Technical Measurement

Lecture 13, v02

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What is Technical Measurement?

- Technical measurement is the set of measurement activities used to provide the stakeholders with insight into progress in the definition and development of the technical solution and the associated risks and issues
  - This insight helps the architect make better decisions throughout the specification and development of the system architecture to increase the probability of delivering a technical solution that meets both the specified requirements and the mission needs
  - This insight is also used in trade-off decisions when performance exceeds the threshold
    - Meaning, unexpected gains in one area can be trimmed to provide additional needed margin elsewhere
  - Technical measurement is planned early in the architecture development and then performed with increasing levels of fidelity as the technical solution is matured

- Margin provides room for growth, or room to maneuver (design-wise)
- Margin occurs where a design is overspecified with respect to the minimum required
- Margin may be desirable to mitigate risk and absorb future changes, but at the same time, may be undesirable if the overspecification negatively affects the design's performance

Which Technical Measurements are of Interest in SE

- Measures of Effectiveness (MOEs)
  - “Operational” measures of success that are closely related to the achievement of mission or operational objectives
  - Provide insight into the accomplishments of the mission needs independent of the chosen solution
- Measures of Performance (MOPs)
  - Characterize the physical or functional attributes relating to the system operations
  - Provide insight into the performance of a specific system
- Technical Performance Measures (TPMs)
  - Measure attributes of a system element within the system to determine how well the system or system element is satisfying specified requirements
- Key Performance Parameters (KPPs)
  - Are a critical subset of the performance parameters
  - They represent the most critical capabilities and characteristics that must be monitored during system development
  - Purpose is to ensure that the system will deliver the expected MOP, and resultingly, the needed MOEs

How are Technical Measurements Useful?

- Communicate effectively and improve visibility
  - Measurement supports communication among the development team and stakeholders
  - Objective measurement reduces ambiguity
- Identify and correct problems early
  - Measurement facilitates pro-active management of the architecture development
  - It allows the architect to identify and manage potential problems early in the development lifecycle
- Make key trade-offs
  - Decisions in one area of the design often impact other areas
  - Measurement helps assess the impact objectively so that architects can make informed trade-off decisions
- Manage risks
  - Architects gain visibility into risk areas such as the system not closing (not meeting its performance objectives)
  - By measuring whether the system closed on its performance goals, architects can determine whether risks have been mitigated
- Defend and justify decisions
  - Having objective data available allows architects to interpret the measures and decide on appropriate actions

Measure of Effectiveness (MOE)

MOEs are specified and assessed at the Enterprise Level

- MOEs are the stakeholder's key indicators of achieving the mission needs for performance, suitability, and affordability across the life cycle of the system
  - MOEs focus on the system's capability to achieve mission success within the total operational environment
  - MOEs represent the stakeholder's most important evaluation and acceptance criteria against which the quality of a solution is assessed
  - MOEs are the overall operational success criteria to be used by the acquirer for the delivered system, services, and/or processes
- MOEs are independent of any particular solution
  - MOEs are specific properties that any alternative technical solution must exhibit to be acceptable to the stakeholder
  - In addition to using MOEs to compare and evaluate alternatives, they can also be used for sensitivity analysis of performance from variations of key assumptions and parameters of the potential alternatives
- MOEs are important for test and evaluation because they determine how test results will be judged
  - Since test planning is directed toward obtaining these measures, it is important that they be defined early

Measures of Performance (MOPs)

MOPs are specified and assessed at the System Level

- MOPs are used to assess whether the system meets requirements that are necessary to satisfy MOEs
  - MOPs should be derived from or provide insight for MOEs or other user needs
  - MOPs are derived from the supplier's viewpoint and look at how well the delivered system performs against system level requirements
- MOPs characterize physical or functional attributes relating to the system operation, measured or estimated under specified testing and/or operational environment conditions
  - They are expressed in terms of distinctly quantifiable performance features, such as speed, payload, range, or frequency
- MOPs are used to compare architecture alternatives to quantify technical or performance requirements
  - They support assessment of system design alternatives and the technical impact of proposed system changes
  - Investigate performance sensitivities to changes in assumptions from the technical view
- MOPs often map to Key Performance Parameters (KPPs) or requirements in the system specification
  - They help refine KPP definitions and assess achievement of KPPs

Technical Performance Measures (TPMs)

TPMs are specified and assessed at the Subsystem Level

- TPMs are derived from or provide insight for the MOPs
  - TPMs focus on the critical parameters of architectural elements of the system as it is designed and implemented
  - TPMs are used to assess design progress, compliance to performance requirements, or technical risks
- Performance of the system or system element is tracked through the life cycle and compared to the projected and required values
  - Early in the life cycle the performance values may be estimated, based on simulation and modeling
  - As the life cycle proceeds, actual data replaces estimates and adds to the fidelity of the information
  - This measurement of the design solution as it evolves allows action to be taken early in the process
- TPMs enable an assessment of the product design by estimating the values of KPPs
  - Provide early identification of risks and prediction of problems (e.g., where negative margins exist)
  - Determine where to make design trades to reduce overall risk (e.g., where positive margins exist)
  - Monitor incorporation and results of new critical technologies
  - TPMs forecast the values to be achieved for KPPs

How MOEs, MOPs, TPMs Relate to Each Other

MOEs	MOPs
Refers to the effectiveness of a solution, and is independent of any particular solution	Is concerned with actual performance of the supplier's solution, which may be quite divorced from the stakeholders' intentions
Will indicate a property which a potential solution must possess in order to meet a need	Will tell what something is capable of doing even if this is not necessarily what the stakeholders want it to do
Can be used to validate that the system meets the users' intended needs	Can be used to verify the system meets the users' stated requirements - which in turn enables the requirements to be validated to meet the users' intended needs
"Effectiveness" is a quality of fitness for service or of producing the results for which the system was intended	"Performance" is the quality of "doing something", and "doing something" does not necessarily indicate fitness for service

- After the solution alternative has been selected, the TPMs then provide a lower level view of specific aspects of the performance of the solution
- The lower level measures (MOPs and TPMs) should be defined with the higher level measures (MOEs and MOPs) in mind in order to ensure the measures can be aggregated (brought together, assembled) to provide the necessary insight for system and operational decision-making

As a simple example of how MOEs, MOPs, and TPMs work together:

- An MOE may be that a data system is needed that does not fail when processing specific mission critical functions
- The MOP could be the derived requirement that the system be able to provide uninterrupted computing for at least 100 hours (although usually there will be multiple MOPs)
- The TPMs that are tracked may include fault tolerance, redundancy, and failure rate

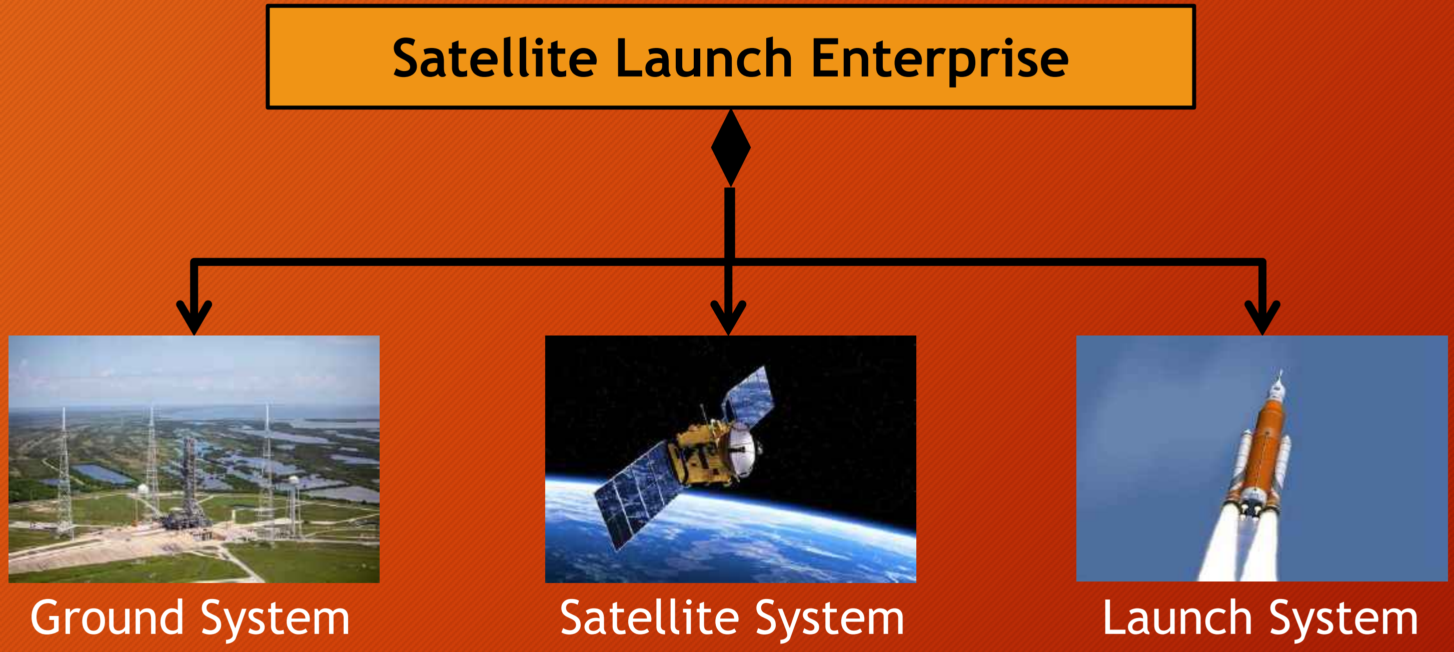
Key Performance Parameters

KPPs are MOPs or TPMs that the stakeholder has decided are critical to program success and wishes to specifically track

- KPPs are the minimum number of performance parameters needed to characterize the major drivers of operational performance, supportability, and interoperability
- KPPs represent the critical performance requirements and collectively characterize the overall performance in summary form
- KPPs allow the stakeholders to evaluate architectural and top-level design decisions against what is considered to be most important
- The stakeholder defines the KPPs at the time the operational concepts and requirements are defined
- The following questions may be useful in determining whether a MOP or TPM should also be a KPP:
  - Is it essential for defining the required capabilities?
  - Does it contribute to significant improvement in the operational capabilities of the enterprise?
  - Is it able to by analyzed throughout the life cycle?
  - If not met, will the sponsor of the project be willing to cancel or significantly restructure the project?

Example: Satellite Launch Enterprise

- In order to demonstrate a specific application of technical measures for a system architecture, a simplified Satellite Launch Enterprise example is used, consisting of:
  - Ground System – All the ground facilities that support launch and space operations
  - Satellite System – The satellite vehicle itself
  - Launch System – The vehicle that launches the satellite into orbit



Ground System Image - https://blogs.nasa.gov/kennedy/2020/05/06/launch-complex-39b-prepared-to-support-artemis-i/
Launch System image - https://www.technowize.com/worlds-most-powerful-rocket-engine-a-definitive-ranking-technowize
Satellite System image - https://www.carriermanagement.com/news/2019/08/01/196089.htm

Example Traceability of Technical Measurements

J.G. ARTUS Systems Engineering

EperV = propellant energy per unit volume

Service Life is a function of
- DeltaV
- BatteryCycle
- SolarCellLife

DeltaV is a function of
- PropellantCapacity
- ThrusterEfficiency
- PropellantEperV

Enterprise MOEs
- «moe» **ServiceLife**

Satellite System MOPs
- «mop» **DeltaV**
- «mop» **BatteryCycle**
- «mop» **SolarCellLife**

Propulsion Subsystem TPMs
- «tpm» **PropellantCapacity**
- «tpm» **ThrusterEfficiency**
- «tpm» **PropellantEperV**

Assume that PropellantEperV is a fixed property (it cannot be changed)

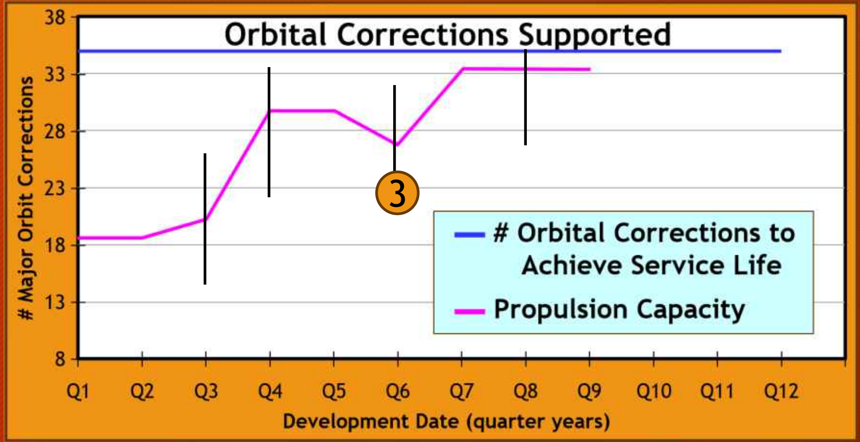
Measure Type	Item	Threshold (Goal)	Indicator
MOE	Service Life	8 Years	Length of time satellite system is expected to remain fully operational
MOP	Delta-V	35 Major Orbital Corrections	The number of orbital corrections the system is expected to support
TPM	Propellant Capacity	17.5 Liters	The capacity of the propellant tank

Example Impact of System Changes

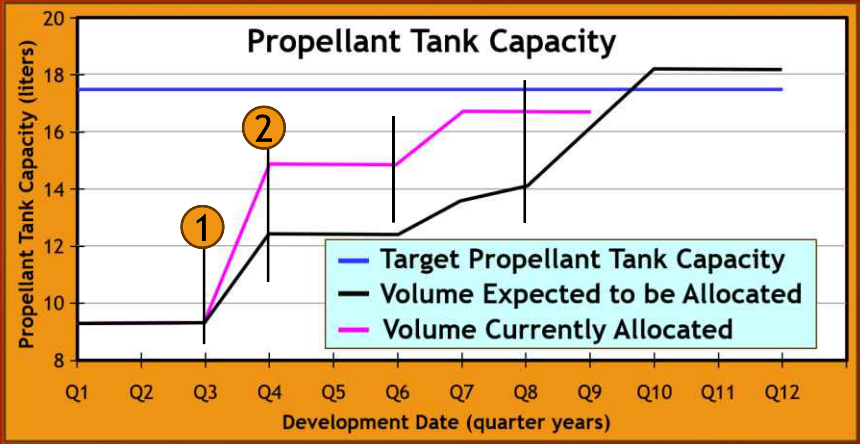
Timeline of Development Events

1. Q3: Due to the use of new technology and materials, a reduction in battery size and weight is announced
    1. This provides a total satellite weight and volume margin growth that permits growing the propellant tank size
    2. This leads to an increase in the number of orbital corrections that can be made immediately due to satellite mass reduction requiring less fuel for corrections
2. Q4: A reallocation of battery weight and volume for more propellant was put into the design
    1. Thus, propellant capacity (TPM) is increased
    2. This positively impacts the number of orbital corrections possible (MOP) and extending service life of satellite (MOE)
3. Q6: However, testing of thrusters and batteries indicated slightly worse efficiency than planned
    1. This has a negative impact on the number of orbital corrections (MOP) that can be achieved
4. Q8: Hence, a reduction in Service Life (MOE) is predicted

MOEs influenced by MOPs



MOPs influenced by TPMs



Summary of the Relations Among Technical Measures

- The MOEs apply at the top level, focusing on acquirer needs and validation
  - MOEs provide a quantification of value to aid in procurement justification, and at the end of the development to quantify the system validation
- KPPs are used by the developer to establish the key requirements necessary to achieve the MOEs
  - KPPs are used to establish the MOPs, which are measured as soon as possible and repetitively throughout development, testing and evaluation
- MOPs can be used to verify the system meets the system technical requirements
  - This in turn enables these requirements to be validated to meet the mission requirements and acquirer needs
- TPMs are a further break-down of the MOPs intended to provide measurable and ongoing insight into the technical progress
  - They are measured through analysis, modeling and simulation, and then test or the appropriate verification method
- During the progress through the development, periodic estimations of the MOEs are derived using the MOP and TPM values to ensure the MOEs are likely to be met
  - If not, appropriate actions are taken

Technical Measurement Checklist

	General Checklist Item
✓	Have the Technical Measures been developed with a common understanding of the information needs from the relevant stakeholders?
✓	Are the Technical Measures for this project identified? Have they followed the selection and specification guidance and criteria?
✓	Have the Technical Measures been submitted (and incorporated as necessary) into the project risk and opportunity management program?

	MOE Checklist Item
✓	Are the MOEs traceable to the applicable acquirer needs, goals, objectives, and risks?
✓	Are the MOEs clearly defined with associated KPPs identified?
✓	Does each MOE provide insight into at least one operational objective or mission requirement?
✓	Are the MOEs independent of each other? Does each MOE provide insight into different aspects of the operational alternatives?
✓	Are the MOEs independent of the technical solution alternatives?
✓	Does the set of MOEs address any required KPPs?

Technical Measurement Checklist (continued)

	MOP Checklist Item
✓	Are the MOPs traceable to the applicable MOEs, KPPs, system-level performance requirements, and risks?
✓	Do the MOPs focus on technical risks and support trades of alternative solutions at the system level?
✓	Do the MOPs collectively provide insight into the system affordability?
✓	Have MOPs been decomposed, budgeted, and allocated to the system elements that satisfy them?
✓	Are there MOP reporting mechanisms for each MOP that show progress toward meeting MOPs through aggregation of applicable TPMs and projections analyzed against thresholds at which corrective actions are to be taken?
✓	Have prototypes, simulations or models been developed to support analysis of MOPs, where warranted to provide necessary insight? Have these activities been incorporated into the project planning and execution?
✓	Has each MOP been assigned to an "owner" or responsible individual/IPT for tracking, making recommendations, and taking action?
✓	As a result of MOP analysis, is a revision to the measure warranted? If warranted, has the revision been analyzed and reviewed by the appropriate approval authority or control board?

Technical Measurement Checklist (continued)

	TPM Checklist Item
✓	Are the TPMs traceable to the applicable MOPs, system element level performance requirements/allocations, quality objectives, risks, and WBS elements?
✓	Are there TPM reporting mechanisms for each TPM that show progress toward meeting TPMs, and thresholds at which corrective actions are to be taken?
✓	Have TPMs been further decomposed, budgeted, and allocated to lower level system elements that satisfy them, where more granularity is needed based on risk?
✓	Have TPM budgets been flowed down to development organizations, procuring organizations and subcontractors?
✓	Have prototypes, simulations or models been developed to support analysis of TPMs, where warranted to provide necessary insight? Have these activities been incorporated into the project planning and execution?
✓	Has each TPM been assigned to an "owner" or responsible individual/IPT for tracking, making recommendations, and taking action?
✓	Have the sources of the TPM measures been identified and the processes generating those measures instrumented in such a manner as to collect the required data?
✓	Are TPMs integrated into the project scheduling process? Can any TPM risks be retired early? Is there sufficient schedule/budget to deal with TPM issues late in the project?
✓	As a result of TPM analysis, is a revision to the measure warranted? If warranted, has the revision been analyzed and reviewed by the appropriate approval authority or control board?

Approach to Modeling Measures in Architecture

This approach describes the process used to establish system measures and to define them in a SysML model

- All measures established for a system under development are based on a set of mission objectives derived from stakeholder concerns
  - The objectives and concerns are represented as elements captured in the system model
- Next, Measures of Effectiveness (MOEs) are derived from the mission objectives
  - Initially, these MOEs are captured in a special model element that allows for the MOEs to be described in a natural language format that stakeholders will understand
  - Those initial MOEs are then quantified and captured as value properties of the Enterprise block in the system model
  - The MOEs are traced back to their originating source in the mission objectives
- Next, Measures of Performance (MOPs) are derived from the enterprise-level MOEs and captured as value properties of the System block
  - The derivation of the MOPs is captured through the development of constraint blocks and parametric diagrams
  - This provides for traceability between MOPs and MOEs and supports performance analysis of the MOPs to predict if the MOEs will be met
  - MOPs are also traced to system requirements captured in the system model
- Next, the process steps at the system-level are repeated recursively at the subsystem-level to derive Technical Performance Measures (TPMs)
  - These TPMs are traced back to MOPs and subsystem requirements in the same manner as described for MOPs

Stakeholder Concern

- Stakeholder concerns encompass the following types of issues
  - The purposes of the system
  - The suitability of the architecture for achieving the system’s purposes
  - The feasibility of constructing and deploying the system
  - The potential risks and impacts of the system to its stakeholders throughout its life cycle
  - The maintainability and evolvability of the system

«StakeholderConcern»
Operational Lifetime

“Will the system be operational for the duration of the mission?”

Addresses the stakeholder’s concern regarding the suitability of the architecture for achieving the system’s purposes

Mission Objectives

- Mission Objective
  - An unquantified statement, which expresses the stakeholders views of the properties which any successful solution the need must possess
  - A concept associated only with the stakeholders
  - Gives a direction for the verification and validation phase on which tests can be planned
- Example
  - “The system must be operational throughout the duration of the mission”
  - Note that the phrase “must” is used instead of “shall” since an objective is not the same as a requirement

«MissionObjective»
Lifetime

“The system must be operational throughout the duration of the mission”

Unquantified statement expressing the stakeholder’s view of the properties which any successful solution the need must possess

Measures of Effectiveness

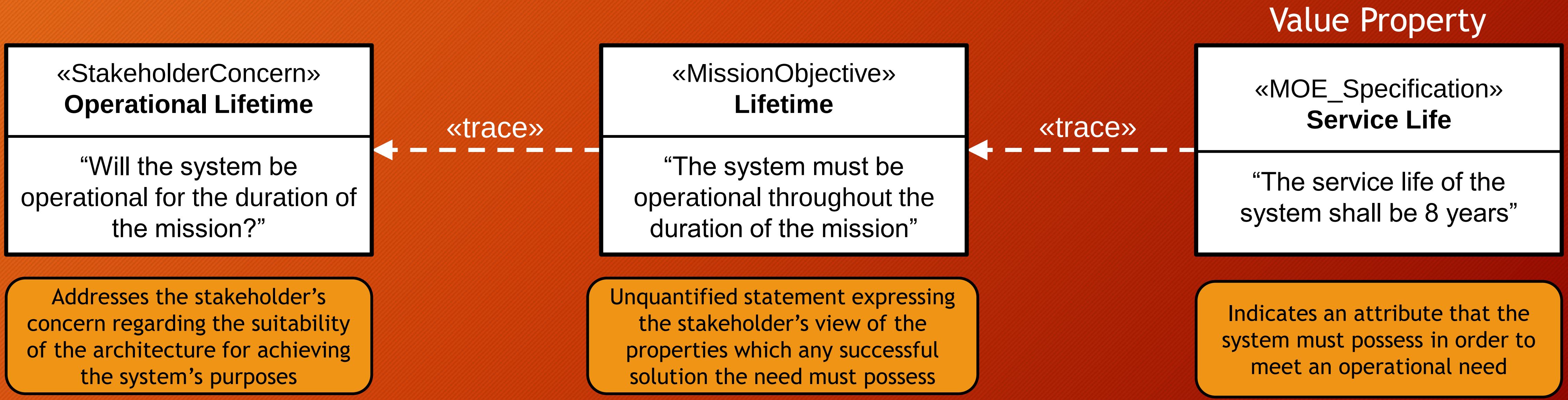
- MOEs are operational measures of success
  - Closely related to the achievement of the mission objective being evaluated
  - Measured in the intended operational environment under a specified set of conditions
  - Stated from the user’s viewpoint and represent the most important criteria against which the quality of a solution is assessed
- MOEs reflect the stakeholder’s intention
  - MOEs represent stakeholder expectations and are used to validate that the system meets the user’s needs
  - They indicate an attribute a system must possess in order to meet the operational need

«MOE_Specification» **Service Life**
“The service life of the system shall be 8 years”

Indicates an attribute that the system must possess in order to meet an operational need

Development of MOEs

- The qualitative descriptions captured in the MOE specifications are represented as value properties of the mission enterprise
  - The mission enterprise is defined as the aggregation of systems and users that work together to accomplish a mission objective
  - Example: For a satellite system, the mission enterprise could be comprised of a ground system, launch system, and the satellite system
- In the example below, a value property is created corresponding to the Service Life MOE
- Traceability of the MOE specification is established back to the Mission Objective
- This allows for complete traceability from the quantified value properties of the mission enterprise back to the originating stakeholder concern
- One benefit of this approach is that it enables quick assessment of the impact of any changes to stakeholder concerns



Installing MOEs in to the System Model

- MOEs are operational measures of success
  - Closely related to the achievement of the mission objective being evaluated
  - Measured in the intended operational environment under a specified set of conditions
  - Stated from the user’s viewpoint and represent the most important criteria against which the quality of a solution is assessed
- MOEs reflect the stakeholder’s intention
  - They indicate an attribute a system must possess in order to meet operational needs
  - They are used to validate that the system meets those needs

«MOE_Specification»
Service Life

“The service life of the system shall be 8 years”

Indicates an attribute that the system must possess in order to meet an operational need

Enterprise Level

«block»
Mission Enterprise

constraints
SL: ServiceLife

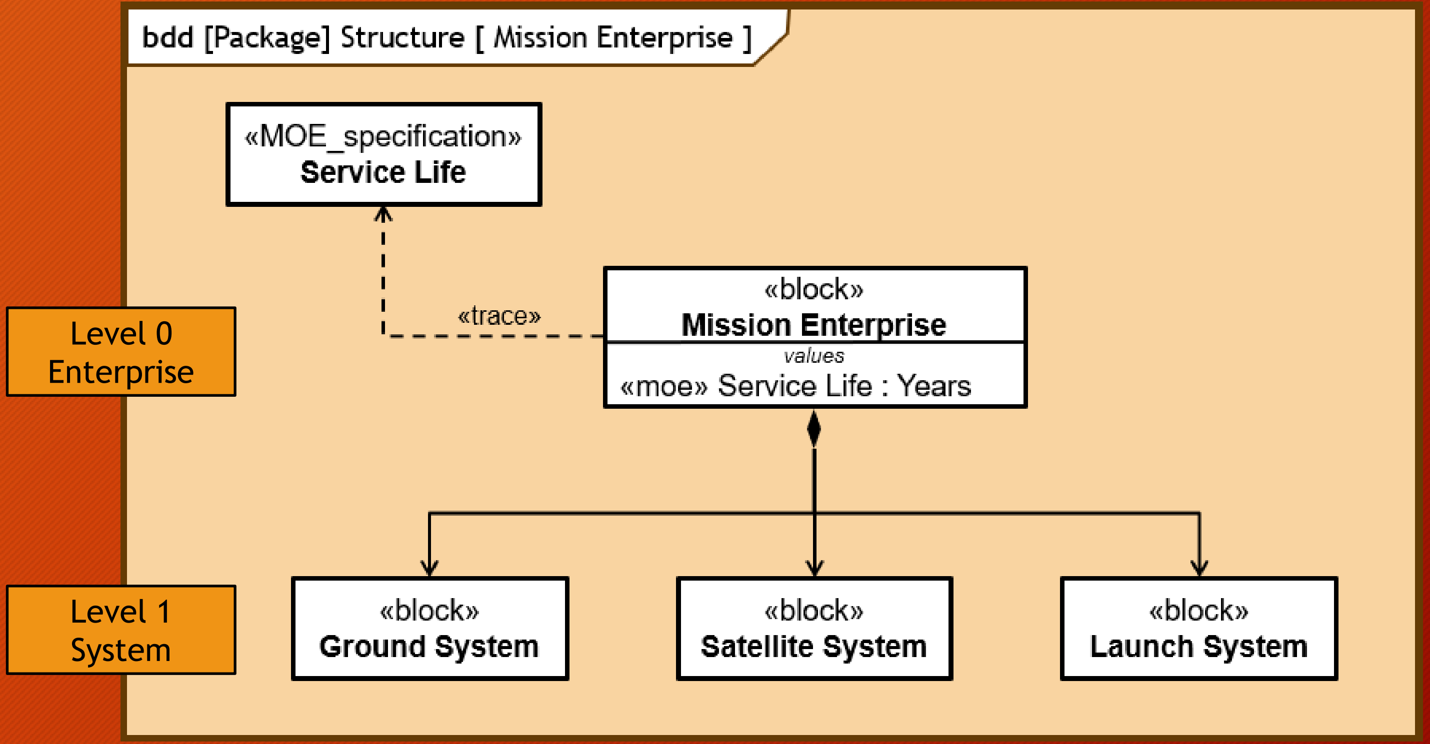
values
«moe» Service Life : Years

The MOE is installed in the system model as an enterprise-level value property

Example System Model

- This SysML Block Definition Diagram illustrates the structure of the Enterprise over two hierarchical levels
  - Enterprise Level
  - System Level
- At the System Level, the model identifies three system-level components
  - Ground System – including all the support elements on the ground
  - Launch System – the specific elements involved in preparing for launch, and launching the satellite
  - Satellite System – the System of Interest (SOI)
- Further levels of decomposition are certainly advisable
- Here, it is shown how the MOE as a value property of the Enterprise is traced back to the MOE specification established earlier

SysML Block Definition Diagram



A constraint will be developed for this example by which the Service Life MOE will be defined as a function of three system-level attributes:

- The delta V required to maintain the orbit for the duration of the mission
- Battery cycles
- Solar cell life

Measures of Performance

- MOPs are measures that characterize physical or functional attributes relating to system operation
  - They are measured or estimated under specified testing and/or operational environment conditions
  - They are stated from the developer's viewpoint and look at how well the delivered system performs, or is expected to perform, against system requirements
- MOPs are concerned with the actual performance of a system solution
  - They are used to assess whether the system meets requirements that are necessary to satisfy the MOEs
- MOPs represent the key performance characteristics the system should have in order to satisfy the MOEs and are used to verify that the system meets the stated requirements

System Level

The Service Life MOE is defined as a function of three system-level attributes (MOPs):

- The delta V required to maintain the orbit for the duration of the mission
- Battery cycles
- Solar cell life

«block» **Satellite System**
constraints
dV : DeltaV
values
«mop» DeltaV : real
«mop» BatteryCycle : real
«mop» SolarCellLife : real

The DeltaV MOP will be defined as a function of three subsystem-level attributes (TPMs):

- PropellantCapacity
- ThrusterEfficiency
- PropellantEperV

Technical Performance Measures

- Technical Performance Measures (TPMs) are critical technical parameters that a project monitors to determine how well a system element is satisfying, or expected to satisfy, a technical requirement
  - TPMs are derived directly from MOPs
  - They are used to confirm progress and identify deficiencies that might jeopardize meeting a system requirement
  - Typically, TPMs have planned values at defined time increments, against which the estimated and actual values are plotted
- Collection of TPMs
  - Allows trend detection and correction
  - Supports risk identification and assessment

The DeltaV MOP will be defined as a function of three subsystem-level attributes (TPMs):

- PropellantCapacity
- ThrusterEfficiency
- PropellantEperV

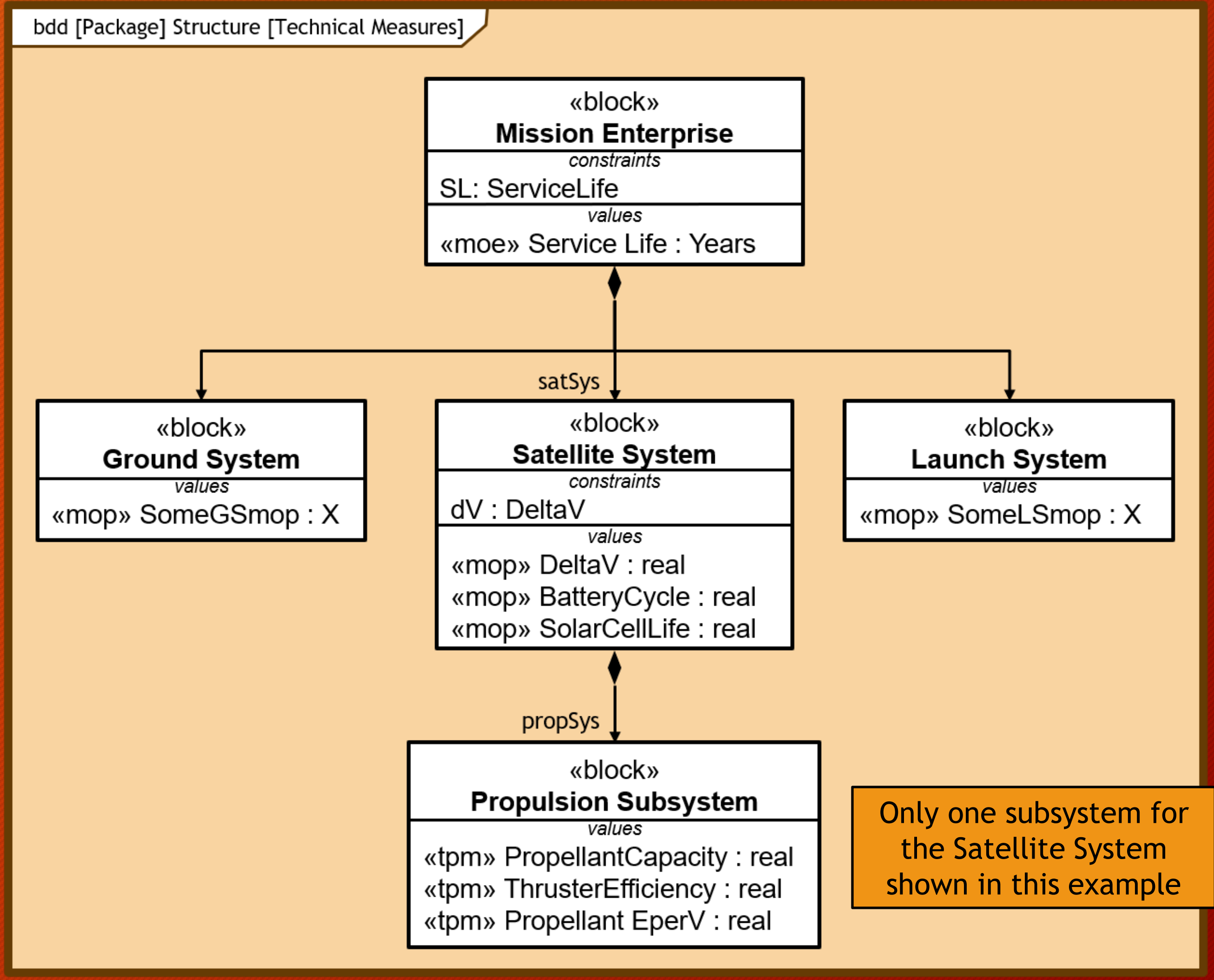
Subsystem Level

«block» **Propulsion Subsystem**
values
«tpm» PropellantCapacity : real
«tpm» ThrusterEfficiency : real
«tpm» Propellant EperV : real

Defining MOPs and TPMs

- Once MOEs are defined, then MOPs can be defined
  - Quantitative relationships between the two can be established
  - MOPs are derived based on the technical requirements that address the MOEs that trace to mission objectives
- Example: the service life MOE service life of a satellite is a function of
  - The delta V required to maintain the orbit for the duration of the mission
  - Battery cycles
  - Solar cell life
- These factors are captured as MOPs of the satellite in the form of value properties
- TPMs are derived in much the same way as the MOPs were derived
  - In this example, delta-V is a function of propellant capacity, thruster efficiency, and propellant energy per volume
  - These are captured as value properties of the propulsion subsystem of the Satellite System

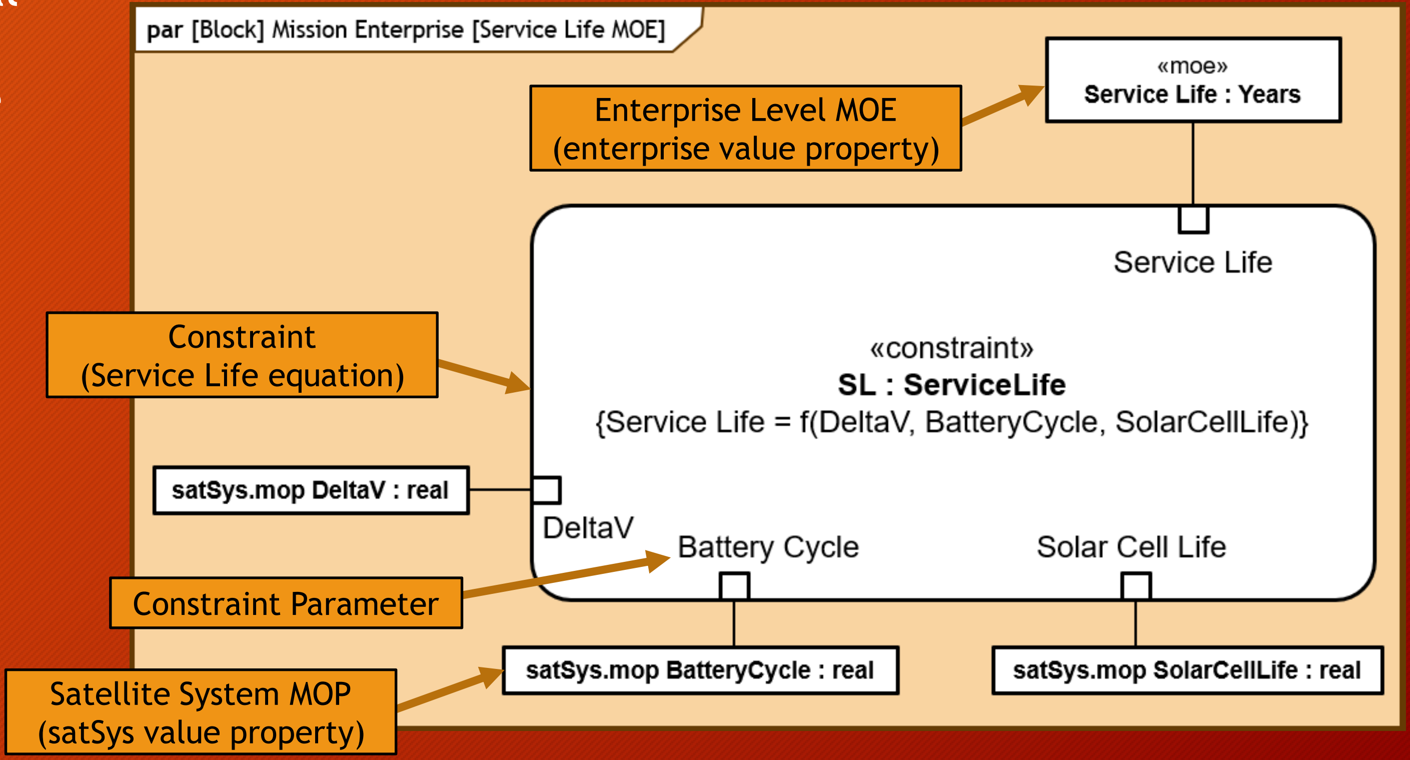
SysML Block Definition Diagram



Relating MOPs to MOEs

- MOEs can now be determined empirically through analysis of the MOPs
  - In SysML, constraint blocks and parametric diagrams are used to perform this type of analysis
- First, a constraint block is created that captures the empirical relationship between the MOPs and MOEs
  - In this example, service life is a function of delta V, battery cycles, and solar cell life
  - A constraint block is created to capture this function and its required parameters
- Then, a parametric diagram is created to bind the values of these parameters to the technical measures
  - This allows different satellite system solutions to be evaluated against the MOEs
- In the example here, Service Life is a function of the Satellite System MOPs (satellite system value properties):
  - DeltaV
  - BatteryCycle
  - SolarCellLife

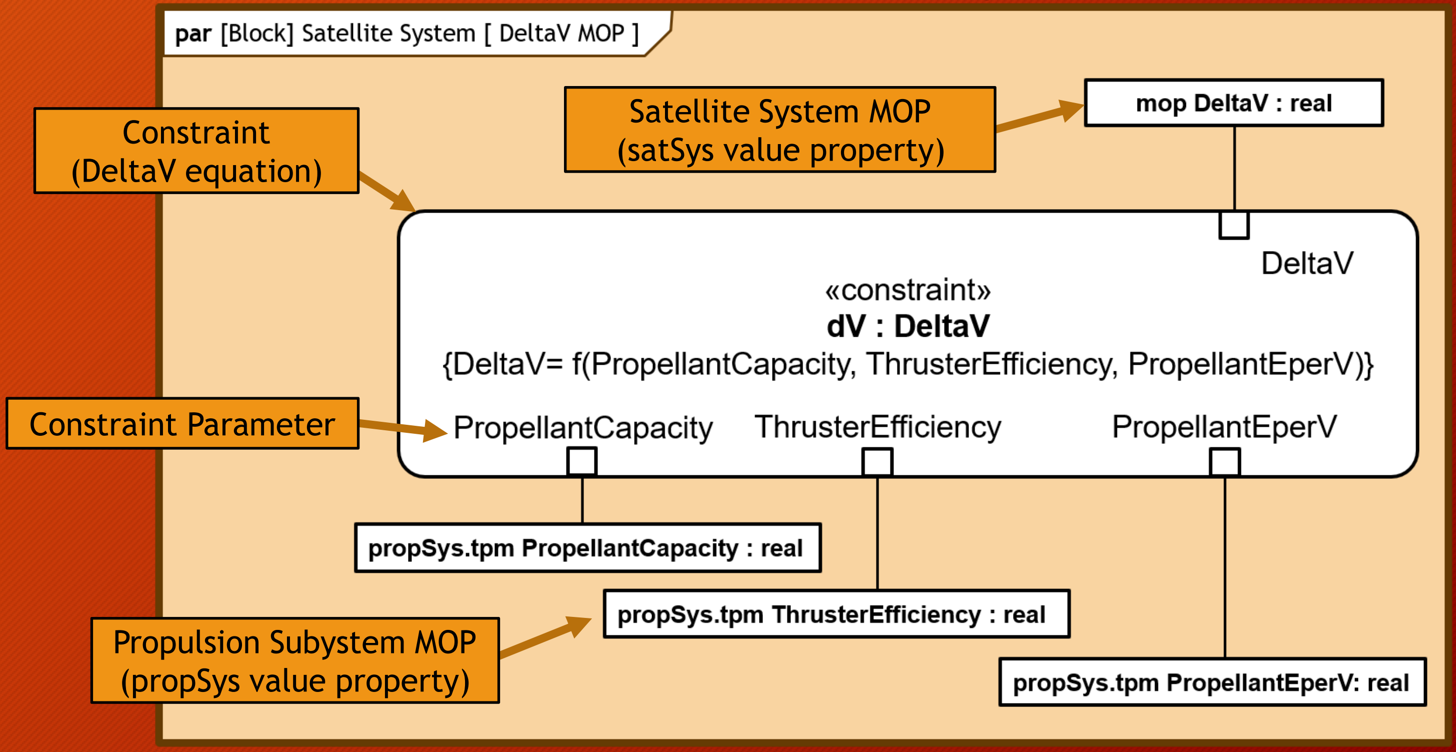
SysML Parametric Diagram



Relating TPMs to MOPs

- TPMs are related to MOPs in much the same way as MOPs are related to MOEs
  - Constraint blocks and parametric diagrams are used to calculate MOP values based on the TPM values
  - This allows for evaluation of different subsystem solutions based on their impact to the MOP
- First, a constraint block is created that captures the empirical relationship between the TPMs and MOPs
  - In this example, delta-V is a function of propellant capacity, thruster efficiency, and propellant energy per unit volume
  - A constraint block is created to capture this function and its required parameters
- Then, a parametric diagram is created to bind the values of these parameters to the technical measures
  - This allows different propellant subsystem solutions to be evaluated against the MOPs
- In the example here, DeltaV is a function of the Propellant Subsystem TPMs (propellant system value properties):
  - PropellantCapacity
  - ThrusterEfficiency
  - PropellantEperV

SysML Parametric Diagram



Notes about Modeling Measures in SysML

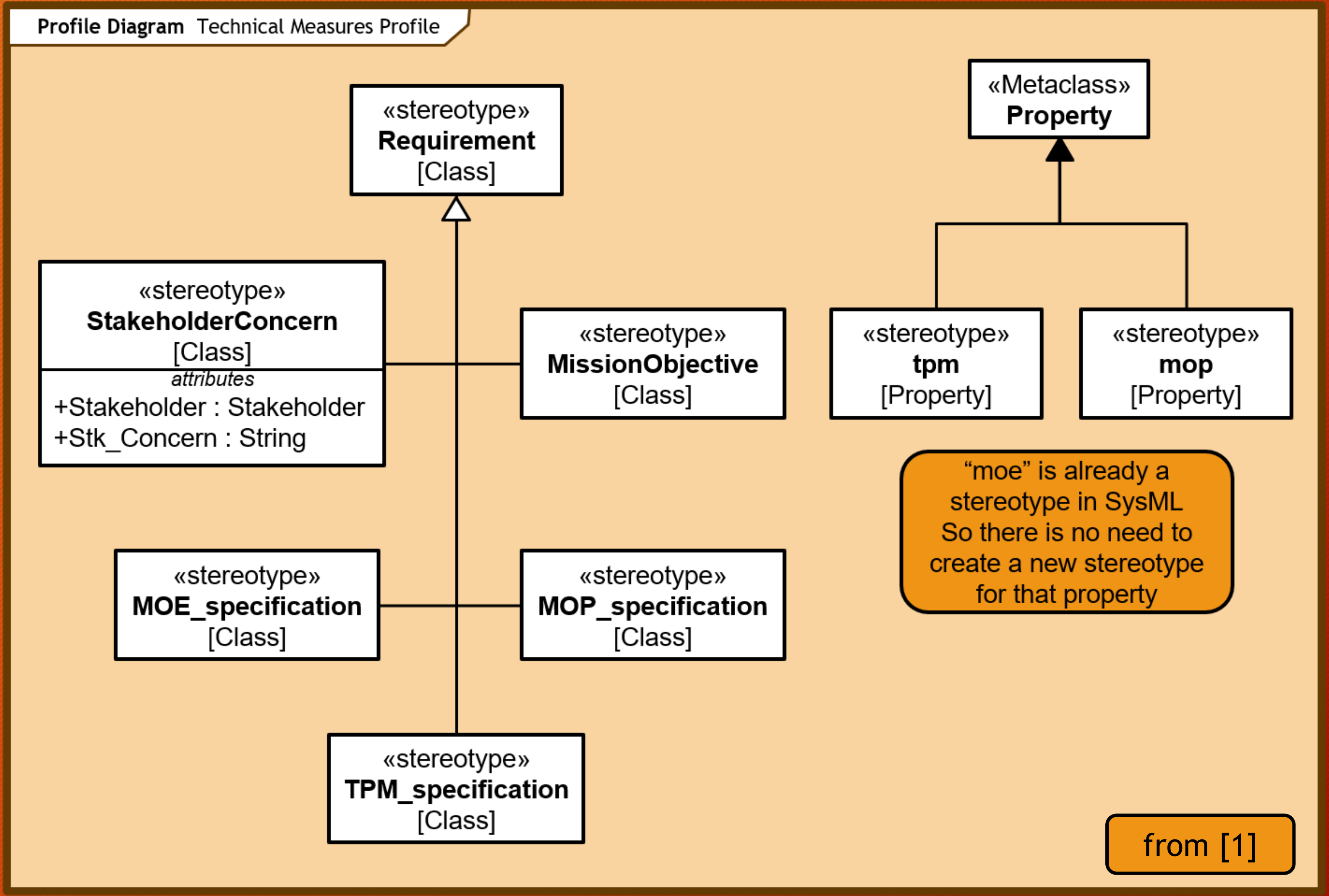
- The approach taken to represent the capture of measures in a system model is taken from Reference [1], as described below
- The approach described here (from Reference[1]) uses SysML profiles to incorporate measurement-domain-specific language into the system model
  - This requires the creation of customized model elements that are not part of the native SysML language, as listed below
- Stakeholder Concern
  - SysML does provide a means for capturing the concerns of stakeholders through the use of the “comment” model element
  - However, this element does not allow for traceability
  - As such, a new element is created that will allow for that traceability
- Mission Objective
  - This is a unique element that is used to capture the broad set of goals that must be achieved to satisfy a mission need
- MOE
  - Currently treated as a non-normative extension to SysML
- MOP
  - Not part of SysML requiring a new model element to be created

Notes about Modeling Measures in SysML (continued)

- TPM
  - Not part of SysML requiring a new model element to be created
- MOE Specification
  - This approach allows for capturing textual descriptions of measures that can then be translated to properties that can be quantitatively assessed
  - Users may be well versed at stating the need verbally, but not at capturing value properties
  - The MOE Specification is a model element created for capturing a user's description of the MOE
  - Additionally, MOEs may be qualitative and do not have to be quantitative
  - This element allows for the capture of qualitative MOEs
- MOP Specification
  - This model element is used to capture qualitative descriptions of MOPs that can then be translated into properties of the system
- TPM Specification
  - This model element is used to capture qualitative descriptions of TPMs that can then be translated into properties of system elements

SysML Profile for Modeling Technical Measurement

- To provide the modeling features in SysML described in this presentation, a SysML profile needs to be constructed that provides for the special features needed for a model of this type



References

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