Digital requirements engineering with an INCOSE-derived SysML meta-model

James S. Wheaton and Daniel R. Herber

Colorado State University – Department of Systems Engineering

james.wheaton@colostate.edu
daniel.herber@colostate.edu

➞ Outline

1

Introduction

➞ Greater systems complexity calls for digital requirements engineering

- As complexity of space missions continues to grow, demand for more cost-effective system development programs grows.
- Traditional requirements engineering does not leverage graph connectivity of the system architecture model.
- Ad-hoc duplication of system architecture elements in a Requirements Management Tool (RMT) confounds the Authoritative Source of Truth (ASoT).
- Data synchronization between RMTs and SysML-defined architecture modeling tools mitigates these problems, but primary use of SysML tools offers deeper model integration.

How can we improve requirements quality by leveraging new INCOSE guidance and existing SysML architecture modeling facilities?

➞ Introducing digital requirements engineering

Definition (Digital Engineering (DE))

An integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal.[1]

DE is not a new discipline of engineering but rather an intentional transformation of how an organization integrates and performs its engineering activities to achieve higher quality and efficiency.[2]

***Digital requirements engineering** further integrates requirements with the ASoT, enabling formal verification and validation (V&V) activities that may be automated to improve model confidence and ease stakeholder reviews.*[3]

[1] Office of the Deputy Assistant Secretary of Defense for Systems Engineering 2018 [2] Noguchi, Wheaton, and Martin 2020 [3] Duprez et al. 2023

2

Model-Based Structured Requirements (MBSR)

→ MBSRs derive from requirement statement templates/patterns

CARSON TEMPLATE[1]

The **[Who]** *shall* **[What] [How Well]** under **[Condition]**.[2]

ISO/IEC/IEEE 29148:2018 TEMPLATES[3]

[Subject] *shall* **[Action] [Constraint of Action]**.

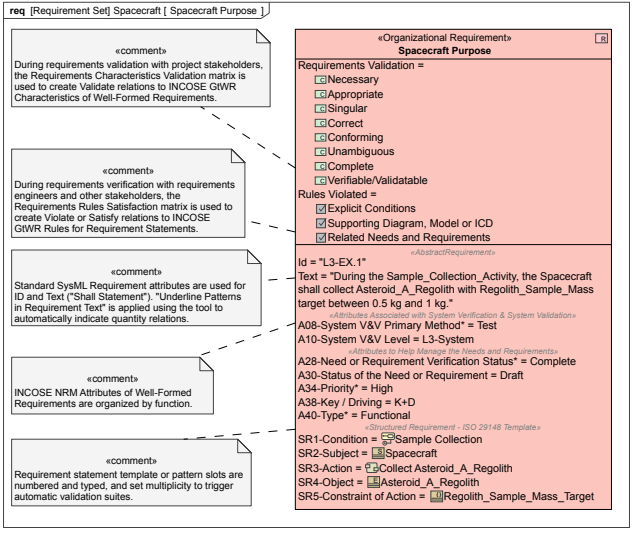
OR

[Condition], **[Subject]** *shall* **[Action] [Object] [Constraint of Action]**.

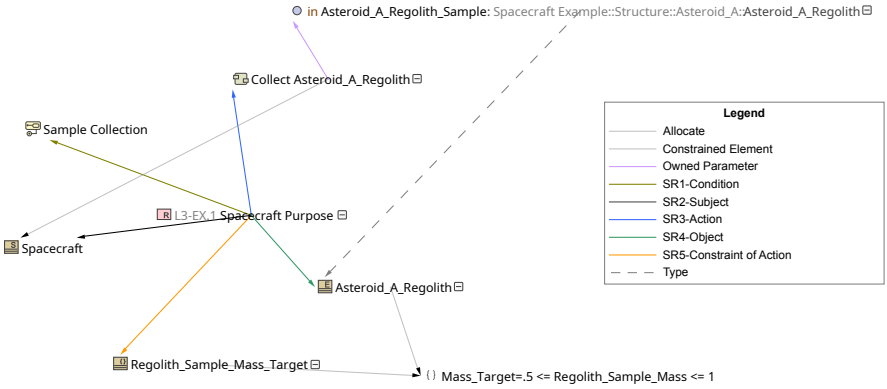
Additional requirement statement patterns are discussed in Appendix C of INCOSE Guide to Writing Requirements (GtWR).[4]

[1] Carson 2015 [2] Herber and Eftekhari-Shahroudi 2023; Herber, Narsinghani, and Eftekhari-Shahroudi 2022 [3] "ISO/IEC/IEEE International Standard - Systems and software engineering – Life cycle processes – Requirements engineering" 2018 [4] Wheatcraft and Ryan 2023

➞ Example MBSR with INCOSE GtWR Attributes



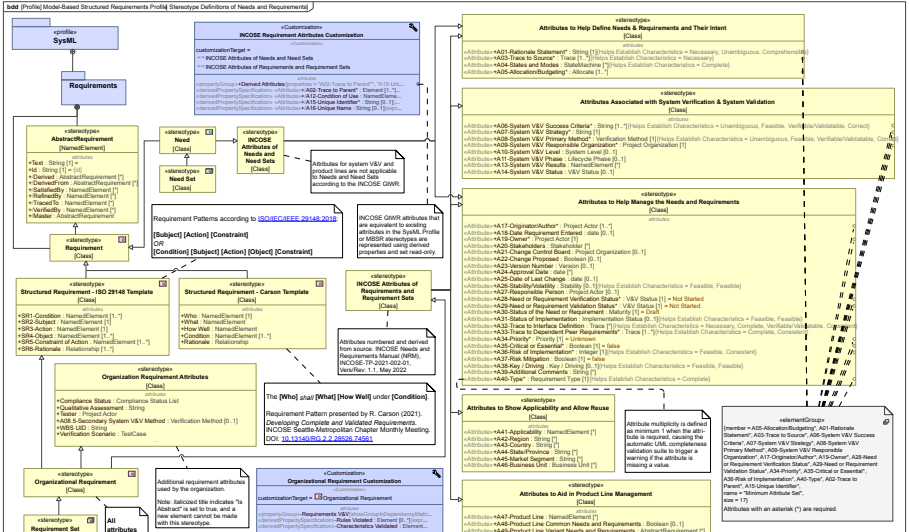
➞ Relation Map derived view of example MBSR



③

INCOSE-derived SysML Meta-model

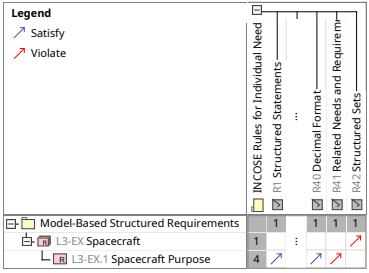
➞ MBSR stereotype definitions with INCOSE GtWR Attributes



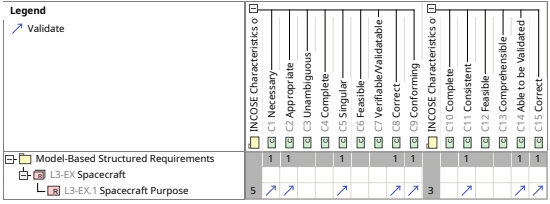
➞ Key features of MBSR with INCOSE GtWR Attributes

- Attribute values are model elements or relationships which afford advanced queries (i.e. Structured Expressions)
- Attribute values are typed with SysML-defined element types, facilitating data entry and verification
- Multiplicity values automate verification of organization-defined minimum attribute set
- Additional attributes are easily added to Organizational Requirement Attributes stereotype
- Numbering scheme matches INCOSE GtWR while facilitating search/filter operations
- Duplication of standard SysML attribute values is avoided using derived properties

➞ Model-based requirements V&V using the SysML Profile



Satisfy or Violate relations are mapped from MBSR to INCOSE GtWR Rules for quick verification.



During requirements validation activities, Validate relations are mapped from MBSR to INCOSE GtWR Characteristics for Well-Formed Requirements.

- SysML documentation field or comments with anchors may be used to record rationale
- SysML relations created against Rules and Characteristics produce metrics
- Legend items may be used to highlight requirements in violation
- Built-in documentation aids in definition lookup

4

Discussion

→ Advantages & disadvantages of this approach

ADVANTAGES

- Requirements stakeholder views are generated from the model, e.g. PowerPoint, Excel, Web Report
- SysML enables near-limitless customization, empowering the engineer
- Collaboration is supported with Teamwork Cloud plugin
- Full ISO 80000 units of measurement, and other SysML Profiles are available for requirements use
- TBX summary table is easily created
- Requirements V&V metrics support system architecture metrics
- Glossary terms are underlined & reference documentation is easily accessible

DISADVANTAGES

- Many requirements management tasks are not well-supported by the SysML tool, or become tedious to perform
- Customization of default styles is recommended to prevent disrupting well-formed diagrams
- SysML model is not backed by a database and data loss may occur
- Reports and tables can be slow to render
- While some requirement management tasks may be scripted, API documentation is lacking

5

Conclusions and Future Work

➞ Conclusions and future work

This digital requirements engineering method is being tested at NASA Jet Propulsion Laboratory on the Mars Returned Sample Handling project currently in Pre-Phase A.

- By applying INCOSE GtWR in the MBSR framework, over 150 requirements were rapidly improved and passed early validation
- Flexibility afforded by SysML meta-modeling and Velocity Template Language provide familiar stakeholder views
- Requirement statement patterns ensure consistency, and MBSR with INCOSE-derived SysML meta-model aids requirements definition and V&V
- Feedback from NASA JPL stakeholders is positive and supports continued application of this approach

Our MBSR SysML Profile is open source to support future work:

- Translation of this SysML Profile to SysML v2
- More system applications and stakeholder validation
- Improved scripted behaviors and stakeholder-targeted derived views
- Improved robustness of SysML modeling tools

➞ References

- R. S. Carson (2015). "Implementing structured requirements to improve requirements quality". *INCOSE International Symposium*. Vol. 25. 1. Wiley Online Library
- J. Duprez et al. (2023). "An Approach to Integrated Digital Requirements Engineering". *INCOSE International Symposium*. Vol. 33. 1. Wiley Online Library
- D. R. Herber, J. B. Narsinghani, and K. Eftekhari-Shahroudi (2022). "Model-Based Structured Requirements in SysML". *2022 IEEE International Systems Conference (SysCon)*. IEEE
- D. R. Herber and K. Eftekhari-Shahroudi (2023). "Building a requirements digital thread from concept to testing using model-based structured requirements applied to thrust reverser actuation system development". *Recent Advances in Aerospace Actuation Systems and Components*
- "ISO/IEC/IEEE International Standard - Systems and software engineering – Life cycle processes – Requirements engineering" (2018). *ISO/IEC/IEEE 29148:2018(E)*. DOI: 10.1109/IEEESTD.2018.8559686
- R. A. Noguchi, M. J. Wheaton, and J. N. Martin (2020). "Digital engineering strategy to enable enterprise systems engineering". *INCOSE International Symposium*. Vol. 30. 1. Wiley Online Library
- Office of the Deputy Assistant Secretary of Defense for Systems Engineering, ed. (2018). *Department of Defense Digital Engineering Strategy*.
- L. Wheatcraft and M. Ryan (2023). *Guide to Writing Requirements*. Tech. rep. INCOSE-TP-2010-006-04. International Council on Systems Engineering

Questions?

Digital requirements engineering with an INCOSE-derived SysML meta-model

James S. Wheaton
Daniel R. Herber

https://www.engr.colostate.edu/~drherber/
https://github.com/danielrherber/model-based-structured-requirements