

REQUIREMENTS

ME 481 Senior Design

Fall 2022

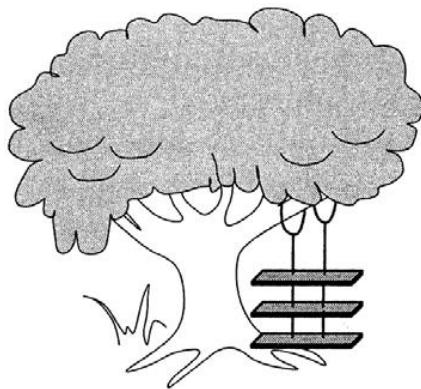
Dr. Trevor C. Sorensen

Requirements Definition

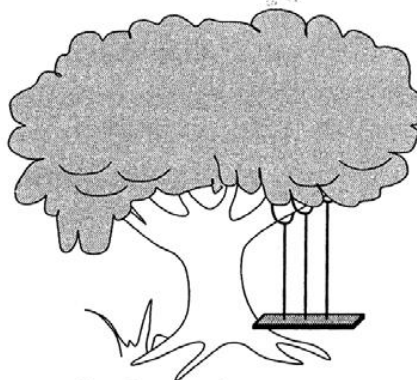
- “... *a thing demanded or obligatory...*”
- “... *a need or necessity*”
- “... *some quality or performance demanded*”
- Requirements are the single thread that goes through a project from conception through build, test and flight
 - Whole project is constructed so you can meet the requirements
- Based on the need to measure a physical phenomena high level requirements are envisioned for a system to meet the need.
- Requirements are then refined, expanded, and flowed down to lower levels through an *iterative process*

Requirements Definition

- Project requirements start with what the user really needs (not what the provider perceives that the user needs) and end when those needs are satisfied



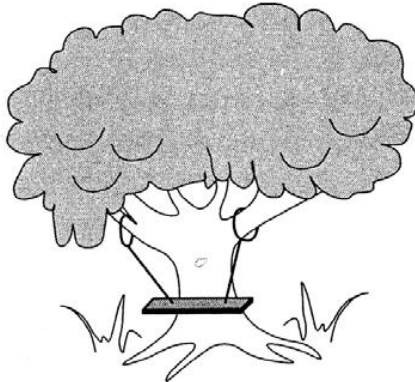
As the RFP requested it



As the work statement specified it



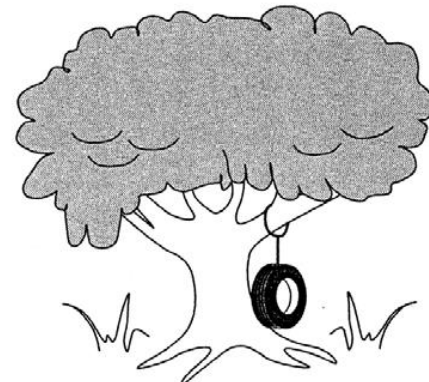
As it was negotiated



As engineering designed it



As it was built

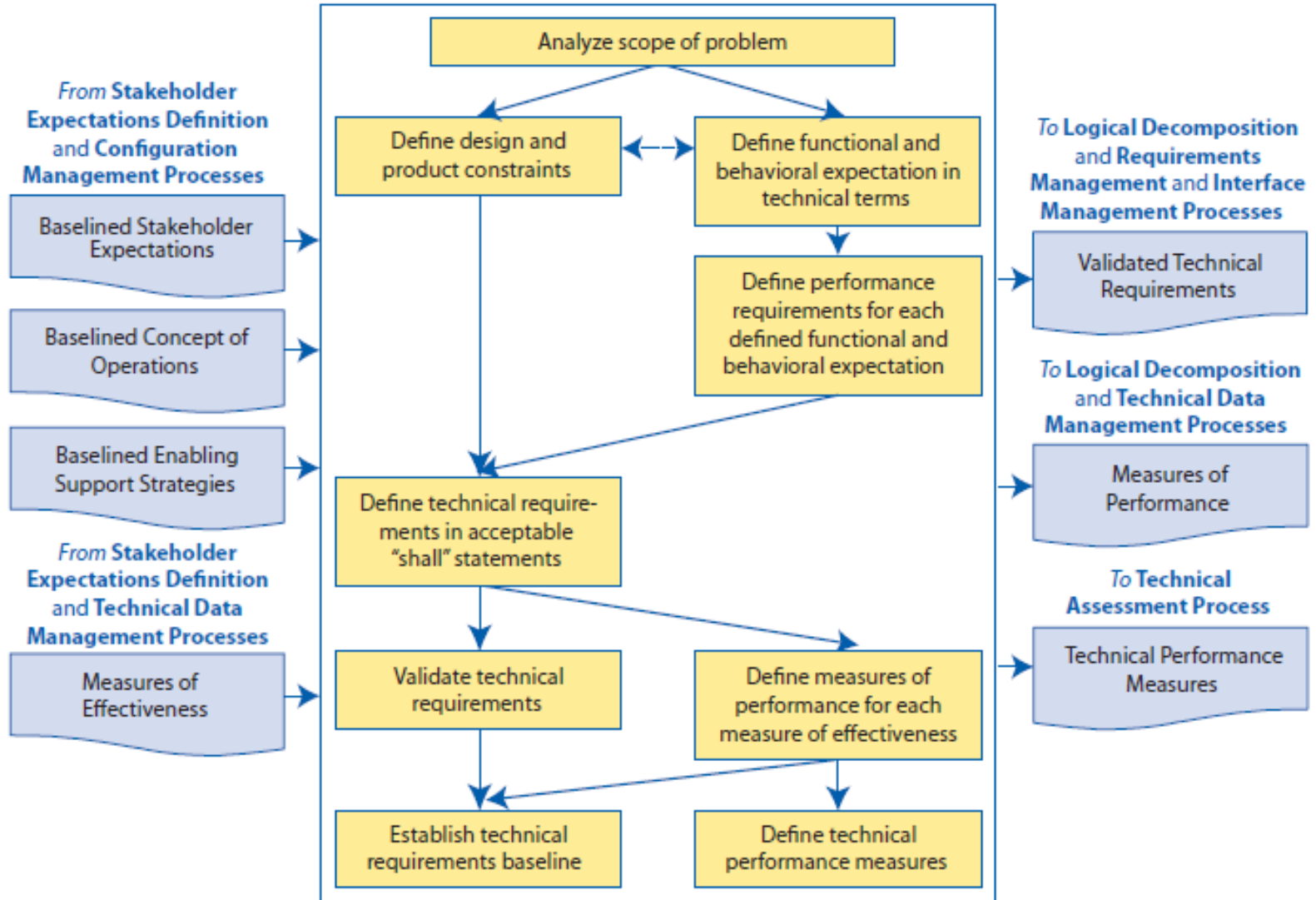


What the customer wanted

Define System Requirements

Define System Requirements

Requirements Definition Process



Define System Requirements

Critical Features of System or Subsystem Requirements:

- Should be based on the fundamental mission objectives
 1. Mission or payload derived
 2. Flow down from basic requirements
- Should be part of the system trade process
- Should state what is to be done (e.g., pointing, mapping, and timing), rather than how to do it (orbit, attitude, and on-board clock)
- Are the quantitative expressions of how well the objectives are met, recorded in the system specification

Types of Requirements:

- *Functional requirements* = how well it must perform
- *Operational requirements* = how it is to be used
- *Constraints* = what limitations are imposed on the system

Elements which Should be Documented for Each Requirement in the System or Subsystem Specification:

- *Function* = what is to be done
- *Performance requirement* = how well it has to be done
- *Verification* = how the performance is to be verified
 1. Inspection
 2. Test
 3. Analysis

Key Element which Should be Documented (though typically omitted from the system specification):

- *Reason* = *why* it is required

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Define System Requirements

Rules for Defining Requirements

- Requirements are *edicts* and use the verb “*shall*” and not “*will*”, “*must*”, or “*should*”
- The central, system-derived requirements (system specifications) are *decomposed* and *allocated* to individual segments or system elements, the interfaces between them, and the interfaces to external elements.
- Requirements should not dictate nor impose *needless limits* on a design, but should specify constraints and what is essential to operate the system and perform the desired mission.
- Requirements should *not include unverifiable terms* or goals such as “maximize”, “optimize”, “sufficient”

Define System Requirements

Rules for Defining Requirements (cont.)

- Constraints are limits (requirements) on the system that cannot be changed - they define the *design space* (e.g., a cost ceiling constraint causes a “design-to-cost” design)
- The role and characteristics of requirements change in each development phase of the system life cycle.
- Detailed requirements should not be introduced prematurely. They should be appropriate to the level of maturity of the system design.

REMEMBER - Requirements definition is an iterative process!

Define System Requirements

Rules for Defining Requirements (cont.)

- Common pitfalls of defining requirements that lead to cost growth or inflation as the project progresses:
 - *Not fully accounting* for all elements of cost in early estimates
 - *Over-specifying* the system can inhibit the trade space and may preclude options that could save money or increase effectiveness.
 - Major or frequent *changes in requirements* during the later phases of development usually causes cost growth and impacts schedule, often seriously. Customer changes in requirements that went unchallenged have resulted in project/mission cancellation!
 - Process of defining and flowing down (allocating) requirements affects cost more than any other activity
 - *Not consulting with vendors, designers or operators of system elements* can cause misunderstanding and inaccurate cost estimates

[Solution: Integrated Product Teams]

Define System Requirements

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Voice of the Customer (VOC) must be solicited constantly and clearly factored into requirements!

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[Solution: Integrated Product Teams]

Define System Requirements

Examples of Top-Level Requirements

Requirement	Factors which Typically Impact the Requirement	FireSat II Example
FUNCTIONAL		
Performance	Primary objective, payload size, orbit, pointing	0.12 K sensitivity at 300 K 500 m resolution 500 m location accuracy
Coverage	Orbit, swath width, number of satellites, scheduling	Daily coverage of 750 million acres within continental US
Responsiveness	Communications architecture, processing delays, operations	Send registered mission data within 30 min to up to 50 users
Secondary Mission	As above	Land and sea surface temperature, high resolution water vapor imagery and crude winds over the continental US
OPERATIONAL		
Duration	Experiment or operations, level of redundancy, altitude	Mission operational at least 10 yrs
Availability	Level of redundancy	98% excluding weather, 3-day maximum outage
Survivability	Orbit, hardening, electronics	Natural environment only
Data Distribution	Communications architecture	Up to 500 fire-monitoring offices + 2,000 rangers worldwide (max. of 100 simultaneous users)
Data Content, Form, and Format	User needs, level and place of processing, payload	Location and extent of fire on any of 12 map bases, average temperature for each 30 m ² grid
CONSTRAINTS		
Cost	Manned flight, number of spacecraft, size and complexity, orbit	< \$20M/yr + R&D
Schedule	Technical readiness, program size	Initial operating capability within 5 yrs, final operating capability within 6 yrs
Regulations	Law and policy	NASA mission
Political	Sponsor, whether international program	Responsive to public demand for action
Environment	Orbit, lifetime	Natural
Interfaces	Level of user and operator infrastructure	Comm. relay and interoperable through NOAA ground stations
Development Constraints	Sponsoring organization	No unique operations people at data distribution nodes

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Allocation of System Requirements

Allocation of System Requirements

- Requirements Analysis and Performance Budgeting
 - Every system requirement is decomposed into progressively-lower levels of design by defining the lower level functions that describe how their higher level function performs
 - **Allocation** assigns the function and its performance requirements to a lower level design element.
 - Decomposing and allocation begin at the system level, then progresses through segment, subsystem and component levels.
 - **Closure** means that satisfying the lower-level requirements ensures performance at the next higher level, and all requirements can thus be traced back to satisfying the mission objectives.

Allocation of System Requirements

Performance Budgets

- Analysis of requirements leads to performance metrics and budgets.
- A performance budget is a certain defined level, quality or quantity of a system driver which can be decomposed and allocated into lower level functions or parameters that can be traded to accomplish the system performance metric.
- Initial performance budgets are usually taken from experience and analogous systems or missions.
- Initial budgets are usually defined by systems engineers with a broad understanding of the entire system and major elements, but design studies at lower levels, where new technology or better analyses are used, can result in changes being made in the allocated budgets (“*flowup*”). An initial budget allocation should anticipate this and be robust enough to accept changes.

Allocation of System Requirements

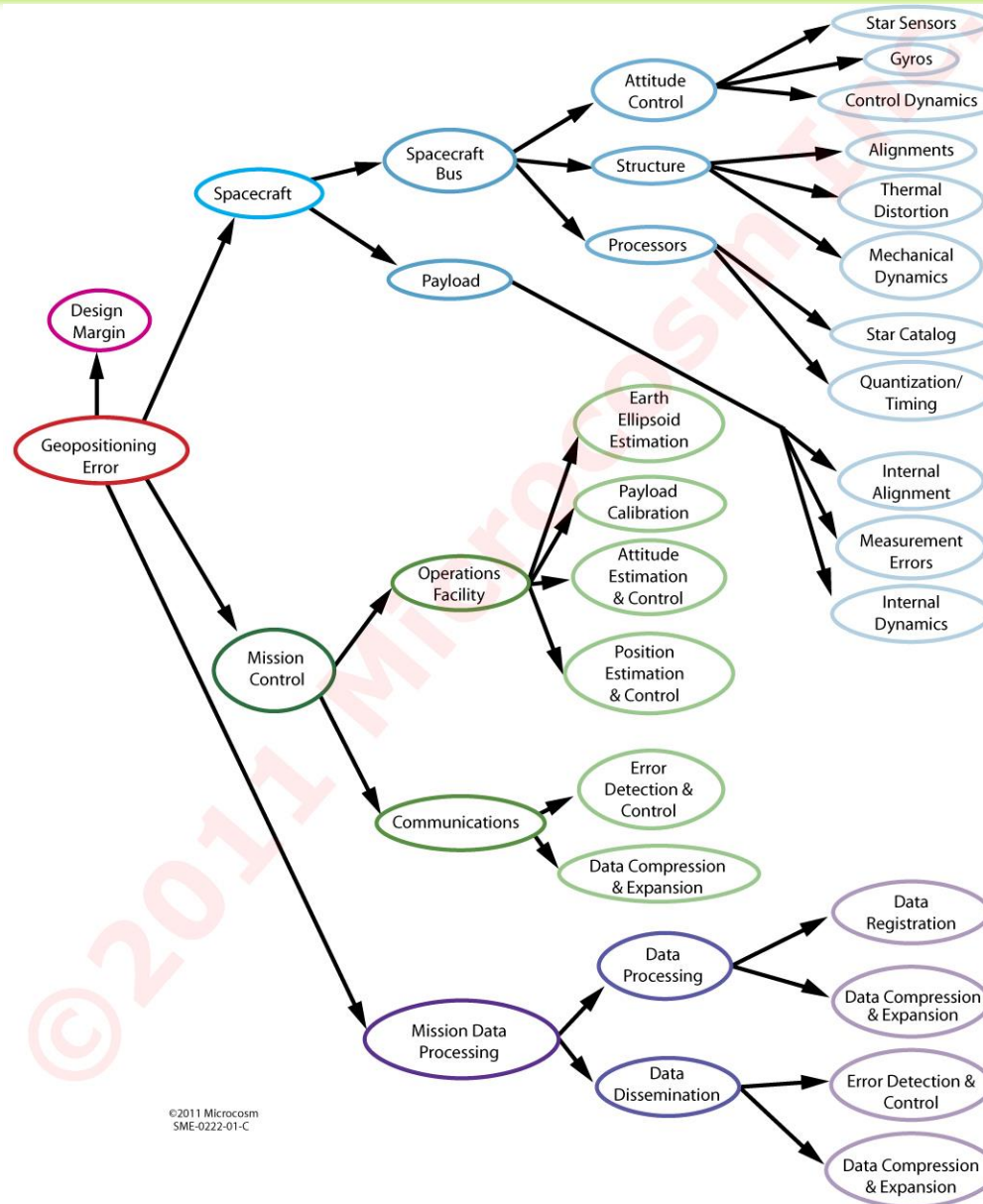
Items Frequently Budgeted in Space Missions

- Overall budgets are typically established at the systems level and flow-down or allocated to the subsystems.

Primary	Secondary
Weight	Subsystem Weight Power Propellant
Geolocation or System Pointing Errors	Pointing and Alignment Mapping, Attitude Control, Attitude Determination Position Determination
Timing	Coverage Communications Operations Processing
Availability	Reliability Operational Availability
Cost	Development Cost Deployment Cost Operations and Maintenance Cost

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Allocation of System Requirements



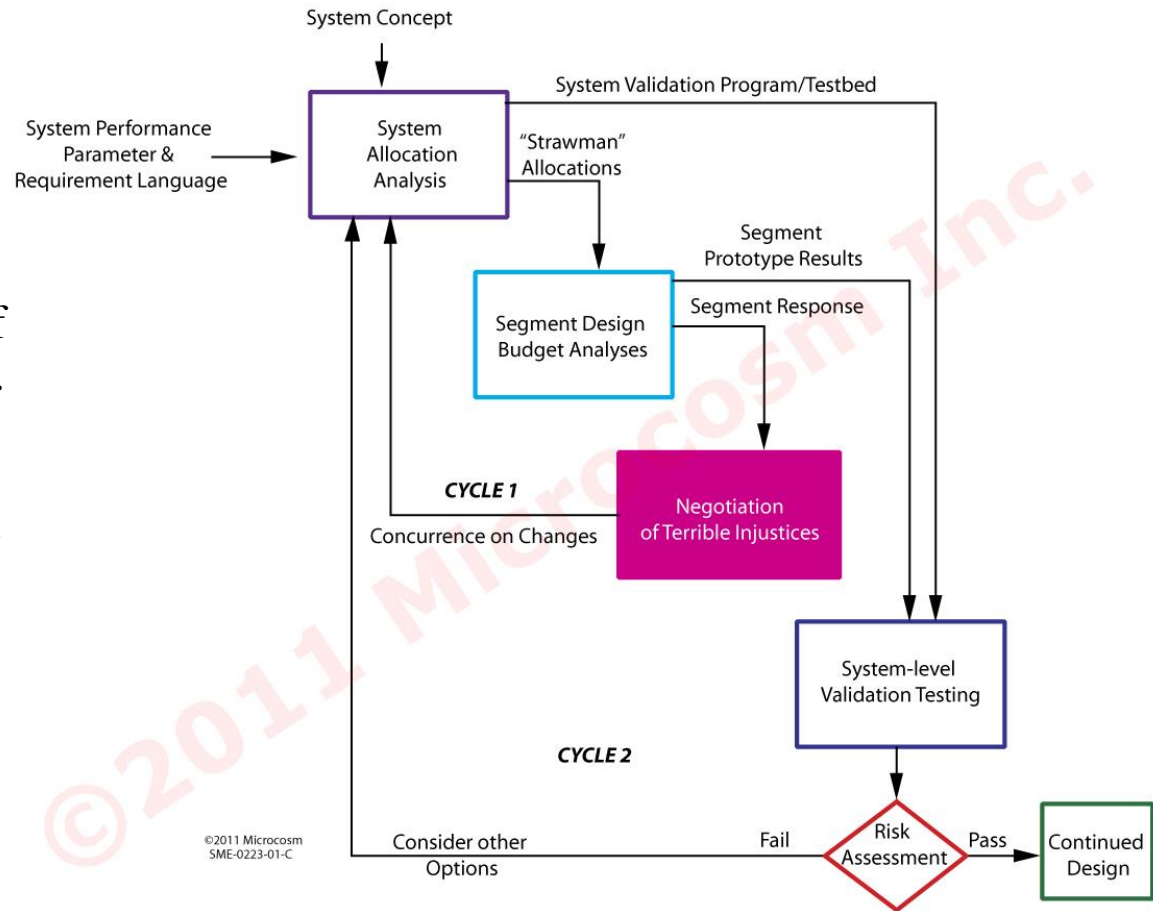
Example of
Allocation of
Mission
Requirements or
Error Budgets to
Component Level

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Allocation of System Requirements

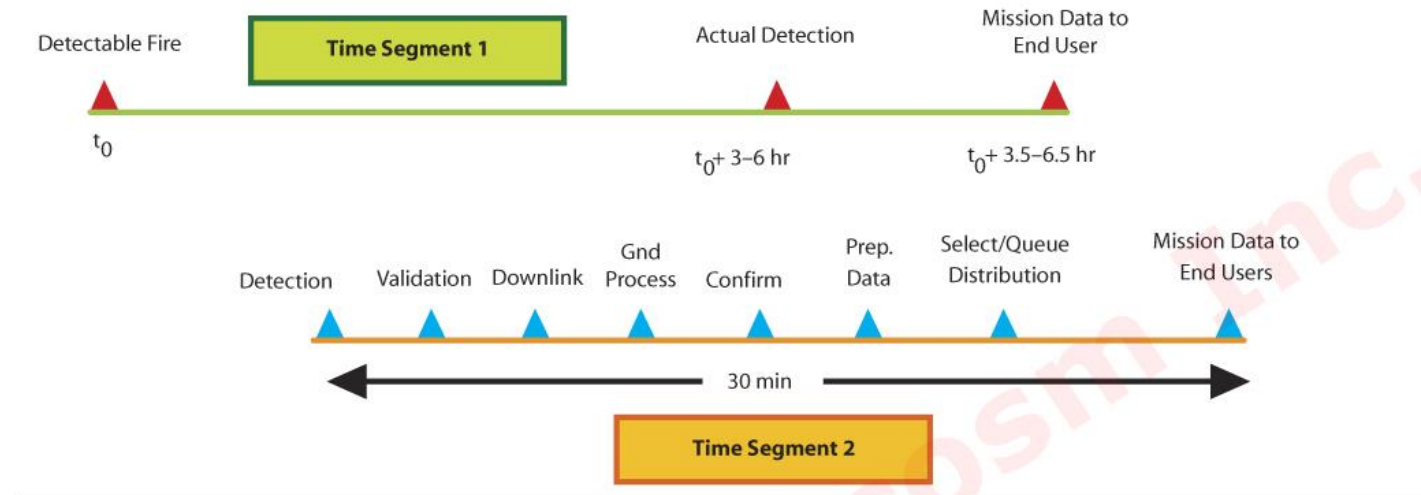
Error/Budget Analysis Process

- Initial performance budget is a baseline for later evaluation of system element design and validation testing. Through an iterative process the design will converge to a validated state which may require negotiation of system-level budget adjustments.
- In any performance budget there should be a *design margin*, sometimes called a *management reserve*. After a budget size is determined, 15-20% is usually added to allow for system cost growth. This is usually available for altering allocated performance budgets without affecting the overall system design significantly.



Allocation of System Requirements

Time Utilization Budget Analysis – FireSat II



Time Segment 1 Requirements

Time to Actual Detection

- Coverage (Number of Spacecraft, Orbit, Elev. Angle)
- Detection Time Given Coverage (Payload Scan Options & Sensitivity)

Time Segment 2 Requirements

Time from Detection to Data Delivery	Initial Validation (PD/PF A, No. of Hits, Processing Time Given Detection)	Initial Allocation
	Downlink (Link Avail., Link Acquisition/Closure)	1 min
	Orbit and Attitude Determination	3 min
	Ground Look Point Determination	6 min
	Completion of Ground Processing (Front End Processing Arch., No. of Channels, Process. Rate)	2 min
	Confirmation of Fire (Auto vs. Manual, Number of Exploiters and Workstations)	3 min
	Data Preparation (Sorting, Formatting, Internal Routing)	3 min
	Queuing for User Distribution (Sorting, Distribution, Queue Processing)	2 min
	Distribution to End User (Network Mgmt., Channel Rates)	3 min
	Margin	2 min
		<u>5 min</u>
		30 min

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Requirements Management

Requirements Management

- Requirements management activities apply to the management of all stakeholder expectations, customer requirements, and technical product requirements down to the lowest level product component requirements
- The *Requirements Management Process* is used to:
 - Manage the product requirements identified, baselined, and used in the definition of the WBS model products during system design;
 - Provide bidirectional traceability back to the top WBS model requirements; and
 - Manage the changes to established requirement baselines over the life cycle of the system products

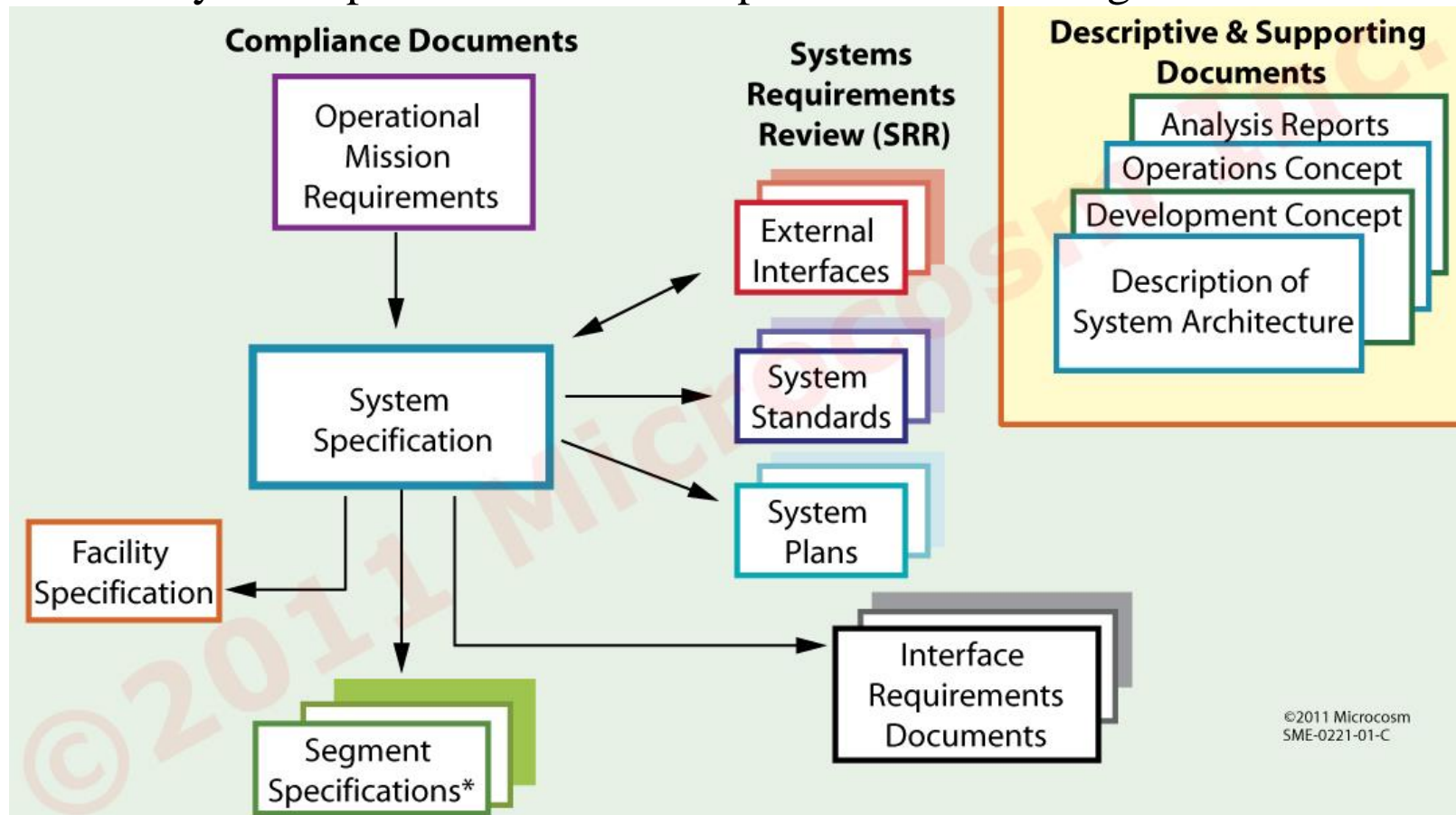
Requirements Management

- Requirements reviews are necessary predecessors to system design reviews
- Requirements-related issues must have same weight as design issues in readiness decisions by program to proceed to next level of development
- The primary review of the requirements is held in the System Requirements Review (SRR) at the end of Phase A in the project life-cycle

Requirements Management

Typical Specification & Requirement Documents

- Requirements form basis of System Specification
 - Requirements give source and reason
 - System Specification defines parameters for design and build



Requirements Management

System Specifications Document

- The project requirements are usually captured in the *System Specification Document (SSD)*, *System Requirements Document (SRD)*, or the *System Requirements Specification (SyRS)*
 - Note: “*SRS*” usually stands for the Software Requirements Specification
- The SSD is a structured collection of information that embodies the requirements of a system and is used throughout the project life cycle

Requirements Management

Interface Requirements Document

- An interface is any boundary between one area and another
 - It may be cognitive, external, internal, functional, or physical
- Interface requirements are documented in an *Interface Requirements Document (IRD)*
- Care should be taken to define interface requirements and to avoid specifying design solutions when creating the IRD
 - The *Interface Control Document (ICD)* describes the detailed implementation of the requirements contained in the IRD

Requirements Management

Requirement Qualification Methods

- The qualification/verification method(s) to be used to ensure that a requirement has been met should be identified.
- The qualification method(s) for each requirement is contained within a qualification method attribute for that requirement.
- Qualification methods may include:
 - a. *Demonstration*: The operation of the system, or a part of the system, that relies on observable functional operation not requiring the use of instrumentation, special test equipment, or subsequent analysis.
 - b. *Test*: The operation of the system, or a part of the system, using instrumentation or other special test equipment to collect data for later analysis.
 - c. *Analysis*: The processing of accumulated data obtained from other qualification methods. Examples are reduction, interpretation, or extrapolation of test results.
 - d. *Inspection*: The visual examination of system components, documentation, etc.

Requirements Management

Example from DataLynx SSD

Object Id	Object Number	DOC Requirements Specification	NEMO	Priority	Risk	Verifiability	Qual Meth	Trace
DOC523	3.2.2.1.3.1.0-3	The FD subsystem shall be capable of propagating a standard NORAD two line orbital element set.	Yes	Mandatory	Medium	Verifiable		SSS186: 3.2.2.4.0-2
DOC92	3.2.2.1.3.1.0-4	Orbit propagation shall use a high fidelity force model, which includes Earth gravitational forces to at least 16x16 degree and order.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC527	3.2.2.1.3.1.0-5	Orbit propagation shall use a high fidelity force model, which includes solar radiation pressure.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC526	3.2.2.1.3.1.0-6	Orbit propagation shall use a high fidelity force model, which includes Sun and Moon gravitational effects.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC525	3.2.2.1.3.1.0-7	Orbit propagation shall use a high fidelity force model, which includes atmospheric drag.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC524	3.2.2.1.3.1.0-8	Orbit propagation shall use a high fidelity force model, which includes spacecraft thrust forces.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC93	3.2.2.1.3.1.0-9	FD shall be capable of generating orbit ephemeris.	Yes	Mandatory	Medium	Verifiable		SSS288: 3.2.4.2.0-2 SSS115: 3.2.2.3.0-4 SSS66: 3.2.4.2.0-2
DOC684	3.2.2.1.3.1.0-9.0-1	Using spacecraft provided GPS position data, the DataLynx shall be capable of definitive orbit accuracy of at least 1 km TBR (3-sigma).	Yes	Mandatory	Medium	Verifiable		DOC93: 3.2.2.1.3.1.0-9
DOC94	3.2.2.1.3.1.0-10	FD shall have the capability to perform checks of onboard ephemeris propagation.	Yes	Mandatory	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC528	3.2.2.1.3.1.0-11	FD shall have the capability to perform orbit lifetime calculations.	Yes	Mandatory	Medium	Verifiable		SSS66: 3.2.4.2.0-2 SSS288: 3.2.4.2.0-2
DOC529	3.2.2.1.3.1.0-12	FD shall permit update of gravitational model coefficients.	Yes	Desired	Medium	Verifiable		SSS115: 3.2.2.3.0-4
DOC95	3.2.2.1.3.2	<i>3.2.2.1.3.2 Orbit Event Data and Product Generation</i>			Medium	N/A		
DOC96	3.2.2.1.3.2.0-1	FD shall be capable of generating spacecraft occultation data.	No	Desired	Medium	Verifiable		SSS287: 3.2.4.2.0-3
DOC97	3.2.2.1.3.2.0-2	FD shall be capable of generating satellite acquisition data for antenna pointing during satellite passes over tracking stations.	Yes	Mandatory	Medium	Verifiable		SSS287: 3.2.4.2.0-3
DOC98	3.2.2.1.3.2.0-3	FD shall be capable of generating spacecraft ground trace data.	Yes	Mandatory	Medium	Verifiable		SSS287: 3.2.4.2.0-3

Space Spectaculars!



STS-98 Launch
2/7/2001



MMIII Launch
VAFB 9/19/02

**Clementine's View of
Earth Over Lunar North
Pole Mar. 1994**

