# Engineering 180
# Systems Engineering

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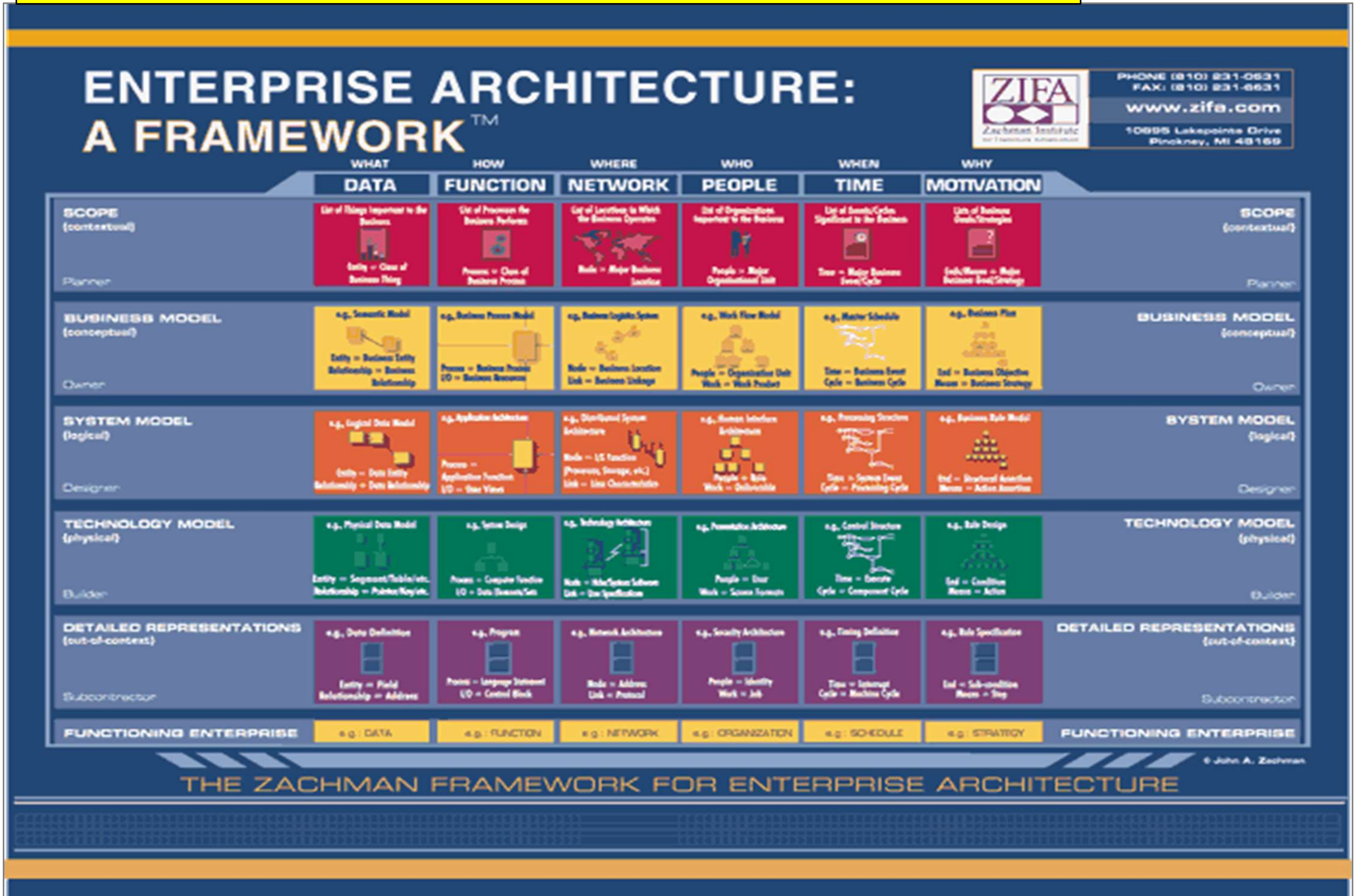
# *Conceptual Design*

# *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

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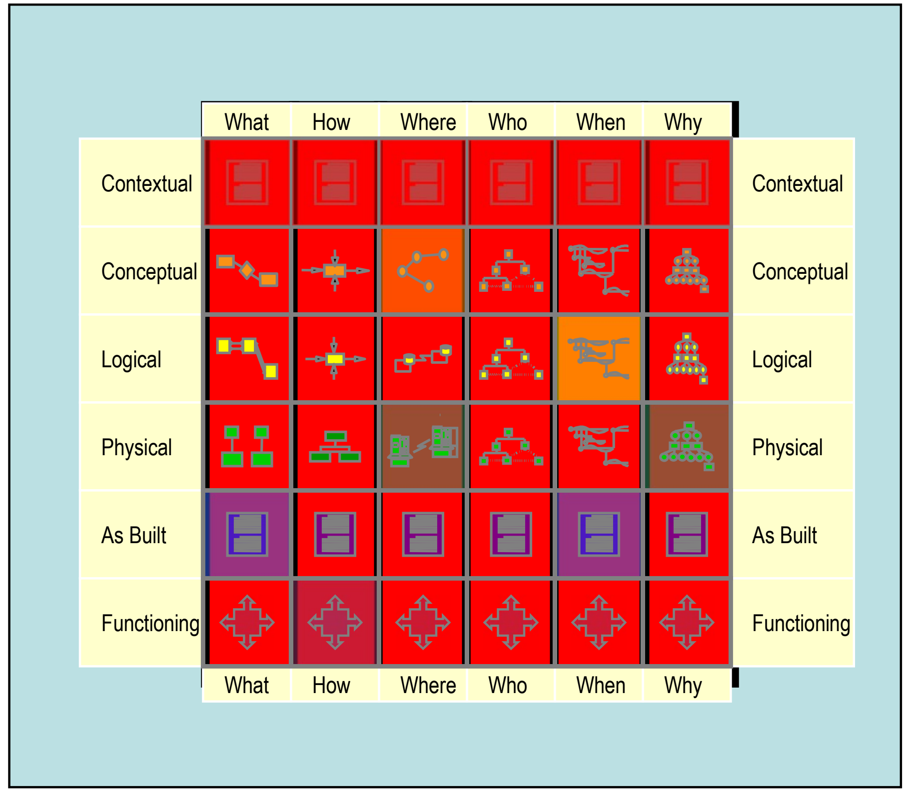
# Zachman Framework: Framework Rules*

**Covered in the last lecture**

- **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**




*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*

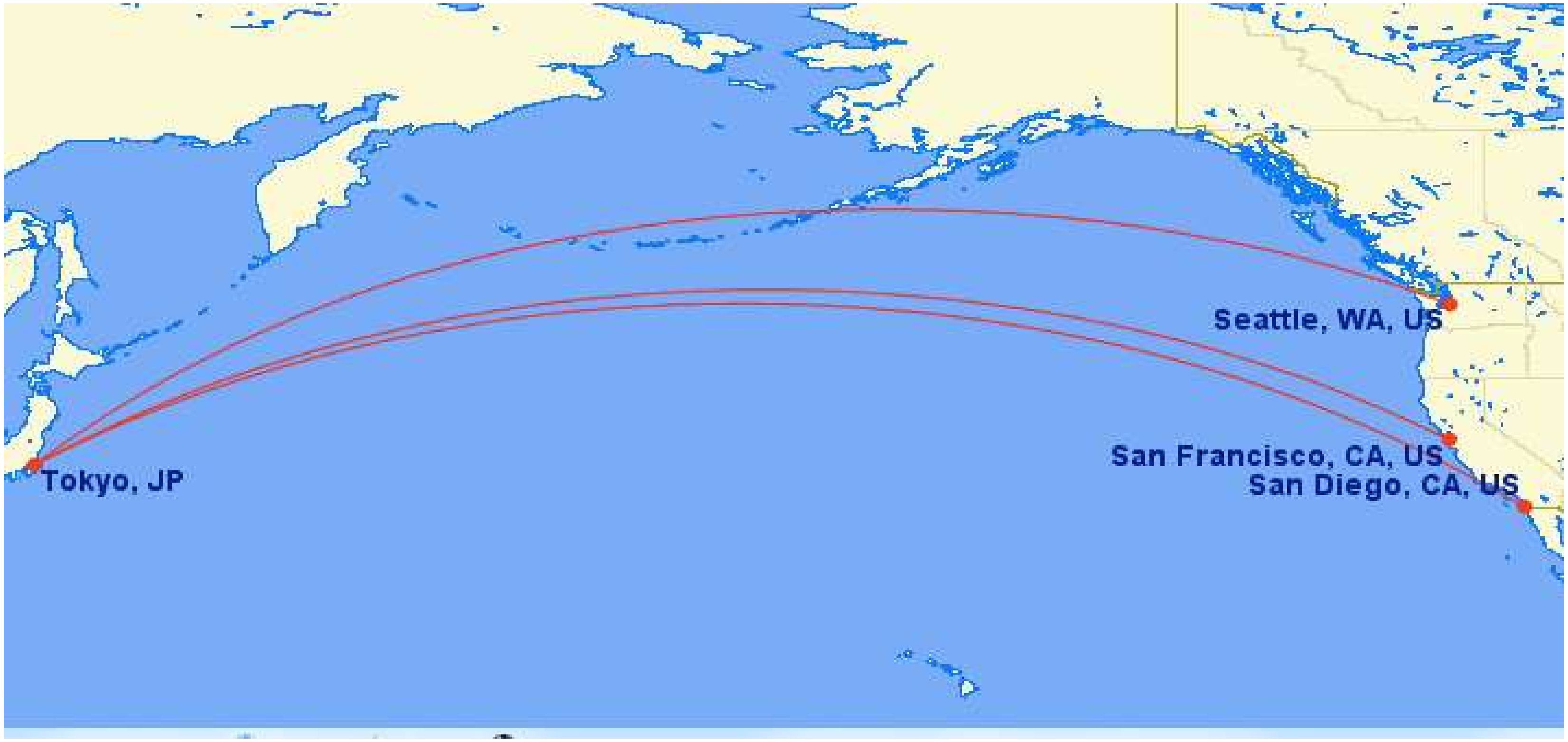
- Define the system to be built
  - What the needs are
  - What the system needs to do
  - How well it needs to do it
- Document the findings into two important documents
  - System Requirement Document (SRD): Articulate the need – more descriptive
  - System Specification : The result of system functional 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*

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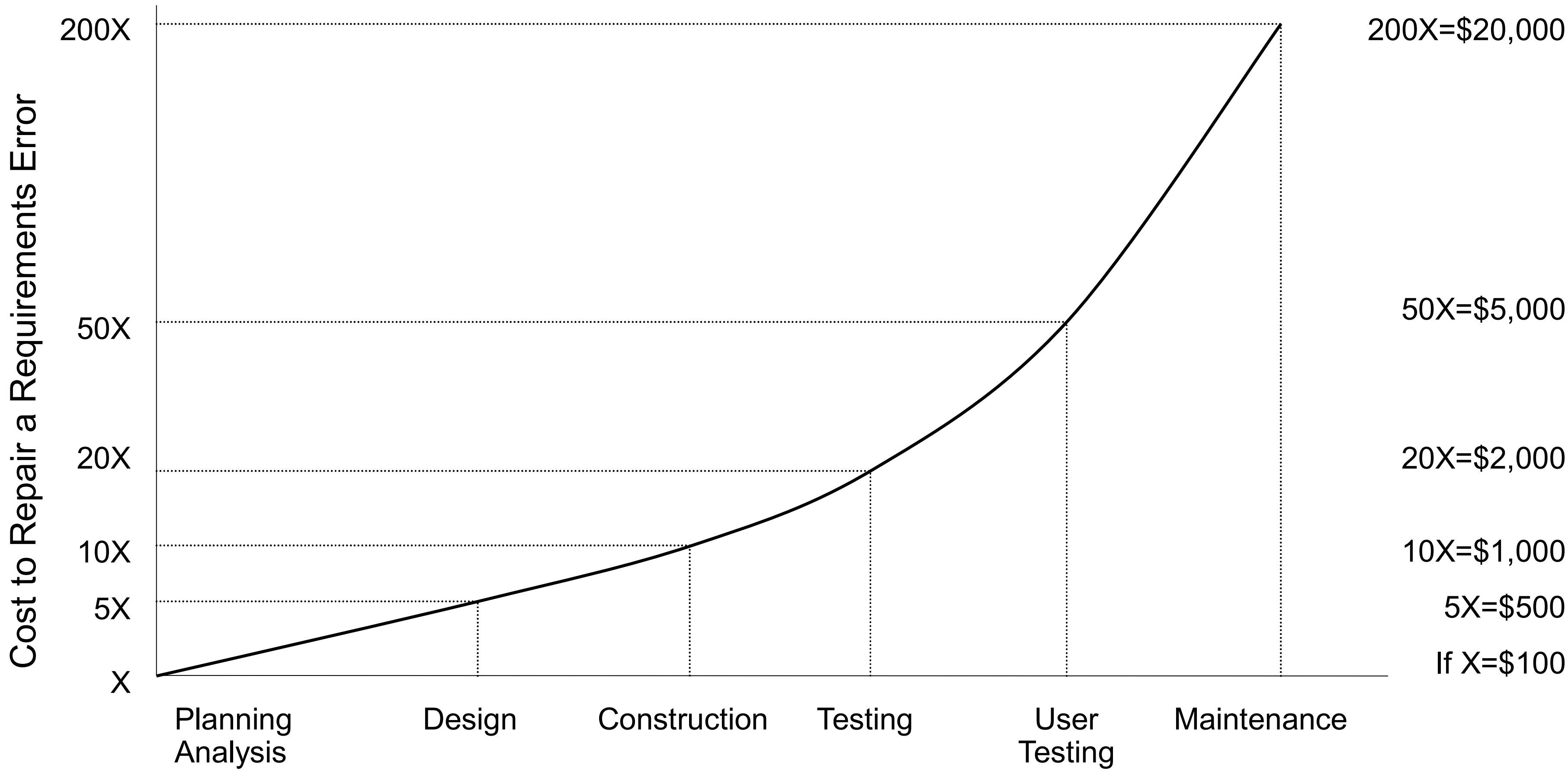
SYSTEM ENGINEERING

**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*

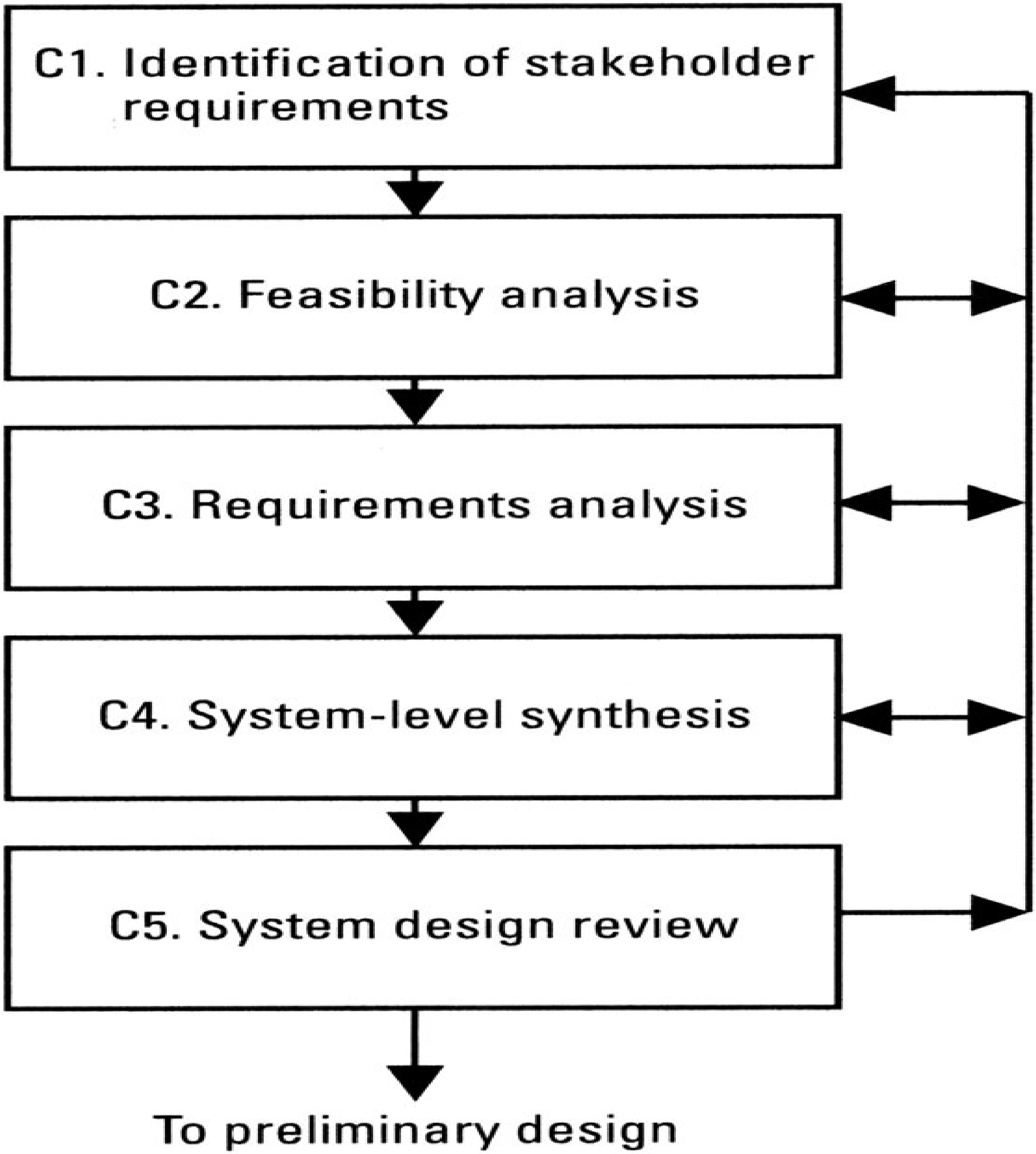
- Conceptual design is when the problem is understood and the solution (the system) is defined
- If mistakes are made, we will be solving the wrong problem and building the wrong system
- It is very expensive and time consuming to correct these mistakes at later date

## *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.

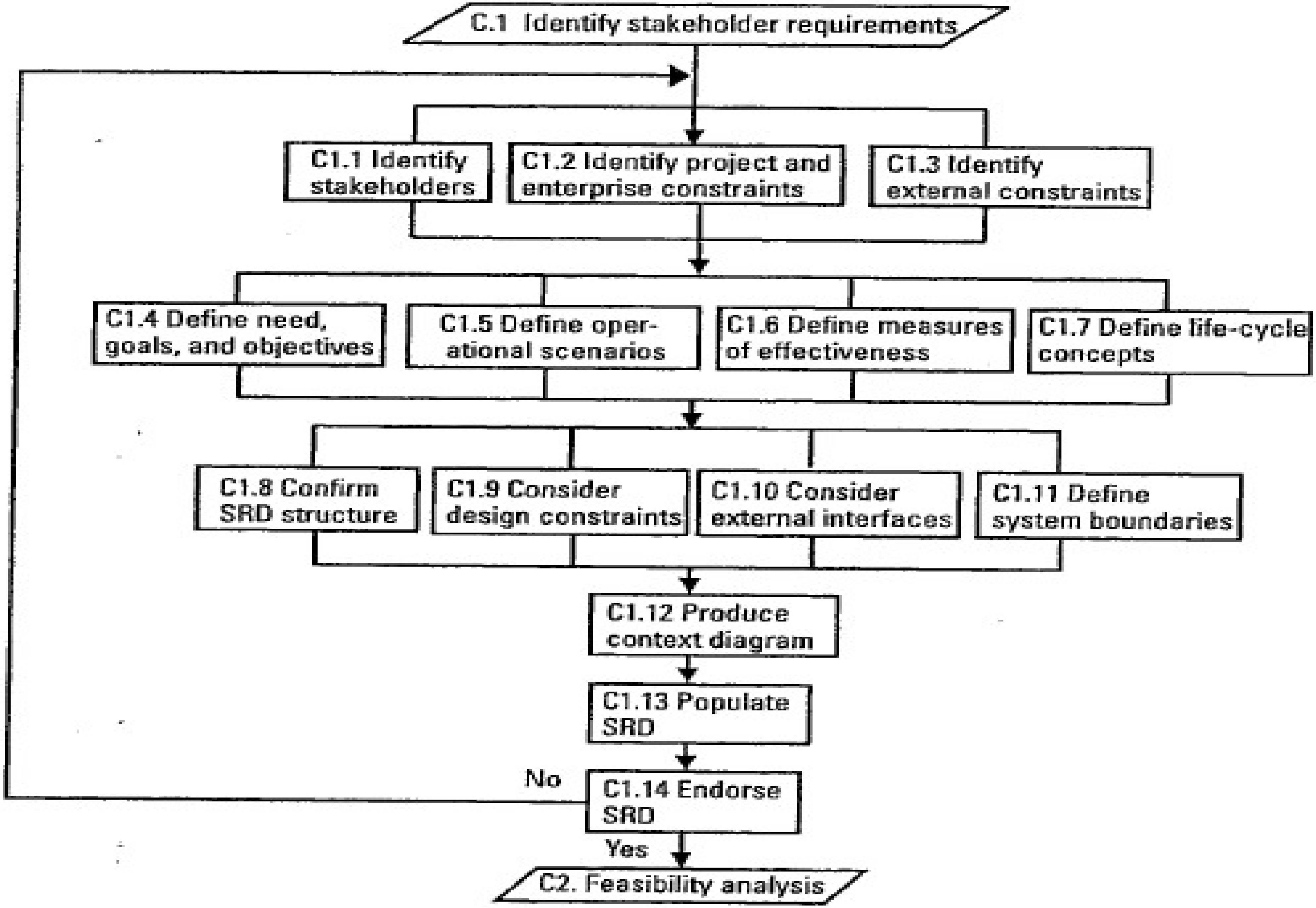
# The Conceptual Design Process





# Identify The System Requirements (C1)

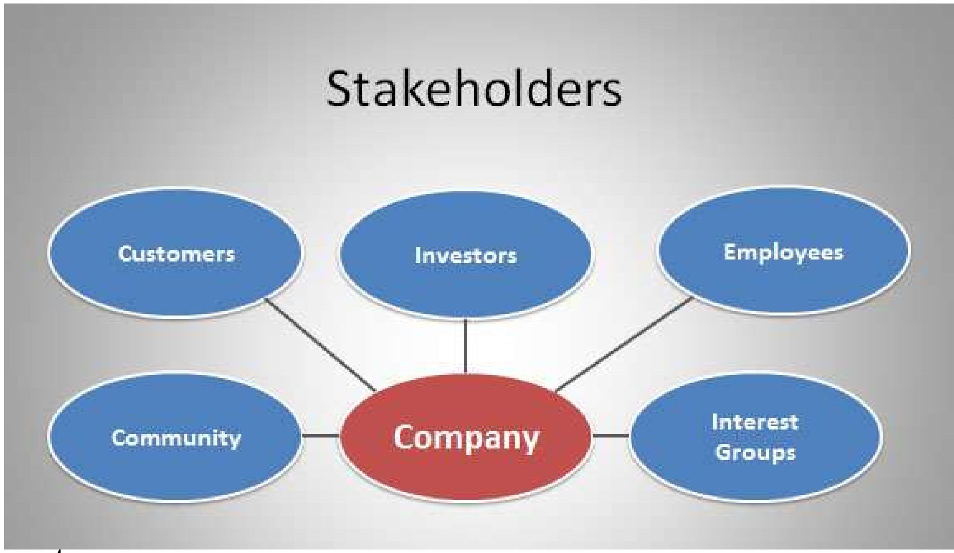




# *Who Are Stakeholders? (C1.1)*

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

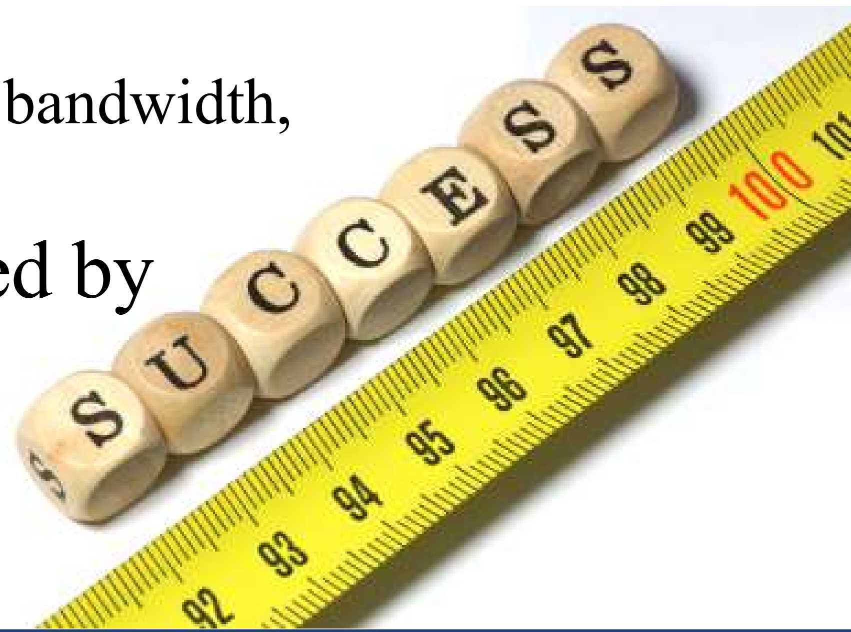


# *Examples: ACME Aircraft System*

- 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

- 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)*

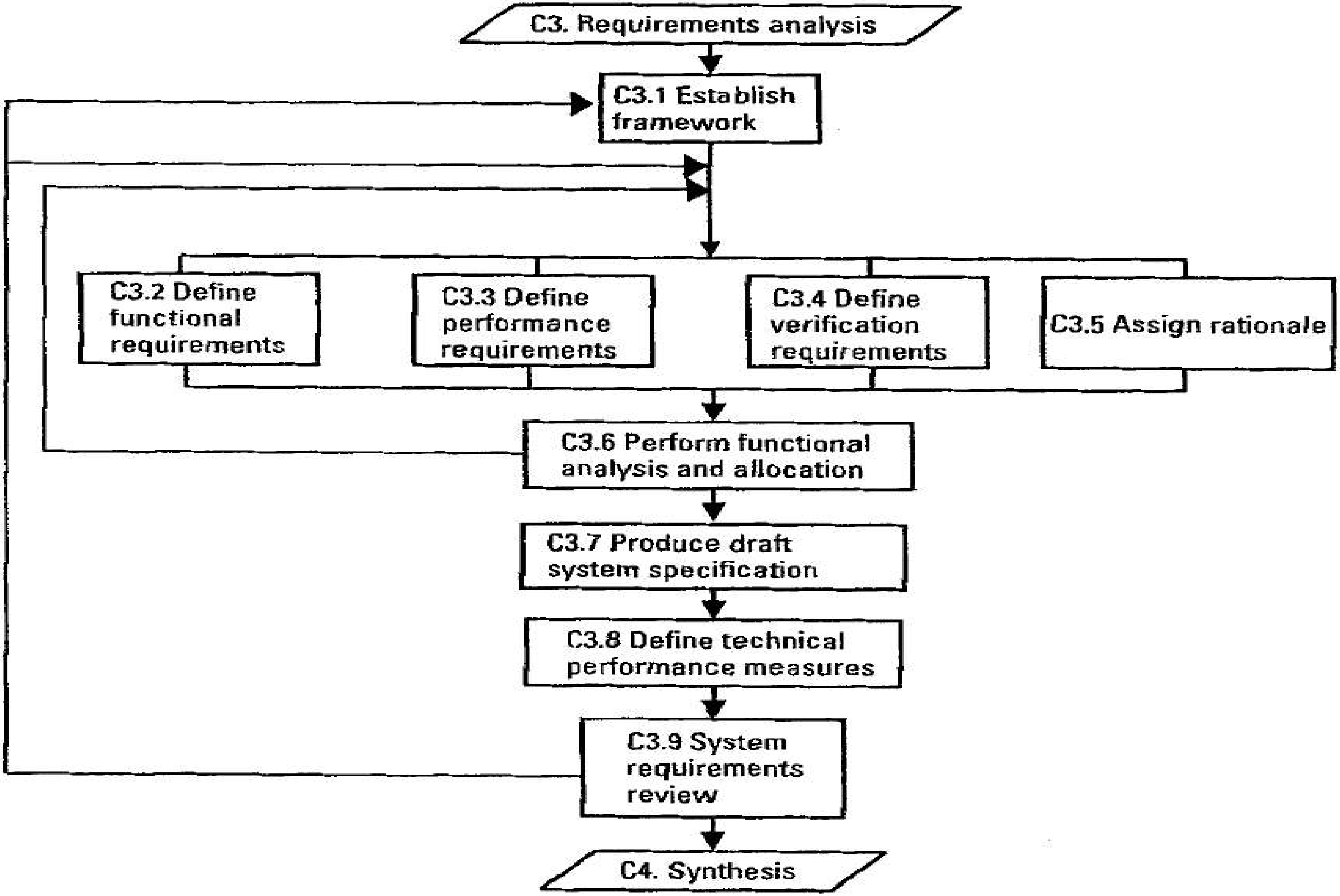
- Identify the possible system-level solutions
- Study the viability of these solutions according to the requirements in SRD:
  - performance, cost, schedule, risk, supportability, …
- Key questions:
  - Can this system (as defined in SRD) be built?
  - What are the key risks?
  - How to reduce the risks?
  - 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
  - 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

## *~~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*

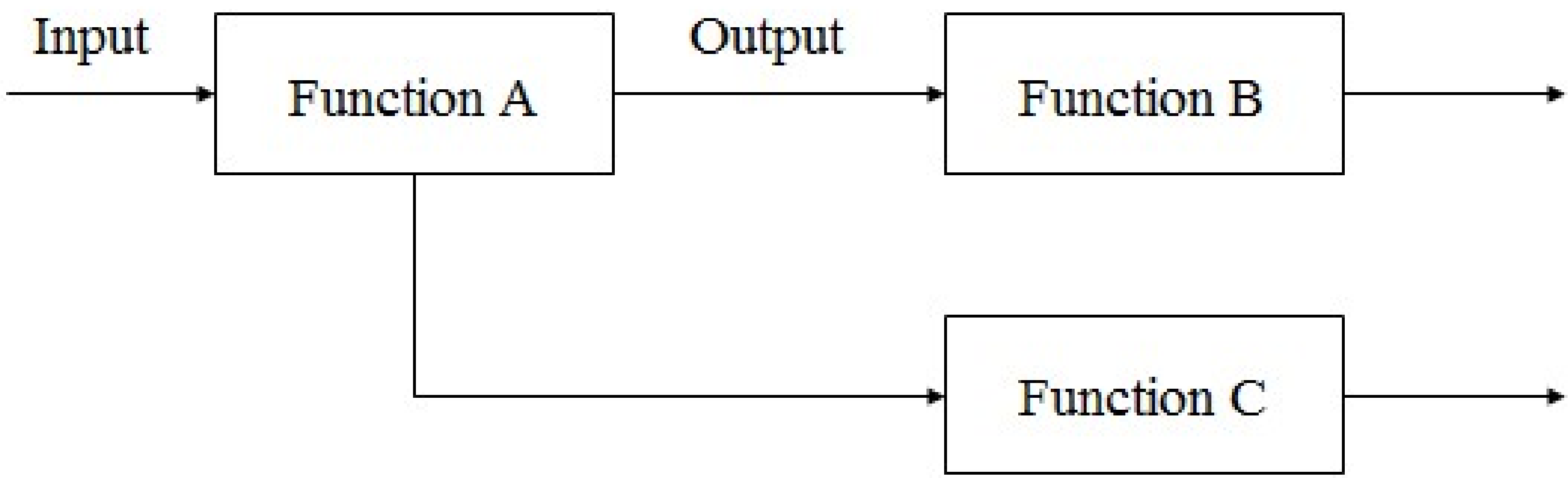
- Aircraft
  - Functional
    - Runway
    - Entertainment
    - Facilities
    - Refueling
    - Loading
    - Unloading
    - Range
    - Cruising speed
    - Fuel economy
    - Rates of climb/ descend
  - Interface
    - Navigation Aids
    - Landing Systems
    - Communications systems
  - Physical
    - Aircraft weight
    - Leg room
    - Seat dimensions
    - Locker space
    - Passenger/cargo capacity
  - • • •
    - • • •

# *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)*

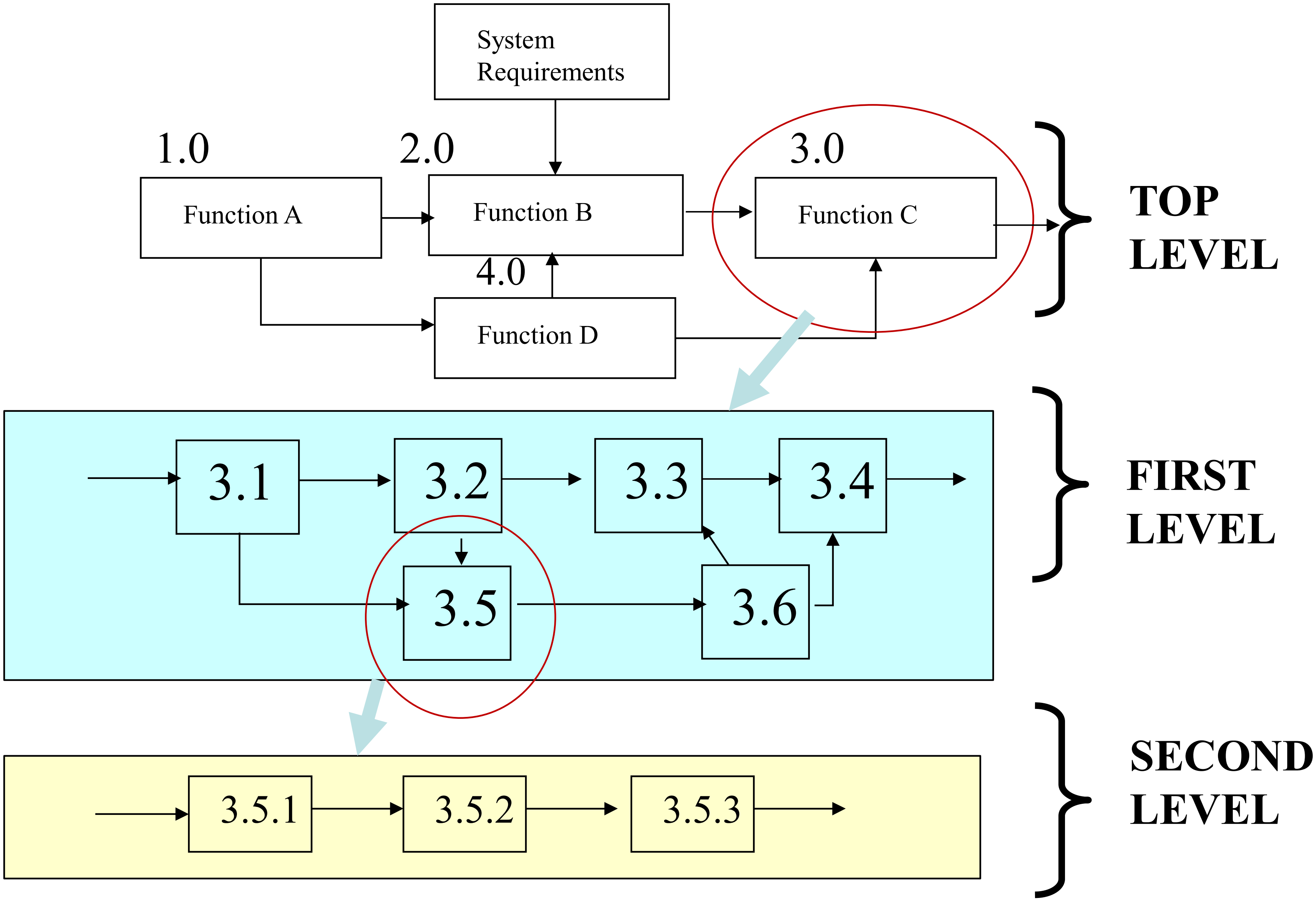
- FFBD is a tool that helps the system engineers to visualize the functional decomposition that logically breaks down a system function into a set of sub-functions, and interfaces



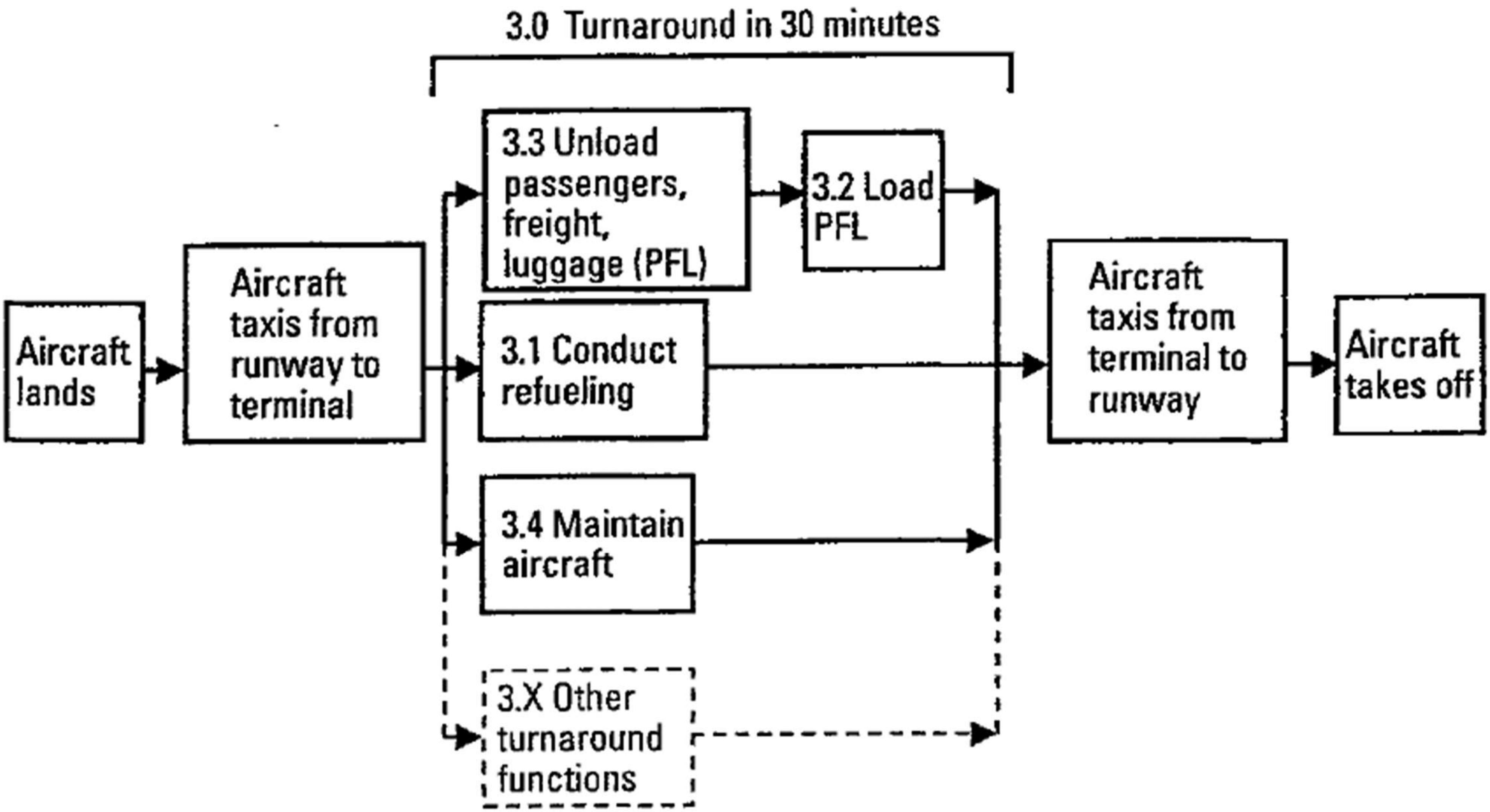

- This tools can be used repeatedly until all components are well defined and understandable

# *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

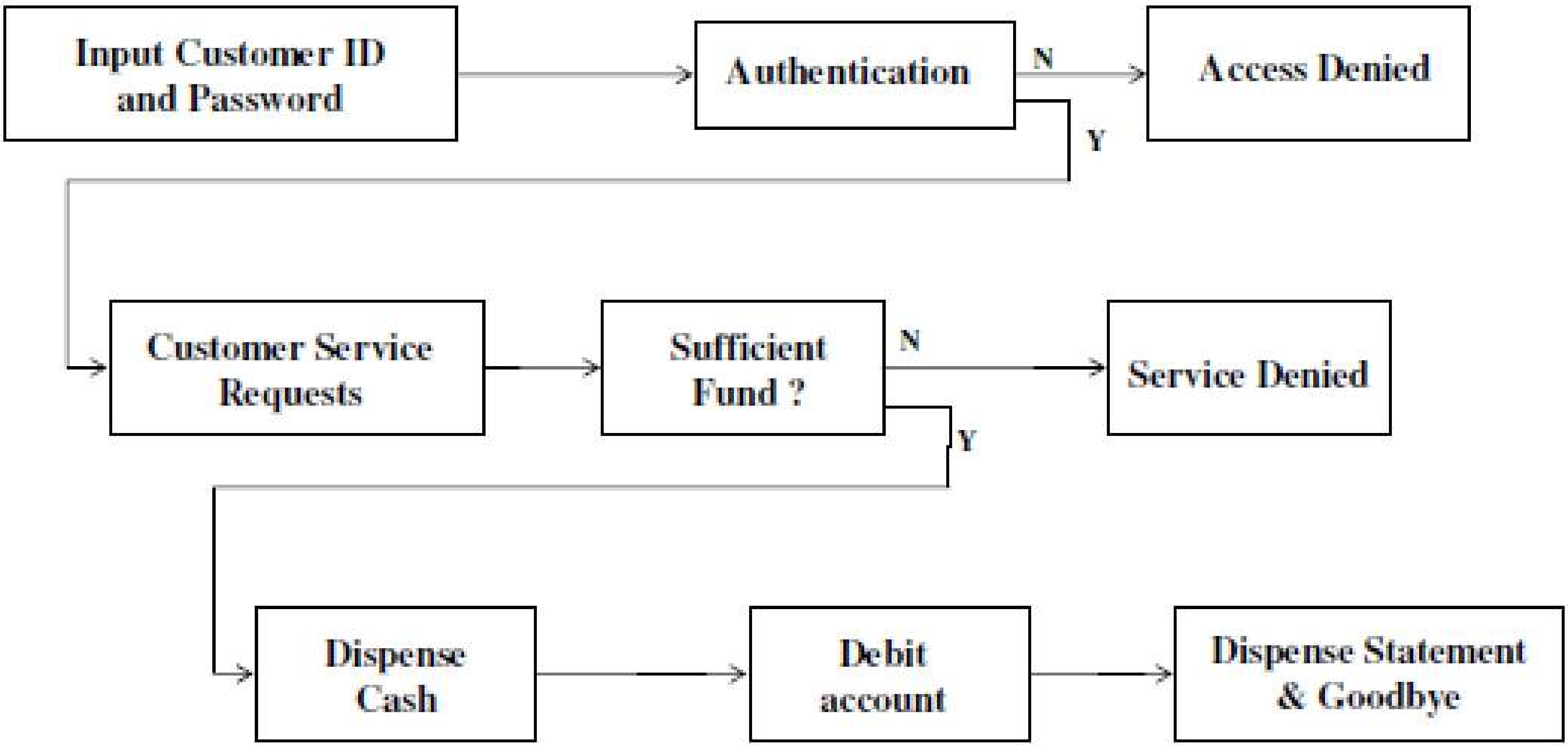
PFL – passengers, freight, luggage

# *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)*

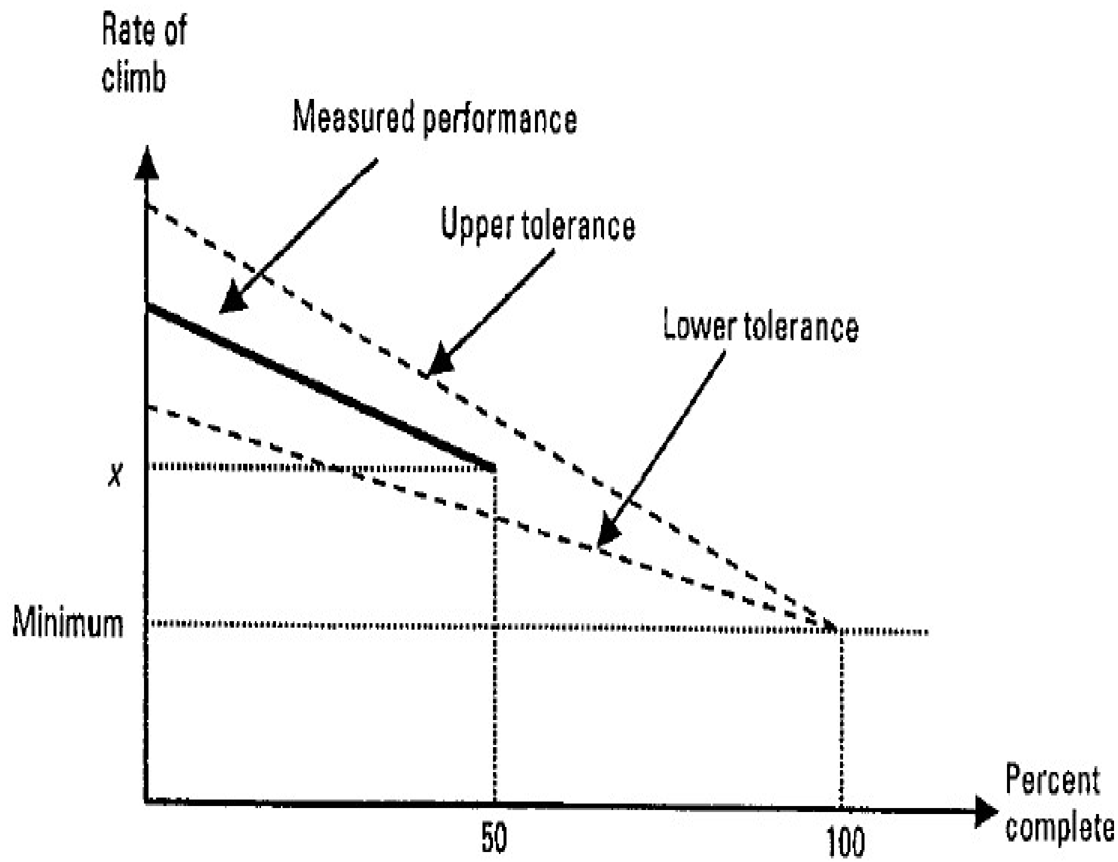
- Analyze this scenario to identify 5 additional derived requirements

# *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*

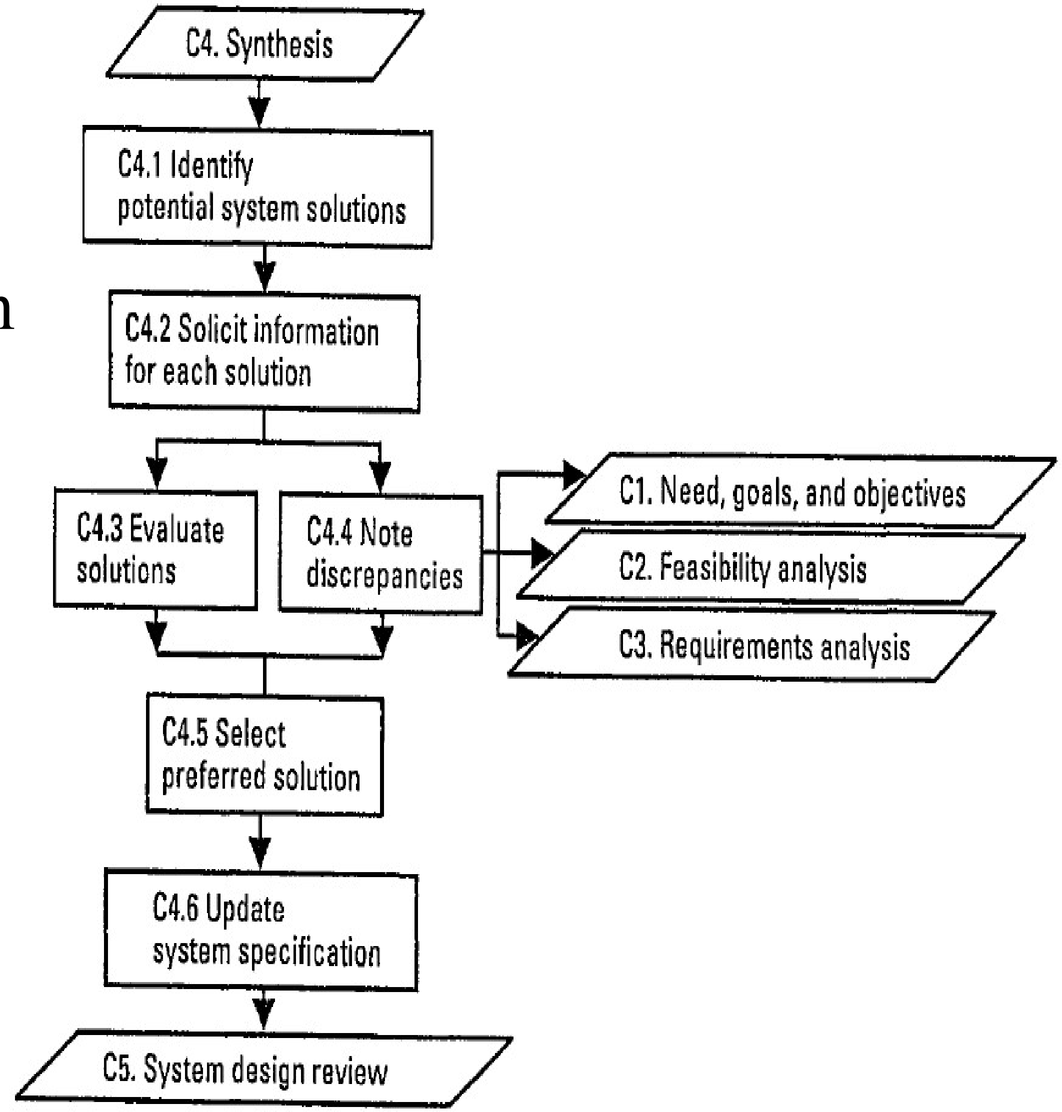
- Expected value and band of acceptable variation are established at the beginning of the program
- Actual performance are tracked through the program
- Variation band should be narrowed as design matures
- Need to pay attention to both actual performance level and the performance trend
- Identify the 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*

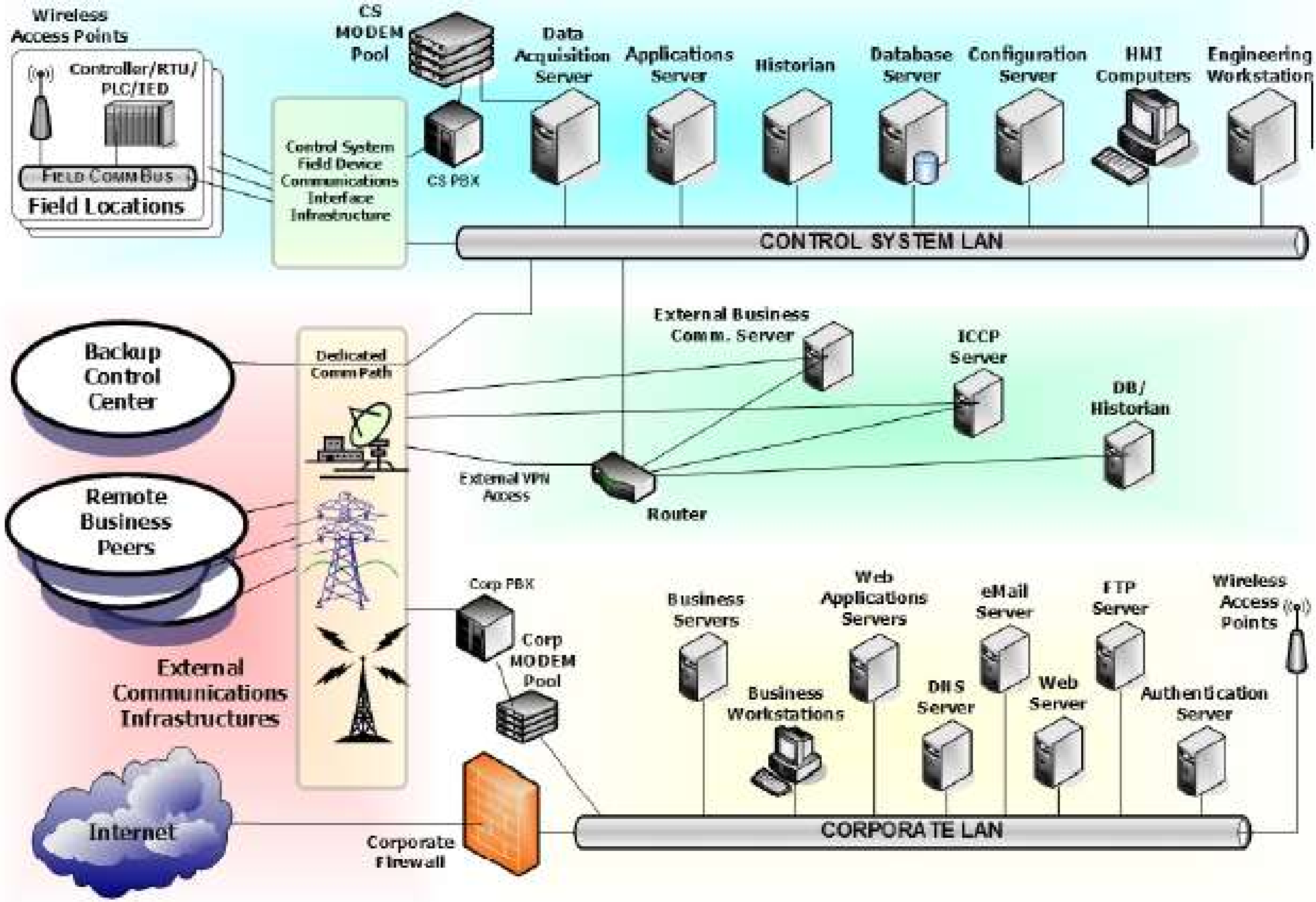
# *Conceptual Domain Diagrams for a Power Grid System*

## *from Engineering 204 Trusted Systems Engineering Risk Management Lecture*

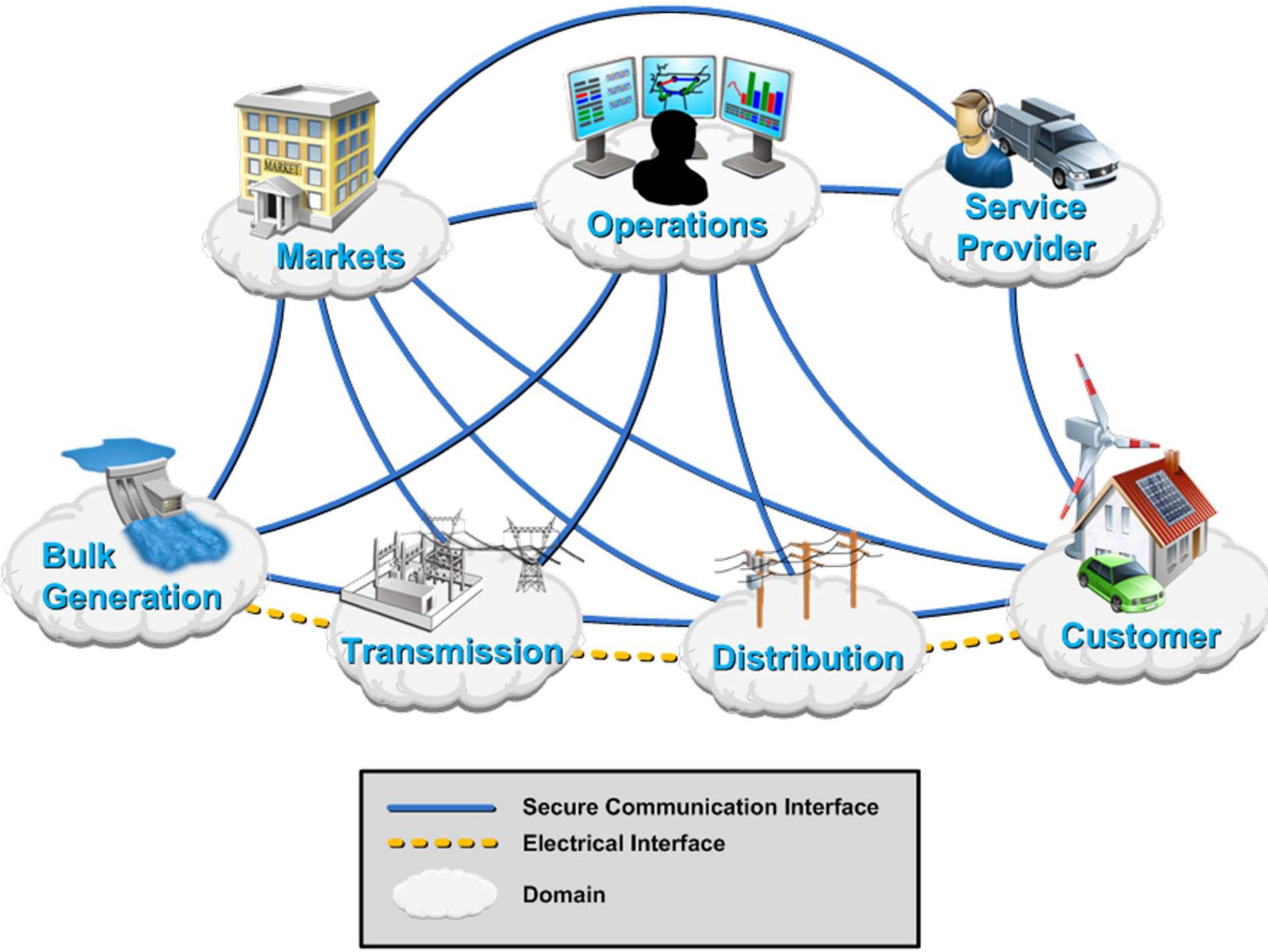
Charts obtained on May 15, 2009, from IEEE P2030 meeting

# Power Control System and Corporate Network

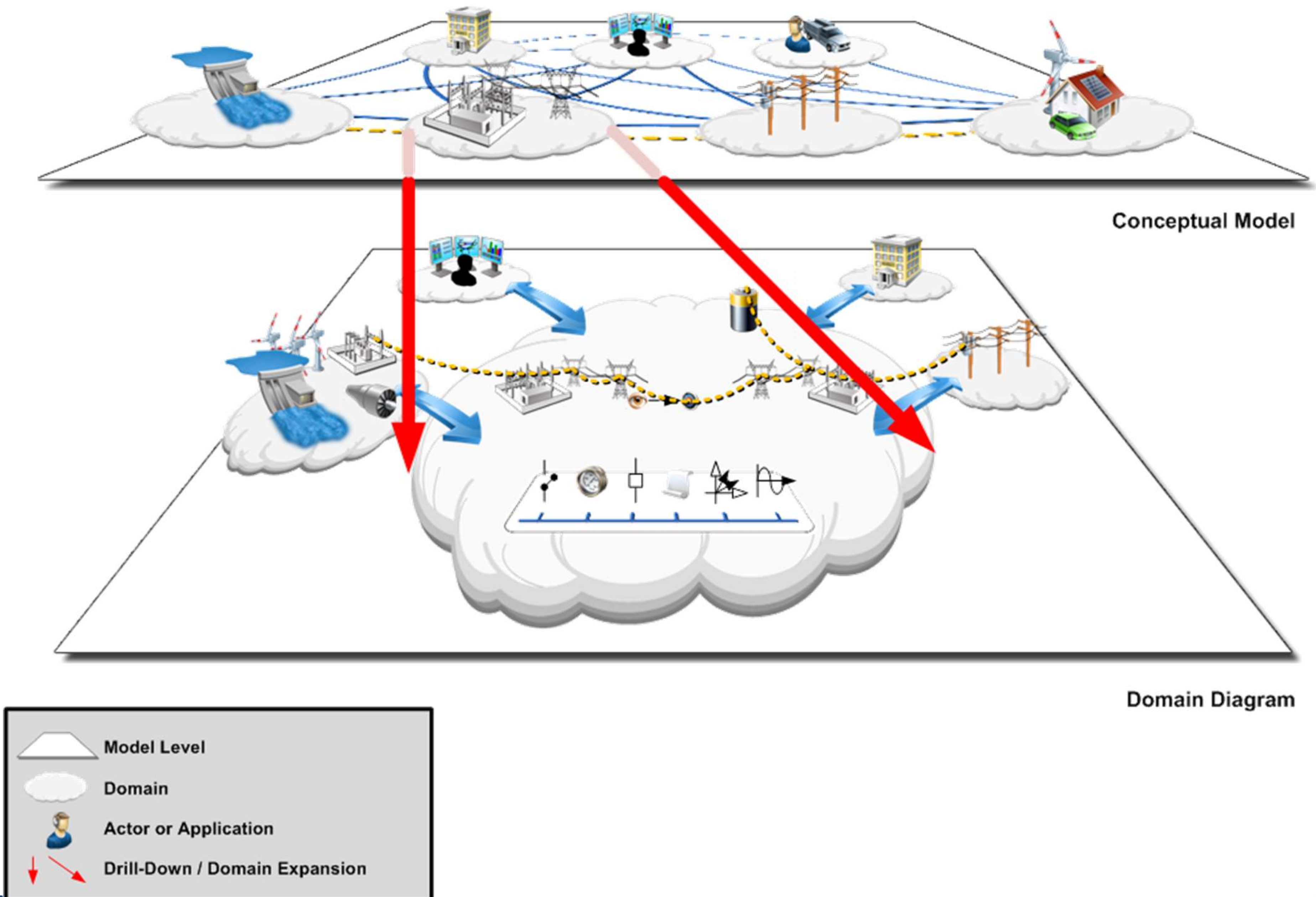




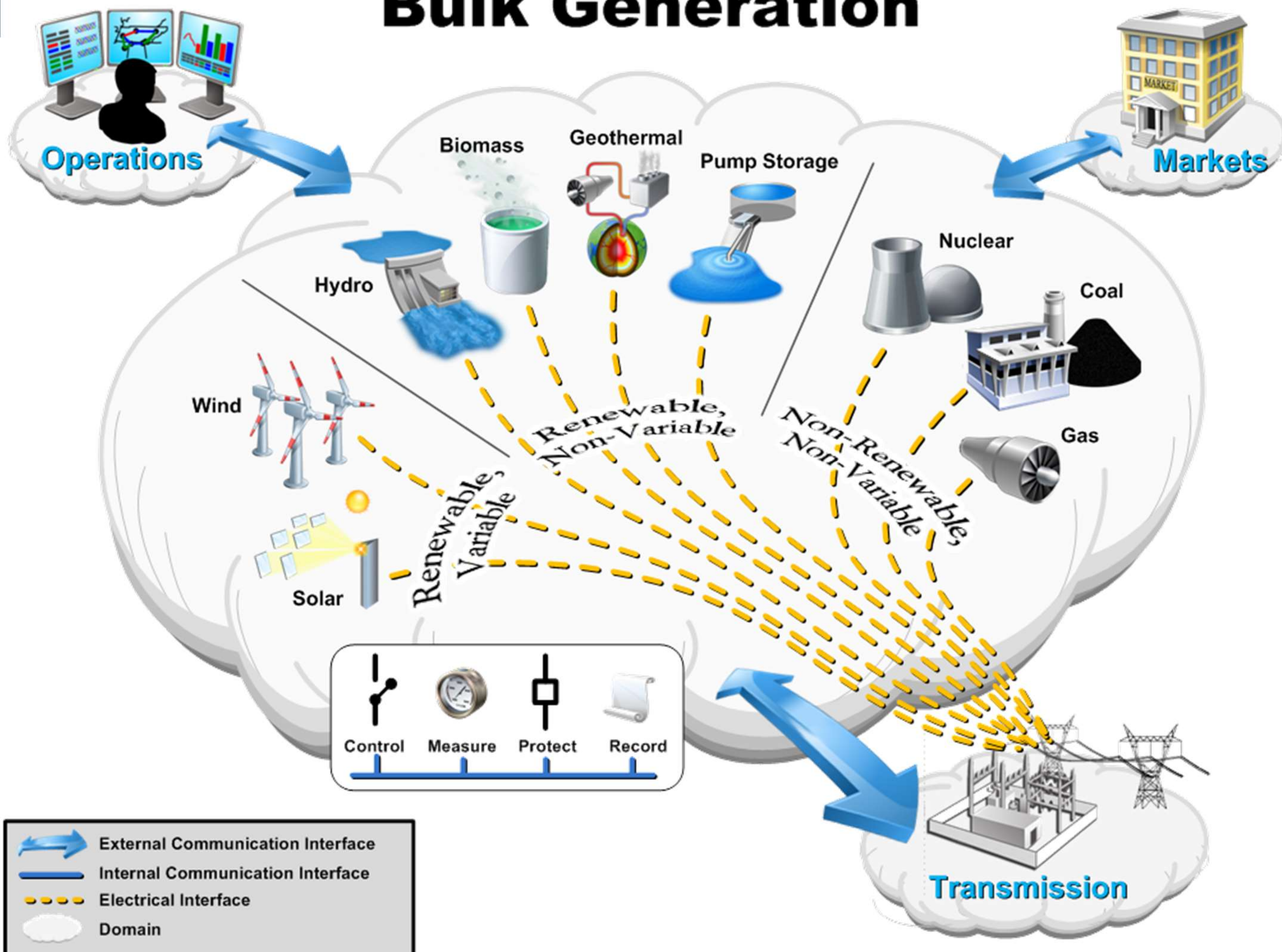
# Conceptual Model



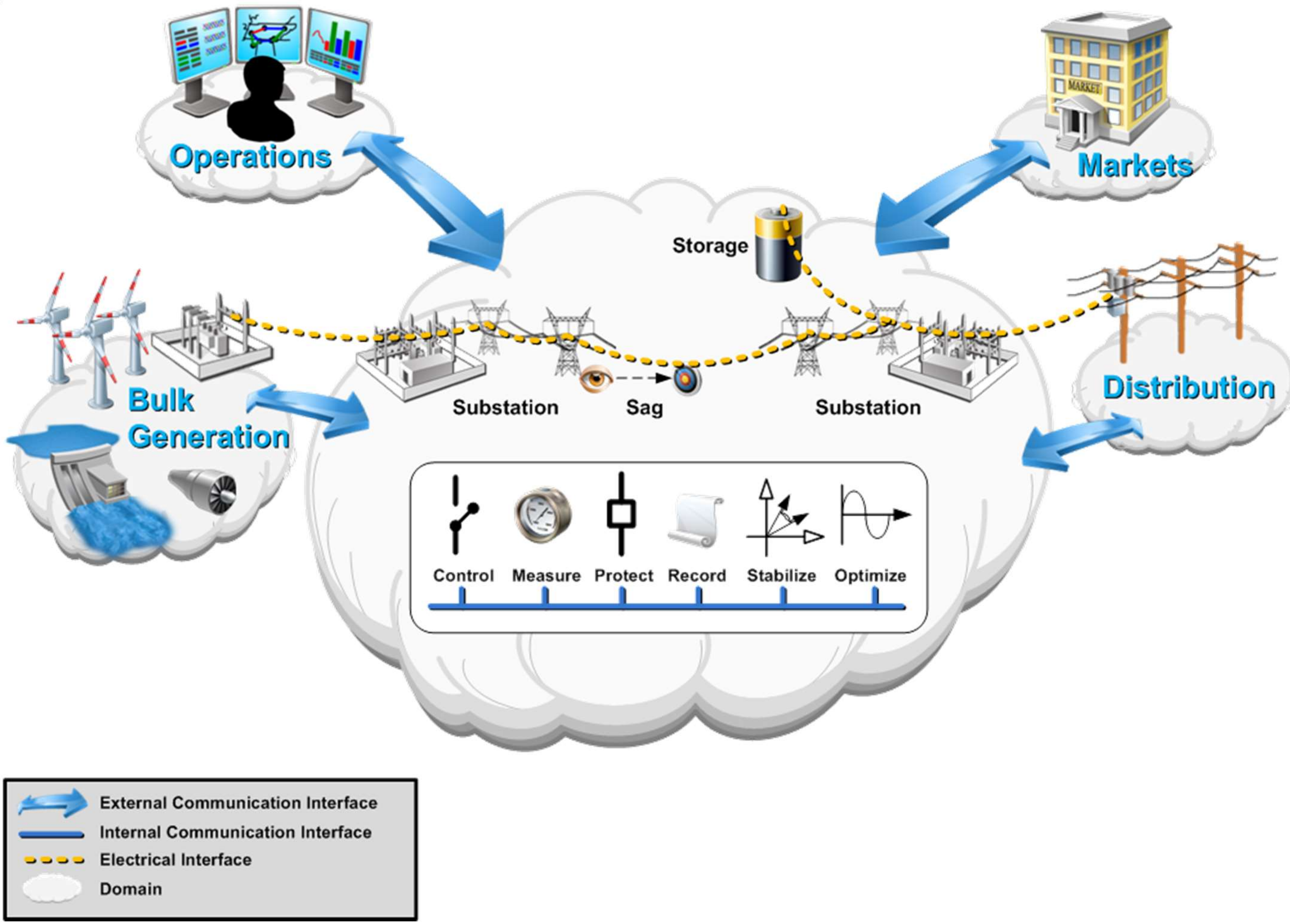
# Levels of the Conceptual Model



# Bulk Generation

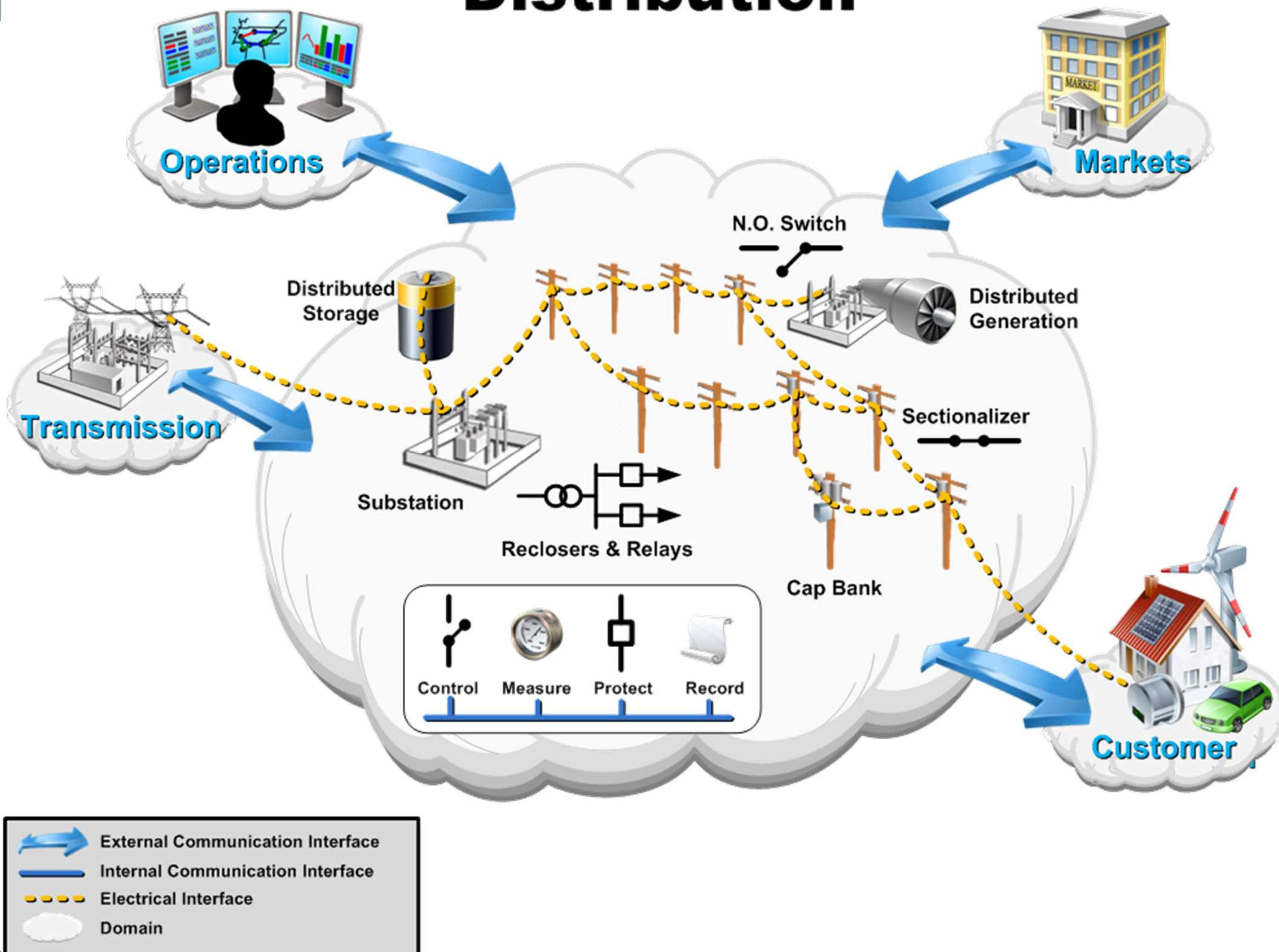


# Transmission

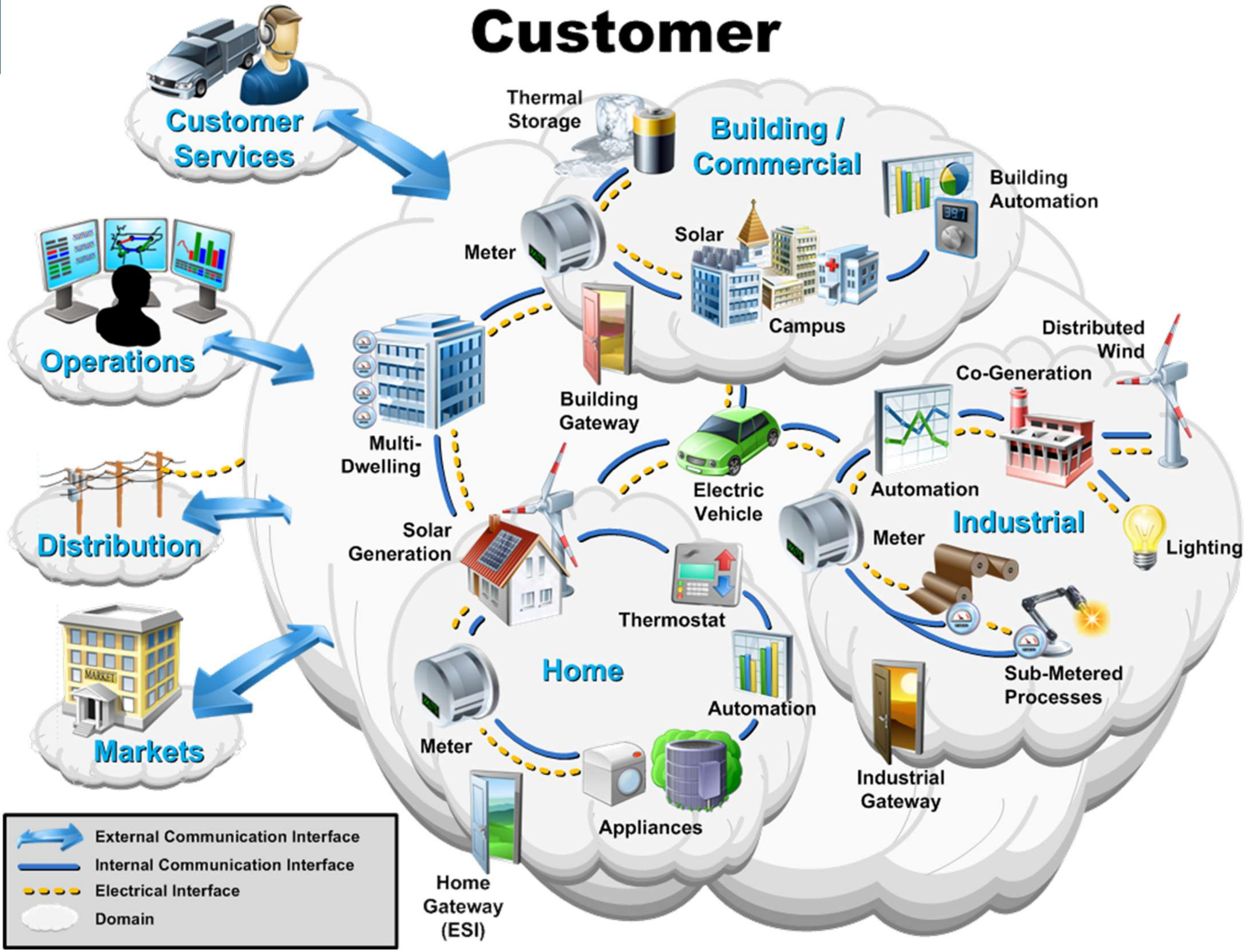


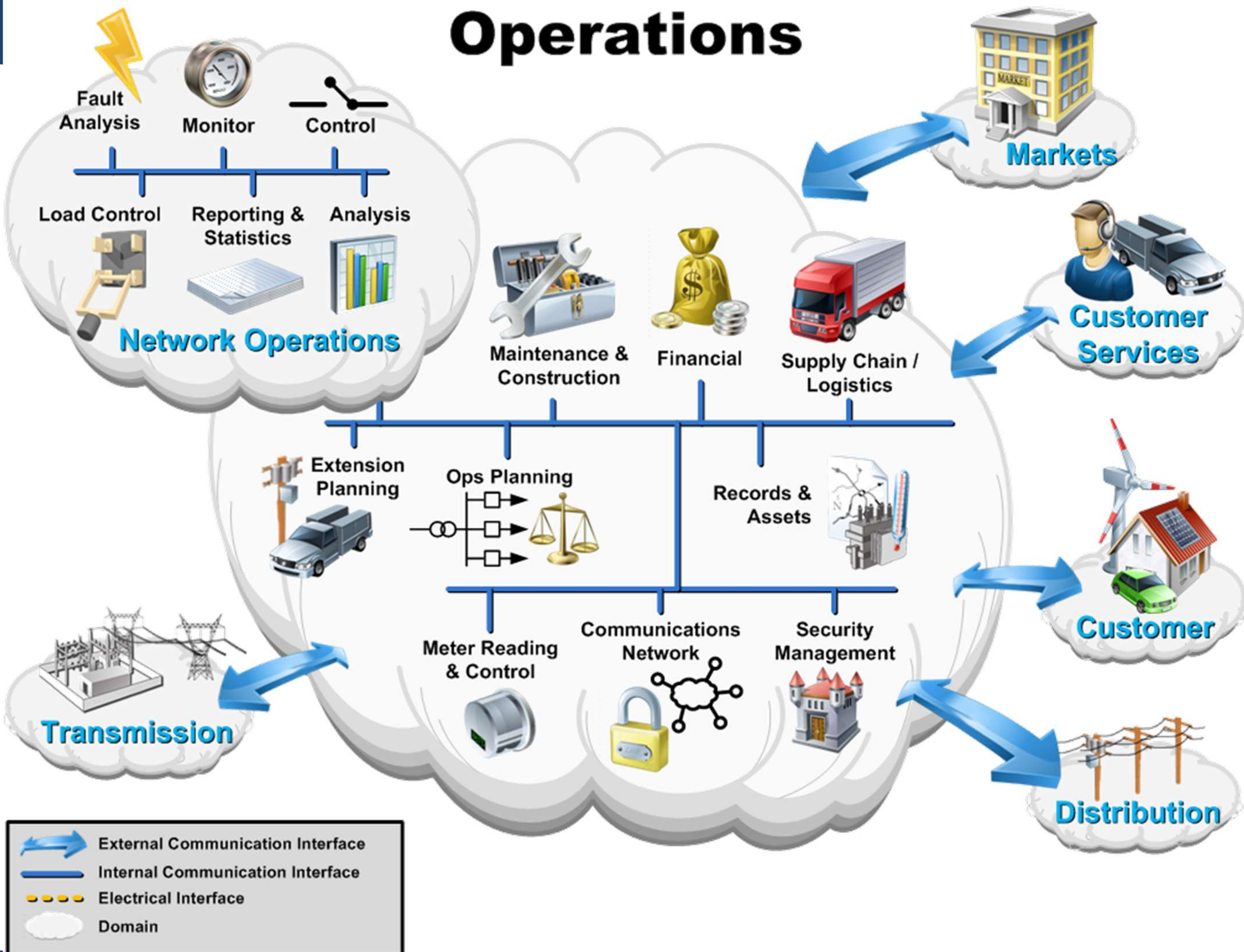
# Distribution



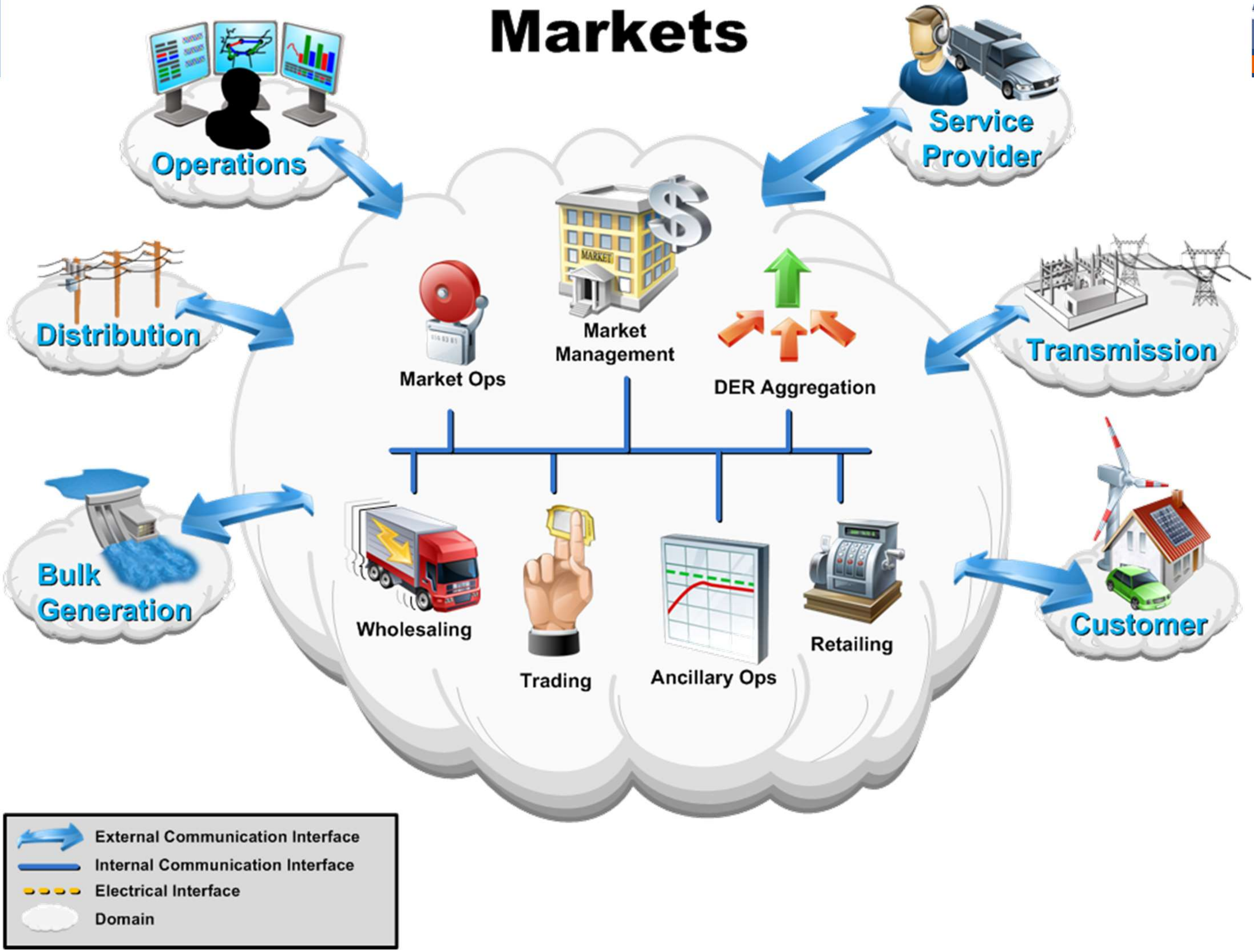
# Customer


Customer Services
Operations
Distribution
Markets
Thermal Storage
Building / Commercial
Building Automation
Meter
Solar
Campus
Building Gateway
Multi-Dwelling
Distributed Wind
Co-Generation
Electric Vehicle
Automation
Industrial
Meter
Lighting
Solar Generation
Thermostat
Sub-Metered Processes
Home
Automation
Meter
Appliances
Industrial Gateway
Home Gateway (ESI)
External Communication Interface
Internal Communication Interface
Electrical Interface
Domain

# Operations

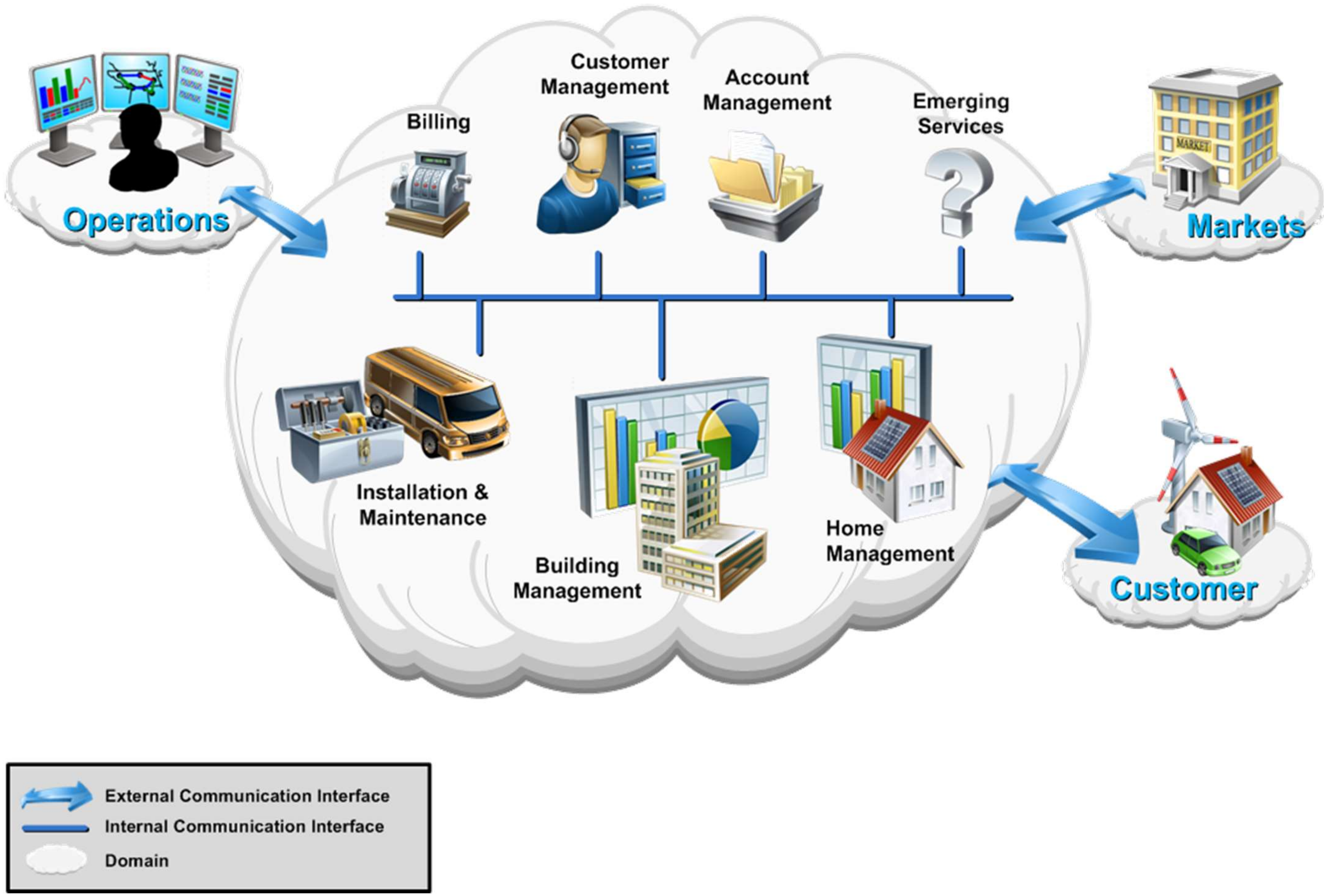

Fault Analysis
Monitor
Control
Load Control
Reporting & Statistics
Analysis
Network Operations
Markets
Maintenance & Construction
Financial
Supply Chain / Logistics
Customer Services
Extension Planning
Ops Planning
Records & Assets
Customer
Meter Reading & Control
Communications Network
Security Management
Transmission
Distribution
External Communication Interface
Internal Communication Interface
Electrical Interface
Domain

# Markets



Operations
Service Provider
Market Management
Market Ops
DER Aggregation
Distribution
Transmission
Bulk Generation
Wholesaling
Trading
Ancillary Ops
Retailing
Customer
External Communication Interface
Internal Communication Interface
Electrical Interface
Domain

# 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)*