - List 5 or 6 shortcomings. Why they are important? If they can be prioritized, list them from high to low priority.

The Conceptual Design Process



Identify The System Requirements (C1)

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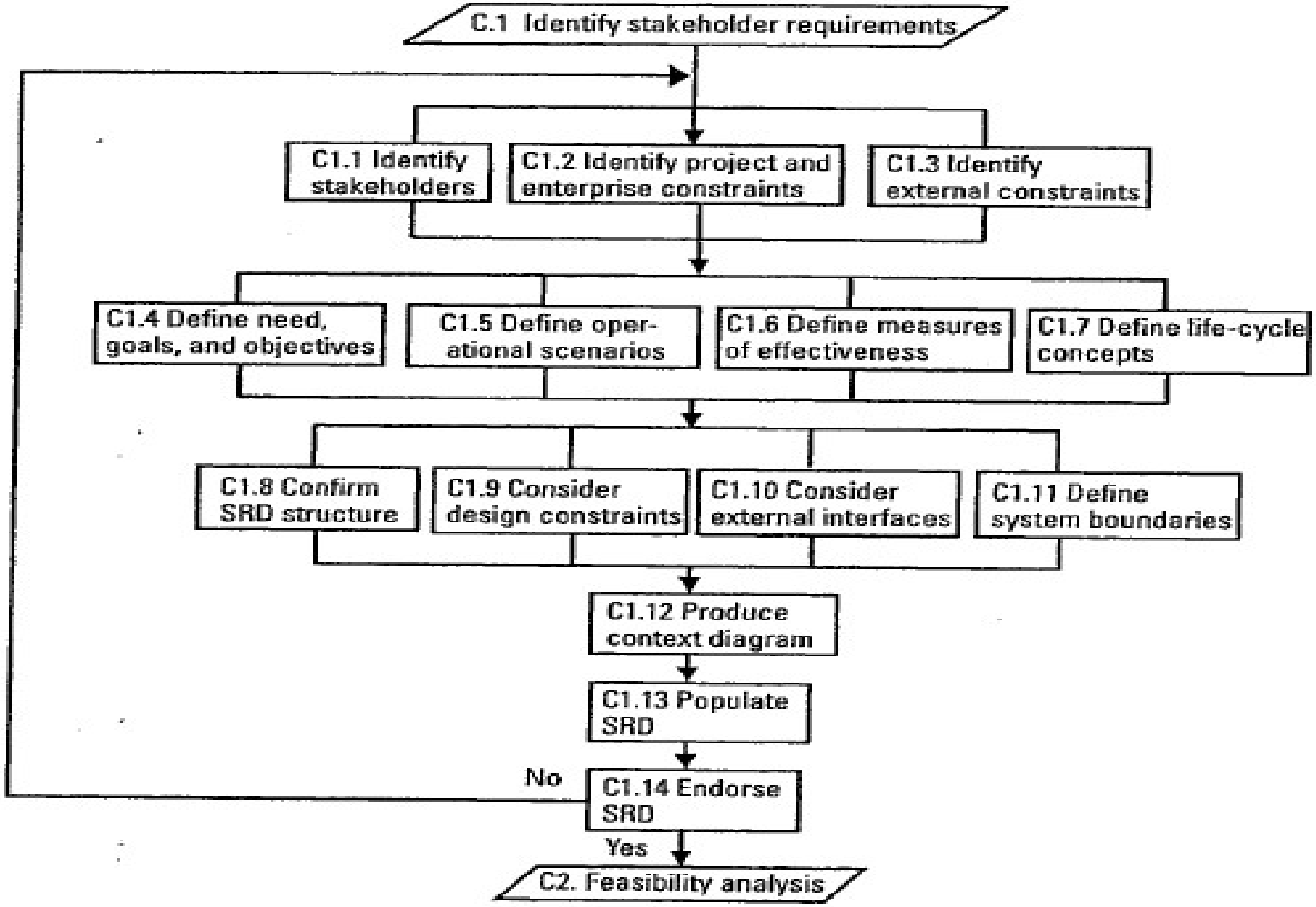
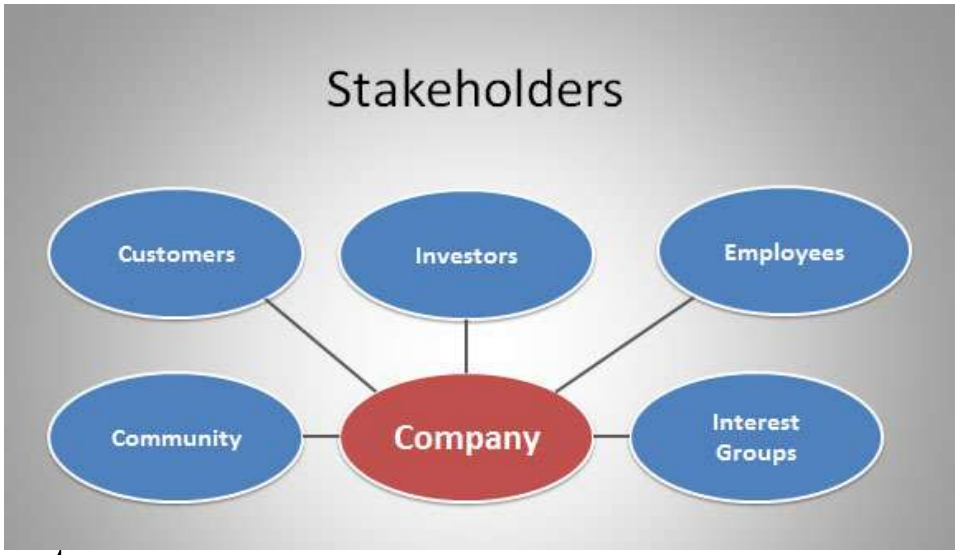


Who Are Stakeholders? (C1.1)

A stakeholder is anyone who is affected by the design of the system, including:

- Customers (Procurement agency)
- Users
- Maintenance personnel
- System developers
- Partners who provide related products or services
- System integrators, Independent Verification &Validation facilities
- Manufacturing

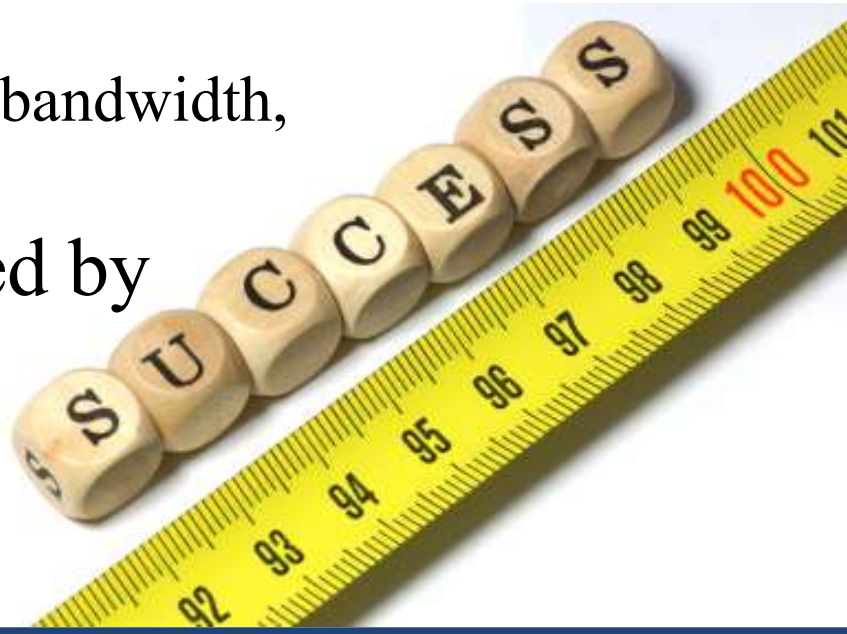


Examples: ACME Aircraft System

- Stakeholders for ACME aircraft system
  - Airlines: Fuel efficiency, passenger and cargo capacity
  - Users (air crew and ground crew): aircraft functional and performance requirements
  - Marketing people
  - Maintainers: Accessibility, reliability, and maintainability, provisioning of spare parts
  - Subsystem suppliers: Engine supplier, avionics suppliers, landing gear, …
  - Manufacturing partners (domestic and international)
  - Airworthiness Certifiers: The organization and persons who give the "air worthiness certificate" for each aircraft

Define Measures of Effectiveness (MOE) (C1.6)

- It defines the levels of performance that are required:
  - Aircraft turn around time
  - System start up time
  - User experience and educational requirements
  - System availability – system down time
  - Aircraft or spacecraft payload (size and weight)
  - Aircraft range
  - Computing systems – data storage, IO bandwidth, through put
- Often, a MOE need to be specified by a number of performance parameters – measure of performances (MOPs)



System-Requirements Documents (SRD)

- The SRD is written in the language of the customers and users
- It documents:
  - the environment where the system will be deployed
  - how system will be used including operational requirements
  - how system will be maintained and supported
  - the system life cycle requirements

System-Requirements Documents (SRD) – cont

- It is "**what do you want**", not "how to do it" document
  - System functions and related requirements should be avoided if at all possible
  - They will be done by system engineers during requirement analysis and synthesis where all requirements are considered to achieve a system level optimal solution
- Understand all requirements first, then design a balanced system to meet *all* requirements!
  - This is the most important reason for top-down design

Example: F-117 Radar Consideration

- F-117 is a stealth fighter bomber
- A radar will provide it the needed situation awareness capability
- But radar adds weight, so reduces weapon capacity
- When Radar is on, the radar microwave energy can be detected, and give away its own location

Question: Should we have a radar on board F-117?

ACME Examples

- Example 1: An operational requirement for an aircraft
  - The aircraft is to be capable of operating from any Class X airport in the world
  - The aircraft is to provide "class leading" comfort for passengers
  - The aircraft is to be capable of being turned around to its next flight within 30 minutes

ACME Examples

- Example 2: An operation scenario for an electronic maintenance manual

  "The maintainer pulls out his electronic maintenance manual which contains all documentation for Boeing 737 E series, searches for landing gear, finds the section, including the diagram, and the latest revisions, all automatically downloaded each night. There is a hyperlink in the text to a knowledge base where actual experiences are tracked. Clicking on it, maintainer spots the problem in a flash, applies the fix, and the plane is on its way."

In Class Discussion

- Identify the stakeholders for your group project
  - Who should be involved in coming up with this solution?
    - Would this be dependent on what solution is used?
- Consider what are the measure of effectiveness for your group project
  - Any specific measure of performances?
  - List several of them
    - Continue this discussion in your group gets together later on

In Class Discussion

- Are the products that you are using meet your needs?
  - Select one for each group: Car, dorm room, equipment in this room, computers, cell phone, freeway toll collection system
- What are missing?
  - List 5 or 6 shortcomings. Why they are important? If they can be prioritized, list them from high to low priority.

If your group project team already identified a system, then do this discussion on current solution to the problem

In Class Discussion

- Consider what are the measure of effectiveness for your group project
  - Any specific measure of performances?
- List several of them
  - Continue this discussion in your group project get together later on

Class Discussion

- Who are the stakeholders for your group project system?
- Who should be involved in coming up with this solution?
  - Would this be dependent on what solution is used?

In Class Discussion

- Who are the stakeholders for the oceanic tracking system?
- Who should be involved in coming up with this solution?
  - Would this be dependent on what solution is used?

Structure of SRD

- Scope (Row)
- Reference Documents (Why)
- Operations – concept of operations (How)
- Operational Needs (What + Who + When)
- System overview (How)
- Operational and support environments (Where)
- Operation Scenarios – use cases (How)

Example mapping to Zachman
A different mapping might be required for each specific system

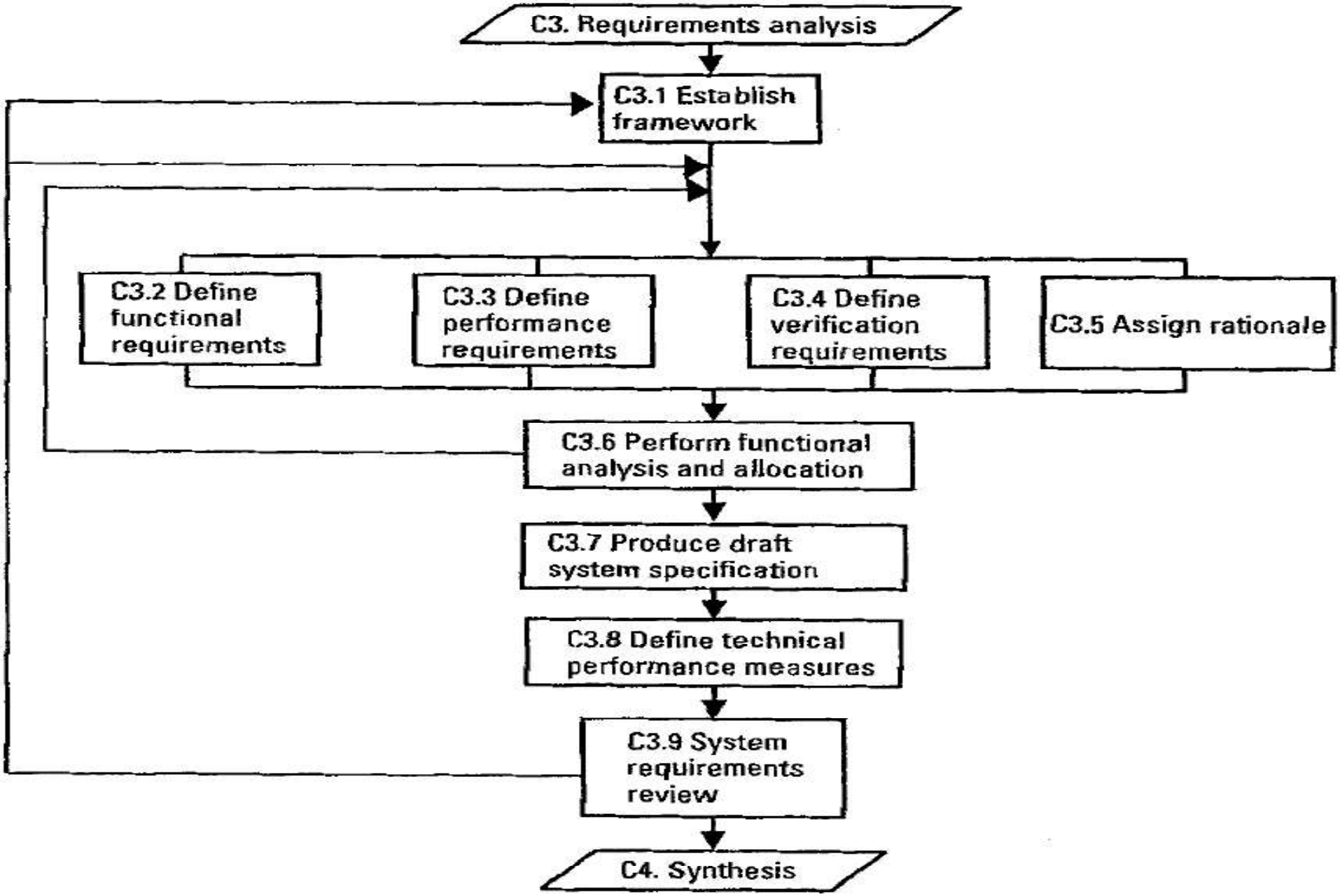
Feasibility Study (C2)

- Identify the possible system-level solutions
- Study the viability of these solutions according to the requirements in SRD:
  - performance, cost, schedule, risk, supportability, …
- Key questions:
  - Can this system (as defined in SRD) be built?
  - What are the key risks?
  - How to reduce the risks?
  - Is SRD reasonable? Could it be modified to reduce the risks and still meets the main system objectives?
- Participations of Contractor (prime and major subcontractors) are critical

Requirement Analysis (C3)

- Goal: Derive the system level functional requirements from the operational level requirements in the SRD
  - What are the required system functions, and how well these system functions have to perform to meet the goals and objectives Defined in the SRD
- Focus on "What is required", not "How to do it"
  - We are still trying to understand the problem at the system level
  - Jump to the solution may lead to suboptimal designs

Requirement Analysis Process



Define Functional, Performance & Verification Requirements (1)

- Objectives: Identify
  - "What need to be done"
  - "How well they need to be perform at"
  - "How to prove it"
- Identify all system functions that are required to meet the systems requirements established in SRD
  - Concept of operation, life-cycle concept, …

Define Functional, Performance & Verification Requirements (2)

- For each of these system functions identify all performance related parameters, Examples:
  - Operational Environmental: weather condition such as temperature range, humidity tolerances, rain, fog, snow, …
  - Mechanical stress: noise, vibration, shock, …
  - Chemical, nuclear, and biological
  - Quality: availability, reliability, and maintainability
  - Storage: storage capacity, spare allowances, training, level of maintenance
  - Utilization requirements: duty cycles, hours of operation

Define Functional, Performance & Verification Requirements (3)

- Identify all verification requirements – How do you know that you met the requirement?
- All of these activities follows logically from the SRD
- It is important to record the rational behind each of these requirements
  - The requirement rational makes the requirement easier to understand
  - Not all requirements are obvious. It could be very important during future system upgrades
  - Example: 80km/h requirement for back windscreen of passenger cars
    - It is required when cars are transported in reversed position

Identification Of System Functions Example: (1)

- Operation scenario for "Electronic maintenance manual"

  "The maintainer **pulls** out his electronic maintenance manual which **contains all documentation** for Boeing 737 E series, **searches** for landing gear, finds the section, including **the diagram**, and the latest revisions, all **automatically downloaded** each night. There is a **hyperlink in the text to a knowledge base where actual experiences are tracked**. **Clicking** on it, maintainer spots the problem in a flash, applies the fix, and the plane is on its way."

- Identify system functions
  - "Pulls": This device need a bag
  - "contains all documentation for Boeing 737 E series": Either have a lot of memory or it is connected to a server, most likely by a wireless interface for mobility

Identification Of System Functions, Example: (2)

- "searches": Need a search function
- "the diagram": Need graphic capability
- "automatically down load each night": Definitely need to be connected to a server, either wireless or by a docking station
- "hyperlink in the text to a knowledge base where actual experiences are tracked":
  - Need to be connected with the computer that host the knowledge base
  - Assume a knowledge base for the 737 maintenance experience. It could be an expert system (need to check it out!)
  - We may even need a customer support system (need to check that out too!)
  - "Clicking": This device need to have …

Example

- Operational Scenario – Aircraft location via self report through satellites
  - Upon engine start, pilots checks oceanic reporting systems and enters appropriate data
  - Once aircraft takes off, the oceanic reporting system will send the aircraft location via satellite to a control center
  - Control center reports the specific aircraft location to the airline and the Oceanic Control Center

Example

- Operational Scenario – Aircraft location via self report through satellites
  - Upon engine start, pilots checks oceanic reporting systems and enters appropriate data
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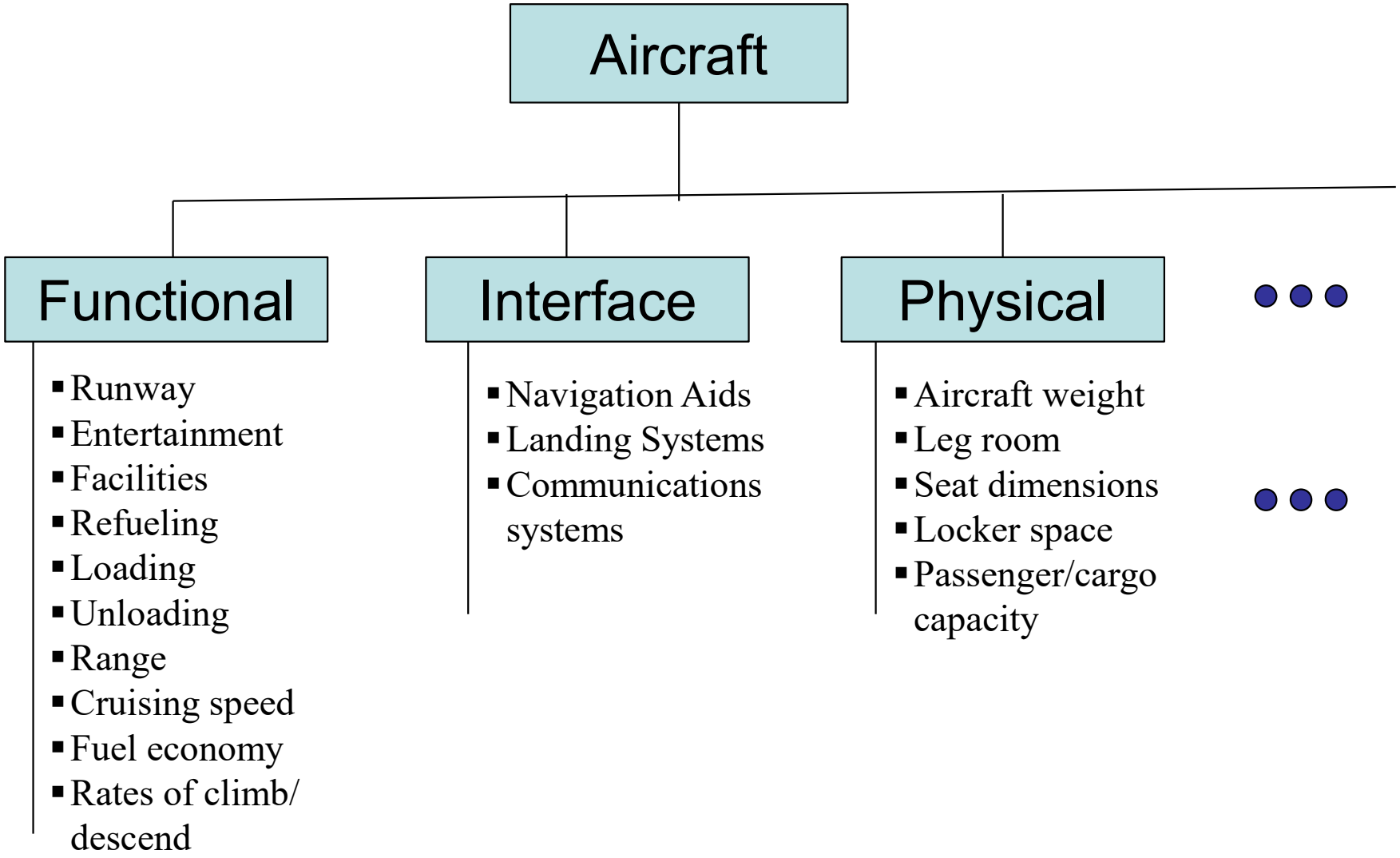
~~*In Class Discussion or*~~ *Lecture Homework*

- For your group project, develop a scenario and identify 5 system functions
- If lecture homework
  - When your group gets together, you can share your scenario

Functional Analysis And Allocation (C3.6)

- Functional analysis
  - Functional decomposition
  - Requirement flow down
  - The lower level requirements – derived requirements
- Functional allocation
  - Functions are allocated to the appropriate group of the RBS (requirements breakdown structure)

Requirements Breakdown Structure (RBS) Example

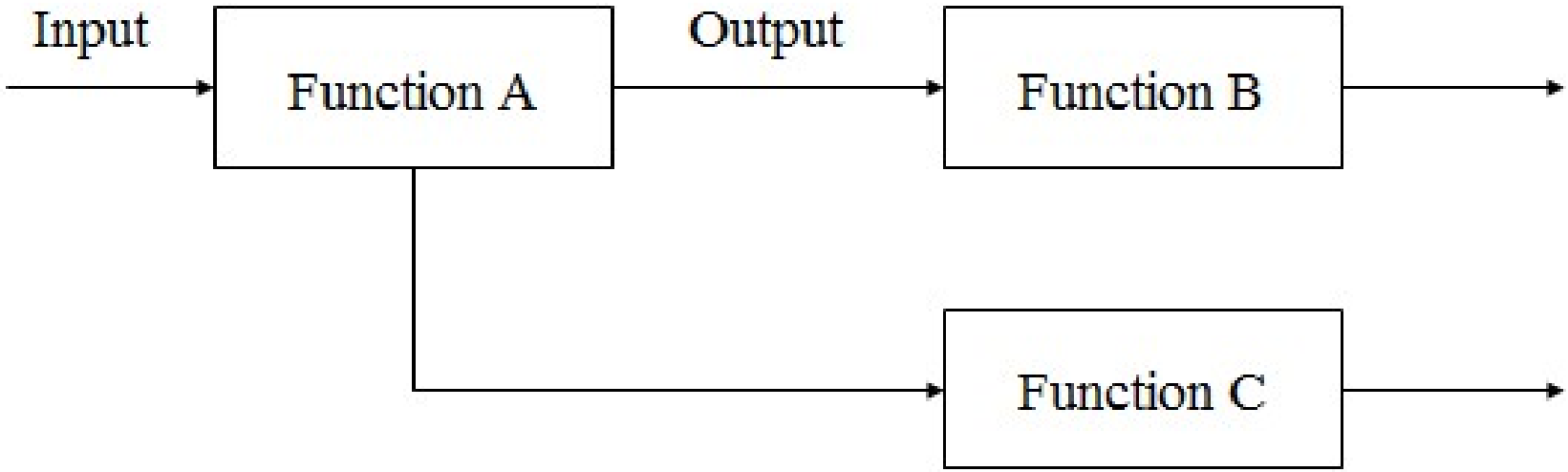


Examples Of Functional Decomposition

- Operate from any class X airport
  - Minimum runway lengths
  - Runway surfaces
  - Maximum allowable aircraft weight
  - Essential navigation aids
  - Essential automatic landing systems
  - Essential communication systems
- Providing class-leading comfort to passengers
  - Leg room, seat dimensions, seat support requirements, entertainment systems, bathroom facilities, catering services

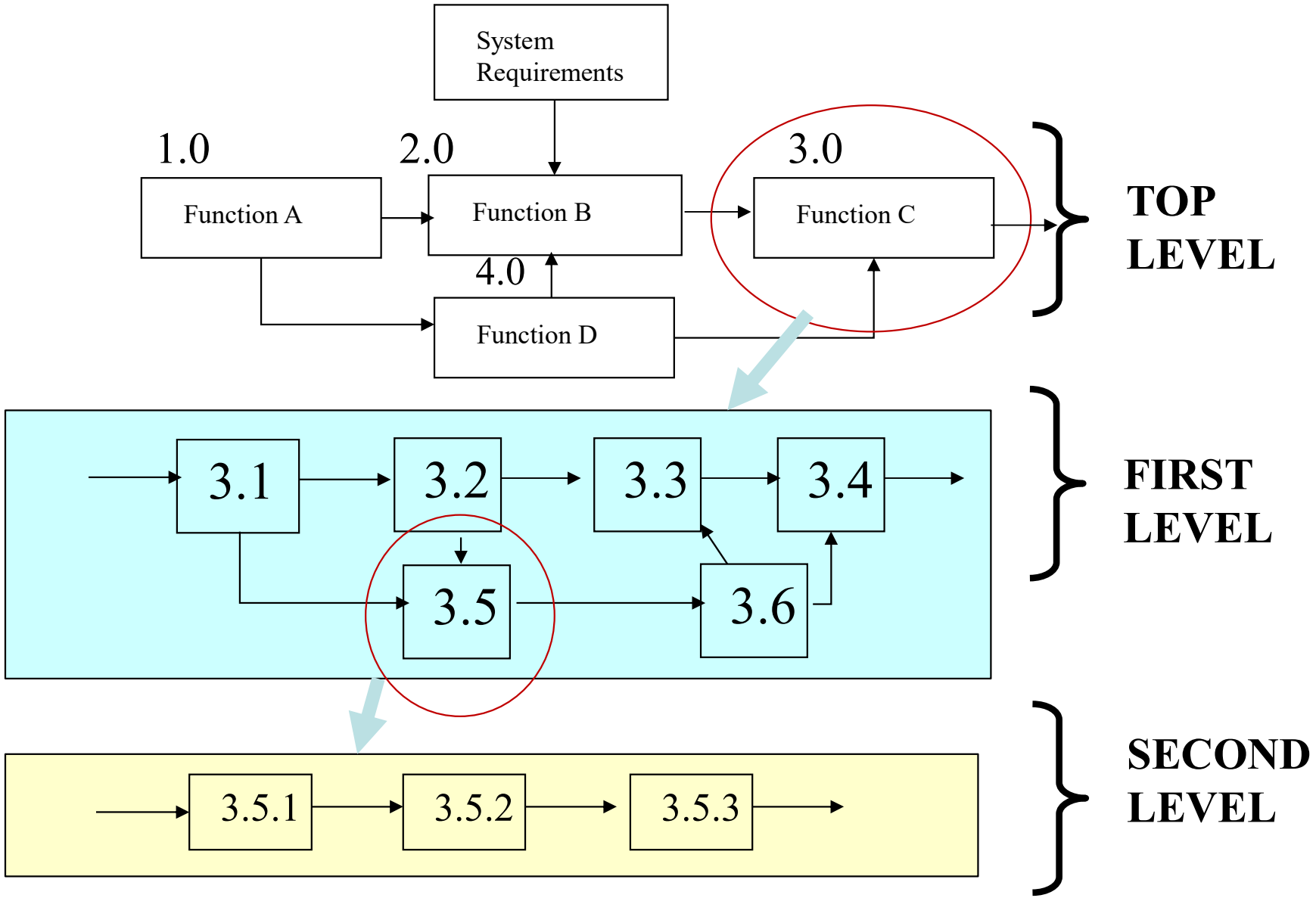
FFBD – Functional Flow Block Diagram (1)

- FFBD is a tool that helps the system engineers to visualize the functional decomposition that logically breaks down a system function into a set of sub-functions, and interfaces

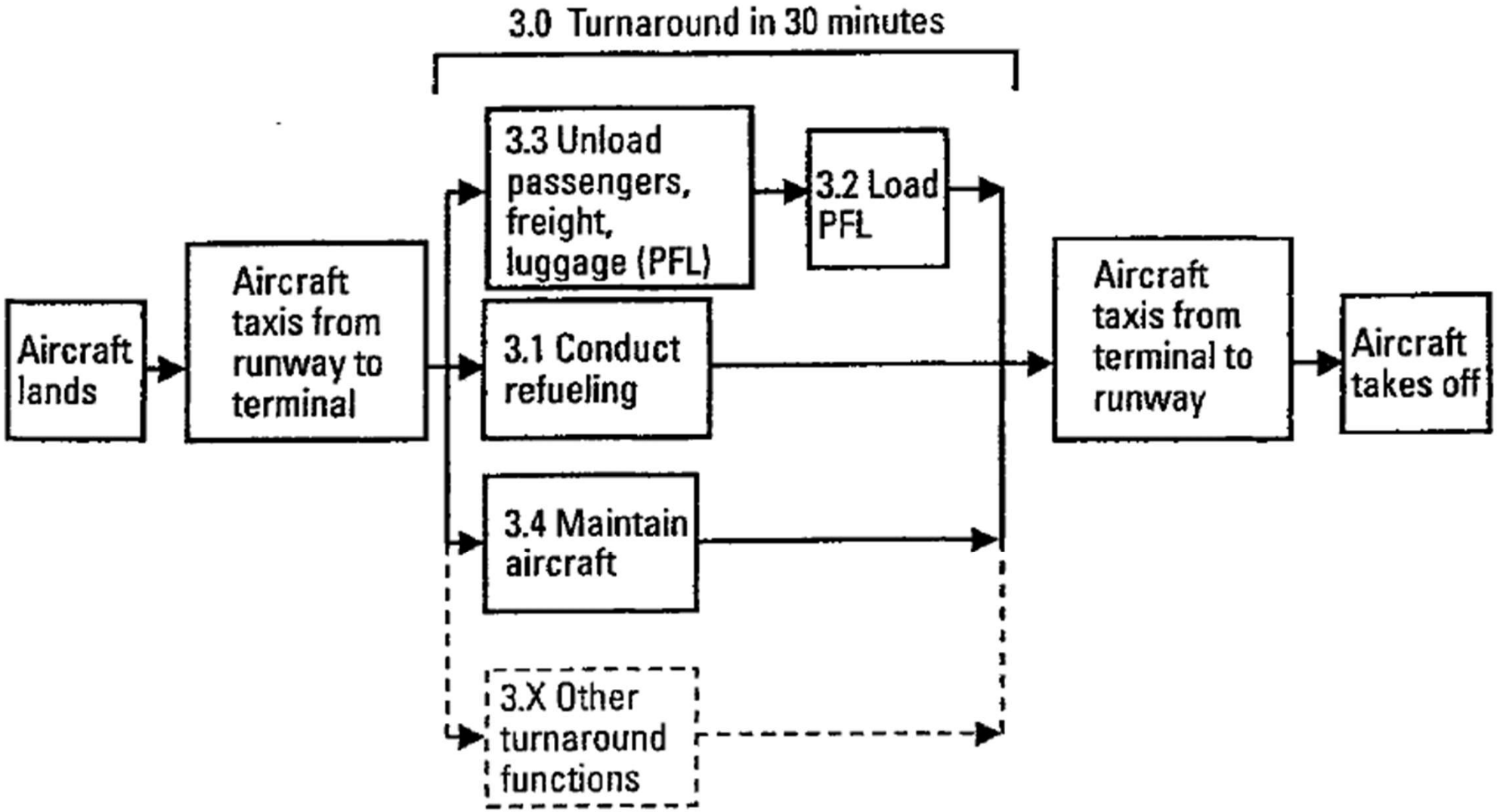


- This tools can be used repeatedly until all components are well defined and understandable

Functional-flow Block Diagram Numbering convention



Functional decomposition and requirement flow down – Aircraft turn around in 30 minutes (1)



Functional decomposition and requirement flow down Aircraft turn around in 30 minutes (2)

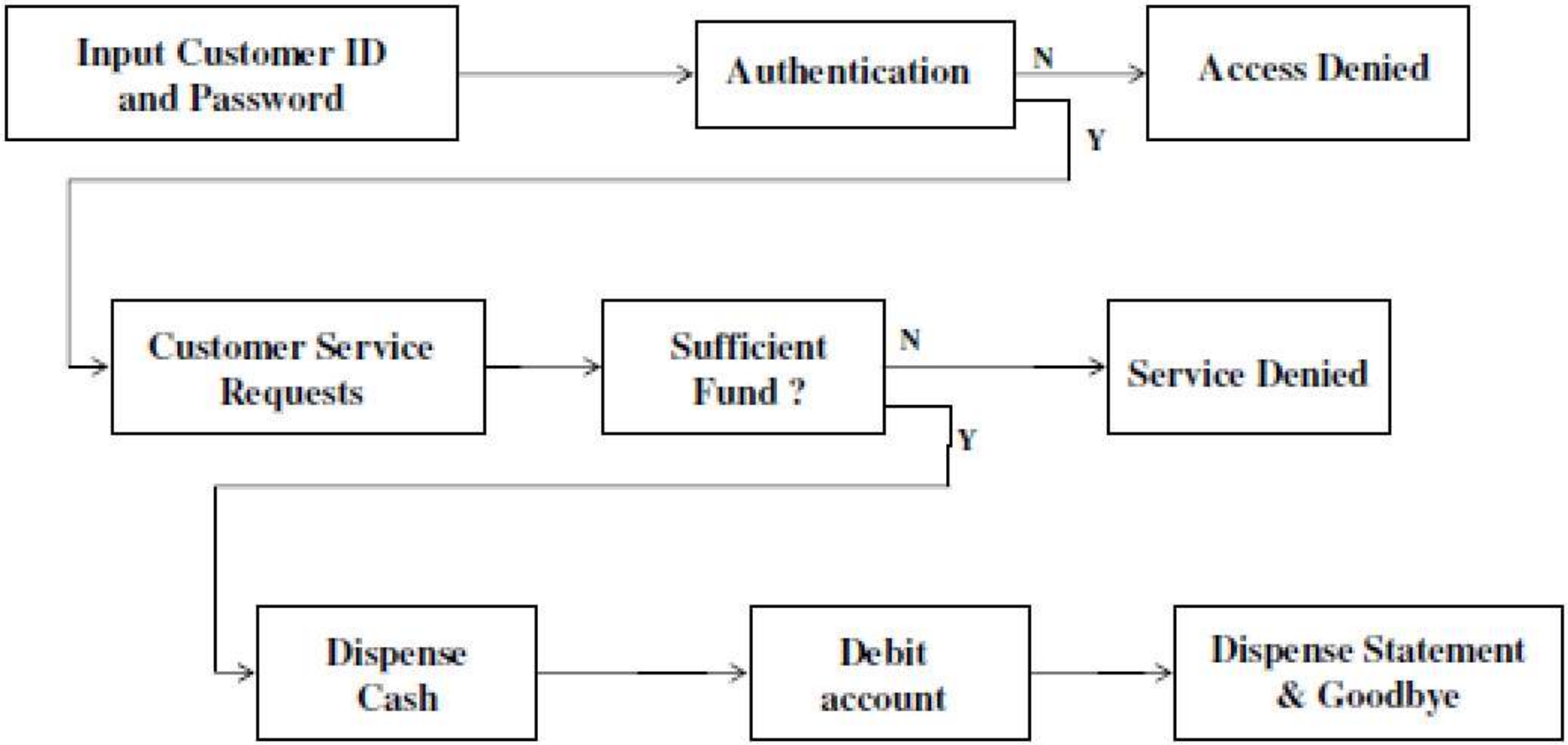
- Unload PFL + Load PFL ≤ 30 minutes
- Conduct refueling ≤ 30 minutes
- Maintain aircraft ≤ 30 minutes

PFL – passengers, freight, luggage

FFBD: An Example

- Assume you were a system engineer who is responsible to develop an ATM system with just one function:
  - Withdraw cash from customer's account
  - Requirements:
    - System response time for each interface can not be longer than 30 seconds ← Is this reasonable?
    - No over drawn allowed
- Please use FFBD to perform function analysis and requirement flow down

FFBD for ATM System (1)



We will continue this example in the next lecture

In Class Assignment (15 minutes)

- **Pick one** of the following
  - For the group project system that your team has selected, draw a top level FFBD diagram
  - For the operational scenario you analyzed in an earlier class, draw a top level FFBD diagram
- Take one of the box, analyze its detailed systems functions and draw a next level FFBD diagram
- Analyze this scenario to identify 5 additional derived requirements

In Class Assignment (cont)

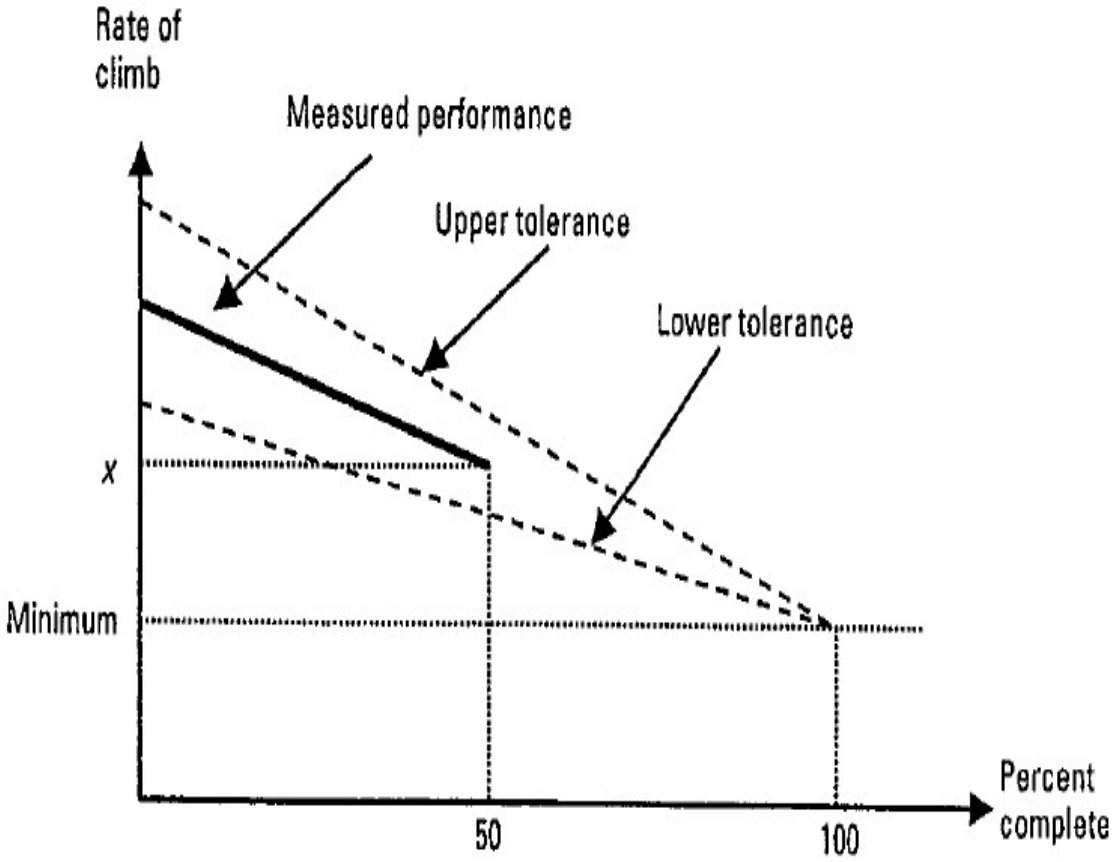
- Analyze this scenario to identify 5 additional derived requirements

TPM – Technical Performance Measures (C3.8)

- TPMs are the key technical performance parameters. They are identified earlier in the program, and monitored and tracked during the development phase of the program. It is a tool to manage technical risk.
  - TPMs are dropped and added depends on the uncertainty and risk factors
- Risk management plans should be in place for high priority TPMs.
  - Examples: Aircraft climb rate, aircraft weight, Radar transmit power, …

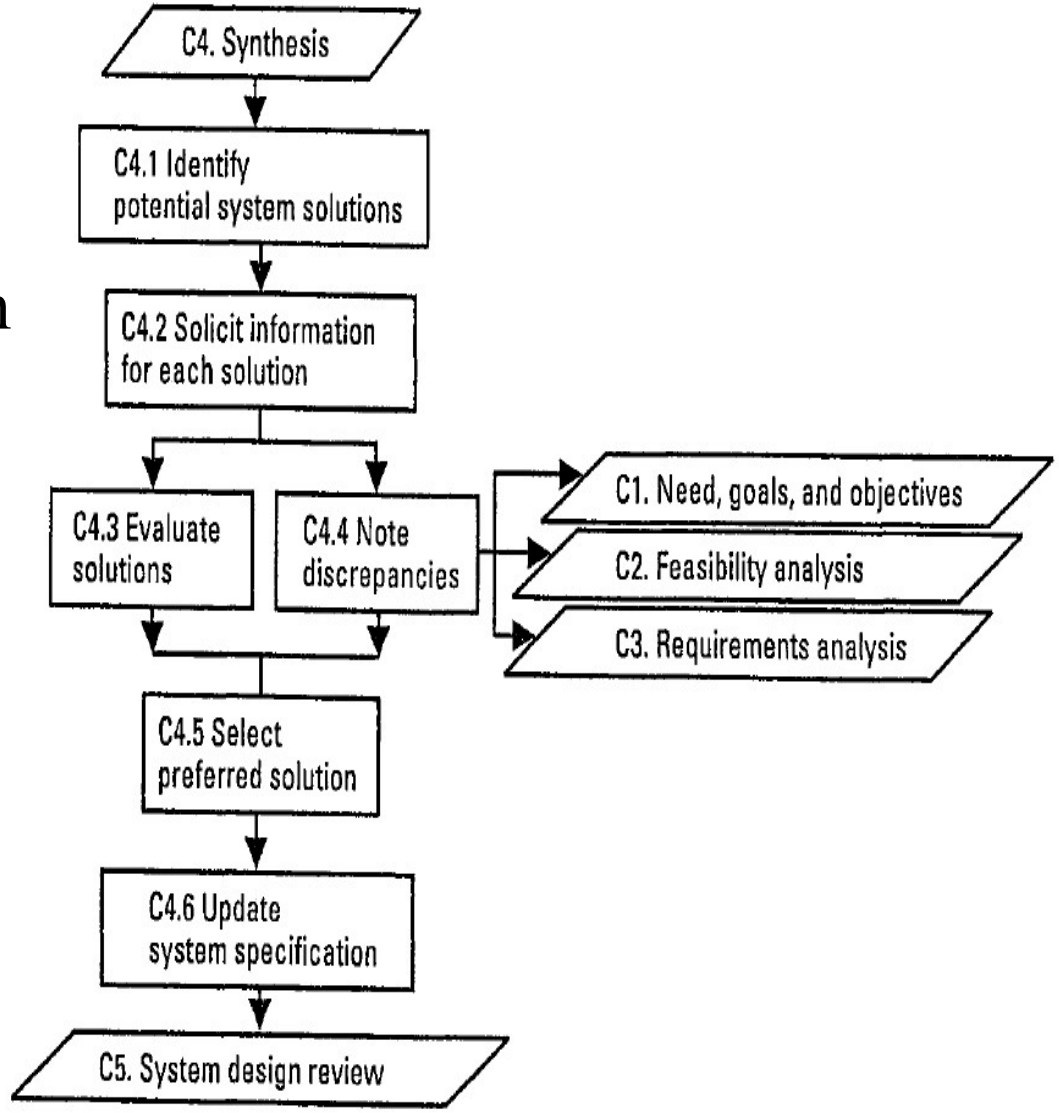
TPM Example: Aircraft Minimum Climb Rate

- Expected value and band of acceptable variation are established at the beginning of the program
- Actual performance are tracked through the program
- Variation band should be narrowed as design matures
- Need to pay attention to both actual performance level and the performance trend
- Identify the root causes:
  - e.g. aircraft weight, drag, engine power, …



System Level Syntheses (C4)

- Purpose: To select a system level functional design.
  - Many trade studies are required
  - Modeling and simulations can be effective tools
  - Contractors are often invited to submit their solutions
- Conceptual design is an iterated process.
  - The SRD are often revised based on the lessons learned during the synthesis
  - Requirement flow down and traceability are key to this process



Attributes of a Good Requirement

- Implementation-free
  - Define what need to be done, not how to do it
  - Provide rationales for requirements
- Concise and unambiguous
- Verifiable
- Complete and consistent
- Feasible

System-Design Review (C5)

- This is a major event, often takes many days
- Formal approval of System Spec are required
- The System Spec, also called the functional baseline, are the foundation of the system development that follows

In Class Assignment (10 minutes)

- From the FFBD that you developed earlier, write 3 requirement statements

An Example of Conceptual Model

Conceptual Domain Diagrams for a Power Grid System

from Engineering 204 Trusted Systems Engineering Risk Management Lecture

Charts obtained on May 15, 2009, from IEEE P2030 meeting

Power Control System and Corporate Network

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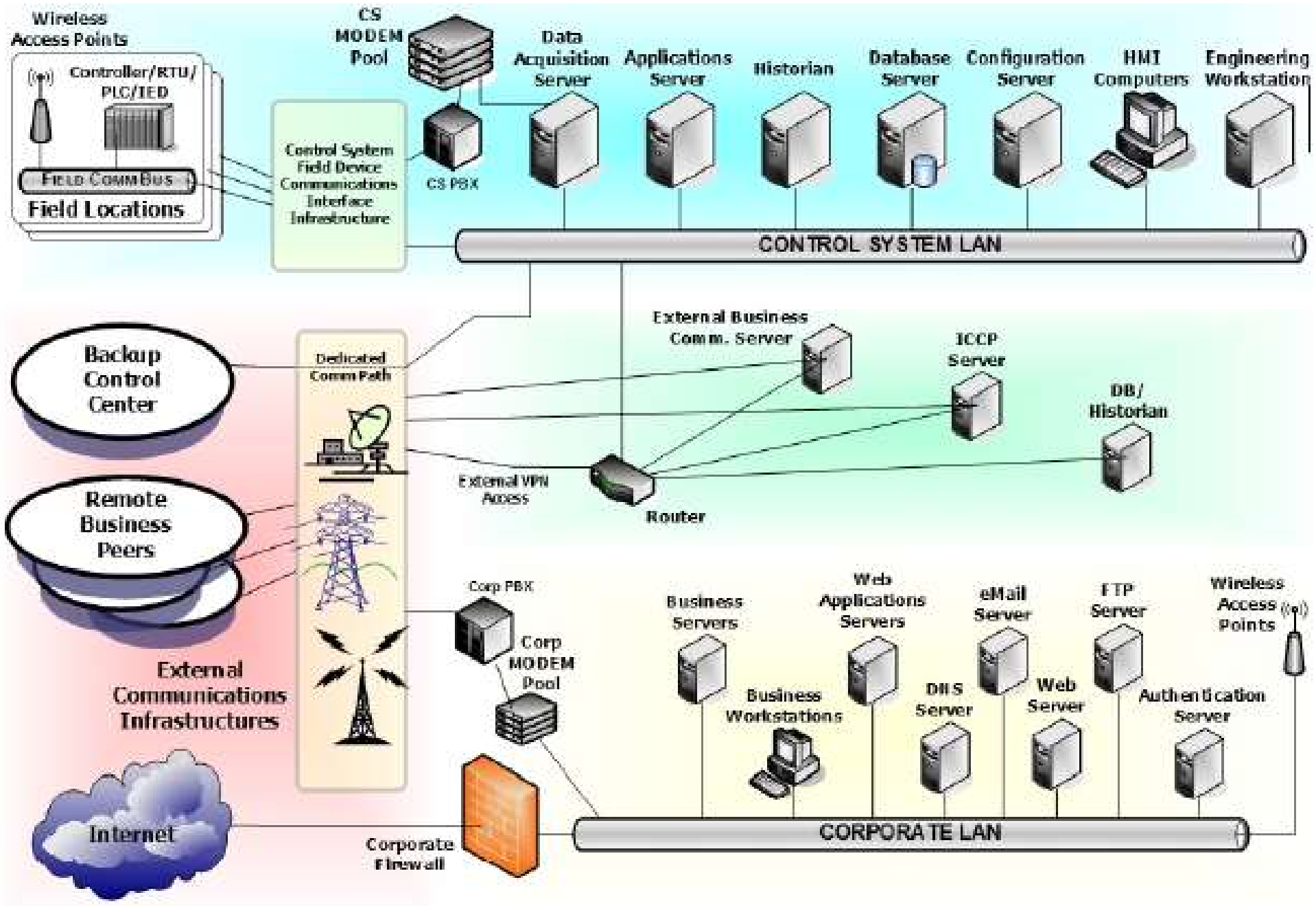
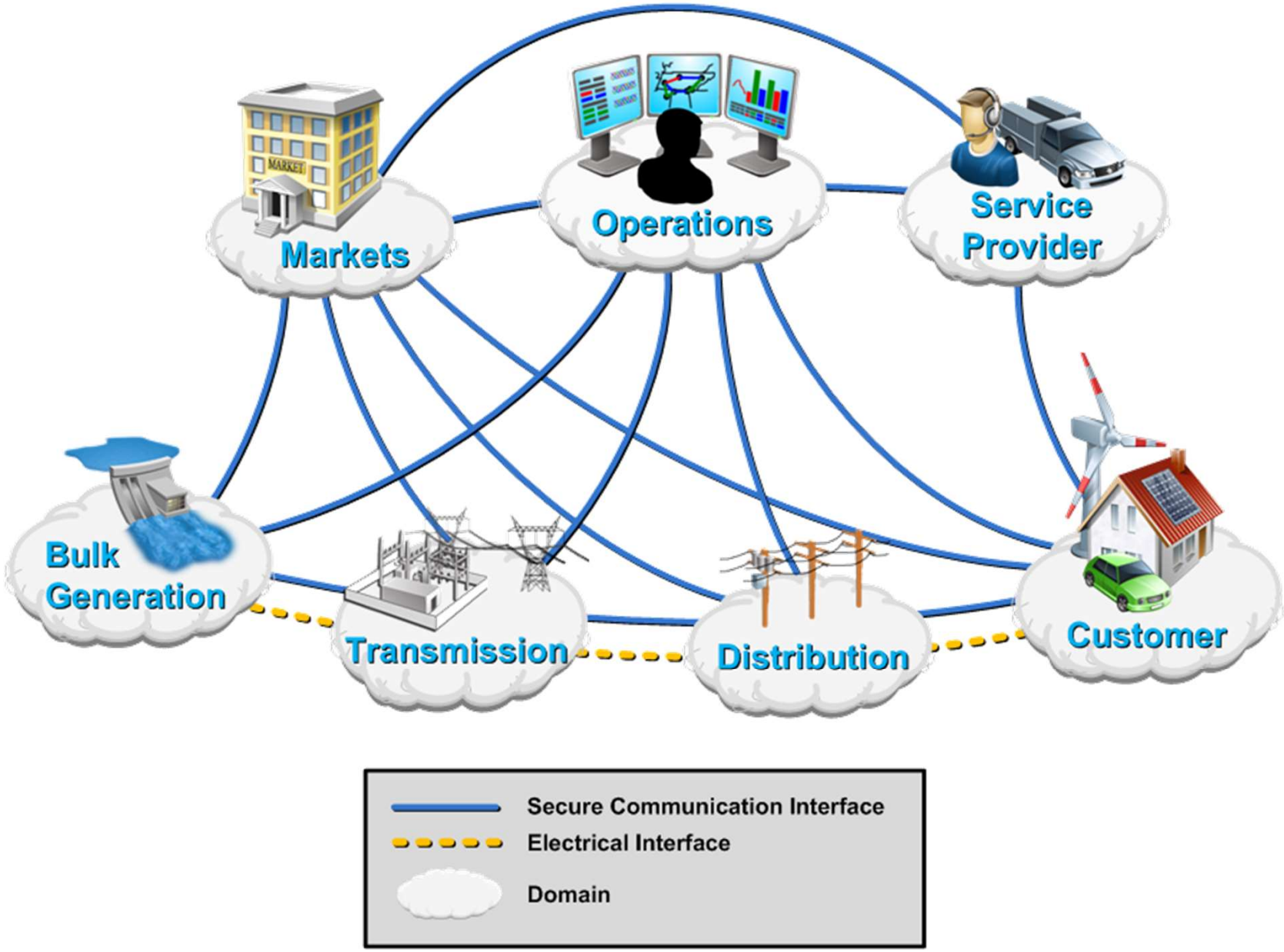
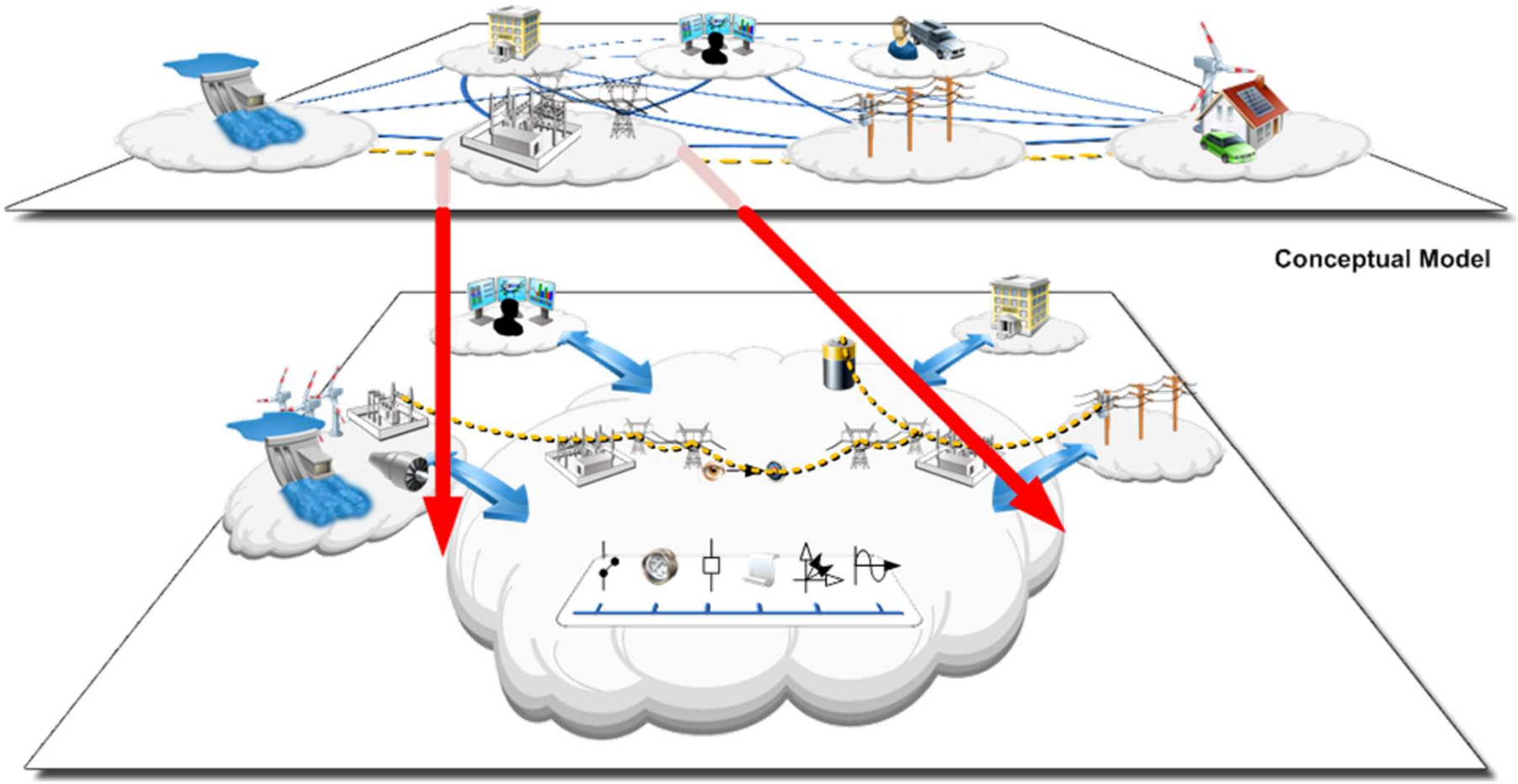
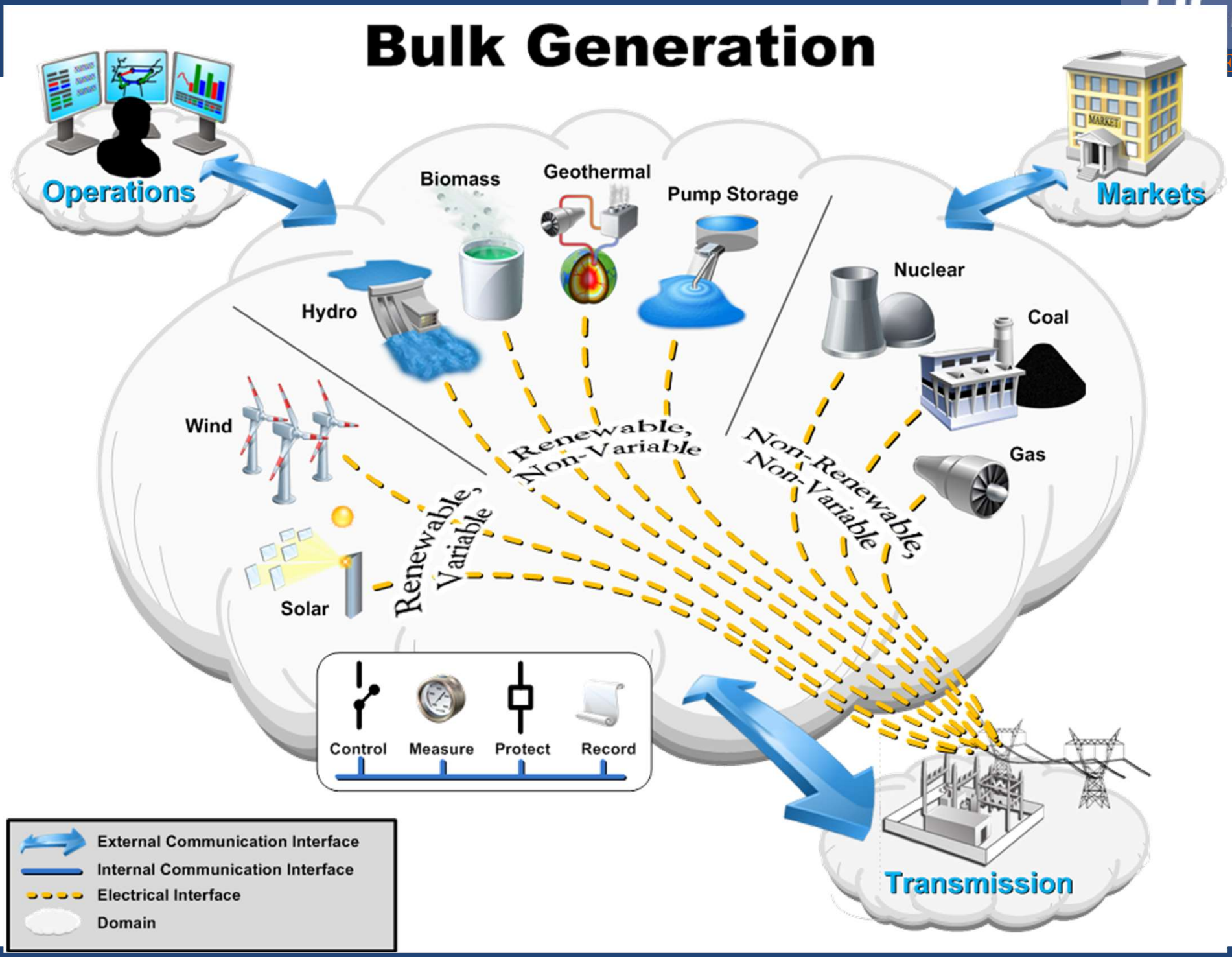


Conceptual Model

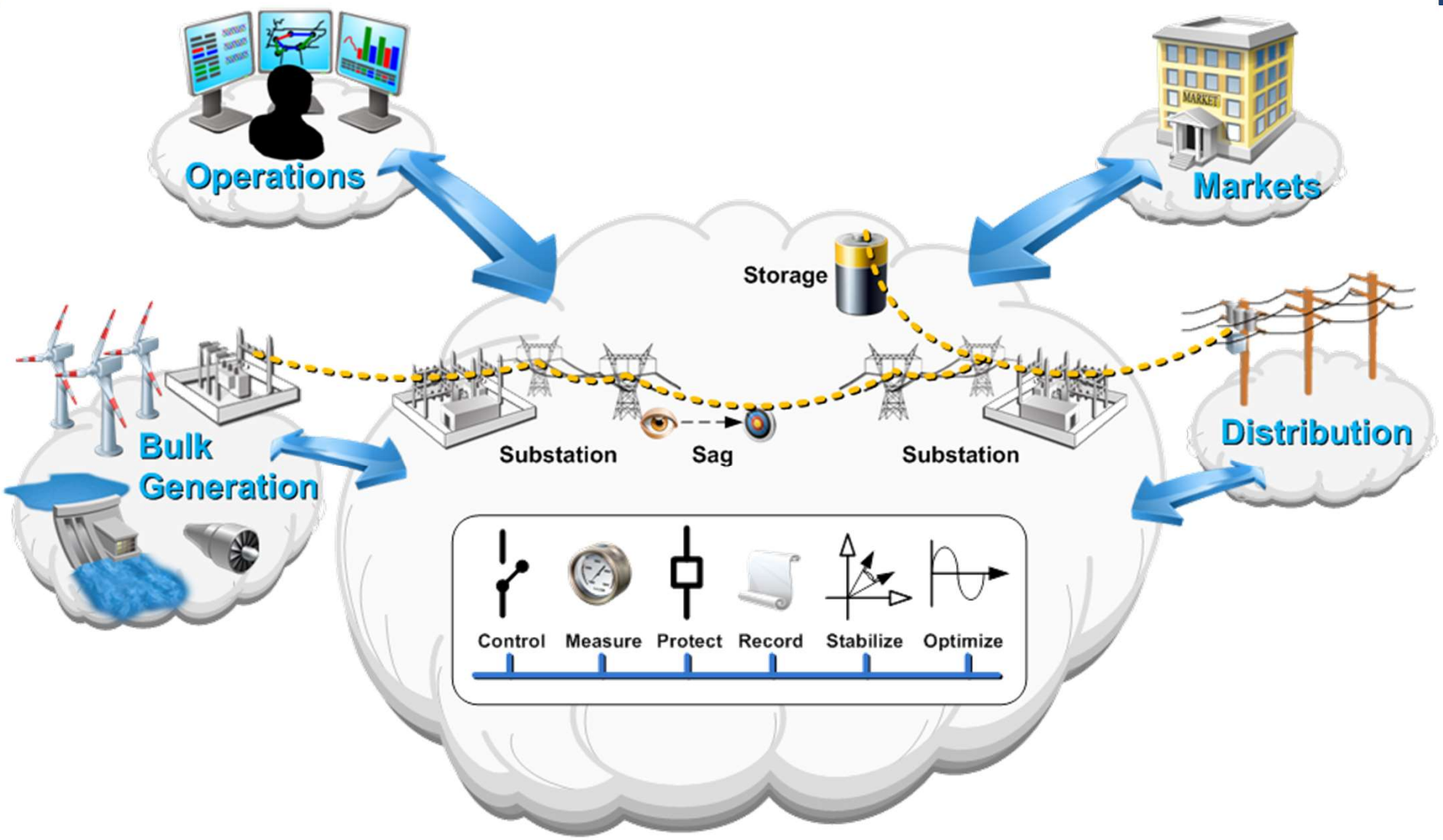


Levels of the Conceptual Model

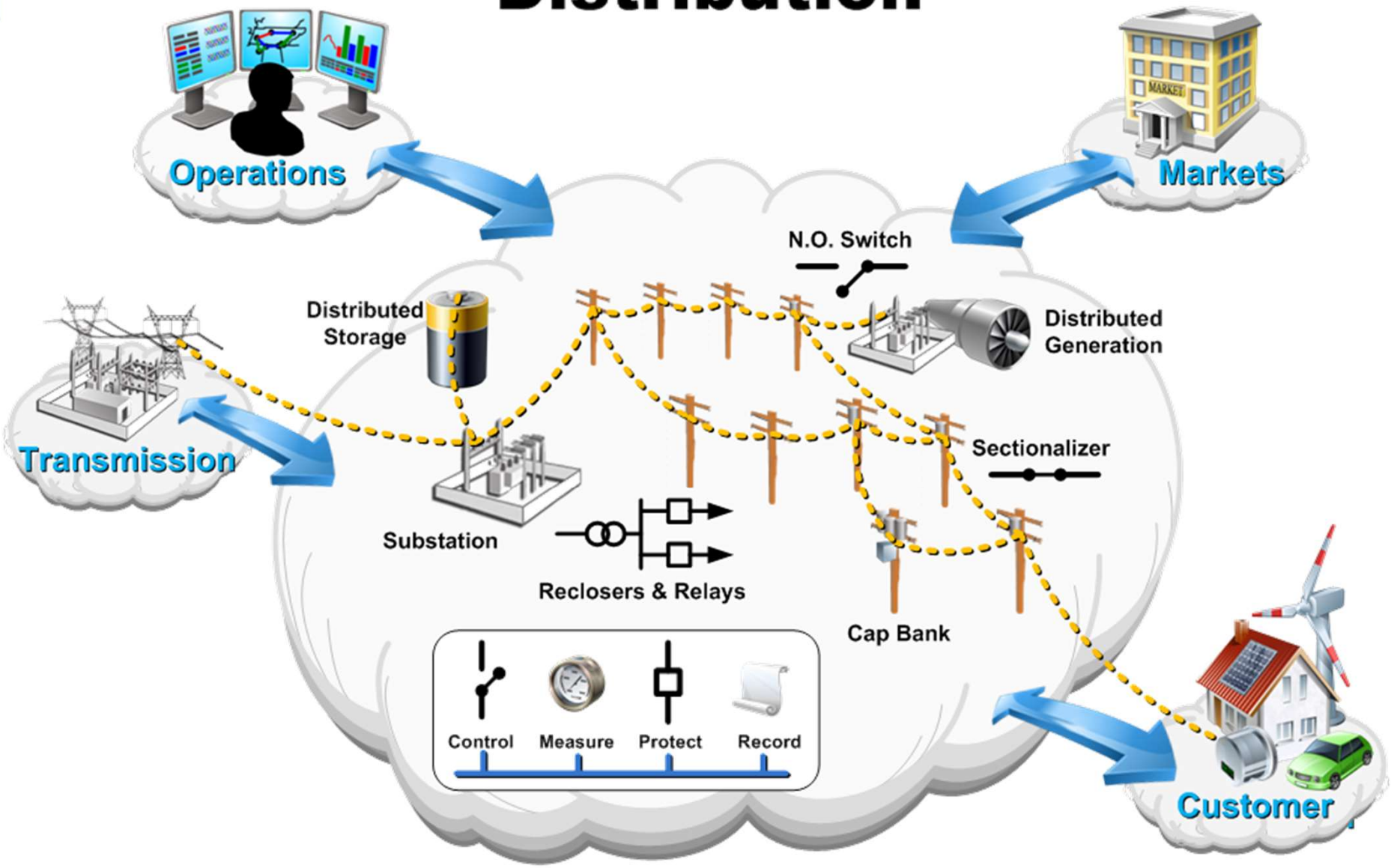


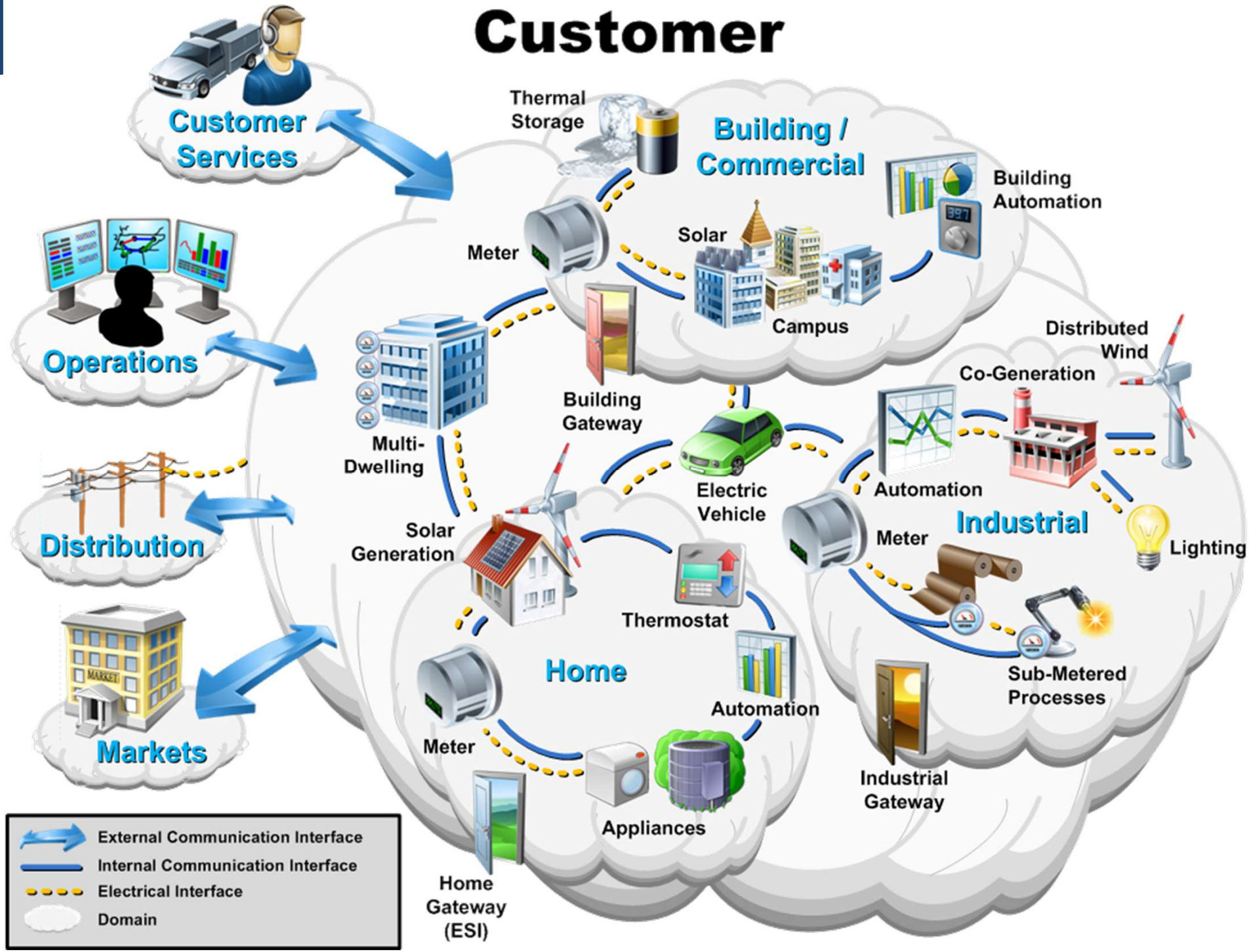


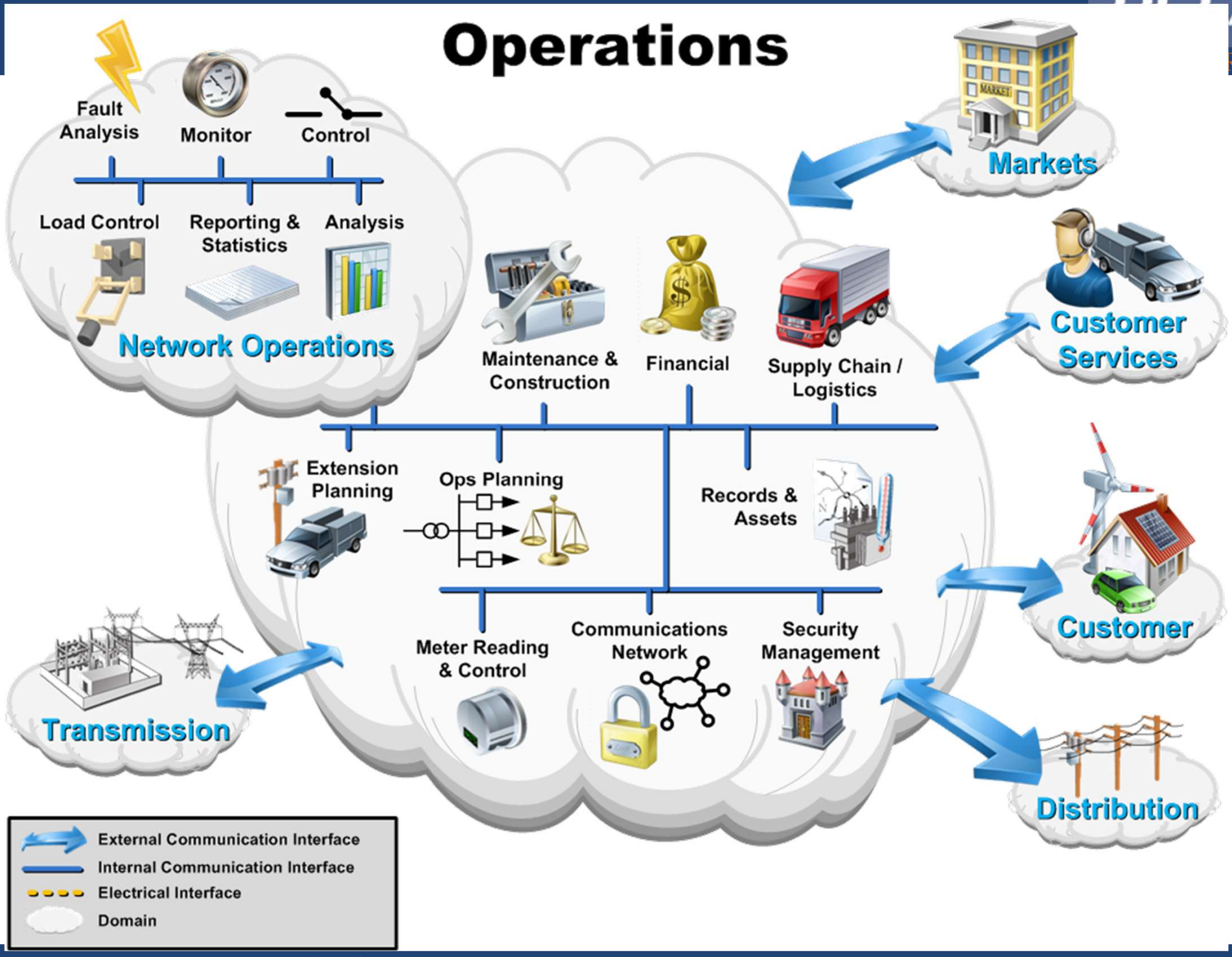
Transmission

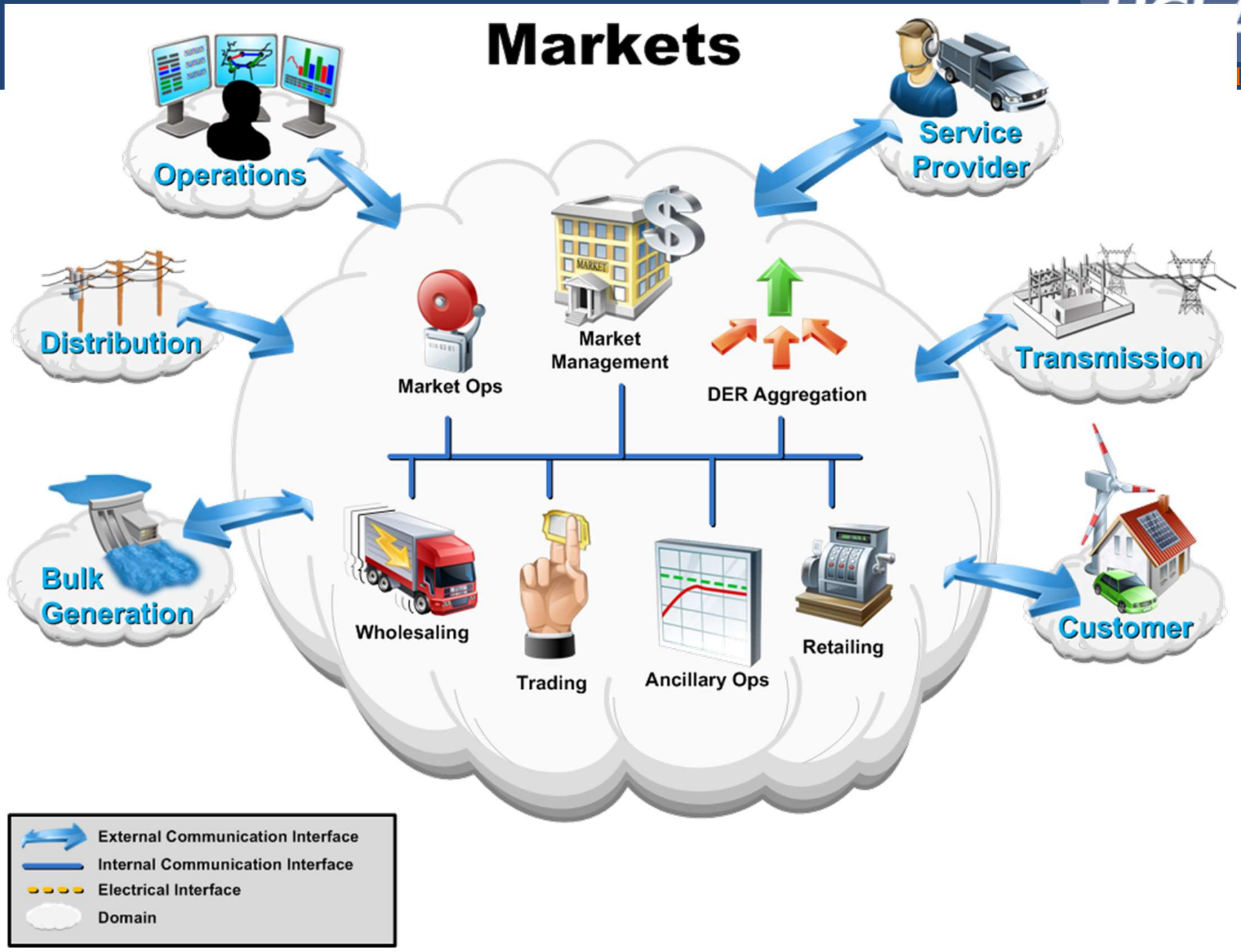


Distribution









Service Provider

A Word on Logical Architecture

- Conceptual Design
  - Zachman Row 2
- Logical Design - Take the System Requirements and perform a more detailed design
  - Zachman Row 3

Backup

Cycle of Needs (from SEBoK)