Requirements Module: The Basics

Space Systems Engineering, version 1.0

Module Purpose: Requirements - The Basics

- Establish the role of good requirements in project success.
  - Requirements capture the understanding of what is to be done.
- Establish the significance of good requirements development.
  - Poor requirements are the single biggest problem for projects.
  - The later a problem is discovered the more costly it is to recover from.
- Describe the different types of requirements.
- Establish how requirements are distributed — allocation, flow-down and derived.
- Define and understand the value of requirements traceability.
- Recognize that system decomposition creates new interfaces that must be defined and owned.

The Importance of Requirements

- Requirements problems are the single biggest cause of project problems.
- Requirements define what is to be done, how well and under what constraints - get the requirements wrong and the design and hardware will be wrong.
- Requirements drive…

  Cost - Design - Schedules - Skills required - Verification plans - Operational procedures - *everything*

- *It is amazing how many teams begin to solve a problem before there is agreement on what the problem is.* Requirements and their associated constraints and assumptions quantify the problem to be solved - they establish how project success will be determined.

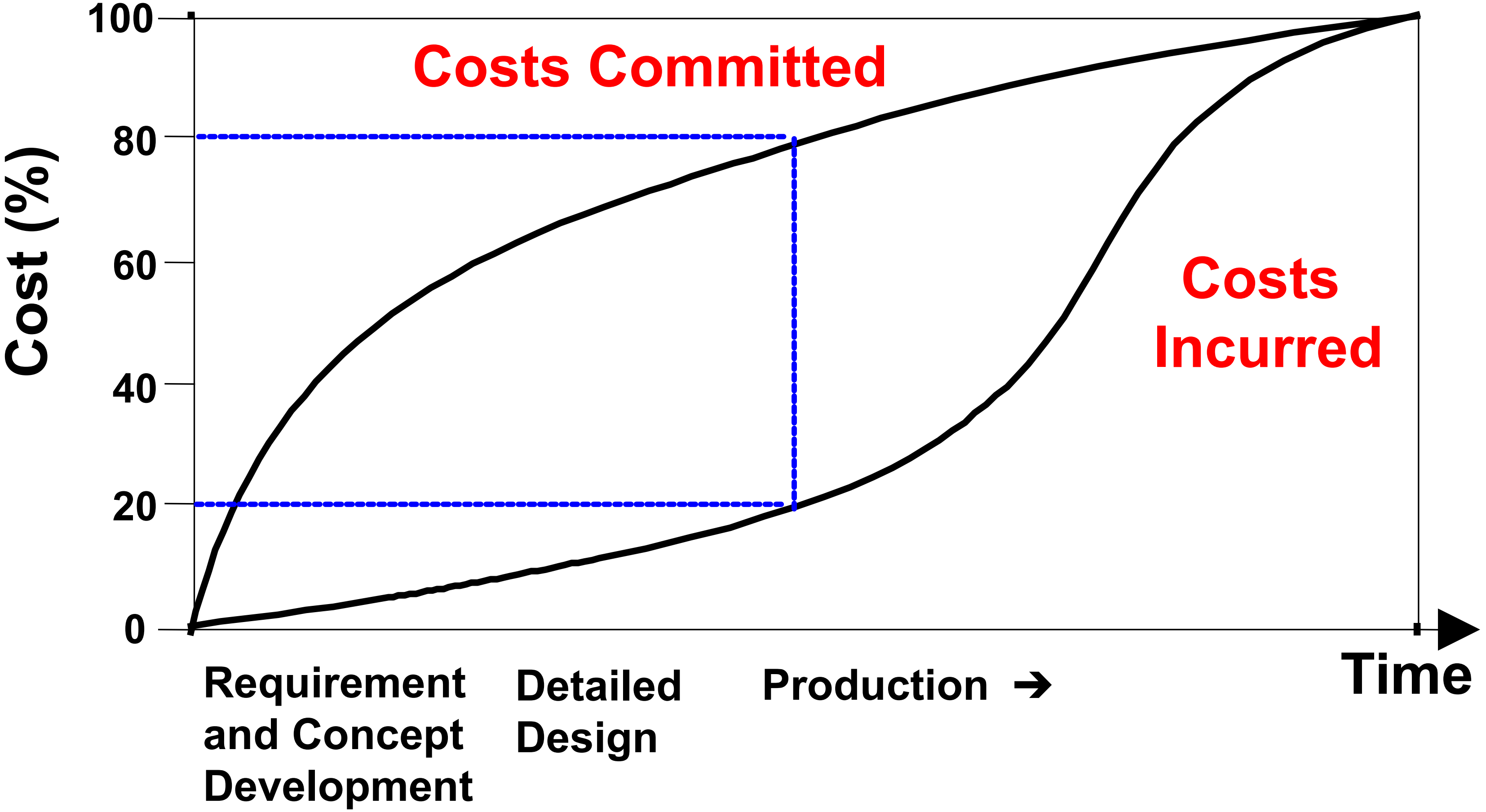
What is a Requirement?

- Statement of some THING you want or need
  OR
  A characteristic of some THING you want or need

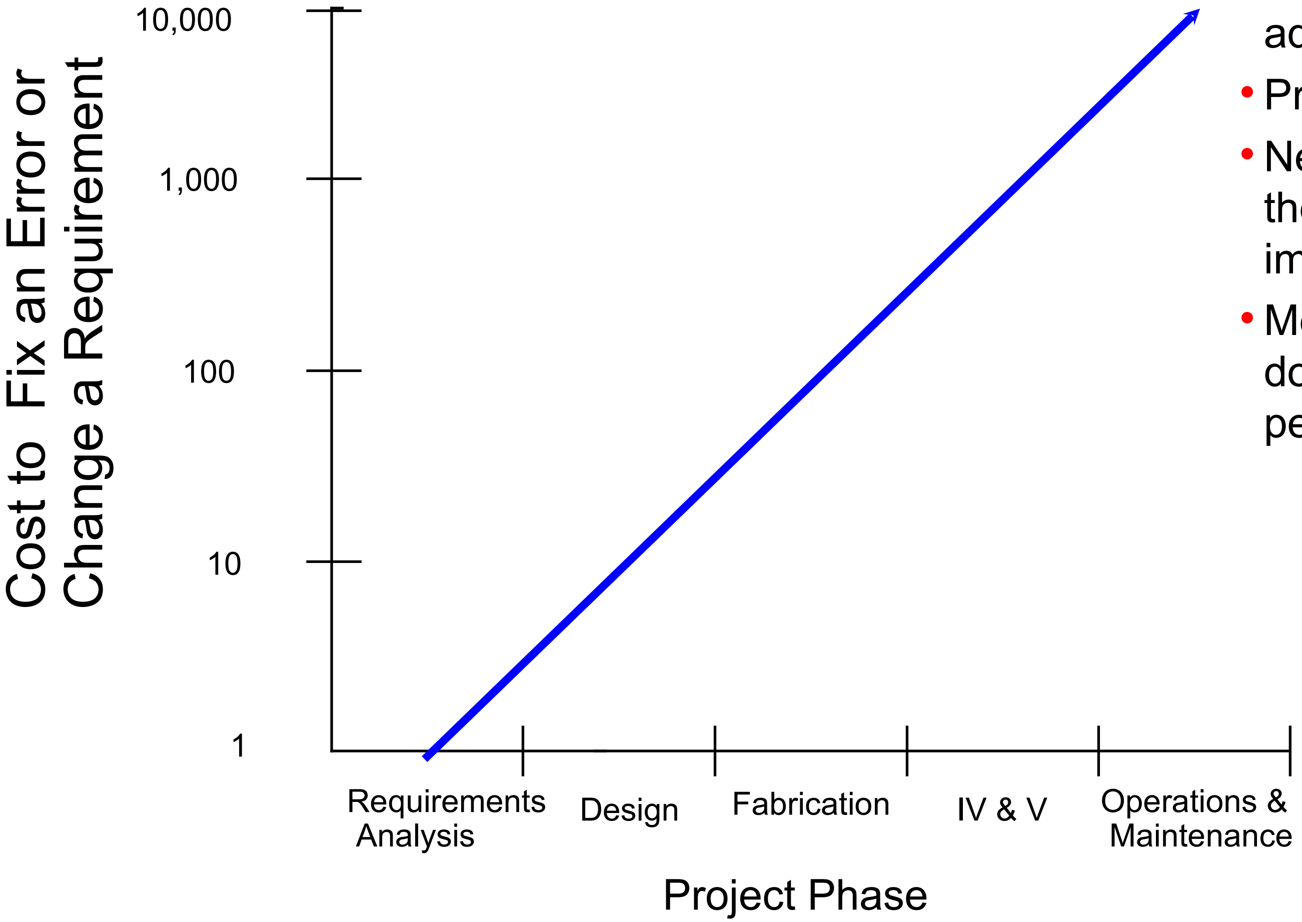
- A requirement is also…
  - A *Contractually Binding* Statement
  - Documentation of *Problem Space*
  - The *Means* We Use to Communicate

The Importance of Getting the Requirements Right

Requirement and concept development commit costs before they are incurred.



The Cost of Error Recovery or a Requirements Change Increases Dramatically with Project Phase



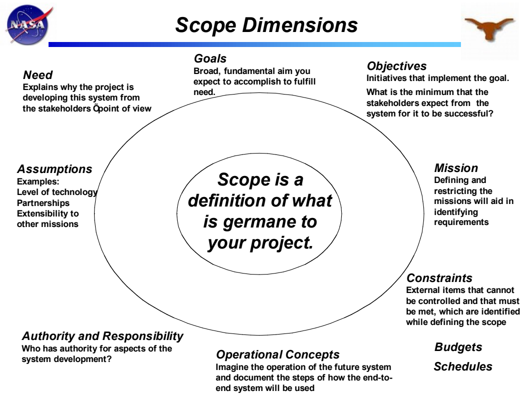
Why requirements change:

- New requirements are added or discovered
- Priorities change
- New understanding of the difficulties of an implementation approach
- Measured performance does not meet required performance

Where Do Requirements Come From?

At the highest level, from your scoping exercise

- Stakeholder and Customer need statement
- Defined goals and objectives
- Assumptions and constraints
- Concept of Operations



Scope Dimensions

Need
Explains why the project is developing this system from the stakeholders Õpoint of view

Goals
Broad, fundamental aim you expect to accomplish to fulfill need.

Objectives
Initiatives that implement the goal.

What is the minimum that the stakeholders expect from the system for it to be successful?

Assumptions
Examples:
Level of technology
Partnerships
Extensibility to other missions

Scope is a definition of what is germane to your project.

Mission
Defining and restricting the missions will aid in identifying requirements

Constraints
External items that cannot be controlled and that must be met, which are identified while defining the scope

Authority and Responsibility
Who has authority for aspects of the system development?

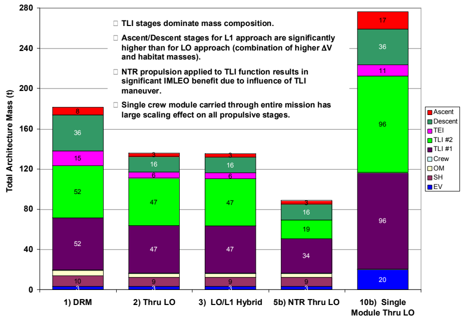
Operational Concepts
Imagine the operation of the future system and document the steps of how the end-to-end system will be used

Budgets

Schedules

Project analysis and trade studies

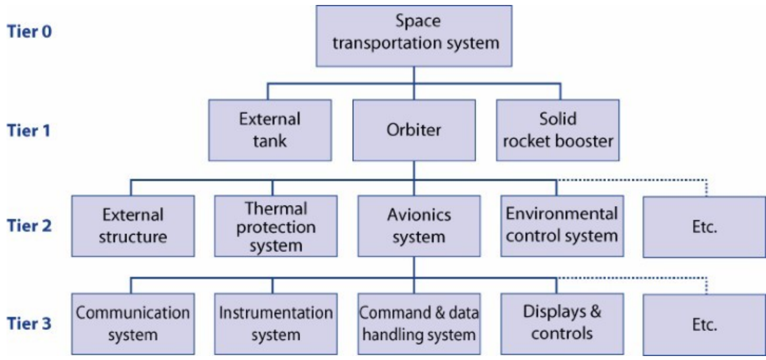
- Figures of merit



- TLI stages dominate mass composition.
- Ascent/Descent stages for L1 approach are significantly higher than for LO approach (combination of higher ΔV and habitat masses).
- NTR propulsion applied to TLI function results in significant IMLEO benefit due to influence of TLI maneuver.
- Single crew module carried through entire mission has large scaling effect on all propulsive stages.

Project system hierarchy

- What *functions* must the system and subsystem do to perform the mission?



Requirements Also Come From Organizational Standards and Government Regulations

Guiding Documents, such as

- NASA Procedural Requirements
  - NPR 8020.12C “Planetary Protection Provisions for Robotic Extraterrestrial Missions”
  - NPR 8705.2A “Human-rating Requirements for Space Systems”
- Launch Vehicle payload/user requirements
- Standards-based Requirements
- Regulation Requirements (e.g. DOE nuclear standards)

Further operational considerations

- System boundaries and external *interfaces*
  - Are other systems driving some of your design requirements, like interfacing with the International Space Station?
- The operating and supporting environments
  - What requirements does the space environment on your system?
- Use of legacy systems
  - What requirements originally designed to?

Requirements Development Is the Most Important Step!

- Requirements are distributed from the broad mission scope into the architecture that defines the project
- Requirements bound the scope of the problems to be solved so we know when we have done well enough
- A hierarchy of traceable requirements ensures that the project is building only what is required, i.e., no frivolous activities
- A hierarchy of negotiated requirements ensures a balanced system design
- Requirements are the basis for the project’s verification and validation efforts
  - Poorly written or unverifiable requirements are trouble!

Requirements are Decomposed Following the Functional Architecture

Requirements are decomposed via three methods — flow-down, allocation and derivation.

1. Requirement flow-down is a direct transfer since a subsystem provides the capability.
   - E.g., The requirements for spacecraft communications may be entirely flowed-down from the spacecraft system requirements to the spacecraft communications subsystem requirements.
2. Allocation is a quantitative apportionment from a higher level to a lower level and for which the unit of measure remains the same. Examples include mass, power, or pointing.
   - A 1,000 kg spacecraft may allocate 200 kg, 500 kg and 300 kg to its three subsystems.
   - Not always a linear combination - e.g., system pointing performance is typically combined via Root-Summed-Squared (RSS).

Requirements are Decomposed Following the Functional Architecture

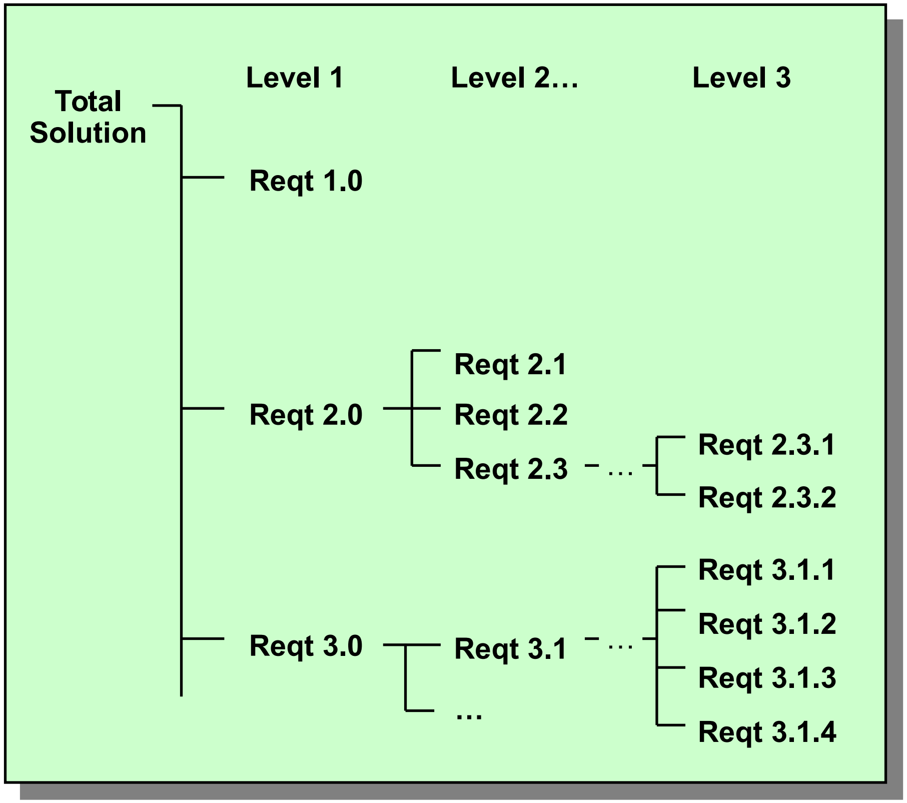
3. Requirement derivation is an apportionment that depends on the specific implementation.

   - E.g., A car may have a 0-100 kph performance requirement that is used to establish a requirement for a maximum mass *and* a minimum horsepower.

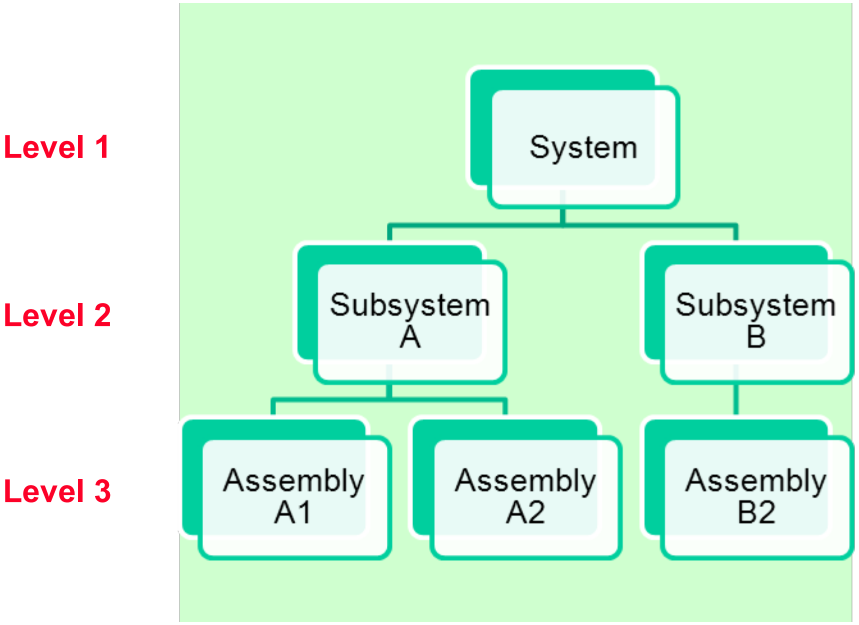
   - Or a launch vehicle's performance might establish a maximum satellite mass for a given altitude and orbital inclination.

Requirements Traceability and Hierarchy

- Once mission level requirements have been decomposed to lower levels, traceability identifies the relationship between requirements.
- Knowing the source and dependencies between requirements is valuable since if a requirement changes, traceability can be used to determine the implications of that change.



Level 1
Level 2…
Level 3
Total Solution
Reqt 1.0
Reqt 2.0
Reqt 2.1
Reqt 2.2
Reqt 2.3
Reqt 2.3.1
Reqt 2.3.2
Reqt 3.0
Reqt 3.1
…
Reqt 3.1.1
Reqt 3.1.2
Reqt 3.1.3
Reqt 3.1.4



Level 1
Level 2
Level 3
System
Subsystem A
Subsystem B
Assembly A1
Assembly A2
Assembly B2

Types of Requirements

- Functional - Requirements which define ***what*** an item *must do*.
  - The system shall provide communications between the ground and the spacecraft.
- Performance - Requirements which define and quantify ***how well*** an item must accomplish a particular function.
  - Provide communications over what range, with what data rate and how often
- Constraints - Requirements that capture operational, environmental, safety or regulatory constraints.
  - The communications system shall use X-band frequencies.
  - The communications system shall operate with a base plate temperature of at least -30 C and at most 40 C.
  - The maximum RF power density shall be less than 10 watts/m^2
  - Design standards (e.g., metric units, programming language, etc.)
- Verification - Requirements capture how confidence will be established that the system will perform in its intended environment.
  - All performance and functional requirements shall be met while the system is in a vacuum chamber with 2.5 Kwatts/m^2 of visible light illuminating the z- side.

Crew Exploration Vehicle (CEV) Requirements Distribution, example

- System Performance Requirements Document
  - The CEV System shall provide two-way voice communications during crewed operations.
- Flight Segment Performance Requirements Document
  - The flight segment shall provide voice communications to the ground through TDRSS.
  - Other derived requirements.
- Flight Vehicle Contract End Item Specification Part I
  - The flight vehicle shall provide four omni directional antennas.
  - The flight vehicle shall provide two S-Band transponders.
  - The flight vehicle shall provide a switch matrix to allow connection of each S-Band transponder with each omni directional antenna.
  - Other derived requirements.
- Flight Vehicle Contract End Item Specification Part II
  - The communications subsystem shall provide the equipment specified in drawing CEVFV-COM1-234.
  - The communications subsystem shall be wired as shown in drawing CEVFV-COM2-234.
  - The communications subsystem equipment shall be mounted on the avionics pallets as shown in drawing CEVFV-COM2-235.
  - Other derived requirements.

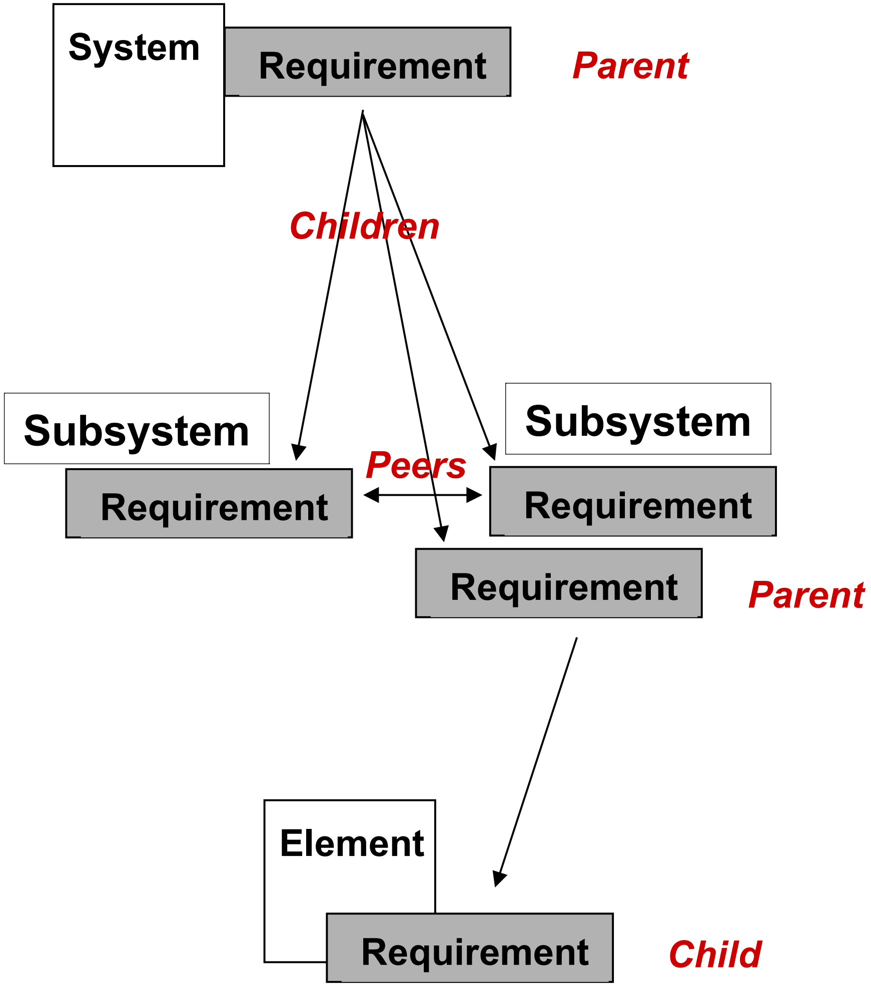
System Functional Performance Requirements

Segment Functional Performance Requirements

Element Design Requirements

Element Fabrication Requirements

Requirement Families

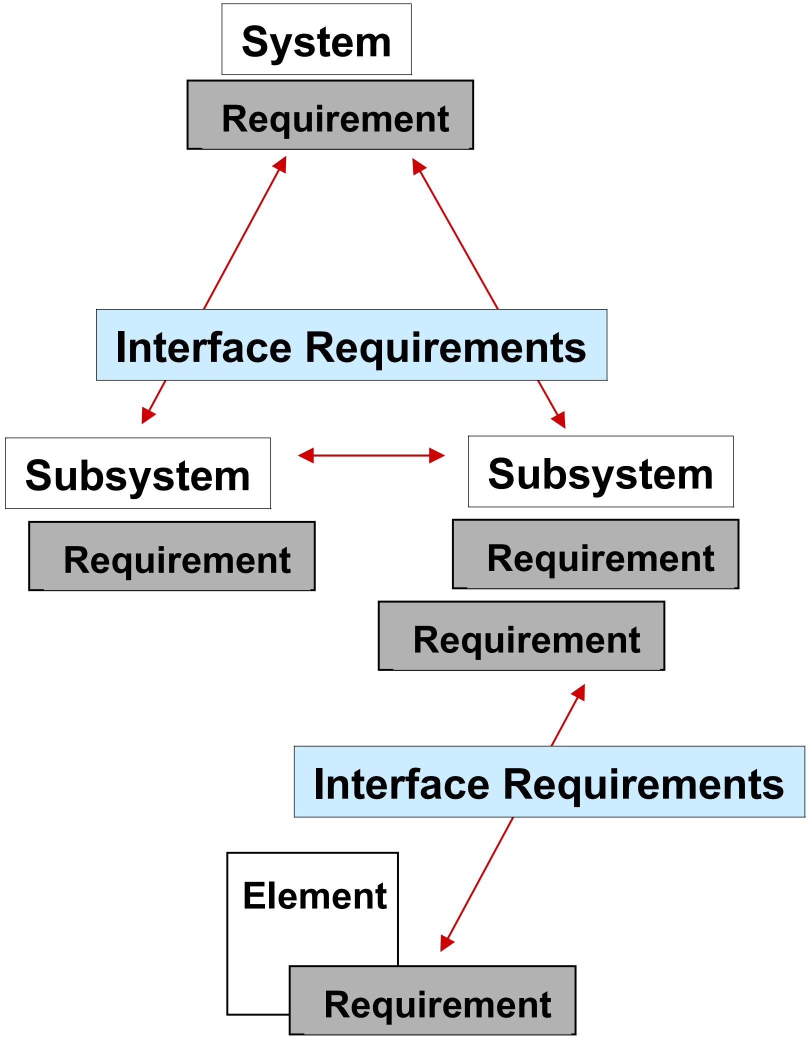


If parent requirements are…

- INCOMPLETE
- INCORRECT
- AMBIGUOUS
- CONFLICTING, or
- UNVERIFIABLE

Then…children and subsequent generation requirements will be progressively worse.

The Decomposition of a System Also Creates Interface Requirements



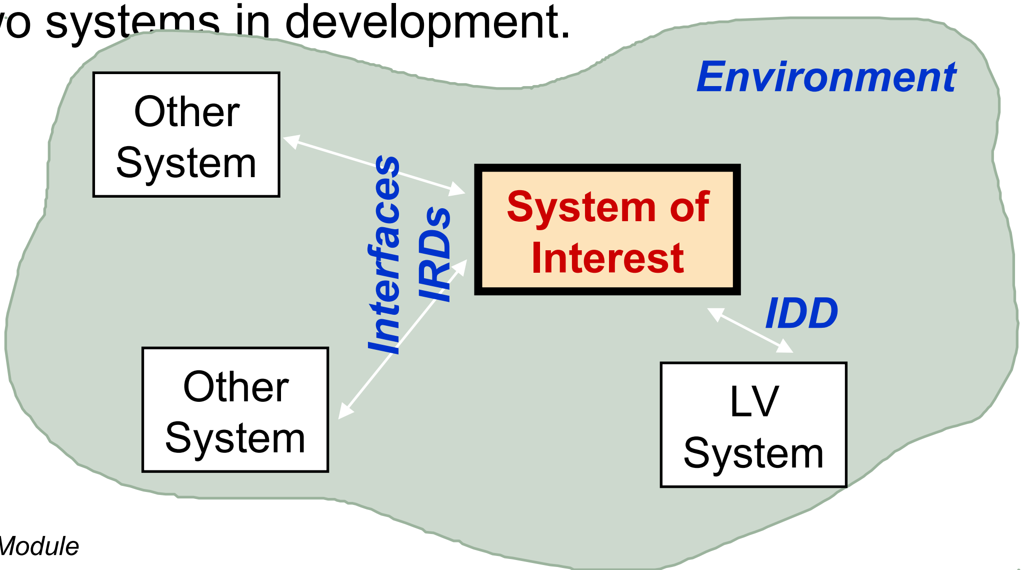
There can be interfaces between each subsystem and between each subsystem and the system.

The functions, performance, assumptions and constraints of these interfaces much be defined and captured in interface requirements.

Interface ownership must be established - since the responsible individual or organization for an interface is not always obvious.

Key Interface Documents

- Interface Definition Document (IDD) - defines interfaces to an existing system such as a launch vehicle. It says what interface someone else must meet to use the launch vehicle. Can be anything, such as mass, type of connector, EMI…
  - Owned by manager of the system with which you want to interface
  - Probably not going to change
- Interface Requirement Document (IRD) - defines interfaces for two developing systems. Includes both physical and functional interfaces and ensures hardware & software compatibility.
  - Jointly managed (NEEDS ONE OWNER) and signed by the managers of the two systems in development.
- Interface Control Document (ICD) - Identifies the design solution for the physical interface (drawings).



Pause and Learn Opportunity

View the James Webb Space Telescope (JWST) requirements hierarchy (*JWST requirements flow down tree.pdf*) as an example of the layers of requirements and relationships throughout the system.

Module Summary: Requirements — The Basics

- Requirements define the problem to be solved and establish the terms by which mission success will be measured.
- Requirements problems are the single biggest problem on development projects so care in creating good requirements always pays off.
- The later a problem is discovered the more costly it is to recover from.
- Requirements are distributed within the system architecture via flow-down, allocation and derivation.
- Requirements traceability is a technique of tracking the source and connections between requirements. It is used to assess the consequences of potential requirements changes.
- When a system is decomposed into smaller segments, interfaces are created that must be defined and managed.

Backup Slides
for Requirements — the Basics Module

Importance of Requirements

Nov 30, 2007

1. GAO recommends NASA shore up Ares I business case. The U.S. Government Accountability Office (GAO) is recommending that NASA not proceed beyond the 2008 preliminary design review (PDR) for the Ares I Crew Launch Vehicle until it establishes a sound business case for the program. "NASA has not yet developed the knowledge needed to make sound investment decisions for the Ares I project," GAO says in a new report. "Principally, there are gaps in knowledge about requirements, costs, schedule, technology, design, and production feasibility." Ares I PDR is expected in late summer or early fall of next year (See related charts below and pp. 7-8). Derived from a five-segment version of the space shuttle's solid rocket booster, the Ares I will boost the Orion Crew Exploration Vehicle to orbit for missions to the International Space Station and the moon. Ares I is set to begin launching operational Orion missions in early 2015. GAO estimates the total price tag for NASA's exploration program over the next two decades at nearly $230 billion. GAO called the Ares I program's gaps in needed knowledge for an informed PDR "fairly significant and challenging given the complexity and interdependencies in the program." As an example of such interdependency, GAO cited "continued instability" in the design of the Orion, which is hampering the Ares program's efforts to firm up their own requirements. Orion has undergone several design revisions in an attempt to keep the spacecraft within desired weight margins, although NASA officials have said those problems are nearly solved (DAILY, Oct. 3). NASA says at least 14 of the 57 risks identified in the Ares projects are "explicitly tied" to requirements instability. On top of this, three major elements of Ares I - the first stage, the upper stage and the Apollo-derived J- 2X upper stage engine - pose "significant development challenges," according to GAO. The J-2X is a new engine development effort, and NASA estimates it will require 29 rework cycles to fix developmental problems. Still, GAO cited NASA's progress in trying to build a business case for the program, including relying on established technology and adopting an acquisition strategy that emphasizes gaining knowledge on cost, schedule and technical feasibility before making significant procurement commitments. NASA agreed with its recommendation not to move beyond PDR until the program's business case improves, according to GAO. "The program also acknowledges that many risks are present and is undertaking an array of activities to track and mitigate those risks," GAO says. "However, NASA has not yet developed the knowledge needed to make sound investment decisions for the Ares I project." GAO's review was requested by Rep. Bart Gordon (D-Tenn.), chairman of the House Science and Technology Committee. Commenting on the report, Gordon promised more lawmaker scrutiny of NASA's exploration plans, saying, "The Administration has undertaken a major new Exploration initiative on a 'business as usual' budget, and that's going to make it difficult for NASA to succeed." - Jefferson Morris (jeff_morris@aviationweek.com)

Types of Requirements

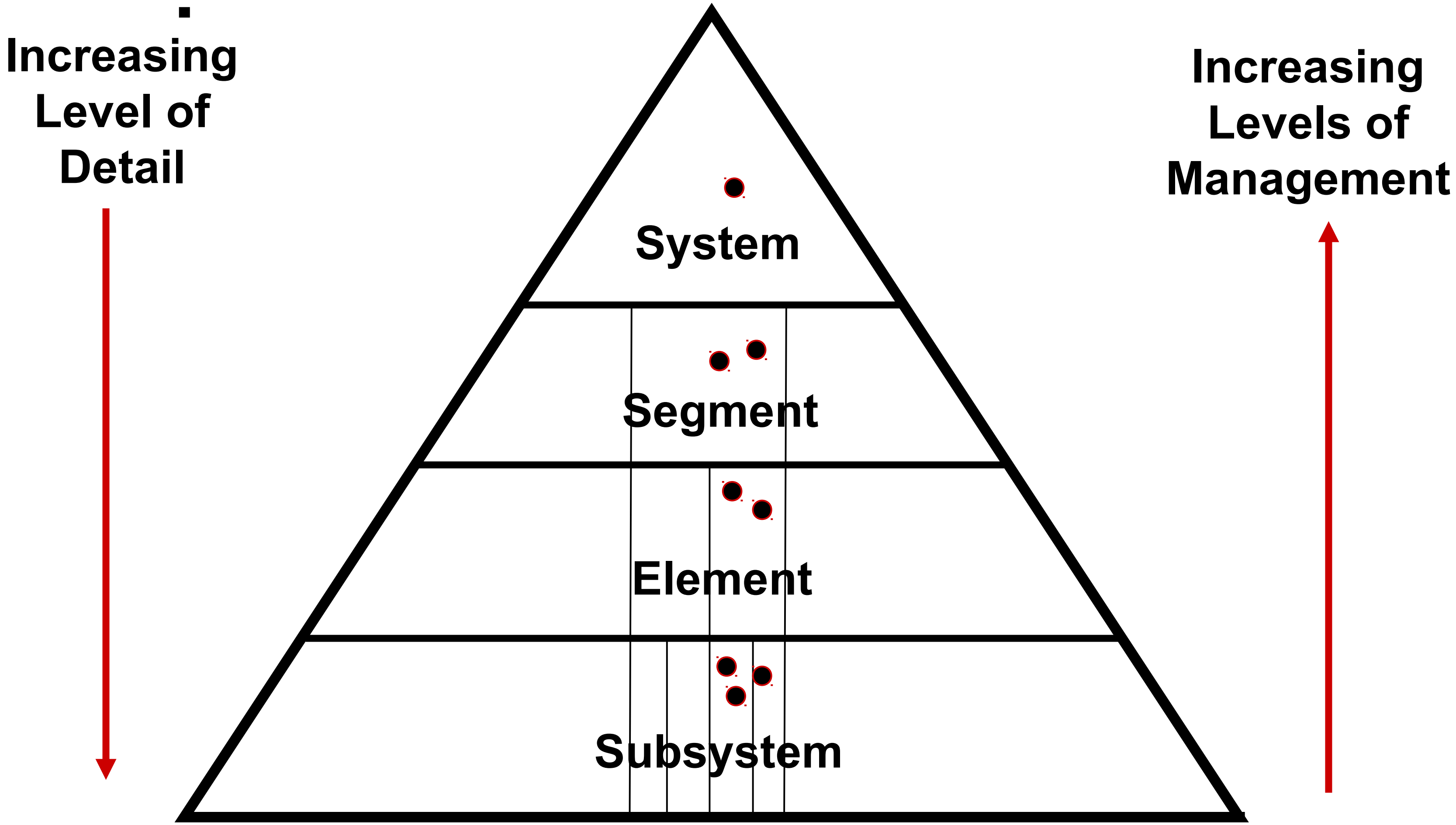
- Stakeholder Expectations
  - Musts
  - Wants
- System Requirements
  - What the system must do
  - Prioritized “wants”
- Imposed Requirements
  - Environmental Requirements
  - Standards-based Requirements
- Interface Requirements
- Regulation Requirements
- Implementation Requirements
- Verification Requirements

Do we have ALL the requirements?

Constraints

- Constraints such as external interfaces imposed by other systems; the storage, transportation, and operating environments (terrestrial or space) such as temperature, electromagnetic, and; and the threat imposed by known or potential enemy capabilities also limit the range of practical design concepts. Note that the precise character of these constraints may depend on the proposed solution. As an example, one set of capabilities might lead to a design concept that might in turn result in a satellite weight within the capability of one launch system (such as the Delta II) and its interface constraints while more demanding capabilities might lead to a satellite requiring a more capable launch system (Atlas V or Delta IV) having a different interface, such as a vibration environment. The range of potential threats is also likely to depend on the design solution.
- Also, policy and public law (legal constraints) involving factors such as environmental impact and safety hazards are important to understanding which concepts will be useful and practical.
- When a system is being acquired to replace an existing system, the plan for transitioning from the current system may place additional constraints on the concept and program (such as the schedule for the current system to be retired).

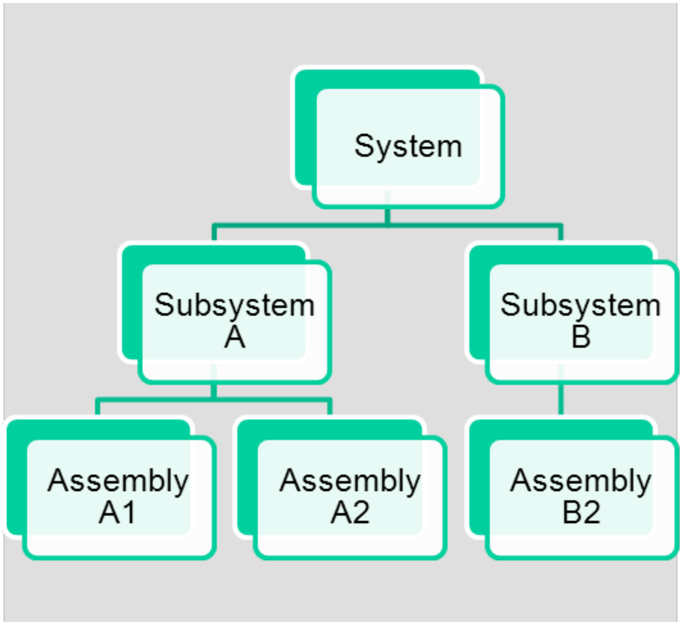
Levels of Requirements



Requirements Hierarchy

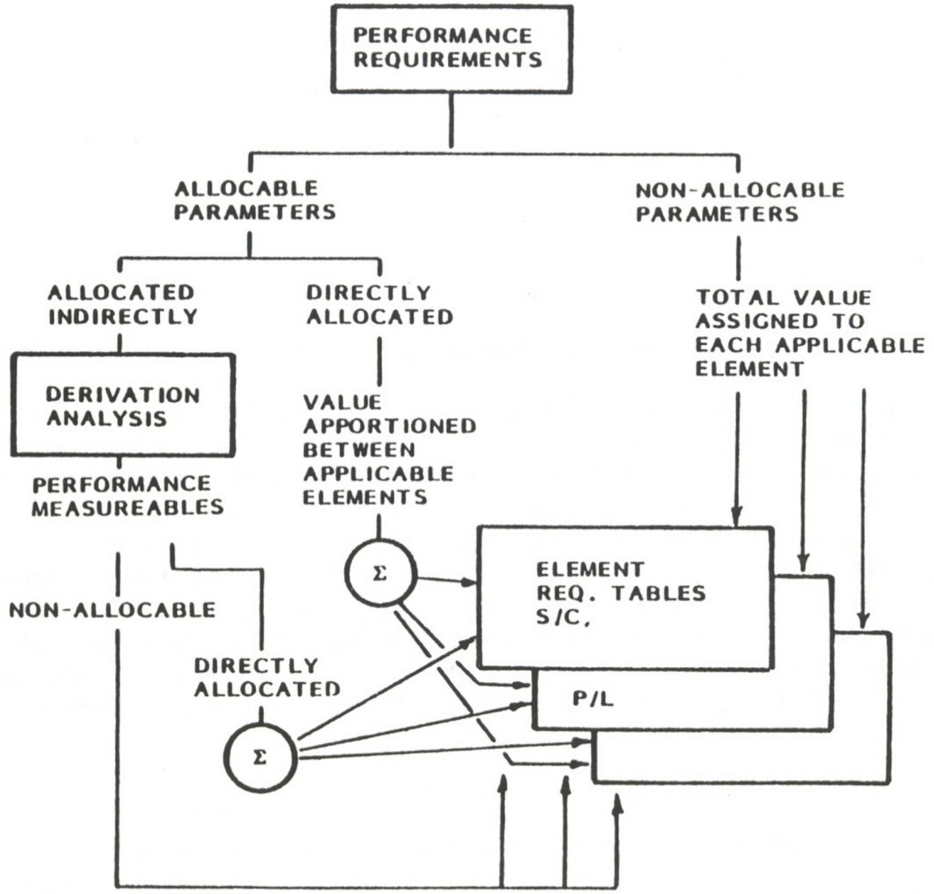
- Requirements are established for every entity in the system hierarchy – the Product Breakdown Structure (PBS).
- The Product Breakdown Structure reflects the system architecture.
- A Requirements Document must be established for each entity in the PBS.
- There should be an individual responsible for each Requirements Document.

Product Breakdown Structure



Requirements Allocation

- Usually Occurs in Functional Analysis, Decomposition, and Synthesis
- But Worth Addressing Because Anticipating that Your Requirements Will be Allocated Helps Create Better Requirements
- Improperly Written Requirements are Very Difficult to Allocate

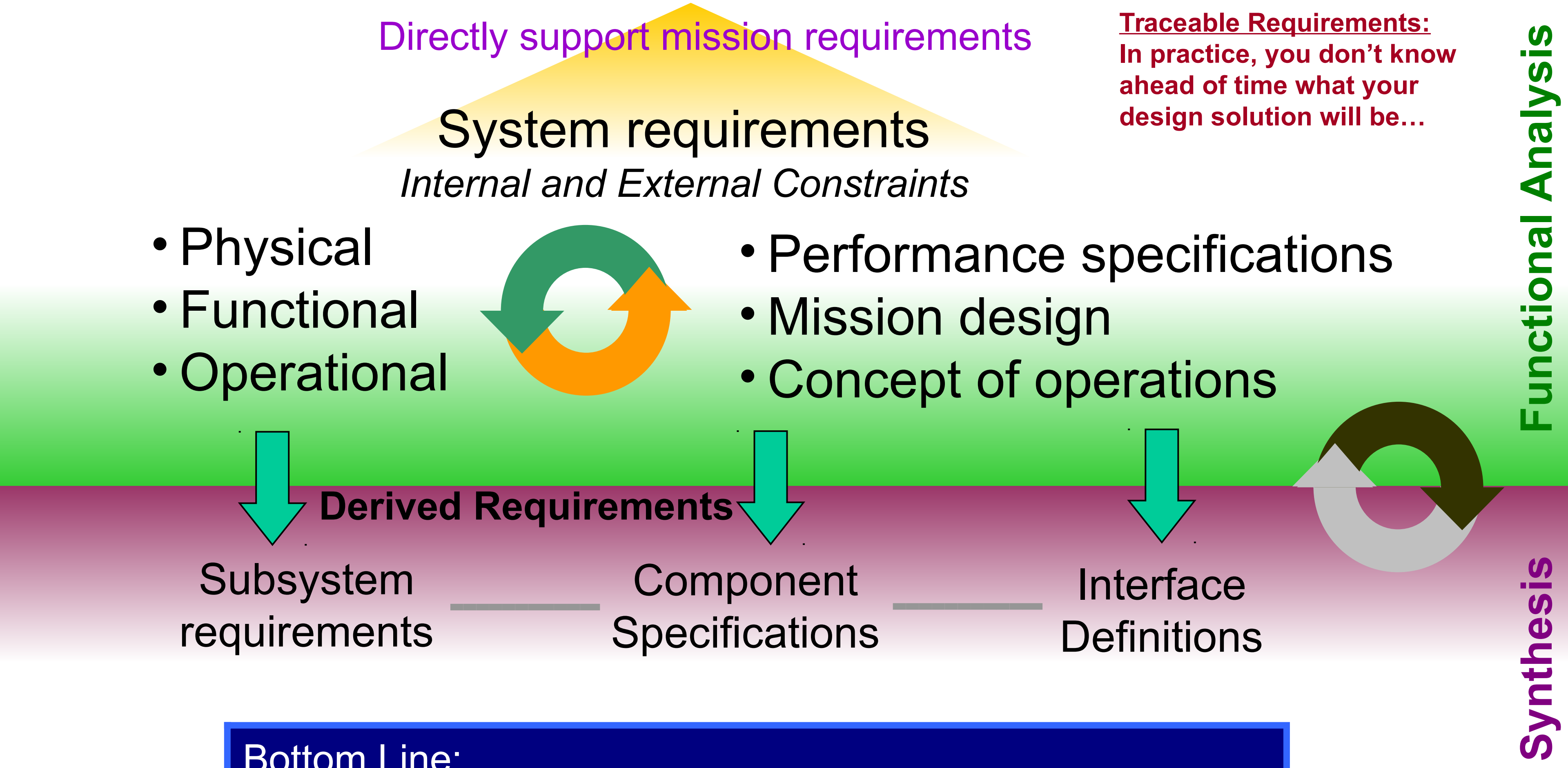


Requirements Flow down - An Analogy

- Functional/Mission
- Functional/Performance
- Design
- End-Item Part I
- End-Item Part II

- TRANSPORTATION
  - To/from work
  - To/from store, cleaners, etc.
  - Available 7 days per week
  - Trips > 100 miles
  - Ease of maintenance
  - 3 or more persons
  - Cost constraint = $X/yr
- A CAR
  - Mid-size
  - Trunk
  - 4-door
- MAKE-MODEL
  - Toyota
  - Camry
- ACCESSORIES
  - AM/FM Radio
  - Air Conditioning
  - Built-in child seat

Derived Requirements & Synthesis



Directly support mission requirements

System requirements

Internal and External Constraints

- Physical
- Functional
- Operational

- Performance specifications
- Mission design
- Concept of operations

Derived Requirements

Subsystem requirements

Component Specifications

Interface Definitions

Functional Analysis

Synthesis

Traceable Requirements:
In practice, you don't know ahead of time what your design solution will be…

Bottom Line:
- Organized top-down thinking process
- Write a formal requirements document